Leveraging Materials Tracking Technologies to Improve Industrial Project Performance

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ABSTRACT: The perception that the intertwinement between field materials management and advanced sensing technologies can highly benefit field operations has gained widespread acceptance among industry representatives. Indeed, past research efforts have demonstrated the feasibility of technology-based and automated approaches to handle materials. In spite of their success, material components are still manually handled. This lack of innovation is mostly a consequence of the undemonstrated cost effectiveness of these technology-enabled approaches. This study evaluates the impact of an automated tracking approach on project performance. For this purpose, a massive experiment was designed. In this experiment, the site tracking approach was taken as the baseline for comparison with an automated tracking approach, which was supported by localization and identification sensors. For each tracking method, field records associated with four hundred steel components were collected. The experimental results demonstrate that sensing technologies have a clear and positive impact on craft labor and installation processes.

1 INTRODUCTION

In spite of the obvious importance of materials within the construction industry, it was not until the early eighties that the Business Roundtable (1982), a panel of experts from construction-related fields, identified materials management as a crucial contributory process for project success. Since this initial pronouncement was made, both academics and practitioners have shown an increasing interest in improving the way materials are managed. Specifically, the industry advancements have essentially focused on developing computer-aided management systems to keep an updated record of the status of their materials.

Knowing the actual status of construction components is critical for project success. Researchers have consistently recognized the direct influence of materials management on project cost and schedule performance. The efficiency of installation crews and construction equipment depends on the ability of managers to deliver components according to an execution plan or sequence. Ideally, components need to be ready at the correct place and at the correct time so crews and equipment can make an immediate use of them.

New information and sensing technologies are promising to transform materials management processes, with an emphasis on automating their manual site tracking practices, which focus on the control and handling of site materials. The automation of site tracking processes promises to positively affect project performance by 1) improving the craft labor efficiency based on the rapid and effortless collection of actual components data –position and identification, and 2) enhancing erection processes as a result of a more reliable installation sequence, based on the actual availability of the components.

However, the inexistence of tangible data to demonstrate these benefits stands as a fundamental barrier opposing the integration of field handling processes with new sensing and information technologies.

The rest of this paper is organized as follows. A summary of the state of the art on field material handling practices, their importance on industrial projects, and on the previous efforts to automate those practices are discussed to support the research objectives. Then, a sophisticated field tracking process and its latent opportunities for improvement is presented. Similarly, a re-engineered tracking process around sensing and information technologies is presented. The design, results, and analysis of a field experiment based on these distinct tracking approaches is discussed. Finally, the conclusions summarize the findings of this research.

2 BACKGROUND

In reality, the problem of managing construction materials on job sites is not new. One way or the other, managers have historically managed materials throughout each project stage—i.e., design, procurement, manufacturing, delivery, storage, and installation—with very different levels of satisfaction. In spite of the obvious impact that materials management has on project performance, it has not been until a decade or so that industry practitioners have started implementing sophisticated computing tools to monitor the status of every project component. However, these computer databases and support tools have not eradicated the labor-intensive and error-prone materials management practices on the job sites.

Even though the limitations associated with materials handling practices concern the construction industry as a whole, their lack of efficiency is more notable on industrial sites. On these sites, thousands of unique engineered components—such as structural steel, pipes, or valves— need to be controlled over long periods of time and over extensive areas. Since traditional practices rely solely on human skill—i.e., in-person observations and paper lists—the sheer volume of components on industrial projects makes these manual practices inadequate. Indeed, components are frequently moved during their storage, which makes the accurate and manual control over all of them an unattainable task. Moreover, adverse weather conditions can cause the exposure of site components to snow or sand, completely preventing their identification and seriously disrupting installation plans.

