A Case Study for Analyzing the Impact of Stakeholder Decisions on Project Duration

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Abstract

Job cameras are utilized by owners, developers, and prime contractors to communicate with stakeholders, increase site security and improve productivity. Most of the literature on job camera technology is focused on developing automatic object recognition at a jobsite to assess progress. Furthermore, there is insufficient literature regarding how owners may utilize job camera data to make planning, design and construction decisions. This case study analyzes the archived job camera photographs associated with the construction of a popular retail store on twenty-five separate sites in an effort to identify a relationship between planning, design and construction decisions on project duration. Researchers used an Analysis of Variance (ANOVA) to determine if there were statistically significant differences in the mean wall duration (dependent variable) based on four shell designs, five different sequence schemes and four start seasons. Results indicated statistically significant differences (.05 alpha) in mean wall duration based on start season (F=4.835, sig.=.010). The mean wall durations of the single decorative block wall system were not significantly lower than the cavity wall system. Similarly, the mean wall durations of projects with block being installed ahead of steel were not significantly different than projects installing steel ahead of block.

Introduction

Job camera technology has been used since the late 1990s by owners to keep the public aware of construction progress, by developers to showcase their talents, and by construction companies to streamline their processes. Its construction management applications have evolved from manual monitoring to automated tracking of construction progress [1]. While the benefits to existing and future projects exist in the literature, including a cost/benefit analysis [2], there is insufficient literature regarding how the data may be used to determine how project stakeholder decisions impact duration of the construction phase.

The authors present here a case study involving a single retail store developer building the same store on multiple locations in the southeastern United States. The planning, design and construction of each store is unique. While these stores share common corporate standard specifications to keep all stores close to the signature brand, each store has a different architect who designs the particular store to fit the location. Some of the choices made by the architect and engineer include such structural elements as the number of steel columns and the exterior wall composition. Once the store is designed by the local architect and the corporate office has approved the design, the construction manager may determine the order of construction. Upon receiving approval from store's corporate office and local city officials, the developer may initiate construction. The building start, therefore, may be in any of the four seasons.

If the developer knew that a relationship existed between the shell design, sequence scheme, when the project is started and duration of previously completed stores, the completion date of the project could be more accurately predicted and the designer could be better informed to make profitable decisions. In addition, the developer would be able to identify the impact of uncontrollable items on the schedule. For instance, if steel is backordered and the sequence scheme has to shift from installing steel before the block wall to after the block wall, the developer will be able to identify the added duration. Similarly, if pre-construction development activities get delayed so that the project is now starting in the winter months as opposed to the summer months, knowing the impact of such a change ahead of construction will assist the developer in mitigating the risk. Analyzing these variables, which are driven by stakeholder decisions and their impact on the project's construction schedule, was the focus of this study.

Data from the case study are reviewed to address three main research questions with regard to the impact stakeholder input has on project duration. These questions are as follows:

1. Is there a significant difference in the mean duration based on shell design?
2. Is there a significant difference in the mean duration based on sequence scheme?
3. Is there a significant difference in the mean duration based on start season?

Literature Review

While the researchers did not find previous research concerning the use of job cameras to study durations of similar projects on multiple sites, they did find several studies utilizing job cameras. This research will be presented here first. A second underlying principle in this study is the basis for such stakeholder decisions such as shell design, sequence schemes and start seasons. A third idea presented in this review is using job cameras to increase communication between parties in order to make better decisions.

Utilizing Job Cameras

Research based on job cameras is broadly divided into two approaches: human interpretation and computer pattern recognition of the images. In regard to human interpretation, job cameras have been used to train construction management students by requiring them to identify and sequence construction site activities uploaded to publically accessible websites [3]. This allowed students with little to no job-site experience to improve their performance on identifying and sequencing project activities.

