Characterizing the Non-Value-Added Relocation of Non-Bulk Components on Storage Yards

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ABSTRACT: In order to improve the effectiveness of an uncertain process ─the outcomes of which cannot be predicted, key players need to unfold the variables that hide behind it and measure their impact on the process. Currently, the process of relocating non-bulk materials on storage yards mostly falls under this uncertainty domain. While the fact that pre-fabricated items need to be repositioned for purposes other than those strictly productive is widely assumed by industry organizations, there is a lack of detailed research to understand these non-value-added relocations. This research relies on a case study to analyze and to quantify the non-value-added relocation of steel components. The analysis of their daily position coordinates coupled with the characteristics of these steel components is used to characterize their relocations on a typical yard. Preliminary results indicate that the percentage of components unnecessarily repositioned is much larger than actually perceived by industry organizations.

1 INTRODUCTION

In order to improve the effectiveness of an uncertain process ─the outcomes of which cannot be predicted with a minimum level of certainty, key players need to unfold the variables that hide behind it, understand their logic, and measure their impact on the process. Once the hidden factors are understood, their effect on the process can be optimized and process outcomes improved. In this regard, the author should notice the subtle but significant difference between uncertainty and risk that characterize intricate processes, such as those of construction. According to several authors (Eberbach 2005; Zatzman and Islam 2007; Hubbard 2007; Tannert et al. 2007), an uncertain process is that of which key players "have a limited or null knowledge to exactly describe its existing state or future outcome, more than one possible outcome" (Hubbard 2007). The existence of an uncertain process can either remain unnoticed or noticed to the player(s) but its behavior remains mostly unknown for the most part. This is radically different from risk processes. According to the fundamental work by Knight (1921) on risk, uncertainty, and profit, the influence of a risk on a given process can be predicted and the potential outcomes of the process can be forecasted with some level of confidence. This predictability typically results from prior data gathering and analysis efforts that have resulted in the generation of behavioral knowledge about the factors or variables affecting the process. In other words, an uncertain process that can be measured can also be predicted and treated as a risk process to no longer belong to the uncertainty domain, while an uncertain process remains as such when unmeasured or simply unobserved. For instance, the manufacturing industry could have never minimized the utilization of wasted resources ─those not adding any value to the produced goods─ if their existence had not been realized, the logic beyond them understood, and their large negative cost effects estimated. As a result of this new understanding, engineers have developed and implemented lean manufacturing techniques that focus on the elimination of these wasted resources for a more efficient production of finished goods.

In construction operations, many different and sometimes unpredictable variables collide in a kaleidoscopic effect, the negative effects of which are frequently obscured in the eyes of owner, engineering, and contractor organizations. These organizations mostly fail to observe, understand, and predict the negative effect of such variables on their projects. This lack of understanding is most accentuated on project sites, the teams of which are devoted to rapidly shape their projects against tight contractual milestones in a highly dynamic and harsh environment with almost no time left for realizing the effects or even the existence of the factors negatively affecting construction operations.

In terms of materials management, the huge impact of these management practices on construction operations remained unnoticed until a primary study from the Business Roundtable (1982) uncovered them. This study pointed out the strong relationship between the way materials are managed and project success indicators. Since this primary study, materials management processes have been continuously evolving ─mostly with the incorporation of sophisticated databases to better control the status of project components. However, materials management practices on the project site have remained, for the most part, unattended. In particular, the optimization of the movement of project site components has received almost no attention, partially due to the lack of tangible data to signify the importance of the topic. This paper presents a quantitative case study to uncover, quantify, and characterize the non-value-added relocation of non-bulk components on lay down yards, and to estimate their effect on total installed costs.

