Using Global Positioning System to Improve Materials-Locating Processes on Industrial Projects

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Abstract: On-site materials-handling operations are error prone and the errors that occur significantly decrease construction productivity. New technologies and sensing devices can enhance materials-handling management practices on construction job sites. This paper describes a study that aimed to determine the potential benefits of the deployment of global positioning system (GPS) technology within the materials-locating processes on industrial projects. Its main goals were (1) to evaluate the technical feasibility and (2) to quantify the direct benefits in terms of process duration derived from the integration of GPS devices within pipe-locating processes. A field trial was conducted and its results indicated significant time savings. This study also analyzed additional potential benefits derived from the use of GPS in this scenario.

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Introduction

Materials management, the process of planning and controlling all the necessary efforts to ensure that the right quality and quantity of materials are specified in a timely manner, obtained at reasonable cost, and available when needed (The Business Roundtable 1982), plays a major role in the construction industry. Materials management is an essential aspect of project controls that directly affects project cost and schedule performance. In a typical construction project, materials usually account for 40–50% of its total cost and highly influence construction progress. According to the 1997 U.S. Economic Census, expenditures on materials, components, supplies, fuels, and their management services for residential and industrial buildings, heavy construction, and infrastructure projects totaled $124 billion (U.S. Census Bureau 2004). Quality of materials management is also recognized by the Construction Industry Institute (CII) as one of the key influences in project success (CII 2004).

While materials management has repeatedly been the focus of industry research, materials-handling procedures on construction job sites often remain almost primitive. These field materials-management procedures are ripe for improvement. According to an early CII study, the implementation of a basic materials management system on construction job sites would conservatively produce a 6% improvement in craft labor productivity, while the implementation of computerized control tools would provide an additional gain between 4 and 6% (CII 1986). Initial observations by the writers of inefficiencies directly associated with on-site materials-handling operations confirm the potential for obtaining significant benefits with improved procedures.

Locating and identifying materials on construction job sites consumes excessive amounts of working time and labor effort, negatively affecting project safety, schedule, and cost. O'Brien (1989) claimed that the percent time spent on handling materials and preparatory operations by electrical workers was as much as 42%, while the workers devoted only 32% of their working time to productive tasks. Bell and Stukhart (1987) stated that foremen lost 20% of their working time searching for materials and another 10% tracking purchase orders and expediting, while leaving the crews unsupervised and hence cutting productivity down. According to the same writers, the unavailability of materials to begin an activity negatively affected craft labor productivity by increasing both the number of repetitive site trips and the associated amount of time spent. On power plant construction sites, Borcherding and Sebastian (1980) observed that 27.7% of the craft worker's time was idle or nonproductive due to the unavailability of the correct materials and tools at the right time. According to McCullouch (1992), project managers also wasted tremendous amounts of time slowly and tediously collecting and processing field data, distracting them from managing the project. While these studies occurred more than 10 years ago, the sense among the research community is that materials management offers a remarkable potential for improvement, since little has changed on construction sites over the past decades.

Indeed, a recent CII study identified field materials management as the area that company managers thought had both the greatest potential for improvement and the greatest positive development impact on engineering construction work processes (Vorster and Lucko 2002). According to 82% of the surveyed

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construction organizations, the incorporation of technology would significantly improve field materials-management practices, while 85% of those organizations agreed that technology developments would have a clear and positive impact within those practices.

Accurate information of a construction project is important for its success. According to Stone (1995), there is a primary need to obtain instantaneous data from construction job sites. Moreover, construction managers need to know the on-site project status at any given time, including materials' information. Collection of accurate and timely construction data is necessary to promptly detect the discrepancies between planned and actual performances and to minimize their impact. This is fundamental for project control systems.

Significant competitive advantages could come through the incorporation of data collection and positioning technologies within materials handling operations. Additionally, projects and construction companies incorporating those technologies could positively affect returns through the improved efficiency of the existing processes, such as reduced paperwork, enhanced data accuracy, increased productivity, instantaneous data collection processes, and shortened response times. Positioning devices could economically locate materials at any given time, enhancing the efficiency of on-site construction practices. For instance, timeless location of the construction components within the critical path would result in confident and timely execution planning, and therefore minimizing the chance of project delays.

This paper describes a case study that assessed the potential of data collection and positioning technologies to improve the tracking and locating of materials on construction job sites. A field trial was conducted to obtain the experimental data for this study. A global positioning system (GPS) unit and a handheld computer were integrated into current fabricated pipe spool receiving, storing, and issuing processes in lay down yards of a particular industrial project. These processes were broken down into a series of distinct steps. Experiments measured the time required by field workers to execute two of those steps. Time measurements were taken for a baseline case in which crews used current industry work processes to locate spools. The study then measured times for other crews to locate the same pipe spools using GPS technology. The field measurements clearly quantified the time saved by GPS.

