Workflow Analysis in Production Homebuilding

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Homes in the Phoenix, Arizona area are constructed by trade contractors: a typical home requires between 25 and 35 trade contractors for the construction process. (Bashford, et. al., 2005) Typically, the homebuilder controls the construction schedule, allotting specific time slots for each of the trades to complete their work. The amount of time required to complete homes (the cycle time) in the Phoenix market is well documented. However, little documentation exists describing how the cycle time is utilized. The purpose of this study was to provide documentation of the utilization of the cycle time during construction. Data was collected from three single family homes with size ranging from 1,918 to 2,115 square feet, all single story, by directly observing the construction operations over a period of five months in Gilbert Arizona. The data collected included the number and distribution of man-hours needed to build the three homes, and documentation of the tasks being performed at the site. The data was collected from November 18, 2005, the day construction started, until April 28, 2006 when construction was completed. It was found when comparing the number of days in which any work was performed to the number of working days utilized to complete the homes that on average, no work was performed on 45 of the available 120 working days. Of the 1200 hours available for work in these three homes (120 working days at 10 hours per day), an average of 304 hours (25%) were utilized, leaving an average of 896 hours of unutilized time.

Keywords: Residential Construction, Productivity, Workflow Data, Construction Planning, Scheduling

Introduction

The activities required to construct a single family home are generally similar within the Phoenix metropolitan area, and are well-known to the building community. What is not clear is why significant variations occur in the time required to complete the construction of homes (termed the cycle time). Previous work by these authors has shown that cycle time can vary between 90 to 200 calendar days, with variations being independent of weather and season of year, and only moderately attributable to the size of the home (Bashford, et. al., 2005). There is some indication that construction cycle time is generally related to regional volume of construction, which leads to an interesting observation. The popular notion frequently expressed is that as volume of construction increases, builders start building houses faster (Fiscus, et. al., 2001). The truth is the opposite. The authors were curious to document just what does happen during the construction of a typical house during the construction cycle.

A literature review failed to produce any substantive studies documenting the actual activity at a home site during the construction cycle. There is a lack of gathered data in the residential construction sector and consequently there is not a benchmark available for process improvement (Love, 2003). The purpose of this study was to provide that documentation. This study documents the number of man-hours needed to construct a single family residence and the distribution of that time during the construction process, thereby beginning the process of creating a benchmark for the residential construction industry.

Motivation

The existence of significant idle time in residential construction is a subject of debate. Idle time is a span of time where no activity takes place on the construction site. Currently there is no data available that documents idle time in residential construction. The suggested data would be valuable for both homebuilders and the general public. Homebuilders would benefit because they would be able to optimize their construction process, shortening the cycle time of building a home. It would also set the groundwork for further research in the inefficiencies and optimization of residential construction.

Methodology

The purpose of this research is to accurately document the number of man-hours needed to construct a single family residence. Time durations of the various construction activities throughout the construction process will be obtained. In order to accomplish this, the following information was established at the beginning of the project as data to be collected: the lot number of the house being observed; the date the observation was recorded; the trade performing the work; the time crew members arrived on site; the number of crew members; the start of the activity; the start time of breaks; the finish time of breaks; the time an activity ended. Activities being done a second time due to defective construction had its durations attributed as rework.

A list of the trade contractors performing work on the site was obtained from the home builder prior to the beginning of construction, together with a description of the type of work performed by each contractor. This allowed the data collectors to know the work and the contractors that were working on the jobsite on any particular day. As a result, it avoided both complications of observing vehicles of contractors that were not clearly marked and communicating with site workers who spoke little English

Calculation of Man-Hours

The time of arrival, the time of departure and the number of crew members allows for the calculation of daily man-hours. This calculation is as follows.

Daily Man-hours = ((Activity End Time – Activity Start Time) – (Break End Time – Break Start Time))* Number of Crew Members

The sum of the man-hours by activity results in the time duration for each activity in the construction process. The sum of all the activity durations is the total time taken to build the home, termed the cycle time.