The rest of this paper is organized as follows. A review on the state-of-the-art on production and inventory management models for the manufacturing industry and their applicability to construction operations support a more detailed description on the state-of-the art inventory practices on the job sites. Then, the objectives and scope of this study are presented to the reader. In order to achieve these objectives, a valid methodology approach is defined. This methodology approach is supported by a quantitative case study on a real project site. Thus, the data collection, analysis, and results of the case study characterize the non-value-added relocation of non-bulk components on storage yards. Finally, the conclusions summarize the preliminary findings of this research.

2 LITERATURE REVIEW

This section provides a literature review on production and inventory management models, their applicability to the construction industry, the state-of-the art inventory practices within the construction industry, and on the previous efforts to characterize the non-value-added relocation of non-bulk items.

2.1 *Production and inventory management models*

While planned demand of construction components typically remains alterable or even uncertain, manufacturing demand commonly remains very stable and therefore can be predicted. The highly controlled manufacturing environments and the recurrence of most manufacturing production cycles stabilize the demand of the required parts and materials and therefore allow for their timely supply. This predictability has enabled the development of distinct production and inventory management approaches (inventory control, manufacturing resources planning, or just-in-time) to model manufacturing processes. In reality, the objective of any of these fundamental production and inventory management models and their variations is to ensure the correct supply and storage of parts and raw materials in order to strictly follow the planned production of the goods while minimizing expenditures. In case the demand cannot be exactly determined beforehand, a certain amount of randomness can be incorporated into the production and inventory model to replicate the actual demand fluctuation. A brief review on each of these fundamental production and inventory management models follows. First, inventory control models advocate for achieving a cost effective balance of the inventoried parts and materials, their replenishment frequency, and the produced lot sizes. So, inventory control models try to counterbalance between the maximization of product lot sizes that would minimize the costly setup times to ready a production line but will significantly increment the inventory of finished products, and the minimization of product lot sizes that would also minimize the inventory of finished goods but frequently disrupt the production line.

Second, manufacturing resources planning (MRP) models compute and schedule the internal demand of parts and materials to fulfill the external demand of produced goods. Based on the external known demand of physical goods, MRP models work backwards to determine the internal demand of parts and materials (push approach). Finally, just-in-time (JIT) models encompass the control of a smooth production flow ─right materials delivered at the moment they are needed and in the correct amount in each stage of the production line─ in front of external demand fluctuations of finished goods with a minimum (theoretically null) inventory. Then, each intermediate stage in the production system precisely acquires the materials needed from the upstream stage (pull approach). For their proper implementation, these three complex production and inventory management models require the coordinated efforts across the different business units (such as marketing, finance, engineering, and management) of the manufacturing organizations making use of them. In addition, demand, production, and inventory data need to continuously feed these models in almost real-time so they can immediately respond to internal and external events as these happen. So, the actual implementation of these distinct production and inventory approaches is associated with a high degree of complexity in order to realistically shape the manufacturing processes that they support.

2.2 *Applicability of production and inventory management models to construction*

Due to their high level of complexity, the previous sensitive manufacturing models cannot be easily translated into the erratic production flow that currently characterizes the construction industry. The unique characteristics of each construction project, their harsh and unpredictable production environments, and the industry defragmentation in many organizations with wide ranges of size, sophistication, and business structure prevents a steady and reliable demand of materials and components to satisfy installation operations. In addition, the adaptation of these manufacturing models needs to also be consistent with the behavior and characteristics of the construction industry as a whole, its organizations, and the way they interact with each other. Actually, the anecdotal implementation of production and inventory models on the job sites reflects their scarce utilization among contractor and construction-related manufacturing organizations to the present date. However, a few past studies have successfully implemented JIT models to support very specific types of construction applications.