Materials Management

Materials management in the manufacturing sector has extensively been studied and applied for decades. Inventory management, materials-requirements-planning, and just-in-time delivery are the standard techniques for different demand environments, which usually are characterized by their levels of continuity, uniformity, and dependency (Ibn-Homaid 2002). Within manufacturing, these typified demand characteristics are the most influential factors in determining the adequacy of a particular formal technique to materials management.

While construction materials management resembles that of manufacturing at a conceptual level, construction methods to manage materials cannot easily be standardized (Ibn-Homaid 2002). Objectives, inputs, activities, and outputs are the main conceptual parallelisms between manufacturing and construction materials management. However, the common unavailability and inaccuracy of the demand's complete input data for individual construction components at the procurement stage, the need to continuously track and accommodate project changes within materials information and materials plans, and the low degree of interaction between materials management and (construction) operations are substantive differential factors inherent to the construction environment. As a consequence, construction materials management relies on some high level sets of construction procedures and basic paper-based applications rather than automated methods.

Successful approaches to manage construction materials possess intrinsic qualities and characteristics (Bell and Stukhart 1986). Planning, top management support, and site training programs established promptly in the project are basic attributes for a correct materials management policy and for its effective deployment through the project life cycle. Additionally, the implementation of interconnected communication mechanisms among the different construction players is a condition for effective management of construction materials. The presence of these communication channels among owners, contractors, project managers, and job site personnel strengthen the correct flow of materials' information in a precise sequence. Today, the internet network greatly enhances such capability. Finally, an adequate materials-management system has to exert maximum control over materials' distribution and acquisition, including materials-handling processes on construction job sites.

Automated Data Collection on Construction Job Sites for Materials Handling

Recent research initiatives explored the use of new technology and sensing devices to collect data on construction job sites. An early approach by Jaselskis et al. (1995) proposed radio frequency identification devices (RFID) for controlling and tracking high-valued materials on construction job sites. Cheok and Stone (1999) developed a laser-based wireless system to automatically scan a construction site and to create a three-dimensional (3D) model whose data populated project management applications. Wakisaka et al. (2000) integrated barcode technology into a materials-management system in an effort to automate the construction of high-rise reinforced buildings. Furlani et al. (2001) combined laser range finders, barcodes, and computer vision techniques to identify materials' labels at maximum distances between 30 and 40 m. In a study implemented by Cheng and Chen (2002), barcodes and geographic information systems (GIS) were the two basic components of an automated schedule monitoring system to control and track the erection of prefabricated concrete components in real-time. Chen and Wong (2002) developed an incentive reward barcode-enabled program that encouraged on-site workers to decrease avoidable wastes from construction debris, while improving productivity. Akinci et al. (2002) proposed RFID for locating precast concrete elements during their storage at manufacturing plants and for tracking their deliveries, while keeping a record of their life cycle information. Umetani et al. (2003) combined robots, databases, and identification devices to determine the identification, position, and orientation of construction components on job sites. The Defense Advanced Research Projects Agency (DARPA) sponsored a research study to combine the use of microelectromechanical systems (MEMS) with laser range finders for identification purposes (Tanner 2004). DARPA also sponsored a project that combined miniaturized GPS receivers and MEMS to position and track free-moving objects (Brown 2004). The FIATECH (Fully Integrated and Automated Technology) consortium is studying both the use of RFID devices to detect and identify pipe spools loaded on a truck when passing

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through a portal antenna and the deployment of GPS devices to locate materials on large lay down yards (FIATECH 2004). The National Institute of Standards and Technology (NIST) conducted a research study for establishing data exchange standards to support the deployment of different sensing technologies within on-site construction practices (Saidi et al. 2003). Bernold et al. (2003) used magnetic fields and penetrating radars to assess the equipment operator in the detection of existing utilities, improving subsurface operations. Garrett et al. (2003) recently stated that new technologies and sensing devices could be the core of new ways to approach construction, thus altering some of the industry's basics. Finally, Hwang et al. (2004) considered the collection of construction data a key factor for the success of a project.

Successes from these and other research projects have opened the doors to the deployment of data collection technologies on construction job sites. Combined with the latest versions in portable computers and data communications, these technologies may create the data stream for management systems to move materials efficiently on construction job sites, substantially modifying current on-site materials operations.