Site Activity

This same information is used to determine the hours of activity for each house, referred to herein as site activity. Site activity is a measure of activity occurring on the house per day. The man-hour formula described above is modified to represent site activity. For example, the framing subcontractor charged with framing the house began at 7:00 A.M. with a crew of nine, worked until 11:25 A.M. and took an hour break for lunch. The subcontractor began working again at 12:25 P.M. until 5:00 P.M. The daily man-hours and the site activity for the framing activity on this particular day would be calculated according to the formula below.

Daily Man-Hours = ((5:00 P.M. – 7:00 A.M.) – (12:25 P.M. – 11:25 A.M.)) * 9
Daily Man-Hours = 81 man-hours
Site Activity = 9 site hours

As construction was assumed to cease during the weekends, documentation of times followed a five day work week. The following seven holidays were excluded from the calculation: Thanksgiving, Christmas Eve, Christmas Day, New Years Eve, New Years Day, Presidents Day, and Valentines Day.

Treatment of Activities Identified as Rework and Delivery

For purposes of this study, upon the unequivocal identification of any rework activity, the entire rework man-hours were discarded from the data. The rationale for this is that if the work were done correctly the first time rework would not be necessary. Nevertheless, it is a common occurrence in construction and cannot be easily dismissed. For example, if the stucco subcontractor is in the process of installing the foam onto the exterior of the home and one of the pneumatic staples pierces a PVC pipe previously installed by the plumbing subcontractor, the plumber must incur rework time in fixing the pipe even though the plumber was not at fault. Conversely, rework activity durations were not omitted for the calculation of site activity hours as this time represents progress being made on the structure and activity on the site. Material delivery times were excluded from all activity durations.

Pilot Study

A pilot study was performed on 30 September, 2005 to train the data collectors to identify and tabulate data accurately. The construction activities on three homes were recorded to mimic what was planned for the study. The pilot study helped to refine the data collection process by identifying potential data recording errors.

Beginning and End of Study

The beginning of the study was determined to be the first day of field construction activity, with the first activity being the layout of the perimeter performed by the concrete trade contractor. Activities prior to this, such as the design and permitting process while certainly important, were not included in the study.

The end of the study was determined to be the day before the creation of the final construction punch list. A punch list is a final list of corrections usually created during a meeting with the homeowner and superintendent.

Limitations

Although the data collectors were trained, and major efforts were made to coordinate their work, several construction activities including the installation of windows, the setting of the roofing tile on two of the three homes, and the roofing finish activity on two of the three homes were missed. Some variations in the written descriptions of work activities also transpired during data collection. To minimize this impact, a weekly data collectors meeting was held to discuss in detail the activities that took place during the week. Variances were addressed during the meeting and the data was adjusted to bring conformance of work descriptions.

The small sample size of three residential homes may not be valid as a generalization to a larger population. The homes observed in this study were constructed in the Phoenix metropolitan area, which also limits the generalization of the results of the study. No effort was made to quantify the productivity, efficiency, and interaction of the activities performed. As such, the results lack information on how the efficiency of activities affect cycle time and limits the scope to the times and durations of activities in a residential homes construction.

Results and Analysis

The activities and subsequent duration times of the three homes are presented in the form of a process flow diagram (see Appendix A).

Process Flow Diagram

Appendix A shows the activities of lot 2001 as they happened on the construction site. Each construction activity is found in a process box and the associated duration is listed below the activity title. The duration is the sum of the observed man-hours for each activity, not including delivery and rework time. Activities that were part of a larger activity were grouped together. For example, the concrete portion of the construction consisted of the following activities: layout, form work assembly, post tension cable installation, concrete placing, finishing, and stripping and removing forms. All of these activities were grouped together and reported as concrete activity.

Activities missed were recorded either on the process boxes or in annotation boxes throughout the process flow diagram. Most of the activities missed were city building inspections.