Indeed, previous efforts have mostly focused on the applicability of JIT for pre-mixed bulk materials and pre-fabricated components, since these can be immediately supplied and therefore can better adapt to erratic demand patterns. Recently, Low and Wu (2005) have studied the implementation of JIT standards for ready mixed concrete firms, even though Tommelein and Li (1999) have argued that the production and supply of perishable ready-mixed process is, by its own nature, a peculiar instance of JIT production. Pheng and Chuan (2001) analyzed the feasibility to deliver and consume pre-fabricated concrete components for installation without holding minimum inventories, and hence alleviating total installed costs. Complementarily, Tommelein and Weissenberger (1999) have pointed out that manufacturing and construction processes requiring the immediate installation of the pre-fabricated products, such as steel or concrete components, are still distant from true JIT policies. In reality, these supply and installation of pre-fabricated components would still typically contain unproductive time buffers that would need to be eliminated to match a true pull manufacturing approach. In addition to the implementation of these manufacturing systems, lean thinkers (Ballard 2000; Thomas et al. 2002; Thomas et al. 2003) have specifically stressed that a continued and smooth flow of both materials and information results in an increased site efficiency. They have also demonstrated that matching the construction resources to the actual project site demand increases the chances of meeting cost and schedule targets.

2.3 *State-of-the-art inventory practices*

The absence of a modeled production system with a more predictable demand has oversized the storage of non-bulk components at early stages of a given project. This large buffer, coupled with adequate coordination and planning, has been regarded as critical for ensuring the availability of these components (Howell and Ballard 1996). According to the investigations of this researcher, senior project managers for industrial type of projects, which are made up of thousands of unique components, recommend having stored an inventory equivalent to at least 60% of the total number of components required to complete a given project at its early stages in order to ensure their availability on demand and hence to decrease the risk for major schedule delays and cost overruns. According to the interviewed managers, the size of the required buffers increases with the level of uncertainty associated with the supply of components upon demand. Indeed, this contrasted rule of thumb results from the inability to foresee and control both the supply and demand of project components and prevents the minimization of inventories by the implementation of just-in-time or near just-in-time policies.

The project that serves as the case study later in this paper (See section 5) is used to exemplify a typical situation in which a large buffer of components was utilized to decrease project risk. In that project, the production and supply of pre-fabricated steel components had been carefully planned according to distinct sequences of installation. Then, the contractor, which currently implements some of the most sophisticated materials management policies at the industry level, subcontracted the fabrication of a large percentage of the steel components to two large workshops according to the planned sequences of installation. However, at early project stages it already became evident that the supply of steel items could not cope with the installation pace. To solve this shortcoming, the contractor enforced the two primary shops to subcontract part of their steel orders to third parties. Moreover, the contractor also subcontracted new steel orders to other shops in order to further ensure a more reliable supply of fabricated items. As a result, what had been initially planned to be the sequenced delivery of steel items from two shops had suddenly changed to a less ideal and more complex scenario in which the steel was being supplied from fourteen different shops distributed within a large geographical area. In this complex scenario, site managers lost the visibility of individual steel items and hence could not predict their delivery according to the programmed sequences of installation. Accordingly, they urged the steel shops to produce and supply steel at their fastest pace in order to meet the installation demand by safely increasing the inventory of site components.

2.4 *Non-value-added relocation of non-bulk components*

The non-value added relocation of non-bulk materials on the job site has been mostly omitted from previous studies, even though the recognized negative impact of multiple handling practices on the sites on labor productivity (Muehlhausen 1991; Plemmons 1995; Mahdjoubi and Lang 2001; Navon and Berkovich 2006; Thomas et al. 2005; Caldas et al. 2006; Shakantu et al. 2008; Grau and Caldas

2009). Indeed, only a handful of previous studies have successfully addressed a few qualitative issues on the topic. Muehlhausen (1991) has reviewed materials handling and inventory management practices and addressed the potential impact of materials handling practices on estimates and schedule. Mahdjoubi and Lang (2001) have developed a simulation software tool for reducing the movement of non-bulk items on intricate project sites, in consideration of additional factors such as layout, facilities, storage area, and roads, among others. Navon and Berkovich (2006) have developed a framework for the control of construction non-bulk items along the supply chain and until the moment these are site-delivered. Finally, Shakantu et al. (2008) have also modeled and optimized the flow of materials based on a particular case study.