The low efficiency of site control and inventory processes as a result of this imbalance has been historically captured by the scholars. Past studies have observed that the unavailability of required material components is responsible for consuming a third of the total labor time (Borcherding and Sebastian 1980; Bell and Stukhart 1987; McCullouch 1992; Rojas and Aramvareekul 2003; Caldas et al. 2006). If unavailable site components cannot be found after long searches, managers will need to substitute them. In the notice of a lost item, the contractor decides either to re-order and receive a new identical item or to replace it by making use of the "cut and weld" approach -this is achieved by cutting and welding several items into a new one. Given that the process of re-ordering, manufacturing, and transporting a new component usually requires from several weeks to a few months, many contractors choose the "cut and weld" option at the expense of jeopardizing their management of site materials and the entire project.

Increasing project complexity is continuously challenging the ability of manual site practices to effectively track project components. The number of engineered components increases as project demands and regulations increase over time. At the same time, components are more frequently delivered to the site in large batches at early project stages. These large-batch deliveries place a double demand on site tracking practices. On the one hand, they significantly extend the time period to control each engineered component and, on the other hand, they significantly increase the average number of items to be tracked at any given moment. Finally, isolated project sites, such as those in remote countries, commonly rely on overseas or distant manufacturers to provide their components and hence cannot afford losing them. Indeed, losing a component in the critical or near-critical path and the need to re-order it to the remote manufacturer virtually guarantees that the component will not be available for installation when required. This kind of materials management oversight increases total installed costs and can eventually delay a whole project.

In order to respond to this increasing project complexity and to automate traditional tracking practices, recent efforts have focused on the implementation of new sensing and information technologies. These technology-based tracking solutions include a variety of these advanced technologies, such as radio frequency identification (RFID), global positioning systems (GPS), barcodes, or geographic information systems (GIS), among several others. These advanced technologies have been demonstrated to tremendously increase the visibility of site components and to significantly innovate field tracking practices (Caldas et al. 2006; Navon and Berkovich 2006; Song et al. 2006; Ergen et al. 2007; Grau and Caldas 2009). Industry practitioners (inclusive of managers and field workers) have observed that the adoption of these advanced technologies for site tracking promises a high benefit to cost ratio (Vorster and Lucko 2002) with a high return on the technology investment.

So, at this point one may wonder the reason why the industry has not yet taken advantage of technology-supported site tracking processes when their benefits seem obvious. There are two major reasons for this apparent disregard: up to this date no effort has demonstrated the existence of tangible benefits, and, if they exist, how much they can positively affect project performance. Even if one imagines the existence of these benefits, exactly how feasible is the massive of advanced tracking technologies with field materials tracking processes is not yet understood. These standing barriers are still preventing potential adoption of advanced tracking technologies by industry organizations.

3 OBJECTIVES

This study focuses on assessing and quantifying the impact of an innovative field materials management process, which had been re-engineered around an automated tracking approach, on a large industrial project. In particular, the study targeted at evaluating the productivity impact of this innovative tracking approach on both craft labor and erection productivities. In addition, this study also intends to uncover the technical feasibility of this approach and the barriers associated with its large-scale implementation. In order to accomplish with these research objectives, a massive field experiment tracking steel components in a real project site was performed for data collection and analysis purposes.

4 FIELD EXPERIMENT

4.1 *The site*

The Sandow Steam Electric Station Unit 5 project site, located in Texas, was selected among ten prospective sites to host the field experiment. The total cost of the power plant project was estimated at $750 millions and designed to generate 565MWatts of energy. Contracting policies were open shop and direct hire, which allowed the authors to partially modify existing tracking procedures according to the experimental design (Section 4.5).

4.2 *Field materials tacking process*

The steel tracking process was divided in two main steps: the storage of steel components at the lay down yard and their installation at the staging area. Upon arrival, each steel component was marked with their unique code for visualization purposes and unloaded in a 10 acres crowded yard. The yard was subdivided in smaller grids of 15 x 30 m^2, which were uniquely identified by an alphanumeric code displayed in a metallic post at the grid center. The component identification code and that of its grid were manually recorded by craft workers. Then, this data was introduced into an electronic materials management system. If a component was moved to a different grid, craft workers were supposed to write down the new grid code in order to update the inventory records. Once a set of components was recalled for installation, a printed list with their pair of identification and most recent grid codes was given to craft workers (typically a couple of them), who had to search for, find, and flag –with a colored tape- the component.