Activity Durations by Activity by Lot

Figure 1 below compares the number of man-hours for each activity on each lot.

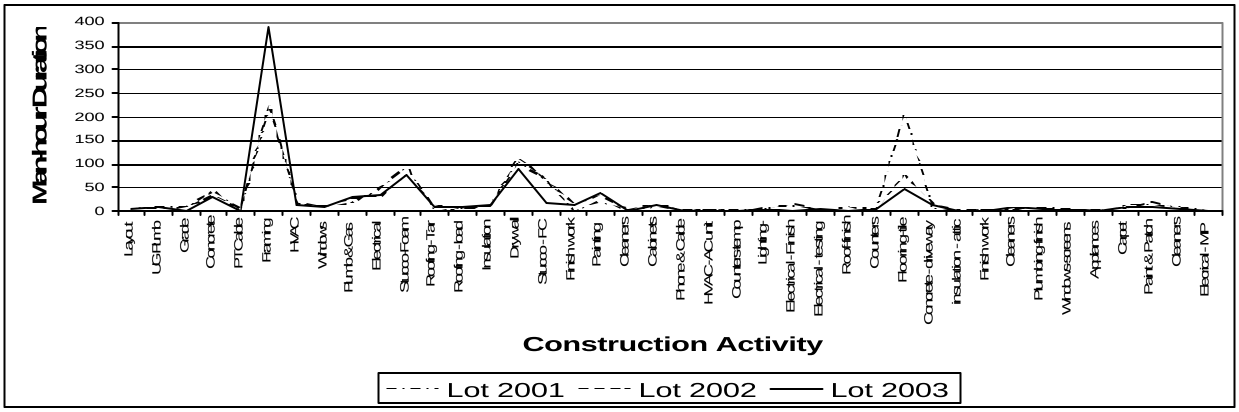

Figure 1. Construction activity duration by lot.

Figure 1 reflects the similarity between the numbers of hours for each activity for each lot. The framing activity consumed the most man-hours and showed the largest difference between lots, requiring 217.58 hours, 226.37 hours, and 390.1 hours for lots 2001, 2002, and 2003 respectively. Lots 2001 and 2002 used prefabricated open panel walls, while the walls for lot 2003 were completely framed on site. This suggests the prefabricated wall panels saved about 80 hours of on-site labor.

The second largest disparity between activities was found in the flooring activity. The flooring activity for lot 2001 was more than double the duration of that of lot 2002 and more than five times that of lot 2003. This difference is attributed to the customization of the type, pattern, and size of floor tiles for lot 2001, resulting in significantly different installation times.

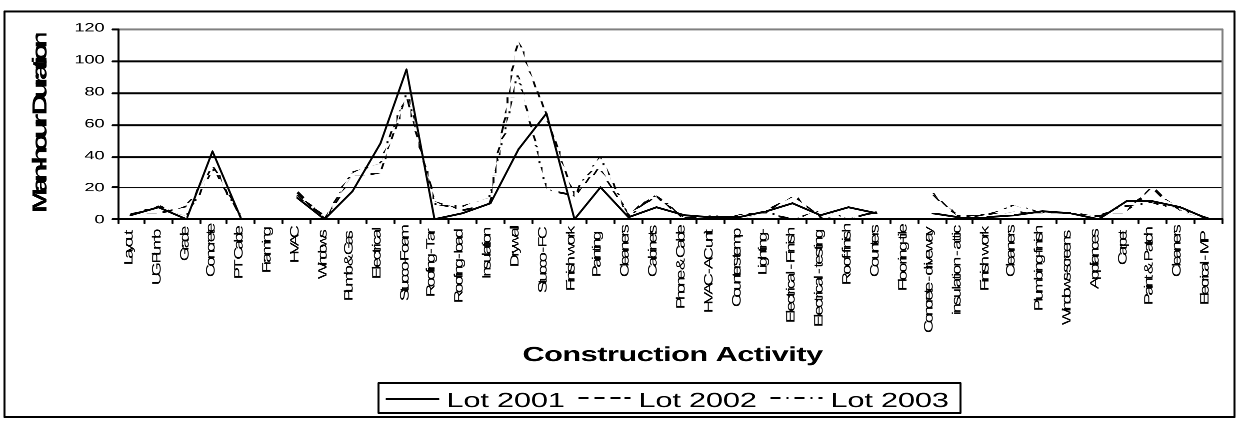

Figure 2. Construction activity duration excluding framing and flooring-tile.