However, to this date the non-value-added relocation of non-bulk components on project sites has not been characterized. Hence, construction organizations are currently left to the resulting consequences from handling non-bulk items as a result of their inventorying policies without a proper understanding on how these handling processes impact their accrued costs. This research intends to fill this lack of detailed research on the subject.

3 OBJECTIVES AND SCOPE

The two-fold objectives of this study are described in the paragraphs below:

1. To analyze, characterize, and quantify the non-value-added handling of non-bulk components on typical lay down yards
2. To predict the impact of these multiple handling of non-bulk items on total installed cost based on project site characteristics

So, this study focuses on the analysis of non-value-added relocation of non-bulk components on lay down yards. Hence, the movement of components adding value for their installation (e.g. handling of components during their site delivery or during their retrieval for installation) are neither considered nor quantified for this study. In reality, any component movement other than those minimally required for their supply or installation could be eventually considered as waste according to lean thinking and just-in-time policies. In this study, though, the storage of components on lay down yards is considered an effective part of the installation process and hence the delivery and retrieval of yard components are regarded as productive tasks.

Due to the characteristics of the automated data collection technologies utilized for the purpose of this study (See section 6.2), the movement of a given component is to be recorded if the component displacement is beyond 10 meters between two consecutive data collection activities ─which happened every early morning and hence in a time span of 24 hours. Therefore, neither the displacement of a component in distances shorter than 10 meters nor the hypothetical relocation of a component backward and forward to the same position within a 24 hours time frame are considered for the purpose of this research.

In order to achieve the previous goals within the scope of this study, a scientific and rigorous methodology was developed.

4 METHODOLOGY

The methodology utilized to serve the previous objectives relies on a case study based on the analysis of reliable data collected on a typical jobsite. In particular, this case study analyzed the relocations of a random and representative sample of three hundred and ninety-one steel pieces that were stored at the site yard.

A brief discussion on the two basic methodology steps follows. First, given the impossibility to reproduce or artificially mimic actual site conditions and the vast and interconnected complexity of site variables affecting construction operations, a non-intrusive data collection approach was designed. Specifically, the data collection process was carefully implemented as not to alter neither the site conditions nor the manner components were managed and handled by craft workers. In addition to this non-intrusive data collection, the author planned for a long and massive collection of site records that could be statistically validated. Second, a descriptive analysis characterizes the non-value-added relocation of components based on the collected data. Complementarily, an exploratory analysis hypothesized on some of the conditions that prompted the relocation of components on the site yard. Site observations complement the previous analyses.

5 CASE STUDY

The case study is based on observations and data collected on a large industrial site located in central Texas. This site required the storage of a large number of non-bulk components, such as pipes, valves, handrails, staircases, steel components, and steel plates, among several others. A ten hectares lay down yard was used to store these non-bulk items from the moment they were delivered at the site till the moment they were required for installation. The yard was divided in grids of approximately 27.43m by 45.72m (30 feet by 50 feet), which contained the stored components, and internal roads around them to facilitate the access of lifting and hauling equipment.

5.1 *Site handling practices*

At the lay down yard, craft workers made use of light and heavy equipment to move the steel components. The type of lifting equipment to be used largely depended on the weight of the piece(s) to be moved. The weight of the steel pieces highly oscillated between 40 Kg and 20 metric Tons. Even though a tiny percentage of the steel components could be manually handled, the vast majority of the steel items required equipment to mechanically lift and displace them. Forklifts were normally used for the lighter type of components that could not be manually handled. Heavier equipment typically required the use of wheel-mounted telescopic boom cranes with a capacity of 30 metric Tons, while the heaviest components required the utilization of a crawler-mounted lattice crane with a capacity of 80 metric Tons (See Figure 1). Both cranes would typically require flat bed trucks to haul the lifted components to their new locations. Whenever possible, workers would use the lighter type of equipment possible to lift and displace stored components.