Once flagged, steel crews would identify and pick up the components required for installation and haul them to the nearby staging area. The staging area was small and crowded with several crawler-mounted cranes among many other units of construction equipment, and therefore only allowed for the storage of a very limited amount of components waiting to be installed. This inability to store components commonly forced steel crews to recall and retrieve items the same day or the day before they were required for installation. Crews controlled neither the identification nor the localization of the retrieved components –components were not controlled beyond the lay down yard. Instead, crews relied in what they could recall about the components to plan for their erection. Eventually, components were erected, bolted, plumbed, torqued, painted, and finally inspected.

4.3 *Latent opportunities for positively impacting craft labor and installation efficiency*

The existing tracking process offered three latent opportunities for improvement to positively affect craft labor and installation efficiency. This opportunities were craft labor time spend per steel component, number of not-immediately-found items, and erection productivity. First, it was observed that workers spent large amounts of time searching for lay down yard components. Finding a component in the 450 m^2 grid size was not evident. Workers had to typically search in a random manner to locate a single component. As a result, searches were time consuming and their unpredictable search times widely varied. In addition to this unsystematic nature of the searching process, inventory records were not always trustful –wrong component identification or/and grid codes. These misleading records could be a result of the manual nature of the tracking process when recording the data on the site or typing it into the materials management system or of the unrecorded movement of steel pieces to different grids –recording of the movement of components from grid to grid could not be enforced. One way or the other, the reality was that these records misled craft workers and seriously extended the time to search for and find a particular component, in addition to potentially delay installation processes.

Second, a large number of steel components could not be immediately found by regular craft labor searches at the lay down yard. If one or more components required for installation could not be found based on the inventory information, extended searches were required. These extended searches would usually require four or five workers and were randomly extended over large areas –sometimes inclusive of the staging area. The average time frame to find these missing components was that of a morning, afternoon, or even a whole day. These exhausting searches had an important demotivating effect on craft laborers. In several occasions during these time-consuming and strenuous searches, distinct participating craft workers could not positively tell the researchers the item(s) they were suppose to look for.

Finally, it was also observed that erection productivity was negatively affected by the inability to rapidly retrieve the steel components recalled for installation. As it has been explained before, steel components were recalled from the lay down yard the same day or the day before their planned installation. The inability to rapidly search and find the lay down yard components frequently compromised the erection planning and forced steel crews to slow down their pace of work, negatively affecting installation productivity. Moreover, the lack of inventory control at the staging area also decreased the efficiency of installation activities. Erection crews were frequently unsure of the components readily available for installation. Crew members had to continuously double check on the existing and newly arriving steel items at the staging area to plan for a feasible installation sequence, preventing them from focusing on installation procedures alone.

4.4 *Re-engineered field materials tracking process*

For the purpose of this trial, a re-engineered field materials management process was implemented. This innovative management process benefited from an existing automated tracking approach (Grau 2008; Grau and Caldas 2009), which is briefly described in this paragraph. This innovative tracking methodology makes use of a combination of identification and localization sensors, and localization algorithms for data collection and location purposes. Each targeted components is tagged using an identification sensor, such as a tag. Then, identification and positioning receivers are held together in a piece of roving equipment for data collection purposes. At any moment in time the identification receiver collects the unique identification codes of the tagged components around the roving unit while the positioning receiver simultaneously determines its geographical coordinates. Then, localization algorithms processes the precise location of the tagged components based on the field sensed data.