GPS

GPS is an outdoor satellite-based worldwide radio-navigation system formed by a constellation of 24 satellites, ground control stations, and end users. GPS uses triangulation from these satellites in order to determine a three-dimensional position. To triangulate, a GPS receiver computes the distances to at least four different satellites at any given time. Distances to the receiver are computed measuring the travel time of radio signals from each one of these four satellites. Atmospheric conditions and satellites' location above the receiver influence the resulting position and its accuracy. By default, any computed position has an intrinsic error of about 15 m (raw data) (Garmin 2004).

Differential GPS (DGPS) systems can decrease this error using a fixed receiver whose position must previously be known. Ground stations, Coast Guard beacons, Wide Area Augmentation System (WAAS), OmniSTAR, and real-time kinematic are examples of differential correctors for a GPS system. These technologies can be summarized as follows:

- Ground stations are fixed GPS receivers that allow postprocessing the raw data acquired by mobile GPS receivers in a matter of hours. Their resulting accuracy is better than 1 m. The presence of ground based stations close to the receiver is required for this DGPS;
- The U.S. Coast Guard operates Coast Guard Maritime DGPS, another type of fixed ground receiver (beacons) that enables real-time differential correction (U.S. Coast Guard 2004). The accuracy is always better than 10 m, being usually between 1 and 3 m. The Coast Guard beacons are present around the coast lines of the U.S., Puerto Rico, Alaska, and Hawaii;
- WAAS is a combination of satellites and ground stations that enables real-time differential correction. The resulting accuracy using WAAS satellites is better than 3 m (Garmin 2004);
- OmniSTAR's satellites and network control stations facilitate real-time differential correction of the raw data with worldwide coverage (OmniSTAR 2004). OmniSTAR offers two levels of DGPS. OmniSTAR VBS is a "sub-meter" service, while OmniSTAR HP provides for a position error better than 10 cm. OmniSTAR requires a license fee to use its differential correction; and
- Real-time kinematic GPS (RTK GPS) minimizes the position's error to less than 1 cm in usually less than a 20 mi radius around a separate base station, having a trade-off in highly increased costs.

GPS is an established location technology that offers a wide range of off-the-shelf positioning solutions for the construction industry. Guidance from one location to another (navigation), monitoring the movement of people or assets (tracking), creating maps (mapping), and precise timing (timing) are the other GPS basic functions. Although GPS applications are common in construction such as automation of processes and guidance of equipment, the potential of GPS to improve the management of materials on construction job sites remains basically unexplored.

Field Trial

A field trial quantified some of the benefits of the deployment of GPS within materials locating operations of large industrial projects. Kellogg, Brown & Root (KBR), British Petroleum (BP), FIATECH, and the University of Texas at Austin were key participants. The goals of the field trial were twofold: (1) to evaluate the technical feasibility and (2) to quantify the direct benefits in terms of time savings derived from the integration of GPS devices within pipe locating processes. The scope of the field trial was limited to measuring specific metrics under unique conditions and processes, as described later in this paper.

Current Materials Locating Process

The materials locating process analyzed in this study is based on KBR's onshore operations. This procedure is typical of most pipe handling operations on industrial projects. The locating process begins when the company receives materials from manufacturers and ends when those materials are expedited to contractors for installation. A project management system stores the collected information for each material and on every job site. The process includes the steps of receiving and unloading, sorting, storing, recalling and flagging, and picking up and loading materials (Fig. 1) in lay down yards that are subdivided in grids of approximately 30×30 m. In the present study, the measures to quantify the potential benefits of GPS to locate materials are collected from the steps of recalling and flagging. The different locating tasks are defined in the next paragraphs.

- Receiving and unloading. On-site workers receive materials or construction components from manufacturers, who previously marked every item on its surface with its unique identification code (usually alphanumeric). During the receiving process, materials are unloaded in predefined areas without identifying or classifying them. The received items are entered manually from the packing list into the project management system, so construction managers can plan and execute activities based on their materials' availability;
- Sorting. Workers sort materials in small grids by their physical characteristics and their marked identification codes. During the sorting period, workers move, group, and mark materials with colored tapes. Each material's identification, grid, and color code are listed manually and entered into the management system for future use. Sorting is time consuming but facilitates the retrieving task;
- Storing. This step covers the storage of materials in lay down yards. Materials usually remain in the same position (and in the same grid) during their storage. However, they may be removed during retrieval of nearby items. Whenever an item