When the framing and flooring tile activities were omitted as shown in figure 2, there were three notable peaks: concrete, stucco-final coat, and drywall. The concrete activity for lots 2002 and 2003 were within two hours of one another. Lot 2001 is about ten hours more. The stucco-final coat activity for lots 2001 and 2002 were extremely close in duration; 66.45 hours and 65.08 hours. The drastic difference for lot 2003, 18.70 hours, was attributed to miscommunication between the project team resulting in only part of the activity duration being recorded for the lot 2003 stucco final coat activity. This should be treated as an outlier.

The drywall duration times for lots 2002 and 2003 are 112.65 hours and 91.32 hours. The drywall activity for lot 2001 on the other hand is an anomaly. Only 43.92 hours, half of that of the other two lots, were recorded for this activity. The variance is attributed to miscommunication within the project team, resulting in a portion of the activity duration not being recorded. The duration of the electrical rough-in activity for lot 2001 is almost 20 hours more than that of lot 2002. The increased duration for lot 2001 is attributed to the use of a new apprentice on lot 2001 who required teaching and on the job training by the other crew members, resulting in longer installation duration. Closely related to the electrical construction activity is the electrical testing activity. The data for this activity showed a large variability. Lot 2001 recorded 2.35 hrs, lot 2002 0.5 hrs, and lot 2003 5.83 hours. Both lots 2001 and 2003 required repairs which were made during the testing activity and recorded as electrical testing.

Table 1
Total man-hours and rework hours by lot.

	Square Footage	Documented Man-Hours	Documented Rework	Estimate of Missed Man-Hours	Total Hours (documented + missed)
Lot 2001	1,918	935.78 hrs	6.17 hrs	98.0 hrs	1033.78 hrs
Lot 2002	2,115	876.9 hrs	22.57 hrs	18.0 hrs	894.90 hrs
Lot 2003	1,918	861.25 hrs	34.62 hrs	60.0 hrs	921.25 hrs

The total man-hours recorded by lot do not include time recorded for delivery or rework. All of the times are within 7.5% of one another. The estimate of missed hours for all lots was determined using information in the man-hour activity durations found in figure 1 and 2. The partial activities not recorded due to the miscommunication within the project team were estimated using the complete activity durations on the other lots. Lot 2001 was missing 16 hours from the painting activity, 12 hours from the concrete driveway, an estimated 10 hours for the installation of the windows, and 60 hours of drywall activity, totaling 98.0 hours.

The missed hours for 2002 were made up of the following. Eight hours were attributed to the roofing finish activity and the remaining 10 hours for the installation of the windows, totaling 18 hours. The estimate for the missed hours for lot 2003 consists of the 50 hours for the stucco final coat activity and 10 hours for the installation of the windows, totaling 60 hours.

Site Activity by Day

Site activity by day is a measure of the activity occurring on each lot. The hours from 7:00 A.M. to 5:00 P.M. have been used for the standard workday, resulting in a ten-hour day. The site activity is shown on figures 3, 4, and 5 in black. The idle time is its complement and represents no activity taking place on the construction site. For purposes of this calculation rework time has been included. The construction site is active while the rework activity takes place and therefore has been included to portray the true workload through the project. The site activity figures 3, 4, and 5 for each of Lots 2001, 2002 and 2003 were very similar. Each has periodic spikes of activity connected by large amounts of idle time. There was more site activity towards the end of the construction cycle in lots 2001 and 2002.