Based on this automated tracking approach, the traditional tracking process described in the previous section was re-engineered. On the lay down yard, the steel components were uniquely tagged. Then, field data was collected on a daily basis by a roving bobcat unit (See Figure 1) equipped with RFID and GPS sensors ─the RFID sensor with a maximum communication range of 30m and the GPS sensor with a sub-meter positioning accuracy. Every time a set of the tagged components was recalled for installation, craft workers flagged the listed components based on a map that depicted their most recent situation in reference to site landmarks.

Once flagged, components were hauled to the staging area. There, the presence and position of the tagged components were also updated based on the same automated data collection approach. As a result, a list of the steel components present for installation and a map with their situation were generated for erection planning purposes. Finally, each tag was removed from its component during the rigging activity preceding its erection.

Figure 1. Data collection roving unit

4.5 *Experimental design*

Four hundred components from two identical boiler-support steel structures (A and B from now on) were at the core of the experimental design, which lasted a total of twelve weeks. Each boiler structure had assigned its own crews, foreman, and equipment, such as cranes. The existing tracking process was maintained for Boiler A components while the re-engineered tracking process was implemented for Boiler B components. The fact that the sequences of installation in the boiler structures were parallel during the experiment guarantees that the final results are not affected by timely variables such as weather or surface conditions, among others. Hence, records of four hundred steel components were collected both at the lay down yard and at the staging area for extremely similar boiler-unit installation sequences. Then, comparison of the collected records -taking the traditional tracking approach as a baseline- reflected the influence of the re-engineered tracking process on craft labor and erection productivity (See Figure 2).

In the storage yard, the experiment focused on capturing the amount of labor working time spent per steel component and the number of not-easily-found components. For this purpose, every time craft workers were given a list to locate Boiler A items or a map to locate Boiler B components, they had to write down basic search data (number of workers, start and end search times, and number of not found components). In addition, the authors recorded the time necessary both to inventory (Boiler A) and to tag (Boiler B) components. Hence, by direct comparison of the Boiler A and B set of records would clearly depict the influence of the automated tracking approach on craft labor efficiency (See Figure 3).