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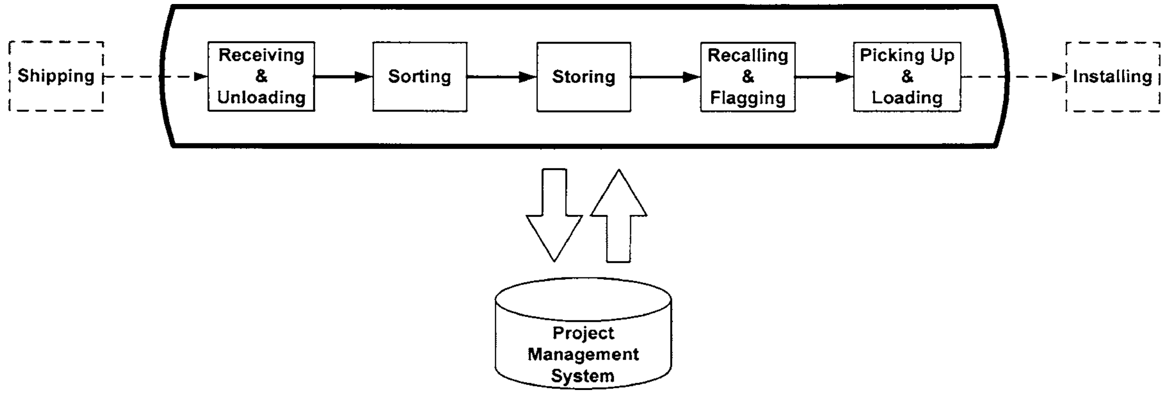

Fig. 1. Current locating process

moves to a different grid, its identification code and grid number are recorded manually and updated into the management system;

- Recalling and flagging. When a construction activity requires stored materials, their grid locations, specific identifications, and color codes are recalled and listed from the management system. Workers try to visually locate the spool pieces in those lists; sometimes they may also need to look at drawings and descriptions of materials. Once an item is located, a flag is attached to facilitate its visual identification during subsequent pick up; and
- Picking up and loading. At a specified schedule, all flagged materials are picked up, loaded into trucks, and released to the contractors for installation.

The efficiency of this locating process is based in the ability to collect, to retrieve, and to transmit the correct location and identification codes for construction components at any given time. The shadowed elements in Fig. 2 detail the possible improvements within the overall locating process, which are (1) its number of intermediate steps and (2) the transmission of information between lay down yards and the management system.

While sorting is the unique task (and eventually storing) that collects information such as materials' codes and locations from yards to populate the project management system, construction workers need to locate each spool at least three times: (1) sorting, (2) recalling and flagging, and (3) picking up and loading. Spool position must be changed at least twice (during unloading and sorting), and construction components need to pass through a minimum of four different steps before they can be released to contractors. These numerous intermediate steps drop productivity down and create bottlenecks. The situation aggravates under the delivery of large quantities of materials, especially when these deliveries are close in time to materials' installation.

Collection of materials' data and its transmission to and from the management system needs also to be enhanced in terms of accuracy and speed. The data collection relies on manual transcription, thus it is a significant source of data entry errors. Indeed, the information in those lists is manually typed into the management system, enlarging the number of possible mistakes. Such errors prevent prompt and reliable location of construction components. An analysis of the recalling and flagging tasks highlights additional potential for improvement. During recalling, the identification and location of the spools that were recorded manually become the base for the flagging step. This last step still requires an in-depth and time-consuming search within each grid and which typically contains hundreds of items, further reducing productivity. In the field trial here described, the integration of data collection and positioning technology devices within recalling and flagging steps was used to measure their potentials for process improvement.

Technology Used

Trimble's GPS Pathfinder Power (Trimble 2004) was the GPS system used. It determined its own location at any given time. The GPS reader was a combination of GPS backpack-mounted receiver and antenna. Position was defined in terms of three coordinates (X, Y, and Z). The GPS device enabled real-time sub-