The majority of the published literature regarding the use of job cameras has focused on developing electronic hardware and computer software to automatically recognize and interpret camera images. Even the research based on human interpretation (manual) can be assisted by hardware and software pre-processing of the image database. Some of the earliest work using this approach linked the images chronologically with the planned schedule [4]. The purpose was to later compare the actual progress of construction with the planned schedule. A real-time adaptation of this comparison between planned and actual progress was accomplished using secured Internet tools like video conferencing and shared whiteboards [5]. This allowed the remote jobsite to be electronically linked to the company's headquarters where analysis and decisions could be made in real-time.

Researchers have used four-dimensional models (4D: space and time) overlaid onto job camera images to enhance the comparison between as-planned and as-built construction progress [1]. A system of color coding was used to mark the as-built progress onto the as-planned model and schedule, thus providing a visual 4D progress report that claims to convey much more information than textual reports could.

Manual analysis of job camera images is time-consuming and tedious. Computer-automated image analysis was developed to identify (track) types of materials and equipment in jobsite images [6]. The purpose of the research was to automatically index images based on their content so that they might be easily retrieved later for a variety of planning and scheduling purposes. The research was continued by developing an interface between those indexed images and typical construction management systems and tools [7]. The concept of tracking construction resources (via jobsite images) was extended to a real-time capability [8]. The research showed it was possible to track not only static construction resources but also moving objects, including humans, and had the potential of improving safety at jobsites. Brilakis and Soibelman [9] streamlined the automated classification of objects within job camera images based on the expected shape of objects by considering the material type, date, time, location, etc. Another approach to enabling automated classification is based upon breaking down a construction project into work packages assigned to specific individuals or subcontractors [10]. The goal was to allow construction projects to be monitored more effectively by comparison of the as-built to the as-planned schedules. Teizer and Vela [11] focused on the automated tracking of personnel by using both stationary and moving cameras. The accuracy of automated object recognition can be enhanced by using 3D CAD information overlaid onto jobsite images [12]. The research reported 75% accuracy in the automated detection of 84 concrete columns within one jobsite.

Bohn & Teizer [2] reviewed state-of-the-art job cameras for project monitoring. The review reported that the benefits of using job cameras greatly outweighed the costs and that interviews of construction managers indicated they planned to continue to use job cameras in the future.

Case Study Stakeholder Decisions

Like most project types, construction projects include stakeholder decisions throughout the project life cycle including planning, design and construction. In regard to this case study, the independent variables were based on decisions from three entities. The developer is responsible for determining the start season in the planning phase; the designer selects the shell design in the design phase; and, the construction manager chooses the sequence scheme in the construction phase. Start season is usually driven by the desire to open the store as soon as possible. Thus, as soon as the developer is able to secure an agreement with the tenant to rent the completed store, the developer hires a construction manager and starts construction of the project. The goal at that point is to deliver the store as soon as possible so the developer/landlord is able to start receiving monthly rent payments from the tenant.

Shell design for the case study involved the selection of either a single-wythe or double-wythe (cavity wall) system. The benefit of a cavity wall system is that the air space between the two walls provides added insulation [13]. An alternative wall system involves a single-wythe wall with insulation placed either within the block or on the interior surface. Another perceived benefit of a cavity wall is that if water were to drive through the exterior brick it would travel down the inside of the cavity and then out installed weep holes, thus never reaching the structure's interior. While there are now single-wythe systems with drainage mechanisms, the old water permeance issues still plague the decision process. Groot and Gunneweg's [14] study of 26 historic mills in the Netherlands supports the selection of cavity walls for water tightness. This 2004 study found that when water permeates through a single-wythe brick wall, it causes damage to the brickwork, rots the interior wood structure, and adversely affects the living conditions within the mills. While construction methods, quality of workmanship, type of mortar and other variables play a part in both studies, Anand and Ramamurthy [15] found similar water issues in a single-wythe interlocking masonry block. Studies such as these fuel designer skepticism, yet single-wythe systems are used. In the present study, for instance, two of the twenty five stores utilized a single-wythe wall. The remaining stores utilized a double-wythe cavity wall system.