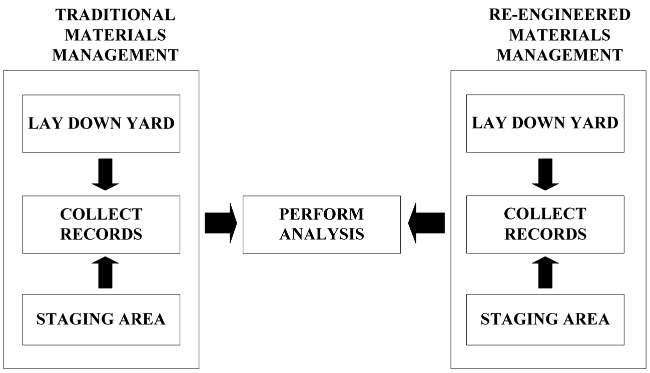

Figure 2. Experimental Design

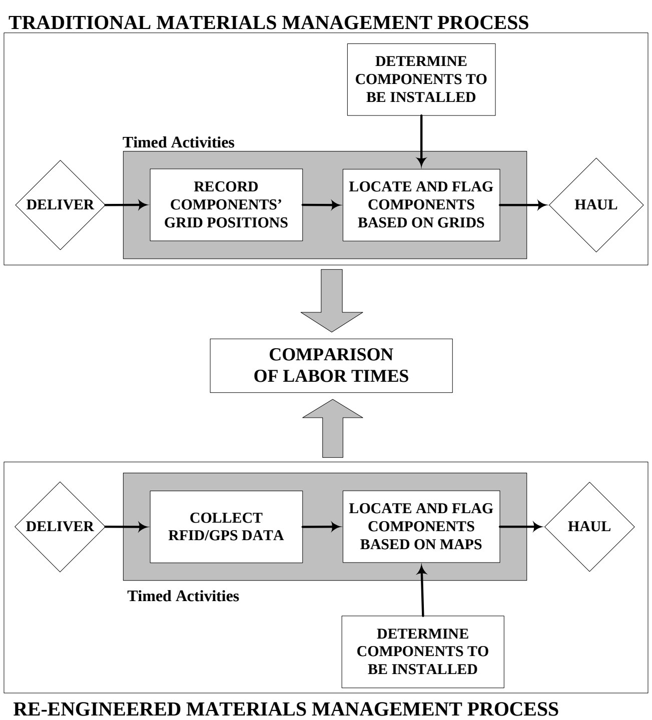

Figure 3. Lay Down Yard Methodology

In the staging area, the experiment focused on capturing the influence of the re-engineered approach on erection productivity. The reader should recall at this point that the manually-tracked steel items were not controlled in the staging area. Project controls and engineering records collected as part of the contractor's routine were utilized for this purpose. Detailed project controls captured the work labor hours for the two distinct boiler-erection crews in a daily basis. Engineering records captured the identification of the daily erected components altogether with their weight. Moreover, both Boiler A and B foreman filled a daily delay survey that captured work disruptions that were not accounted by project controls. Thus, this delay surveys recorded the number of lost work hours by the erection crews as a result of events such as the inability to erect components due to a crane breakdown. Since the activities of bolting, aligning, plumbing, torquing, painting, and inspecting were not affected by the tracking process option, they were not considered for the purposes of this experiment.

4.6 *Results*

The experimental results indicate that automating materials tracking processes can positively increase site project performance.

On the one hand, both the average labor time spent per steel component and the number of items requiring extended searchers by many workers simultaneously were significantly decreased at the lay down yard. Indeed, the number of not-easily-found components was almost eradicated for the steel pieces automatically tracked. The percentage of steel items requiring extended searches was reduced from almost 10% for the traditional tracked items to only 0.54% for the automatically tracked items. Daily update of the inventory records and precise map locations facilitated this minimization of difficult-to-find steel items in a proportion of 19 to 1.

In addition, the average labor time to inventory, search, and flag a steel component was reduced from in a relation of 8 to 1 for automatically tracked components (See Table 1). Craft workers spent 36.80 minutes per each steel component traditionally tracked. These 36.80 minutes are the result of adding the average times for inventorying (1.50 minutes), locating and flagging (6.73 minutes), and performing extended searches (28.57 minutes). The reader deserves a detailed discussion on average extended search time. As previously explained, the authors of this study observed that many workers had to simultaneously search for difficult-to-find components over long periods of time. Even though these extended-search times widely varied, ranging from a few minutes to a whole day or more, a conservative average was considered. Researchers mostly observed that four or five workers would spend four or more hours per each missing component. Conservatively, this study considered that an average extended search was carried by two workers during two and a half hours (300 minutes). Then, on average, 28.57 minute were attributed to each components traditionally tracked as a result of the 9.52% of these components that required extended type of searches. Complementarily, craft workers spent only 4.56 minutes per each steel component automatically tracked. These 4.56 minutes are the result of adding the average times for tagging (0.73 minutes), locating and flagging (2.20 minutes), and performing extended searches -1.63 minutes as a consequence of the 0.54% of difficult-to-find components. Overall, the time to search for the components that could not be initially found with the corresponding tracking process had a high influence on the average times for both the traditional and re-engineered tracking process (See Figure 4).