Figure 1. Crawler-mounted lattice crane lifting a heavy column

Grids were consecutively laid adjacent to each other in a two-column pattern. So, the maximum horizontal distance from an adjacent road to a grid component was the grid width (27.43m). This maximum distance limited the maximum size of the lifting equipment to the crawler-mounted lattice crane. Typically, the heaviest and largest components (such as columns) would be laid in groups not to difficult the access to other items. When grouping of these components was not possible or would required the relocation of many other previously stored components, the heaviest steel items were stored adjacent to the access roads to allow for an easier lifting and hauling operation.

5.2 *Automated inventorying of steel components*

For the purpose of recording localization and identification information on the three hundred and ninety-one steel components on a daily basis, an automated inventorying approach was implemented. In this approach, the steel components were tagged with active radio frequency identification (RFID) technology. Hence, each unique component identification code was associated with the unique numeric code of the tag attached to it.

For data collection purposes, a roving unit equipped with RFID and GPS receivers circulated the roads around the grids containing the steel items (See Figure 2). The RFID receiver would emit a signal that prompted the nearby tags to send their unique identification codes, which were collected by the receiver. Not all the nearby tags would listen to the wake up signal from the receiver, and not all the tag signal responses would be captured by the receiver. Simultaneously to the RFID communications, the GPS receiver determined the location of the roving unit. Therefore, at any given moment the coordinates of this roving unit could be associated with the presence of the nearby components. Time series of RFID and GPS data were collected at intervals of one second, eventually allowing for the detection of all the tagged components. Then, a customized localization algorithm based on a weighted centroide approach (Grau and Caldas 2009) estimated the location of the tagged components by processing these time series of RFID and GPS sensing data. The reader can find a detailed description of this data collection and localization approach in the previous reference.

Figure 2. Roving unit for collection of sensing data

6 DATA COLLECTION

Localization coordinates for the three hundred and ninety-one steel components were recorded on a daily basis during 49 consecutive working days from middle August to late October of 2007. Early in the morning, the author would drive a Bobcat equipped with the RFID and GPS receivers around the grids containing the tagged and the rest of steel components. During the data collection period, the yard grids were crowded with steel and other non-bulk items (See Figure 3). The steel components were stored in a 12,500 m^2 area.

Figure 3. Grid storage of steel components

Once the data was collected, the time series of rover positions and tag codes were post processed to obtain the estimated location of each tagged component as previously indicated. Both the collected and the processed data were stored in a relational database.

7 DATA ANALYSIS AND PRELIMINARY RESULTS

Results have been obtained to characterize critical aspects related to the non-value added relocation of steel components during their storage in a crowded yard for a total of 49 working days. These preliminary results follow. Out of the three hundred and ninety-one components that were tracked, more than twenty percent of them were moved at least once for reasons other than receiving or retrieving them. Since a large percentage of the three hundred and ninety-one components were indeed received for storage after the data collection process had started or retrieved for installation before this ended, the tagged components were only stored for an average of twenty two working days. This large percentage of relocations in such a short period of time contrast with the perception of the managers in charge of the field materials management processes, according to which the unnecessary movement of stored components was “minimal”. A similar perception was also shared by the craft workers who actually relocated the components, according to whom these relocations were incidental. In reality, these material relocations had never been quantified before, leaving a gap as a result of which contractor organizations are not capable of realizing their magnitude.

In terms of component weight, the results show that craft workers tend to relocate lighter items in detriment of the heavier ones. This can be observed by analyzing the number of relocations according to their range of weights (See Figure 4). A large percentage of the relocated components weight less than five metric Tons each, while the percentage of relocated components weighting more than five metric Tons each is much smaller in number. This natural tendency to relocate small components can be explained by two facts. First, lightest type of equipment (forklifts) was always available to relocate the stored items for a cost effectiveness aspect. Even though larger cranes were also present on the yard at all times, they were more dedicated to unload components at their receiving or load components for their retrieval when required for installation operations. Second, movement of light components with a forklift was much faster than a similar movement with the cranes. So, workers were more inclined to move a perhaps larger number of lighter components than a fewer number of heavier ones.

