

Duration Analysis with Job Cameras

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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. These papers examine only one jobsite whereas the present paper compares across many similar jobsites. Furthermore, there is insufficient literature regarding how owners may utilize job camera data to make design decisions. This study analyzes the archived job camera photographs associated with the construction of a popular drug store on twenty-five separate sites. Researchers used an Analysis of Variance (ANOVA) to determine if there were significant differences in the mean wall duration (dependent variable) based on four shell designs, five different sequence schemes, and four start seasons. Results indicated significant differences in mean wall duration based on start season (F=4.835, Sig.=.010). While this may seem an obvious result, what was not obvious was that the mean wall durations of the single decorative block wall system were not significantly lower than the cavity wall system. Similarly, the mean durations of projects with block being installed ahead of steel were not significantly different than projects installing steel ahead of block.

Key Words: Construction Productivity, Job Cameras, Duration, Scheduling

Introduction

Uses of Job Camera Technology

Job Camera technology has been used since the late 1990's 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 (Golparvar-Fard, Pena-Mora, Arboleda, & Lee, 2009). While the benefits to existing and future projects exist in the literature, including a cost/benefit analysis (Bohn & Teizer, 2010), no literature exists comparing the benefits to owners and developers building the same retail store on multiple locations. Furthermore, there is insufficient literature regarding how owners may utilize job camera data to make design decisions.

Chain Store Application

Many retail stores have standard specifications detailing the general shape, look, and feel of their store to keep all the stores looking similar to their brand. These standard specifications are provided to architects who design the particular store to fit the location. Some of the variables left up to the architect and engineer include such structural elements as the number of steel columns and the exterior wall composition. The developer may guide the architect in regard to a cheaper selection of materials or provide a preference in regard to the outside shell.

Need for the Study and Research Questions

If the developer knew that a relationship existed between the shell design, sequence scheme, when the project is started, and duration on 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.

This study addresses the following three research questions:

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

Research based upon job camera data is broadly divided into two approaches: human interpretation or computer pattern recognition of the images. 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 (Abeid, Allouche, Arditi, & Hayman, 2003). The purpose was to later compare the actual progress of construction with the planned schedule. A real-time adaption of this comparison between planned and actual progress was accomplished using secured Internet tools like video conferencing and shared whiteboards (Leung, Mak, & Lee, 2008). This allowed the remote job site to be electronically linked to the company's headquarters where analysis and decisions could be made in real-time. Job camera data has been used to train student construction managers by requiring them to identify and sequence construction site activities uploaded to publically accessible websites (Bruce, McCandless, Berryman, & Strong, 2009). This allowed students with no or little job site experience to improve their performance on planning and scheduling class activities. 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 (Golparvar-Fard, Peña-Mora, Arboleda, & Lee, 2009). 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 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 has been developed to indentify (track) types of materials and equipment in jobsite images (Brilakis, Soibelman, & Shinagawa, 2005). 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 (Brilakis & Soibelman, 2006). The concept of tracking construction resources (via jobsite images) was extended to a real-time capability (Teizer, Caldas, & Haas, 2007). 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 (2008) 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 enable automated classification is based upon breaking down a construction project into work packages assigned to specific individuals or subcontractors (Ibrahim, Lukins, Zhang, Trucco, & Kaka, 2009). The goal was to allow construction projects to be monitored more effectively by comparison of the as-built to the as-planned schedule. Teizer and Vela (2009) 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 (Yuhong, Hyoungkwan, Changyoon, & Han, 2010). The research reported a 75% accuracy in the automated detection of 84 concrete columns within one jobsite. Bohn & Teizer (2010) review the state-of-the-art of using 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.

Methodology

Database

The primary researcher has been utilizing job camera photographs to augment such construction education courses as plan reading, estimating, scheduling, and project control since 2004. In 2006, the author discovered a publicly available website provided by a developer specializing in constructing a popular drug store chain in the southeastern United States. The website includes archived photographs from the construction of 39 of the stores.

Samples and Data Collection

Samples were collected using the previously mentioned site. All data was interpreted by a human including the selection of the stores as samples and duration identification. Of the 38 stores, four were removed 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 for the researcher to identify a start date. This left 25 stores in the sample.

The researchers began listing the projects in MS Excel with the project number, location, model, sequence, 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.

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

Research Questions and Variables

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 the 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.

Statistical Methods

Since a one-way analysis of variance (ANOVA) is used to compare the means of two or more independent groups (Minium, Clarke, & Coladarci, 1999), and all three research questions had two or more independent groups, the statistical analysis tool was utilized on all three research questions.

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. These shell designs would need to have a distribution of duration values in order to assess these two assumptions.

Table 5

Means Comparison of Wall Duration by Shell Design

Shell Design	**Mean Duration**	**N**
1	75.77	22
2	89.00	1
3	87.0	1
4	60.00	1

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 includes just one store. So the same assumptions violations noted above apply.

Table 6

Means Comparison of Wall Duration by Sequence Scheme

Sequence Scheme	Mean Duration	N
1	68	1
2	68	3
3	69.78	9
4	79.33	9
5	96.33	3

The duration data for the start season variable met all of the assumptions for the ANOVA: the samples were independent and the populations were normally distributed and equally variable. The normality assertion was evidenced by the significance of the Kolmogorov-Smirnov Test and Shapiro-Wilk Test being greater than 0.05. The homogeneity of variance assertion was proven by the significance of Levene's statistic also exceeding 0.05. 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 of December 21 through March 19 and those started 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 Duration by Start Season

No.	Mean Duration	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

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. One would assume that like adverse weather conditions, the selection of a cavity wall would take longer than a single block wall. Similarly, one would imagine that the selection of a shell design with multiple exterior columns would take longer than a design utilizing half as many columns. The results of research question one, however, indicate that such selection has no impact on the duration of the project. One would also assume that installing steel ahead of block would be the most efficient way to install the shell of a steel and block-walled structure. However, results of research question two indicated that sequence scheme did not have an impact on the duration of the wall. Given the results of this research, it would not appear that the architect needs to consider shell design to accelerate a schedule.

Future studies could look at 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.

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