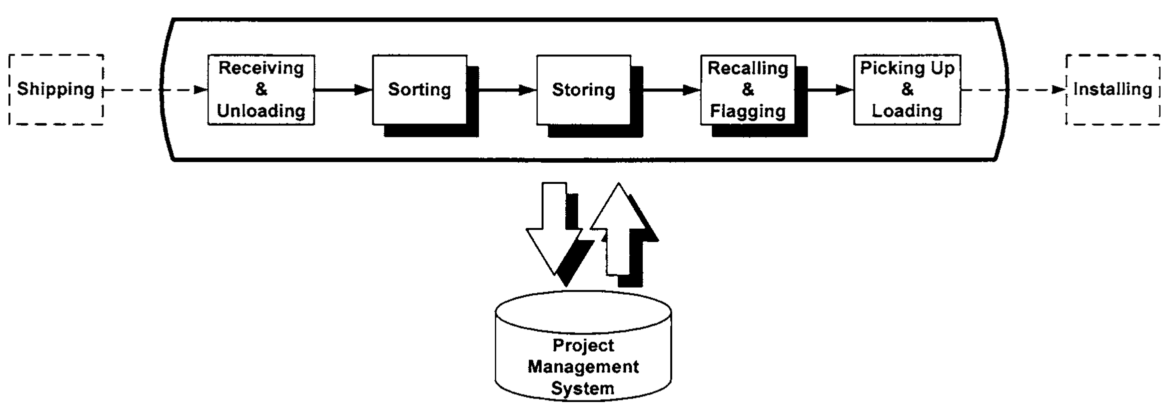

Fig. 2. Areas for process improvement (shadowed)

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meter accuracy using Omni STAR and WAAS DGPS corrections. The use of multipath rejection technology allowed for some removal of the signals from reflective environments, such as pipe spools' metal surfaces.

The handheld computer Symbol PDT 8100 (Symbol 2004) collected the positions determined by the GPS receiver. It was a rugged data collection device. The computer was wired to the GPS receiver in order to collect the measured positions. The PDT 8100 incorporated a key data entry option and sealed joints to withstand construction environments. The device was based on Microsoft Pocket PC platform technology, and its power supplied by a rechargeable lithium ion-battery. A 1/4 VGA display touchable screen allowed the end user to interact with software packages. The handheld computer PDT 8100 supported both Pocket Collector (GSI 2004) software and Microsoft SQL CE 2000, which were two of the systems used in this study. The research team worked on the customization of these software systems specifically for this project.

Pocket Collector had two main functions for the end user. First, it operated as the interface between the end user and the GPS receiver. Pocket Collector established the connections with the satellites through the GPS receiver and antenna, showing at any moment whether or not the quality of the acquired signals were suitable for differential correction. In a similar manner, Pocket Collector allowed one to record in the handheld computer the coordinates of an item as available from the GPS receiver. Second, Pocket Collector software integrated all the GPS position-based functions of navigation, tracking, mapping, and timing with materials' information imported from the management system. Within a display list of pipe spools, search functions by identification codes were used to retrieve the current information associated with a particular spool piece; hence each item could be assigned to the present GPS position by simply clicking the desired spool. The software also offered the possibility of defining a unique origin for a local coordinate system within the jobsite. Within this coordinate system, a map of the lay down yards in the computer screen served as a reference for the end user. Then, navigation tools allowed for moving to any selected spool with the help of a compass, which indicated to the end user the correct direction to a particular item.

SQL CE is a database management system for handheld computers that stored the measured positions by the GPS device. The use of SQL CE facilitated the data transmission from the handheld version to any host computer with another version of Microsoft SQL 2000, and from there to the project information management system.

The project management system was a database management system (Oracle-based) that stored project information. It integrated the project management functions of engineering, procurement, and construction. For on-site materials handling operations, it controlled materials' receiving and materials warehousing, supported site planning, and evaluated work plan processes in terms of schedule. It could potentially track the present status of on-site items, such as ID, color code, and position.

Data integration was a two-way process. On the one hand, downloaded data from the project management system populated Pocket Collector SQL CE's database with information on the spools. On the other hand, the integration software transferred the collected identifications and positions by the handheld device to the management system. SQL's off-the-shelf functions enabled data transmission from the SQL Server CE in the handheld device to another version of SQL 2000 in a host computer, and vice versa. However, originally there was nothing to integrate data from SQL 2000 to the Oracle database; a synchronization software developed as part of this study filled this gap.

The cost of all the hardware (one GPS unit and one handheld device) was about $7,000. The labor effort associated with the different integration software was roughly of a total of 60 work-hours. The basic on-site workers' training was completed in one morning.

Performance Metrics

An interview with KBR's materials and construction managers became the basis for the performance metrics. The number of lost items and the time spent locating spools were the main issues. Those and other problems are of big concern because "you think you are ready to construct but you are not" (KBR managers).

Among them, the average time saved locating a spool was considered the most important and reliable measure in order to quantify the benefits of GPS. Productivity and efficiency are related directly to the time spent locating by on-site workers. Therefore time comparisons between current and GPS-enabled processes quantify the direct labor impact of GPS. Each step of the GPS-enabled process results in an increment or decrement of time when compared with the same step in the current process, resulting in an objective comparison of efficiency.