Sequencing is determined by the construction manager based on several planning factors including physical constraints. An example of a physical constraint is that a below-grade footing would need to be excavated before it could be reinforced. Thus, reinforcement could not take place before the hole was created. Researchers have created sequencing alternatives based on more specific constraints; for instance, driving activities can be delayed whereas non-driving activities may not be delayed [16]. The researchers in this 2007 study also pointed out that, due to the limitation of the current Critical Path Method (CPM) scheduling technique, construction managers often make changes to single activities rather than switching from one activity sequence scheme to another.

Stakeholder Portals

While the preceding section was written from the standpoint of the case study, each one of the preceding decisions is generally made by the party identified. These decisions are often made without consideration of the other two parties. For instance, the architect is not responsible for project duration, thus would not need to be consulted by the developer to determine start season or sequence scheme. The job camera website address, however, could be shared with all stakeholders to increase communication.

This is not a new concept. Web-based collaboration tools have been used for years and include job camera data, schedules, payment applications, requests for information and other communication tools [17]. Where these tools fall short, however, is in their treatment of the other stakeholders in the decision process. Collaboration tools are generally used to exchange files during a particular project rather than analyze past projects. By following the analysis techniques utilized in this study, stakeholders could start to see the possible connections between their past decisions to make better future decisions.

Methodology

Database

The primary researcher (first author) in this study has been utilizing job camera photographs to augment such construction education courses as plan reading, estimating, scheduling, and project control, since 2004. In 2006, he learned of a publicly available website provided by a developer specializing in constructing a popular retail store chain in the southeastern United States. The instructor contacted the provider of the site and was granted permission to use the information in his courses, research and papers. The website includes archived digital photographs from the construction of 38 retail stores. The interface allows the user to select a project and then click on a visual calendar of the project. Upon selecting a day, the user is able to see high-definition digital photographs of the project being constructed. The camera, which is located on an adjacent tower or building, takes a photograph every ten to fifteen minutes and uploads it to a server.

Samples and Data Collection

The researchers accessed the 38 stores on the job camera server. Of the 38 stores available on the server, four were removed from this study because they included various architectural elements that were drastically different from the standard model. Another nine stores were removed because they had one or more weeks blacked out making it impossible to identify a start date. This left 25 stores in the sample.

The researchers began listing the projects in Excel with the project number, location, model, sequence, concrete masonry unit (CMU) start, Brick End, Calendar Days and Start Season. The project number and location were assigned by the developer and had no meaning other than referencing the store on the job camera interface. Tables 1-4 provide the three separate shell design models, five distinct sequence schemes, duration calculations and the four start seasons.

Research Questions and Variables

Table 1. Shell Designs

Shell	Shape	Wall composition	Exterior Columns
1	Box with angled entrance	CMU/Brick cavity wall	thirteen
2	Box without angled entrance	Decorative block	six
3	Box without angled entrance	CMU/Brick cavity wall	thirteen
4	Box without angled entrance	Decorative block	three

Table 2. Sequence Schemes

No.	Order of Construction
1	Footing, starter block, exterior columns, slab, wall, interior columns, joists, roof
2	Footing, starter block, slab, wall/exterior columns, interior columns, joists, roof
3	Footing, wall, exterior/interior columns, slab, joists, roof
4	Footing, exterior/interior columns, wall/slab, joists, roof
5	Footing, wall, exterior/interior columns, joists, slab, roof

Table 3. Wall Durations

Row	Column F	Column G	Column H
Row 1	Block Start	Brick End	Calendar Days
Row 2	11/11/2008	1/9/2009	=(G2-F2)+1

Table 4. Start Seasons

No.	Month CMU Started	Start Season
1	December 21-March 19	Winter
2	March 20-June 19	Spring
3	June 20-September 21	Summer
4	September 22-December 20	Fall

The primary research question asked if there were significant differences between the mean wall durations based on 1) shell design, 2) sequence scheme or 3) start season. The wall duration represents the dependent scale variable for each of the research questions. Wall duration was chosen because it was the only duration that could be consistently identified on each of the projects. Several of the projects started their photographs with the footings already in place making it impossible to identify a true project start date. The independent variable changes for each research question. In the first research question, the independent variable is the shell design. As shown previously, there were four separate and distinct shell design models based on their shape and structural elements. In the second research question, the independent variable is the sequence scheme. Here, there are five separate schemes. In the third research question, the independent variable is start season.