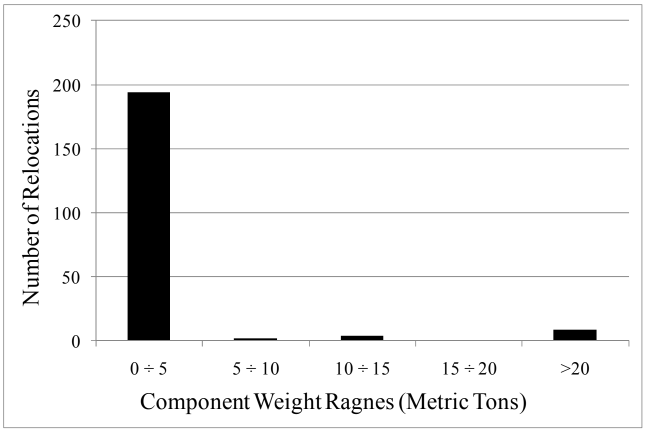

Figure 4. Number of relocations by steel item weight

Figure 5 presents the number of relocations according for components with a weight up to five metric Tons. In this case it is also clear that workers tend to relocate the lightest type of components first, probably motivated by a shorter relocation time. However, it is not clear from these preliminary results if the overall cost of the relocations could have been reduced by decreasing the number of relocations with heavier components.

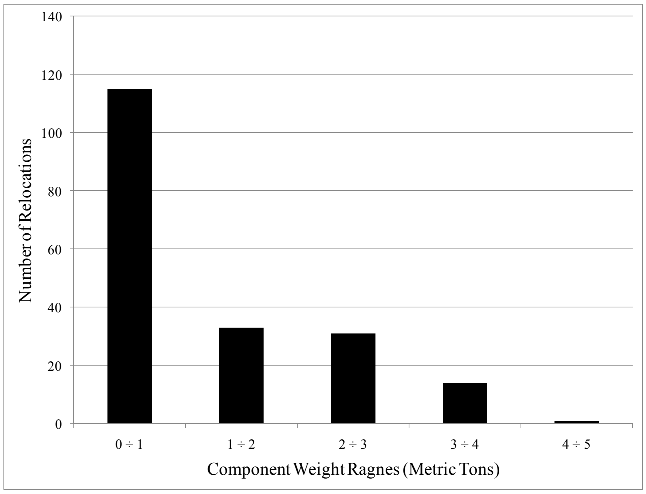

Figure 5. Number of relocations for steel items with a weight up to five metric Tons

This study is expected to provide a larger set of results, including the prediction of the average number of relocations of the stored components based on the average stored time and their incurred costs. These additional results will be presented at the CIB W78 2009 conference in Istanbul.

8 CONCLUSIONS AND RECOMMENDATIONS

This paper has presented a case study to characterize the non-value-added relocation of pre-fabricated components on storage yards. For this purpose, the coordinates of three hundred and ninety-one steel components was collected on a daily basis over a two months period. Having the ability to measure those movements allowed for tapping the collected data in search for novel valuable information for the construction industry prior knowledge. Preliminary results indicate that more than 20% of the tracked items were relocated at least once during their lay down yard storage. These large number of relocations contrast with the contractor perception of a minimal number of relocations.

This study will complement these preliminary results by further unveiling and quantifying other hidden aspects associated with the storage of prefabricated components on project yards. This additional quantitative data will be used to predict the average number of relocations of the stored components based on the average stored time and their associated costs. This cost prediction ability will also result in a more precise estimate of the holding costs of typical lay down yards, and it will also increase the awareness among industry practitioners on the need to reduce both the size of the storage yards and the component storage times.

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