Field Implementation

In the field trial the times spent recalling and flagging for both the current and the GPS-enabled processes were collected. However, the recalling task had time measurements only for the current process, since for the GPS-enabled process there is no need for recalling. The exact field implementation is described next.

First, approximately 1,000 pipe spools data from the management system were randomly selected and transferred to the database in the handheld device. This data contained the identification code for each spool, color code, and some additional information. Second, employees randomly selected 81 of those spools in three different lay down yards and measured and recorded their coordinate positions in the handheld computer with the use of the GPS device. The integration software transferred the collected data back to the management system, which created a list of the 81 identification codes without their measured coordinates. Third, a KBR employee used the previous list to locate the spools according to the normal process. In doing so, the time it took for the employee both to determine spool yards and color codes (recalling step) and to locate each pipe spool (flagging step) were determined. However, no flags were placed on the pipe spools in order not to give a visual clue for the following task. Fourth, the GPS device was used by a different crew to locate once again the 81 spools (Fig. 3). The time to locate each spool was measured (flagging step for the GPS-enabled process).

Quantitative Results

The field trial quantified the influence of GPS when locating spools in terms of time. During the recalling step, the total time invested for the current manual process was 2 h and 20 min. Since this was the time required to recall 81 spools, the arithmetic mean for recalling each spool resulted in 1 min and 45 s. The arithmetic mean of the time invested to locate each pipe spool during the current flagging step was 4 min and 58 s. Therefore the

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Fig. 3. Field trial

total invested time for the current process to recall and flag one spool was 6 min and 42 s. The comparable GPS-enabled process required only 55 s.

Analysis of Results

The differences among the two sets of measures in both their basic statistics (Table 1) and box and whisker plots (Fig. 4) seem obvious. Data from the GPS-enabled measures is more confined around a much shorter average of the time invested for locating a spool than in those from the current practices. However, a statistical test verified that the difference of their correspondent population means is statistically significant.

The test for differences in means determines whether or not the average of time to locate spools within the current process is statistically greater than that of the GPS-enabled process. This test compares the population means (μ) of both samples. However, the data in both samples do not have a normal distribution as required for the most common tests. In the case of the field trial, both sets of measurements are right skewed (positively skewed) as shown in their histograms in Fig. 5.

To test non-normal distributions, other methods are available (Albright et al. 2003). If the estimated measure of the difference between population means (μ) is the difference between sample arithmetic means, the appropriate sampling distribution of this estimate is the t distribution. This assumption is based in the central limit theorem (CLT) that states that "for any population with mean μ and standard deviation σ, the sampling distribution of the sample mean is approximately normal with mean μ and

Table 1. Basic Statistics

Statistic	Current recalling and flagging	GPS-enabled recalling and flagging
Number of observations	81	81
Mean	6′42″ or 401.7 s	54.5 s
Median	5′34″ or 333.7 s	45 s
Mode	3′44″ or 223.7 s	45 s
Standard deviation	4′14″ or 254.0 s	29.3 s
Minimum	2′9″ or 128.7 s	10 s
Maximum	21′44″ or 1,303.7 s	2′43″ or 163 s

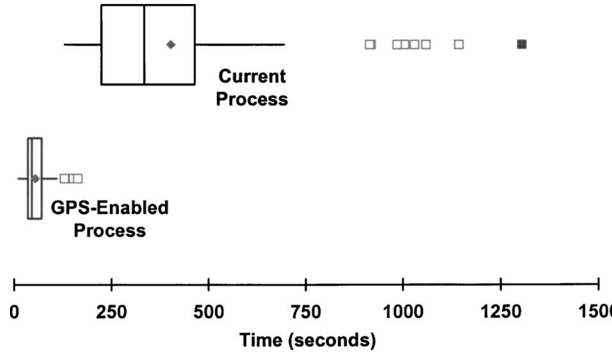

Fig. 4. Box and whisker plots

standard deviation $\sigma/\sqrt{n}$ (n number of observations), and the approximation improves as n increases." Most analyses assess a minimum of 30 observations (n) to consider the CLT. In this paper, 81 measures guarantee that the CLT holds.

The appropriate standard error in the test for differences in population means depends on the equality of population variances (or standard deviations). Therefore a test based in equal population standard deviations has to be first performed, as described next.