Table 1. Average labor time per lay down yard component

Tracking Approach	Time (min.)
Traditional	36.80
Automated	4.56

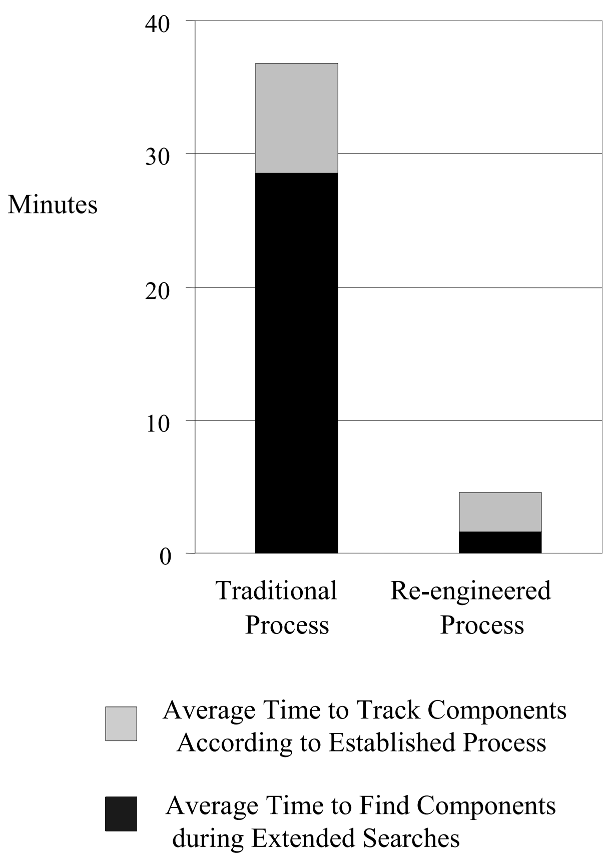

Figure 4. Average labor time per lay down yard item

In addition to this significant labor time reduction per yard component, the re-engineered tracking approach also resulted in more predictable searches of steel components with an average time investment of 2.20 minutes. In reality, individual average times to find listed components ranged from 2.8min to 19.26min for the traditional tracking process, while similar time measures only ranged from 0.82min to 5.16min for the automated tracking process. Coupled with the eradication of strenuous extended type of searches, this increased predictability when looking for steel components should be able to increase labor motivation and thus to further enhance their efficiency. Most importantly, this increased predictability can be used to better support the project execution processes that need to make use of the steel components.

On the other hand, steel erection productivity significantly increased in the staging area. A total of a 4.2% increment on the erection of automatically tracked steel components was determined (See Table 2)based on the collected data over the almost three months experiment. This significant increment has two plausible explanations. First, the crew members in charge of the erection of Boiler B components had the details of the components available for installation at the staging area at any moment, which allowed them to solely concentrate on erection activities. As opposite, the crew members in charge of the erection of Boiler A components had to still spend a significant amount of their time double-checking the availability of components for erection purposes. Second, the automatically tracked components were more readily retrieved from the lay down yard than those traditionally tracked. At this point, the reader should recall that traditionally tracked components were not only easier to find, but, most importantly, were made readily available for installation at the moment they were needed. This advantage allowed the Boiler B crew to more precisely follow the short-term installation planning than the Boiler A crew, which had to accommodate its pace of work to a slower and more unpredictable flow of components from the lay down yard.

Table 2. Improved steel erection productivity

Materials Management	Increment on Erection Productivity
Re-engineered	4.2%

In order to transmit the reader the significance of these results, two considerations need to be discussed. First, the traditional tracking process that served as the baseline for this study was extremely sophisticated. The authors visited ten prospective large sites for the purpose of this study, and selected the Sandow project site on account of the high level of sophistication of the contractor's materials tracking process. This level of sophistication was also well regarded by top management practitioners working for different organizations who, when questioned, emphasized the quality and reliability of the traditional tracking process presented in this paper.

Had this same study relied on a more common materials management process and set an equivalent lower baseline for comparison, the re-engineered tracking process would have likely resulted in more exaggerated project performance improvements. Second, the tracking objectives of this trial were heavy steel components. These bulky items are much easier to be misplaced and found than small and light type of components, such as pipe spools or valves. Had the study focused on tracking this more easy-to-misplace components, the results would have also been magnified.