Since a one-way analysis of variance (ANOVA) was used to compare the means of two or more independent groups [18], and all three research questions had two or more independent groups, the statistical analysis tool was utilized on all three research questions. A significance level of 0.05 was utilized.

Results

Table 5 shows the mean durations for each of the shell designs. There was no statistically significant difference between the mean duration based on shell design (F=.364, sig.=.780). Because models two through four had just one case each, two out of three of the ANOVA assumptions could not be met: normality and homogeneity of variance.

Table 6 shows the mean durations for each of the sequence schemes. There was no statistically significant difference between the mean duration based on sequence scheme (F=1.066, sig.=.399). Here, again, sequence scheme one included just one store. So the same assumptions violations noted above apply.

Table 5. Means Comparison of Wall Duration by Shell Design

Shell Design	Mean Duration (calendar days)	N
1	75.77	22
2	89.00	1
3	87.0	1
4	60.00	1

Table 6. Means Comparison of Wall Duration by Sequence Scheme

Sequence Scheme	Mean Duration (calendar days)	N
1	68	1
2	68	3
3	69.78	9
4	79.33	9
5	96.33	3

Table 7 shows the mean durations and Tukey's post-hoc significant differences test results for each of the start seasons. There was a statistically significant difference between the mean duration based on start season (F=4.835, Sig.=.010). Post-hoc test results indicated the significant difference was between projects starting in the winter months–December 21 through March 19—and those starting in the spring—from March 20 through June 19—as well as between those starting in the winter months and those starting in the summer months—from June 20 through September 21.

Table 7. Means Comparison and Significant Differences for Wall Durations by Start Season

No.	Mean Duration (calendar days)	N	Sig. Differences	Sig.
1	96.00	6	1-2	.039
2	68.25	8		
3	58.80	5	1-3	.011
4	81.17	6		

Conclusions and Recommendations

The focus of this study was to analyze the impact of stakeholder decisions with regard to building shell design, sequence scheme, and start season on project duration for the case study. Researchers analyzed construction progress photographs, acquired with the developer's job camera, of one chain store being built on several locations. The mean duration of each store was compared based on each of the three variables.

While the statistically significant results of the third research question, which indicated that weather adversely affected the duration of an outside activity, was predictable, the other two results were not. Constructing two walls, as in a cavity wall system, should take longer to construct than constructing a single wall. This was found not to be the case. Similarly, installing a building shell with thirteen exterior steel columns should take longer than a shell utilizing only six columns. The results of research question one, however, indicated that such selection had no significant impact on the duration of the project. In regard to sequencing, installing materials out of sequence should take longer than installing per plan. However, results of research question two indicated that sequence scheme did not have a significant impact on the duration of the wall.

Given the results of this research, it would appear that the architect does not need to consider shell design to accelerate a schedule. Furthermore, a cavity wall system is just as fast as a single-wythe wall system; thus, its selection need not be considered in regard to completion time. A future study of this data could analyze the impact of start season and shell design on project duration. In other words, if the project must start in the winter months, is it better to use a single-wythe design or a cavity wall design? Similarly, it appears that the construction manager's decision concerning sequence scheme does not impact the project's duration. If steel is back-ordered, for instance, masonry block may be installed prior to steel without the backlash of a delayed project. Future researchers might consider adding more projects to this sample to determine if average durations using the single decorative block decline. As indicated in Table 5, 23 out of 25 (92%) of the projects utilized the cavity wall design. If one were to add 21 additional projects utilizing the single-wythe design, perhaps the means would be significantly lower.

In addition to assisting future researchers address similar questions, this research may assist project stakeholders in communication. Other chain-store developers with multiple site partners could analyze their projects in a similar manner and share the results with their designers, construction managers and other partners. Future planning meetings may utilize the data to make better decisions before the start of the expensive design and construction phases.

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