Hypothesis Test for Equal Population Standard Deviations

Considering that σ_1 is the population standard deviation for time spent during the current process and σ_2 is the population standard deviation for the GPS-enabled process

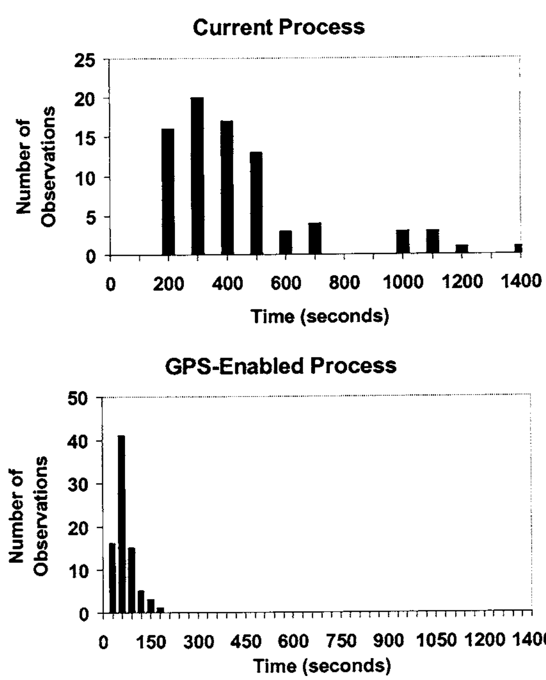

Fig. 5. Histograms

$$\text{null hypothesis } (H_0): \quad \sigma_1 = \sigma_2$$

$$\text{alternative hypothesis } (H_a): \quad \sigma_1 \neq \sigma_2$$

$$\text{significance level:} \quad 95\%$$

Then, the value that compares the standard deviations of the two samples and its equivalent probability within the F distribution are

$$F\_\text{value} = (\text{stdev}_1)\text{\^{}}2/(\text{stdev}_2)\text{\^{}}2 = 75.05$$

$$F\_\text{probability} = 1.85 \times 10^{-53}$$

Hence the resulting probability is lower than the significance level, so it can be rejected that the variances of the populations are equal (null hypothesis). As a consequence, the test that determines whether or not the population means are different needs to include both standard deviations in the formula of the standard error.

Hypothesis Test for Differences in Means (One-Tail)

Considering that μ_1 is the population mean for time spent during the current process and μ_2 is the population mean for GPS-enabled process

$$\text{null hypothesis } (H_0): \quad \mu_1 \leqslant \mu_2$$

$$\text{alternative hypothesis } (H_a): \quad \mu_1 > \mu_2$$

$$\text{significance level:} \quad 99\%$$

The standard error of the difference is

$$\text{SE} = \sqrt{\frac{(\text{stdev}_1)\text{\^{}}2}{n} + \frac{(\text{stdev}_2)\text{\^{}}2}{m}} = 28.41$$

Hence the value that compares the population means of both samples and its equivalent probability within the t distribution are

$$t\_\text{value} = \frac{\bar{x} - \bar{y}}{\text{SE}} = 12.22$$

$$p\_\text{value} = 1.87 \times 10^{-20}$$

Indeed, it can be concluded that there is less than a 1% chance of obtaining two samples with a positive difference between their means of 347.1 s if the population mean for the current process was equal or smaller than that of the GPS-enabled process. Therefore the alternative hypothesis can be accepted, demonstrating that the average of time spent in locating materials using GPS is statistically lower than the average of time spent for the current process.

Potential Economic Benefits

Potential economic benefits can be earned directly by reducing the time to locate each spool by 5 min and 47 s. Based on the current technology implementation costs and considering only the savings associated with the workers involved in the "recalling and flagging" step, the breakeven point is approximately 4,000 spools. On a typical construction project with 8,000 spools and long schedules, it seems reasonable to deploy the proposed technology within materials locating processes since direct labor savings on one project can easily offset the technology costs and those associated with its integration and deployment.

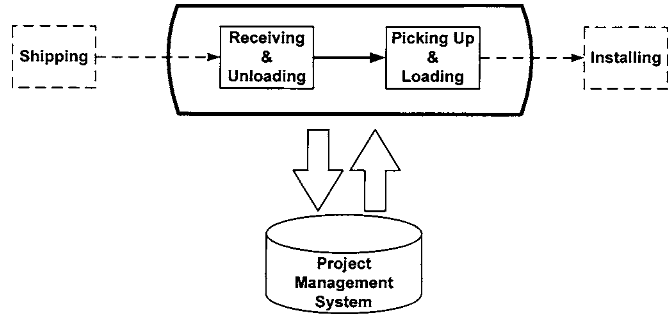

Fig. 6. Reengineered process

Other Potential Benefits

Additional benefits can be derived from the deployment of GPS in materials locating, as discussed in the following paragraphs.