4.7 *Impact on project performance*

Based on the previous results, almost a two to one return on investment (See Table 3) could have been realized by automatically tracking the almost ten thousand steel components belonging to the boiler units. Upfront technology costs per steel component are \$15.70. Each active tag cost \$15, while the rest of sensing equipment expenditures (sensors and antennae) only accounted for \$0.70 per component. Estimated cost benefits per steel component resulted in \$28.26. These benefits were divided in \$10.75 at the lay down yard, and \$17.51 at the staging area. In conclusion, \$12.56 per steel component could have been saved by automatically tracking all the steel boiler items. Even though technology maintenance costs were not considered, the reality is that the active tags –with a six year guaranteed lifespan-could be re-used on different projects or for different purposes, greatly reducing the impact of their upfront cost.

In addition to this positive return on investment, the increase pace of erection work would have resulted in a reduced installation schedule of six days per boiler unit.

Table 3. Cost to benefit results

Concept	Cost/Benefit per Tagged Item
Tracking Benefit	\$10.75
Installation Benefit	\$17.51
Technology Cost	(\$15.70)
Total Savings	**\$12.56**

4.8 *Additional Observations*

Additional observations complement the quantitative results discussed in the previous section as follows.

- *Movement of components at the lay down yard*. Almost 20% of the lay down yard components were moved at least once during the experiment. This result reinforces the need for more efficient approaches to track construction components.
- *Positive feedback from key project players*. The feedback from the project members intimately involved with the field experiment was extremely positive. According to the site materials manager, the re-engineered tracking approach was “a very good deal”. In addition, lay down yard workers repeatedly prompted for the possibility of tagging of all the components resting in the ten hectares lay down yard, since they experienced the high reliability of the daily updated component locations when compared to the traditional grid system. Finally, the general foreman in charge of the steel installation for both boilers considered that the tracking approach could effectively help in reducing installation times. These important remarks reinforce the sometimes undervalued notion that, in addition to positive results, the introduction of advanced sensing and information technologies on the field need to be accompanied by a positive and supporting attitude by the managers and workers making use of them.
- *Tag re-usability*. Out of the four hundred tags used during the almost three months study, only eight of them were eventually disabled at the end of the experiment. The rest of the tags could be re-used for other purposes.

4.9 *Limitations*

The authors recognize inherent limitations associated with the proposed re-engineering materials tracking process and its feasible implementation as discussed below:

- *Human dependence*. Even though the automated tracking methodology allowed for updating the inventory records of hundred of components in a small amount of time, human involvement was still essential in driving the rover unit, and in searching, locating, and flagging the components. A more automated approach should result in a shortened labor time spent per tracked component and an increased rate of return.
- *Short radio frequency signal transmissions*. The theoretical maximum transmission range of the active identification technology was largely limited as a consequence of the highly crowded metallic environment, which dissipated most of the energy from the transmitted signals. More powerful sensors with larger read ranges should result in improved tracking results.

5 CONCLUSIONS AND RECOMMENDATIONS

This paper quantified and assessed the impact of automated tracking technologies on project performance. For this purpose, a massive field experiment was conducted on the premises of tracking structural steel components. During the experiment, a sophisticated manual tracking process set up the baseline for comparison with a re-engineered tracking approach based on an automated tracking methodology.

Results indicate significant benefits derived from the adoption of automated tracking technologies for field materials tracking purposes. The average labor times spent per steel item was reduced in a proportion of eight to one. In addition, the number of components that could not be readily found was almost eradicated. Finally, the erection productivity for the automatically tracked components was increased by 4.2%.

These significant benefits have the potential to positively affect project performance. For this study, a two to one return on the technology investment and a reduced completion schedule could have been achieved.

The continuously decreasing costs of advanced sensing and information technologies coupled with their ever increasing level of possibilities promises to accelerate their presence in the industry in the years to come. Future research efforts should concentrate in incrementing the visualization of the material components throughout the supply chain, from design to installation, inclusive of procurement, manufacturing, and transportation. Complementary benefits should also be quantified in an effort to drive the widespread implementation of materials tracking technologies within construction industry organizations.

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