Process Improvement

Considering the impact of GPS on direct labor savings of traditional handling practices would only reflect a part of the potential benefits of its use. Reengineering current locating processes around GPS has the potential to further improve schedule reliability and productivity. In the current process, workers need to locate each spool a minimum of three times (sorting, recalling and flagging, and picking up and loading) and change their position at least twice (during unloading and sorting). With the precise GPS coordinates, however, the process can be minimized to two steps (Fig. 6): receiving and unloading, and picking up and loading. If the coordinates for each item were recorded when unloading the spools, sorting, storing, and recalling and flagging could be eliminated, since the identification code and precise coordinates of each spool would clearly spell out its location at any subsequent required moment and minimize the number of current "lost" spools.

Moreover, the reduction in the number of locating steps and the introduction of technology would result in a positive trade-off between labor and technology. A decrement in labor would result in a reduction in human errors (i.e., data collection errors), while the implementation of technology devices would enhance process standardization, planning, and productivity.

Reduced Number of Lost Items

In the current process, pipe spools can easily be misplaced. Deterioration of their identification mark (i.e., by rusting), wrong records of their localization and identification codes, and incorrect locating procedures are some of the common reasons. Locating "lost" spools involves redoing the locating process from the beginning with the help of additional information, such as isometric drawings and description of the "lost" pipes. This additional work is effort consuming. GPS theoretically can attain a zero tolerance in lost items and substantially reduce those potential drawbacks. Recording all the pipes' location upon arrival, all the spools should be relocated with minimal failure. Moreover, handheld computers could download and access additional characteristics

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of the spools that would provide workers with additional information (such as isometric drawings) to identify a spool when no ID is visible on the spool.

Impact on Construction

A reliable and precise materials-locating process would have the potential to improve the overall project schedule. Precise distribution of the correct items at the right time would reduce the number of work disruptions due to material unavailability and decrease labor idle-time, positively affecting the construction schedule. As a consequence, it would enhance planning reliability and increase construction productivity.

Standardization and Automation

The implementation of uniform, off-the-shelf, and worldwide-available technology, allows for the standardization of locating processes in any region. In remote countries with very different cultures and environments, it is usual to contract local companies with local workers that are not familiar with locating processes, and this negatively affects planning and decreases productivity. A reduction in the number of workers in a more automated locating process by means of worldwide-available and rugged technology would potentially reduce those drawbacks.

Route Optimization

The knowledge of the components' location in large lay down yards opens the possibility to predetermine routes and pick up sequences for tasks such as materials loading. If a clear sequence and route could be provided to the workers for the picking up and loading process, they would reduce the time spent on traveling between items and improve productivity.

Layout Optimization

Location of construction components on a particular job site would assess in its space organization. Temporary facilities, roads, areas for storage, and other layout elements could be better planned and their present condition evaluated with the precise identification and location of on-site materials.

Improved Data Entry

The automated record of the coordinates for each pipe spool and the elimination of paper work and manual lists would reduce current data entry errors and increase data reliability.

Conclusions

This study assessed some of the benefits of the deployment of GPS devices within materials locating processes of large industrial projects. A GPS unit and a handheld computer were integrated within current pipe spools locating processes on lay down yards. Those processes were broken down into several steps. A field trial measured the time invested by field workers for two of those steps.

Field measurements quantified the time saved by using a GPS receiver. The average time spent locating a spool using the current process was 6 min and 42 s, which was reduced to only 55 s when working with a GPS unit. A statistical analysis validated the 5 min and 47 s difference. A typical project, with thousands of spools, would benefit with significant savings in labor time and costs. These savings can easily offset the cost of the technology deployment.

In addition to these direct savings, based on our observations the use of a GPS receiver can provide other benefits to on-site construction operations. It may improve processes, reduce the number of lost items, and create positive effects on construction performance. It can also standardize and automate processes, enhance data entry, and optimize route sequences and layout.

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Notation

The following symbols are used in this paper:

F_value = statistical value within an F distribution;
F_probability = probability to the right of an F_value within an F distribution;
H_0 = null hypothesis;
H_a = alternative hypothesis;
m = number of observations from the GPS-enabled process;
n = number of observations from the current process;
p_value = statistical value within a t distribution;
SE = standard error;
stdev_1 = sample's standard deviation for the current process;
stdev_2 = sample's standard deviation for the GPS-enabled process;
t_value = one tail probability of a p_value within a t distribution;
$\bar{x}$ = sample's mean for the current process;
$\bar{y}$ = sample's mean for the GPS-enabled process;
μ_1 = population mean for the current process;
μ_2 = population mean for the GPS-enabled process;
σ_1 = population standard deviation for the current process; and
σ_2 = population standard deviation for the GPS-enabled process.

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