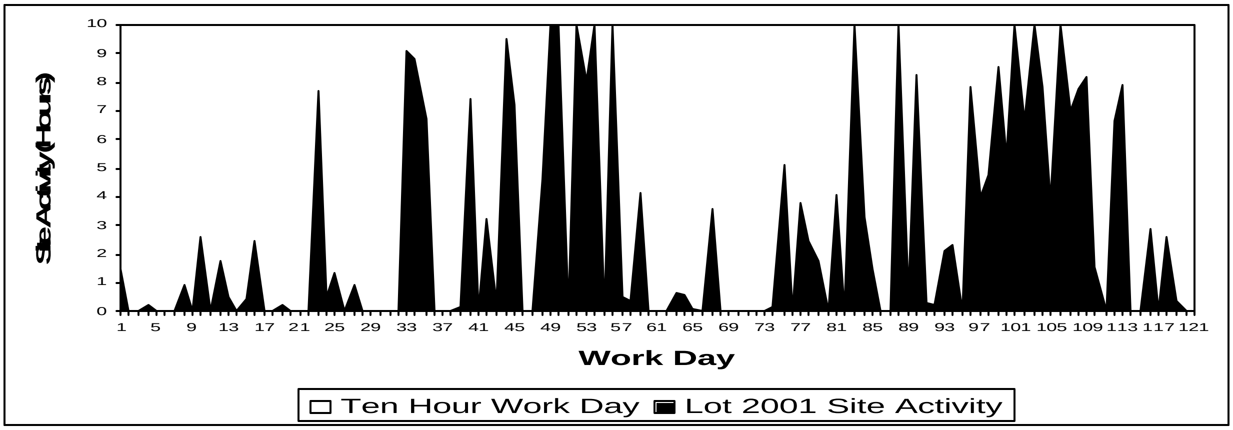

Figure 3. Lot 2001 site activity by work day.

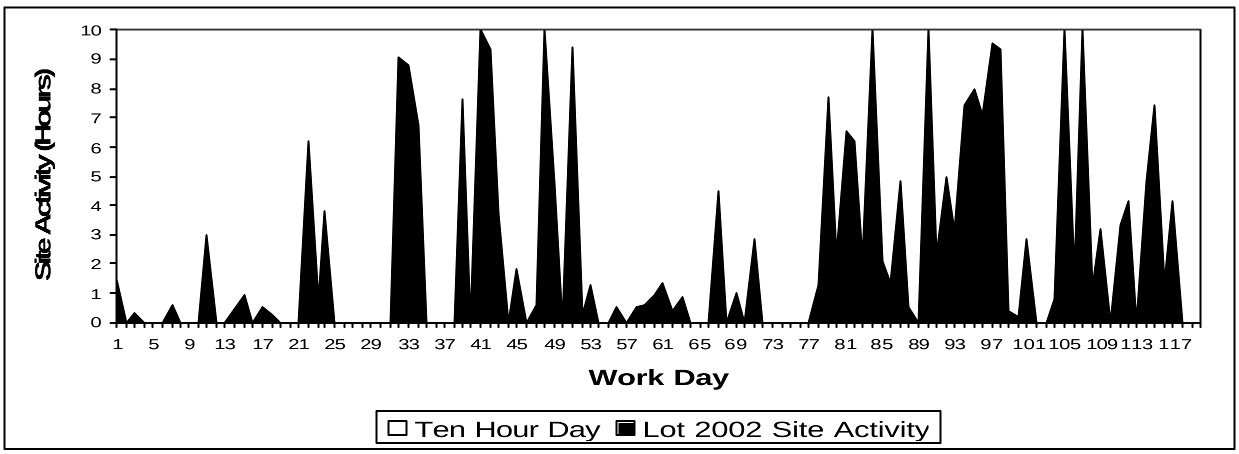

Figure 4. Lot 2002 site activity by work day.

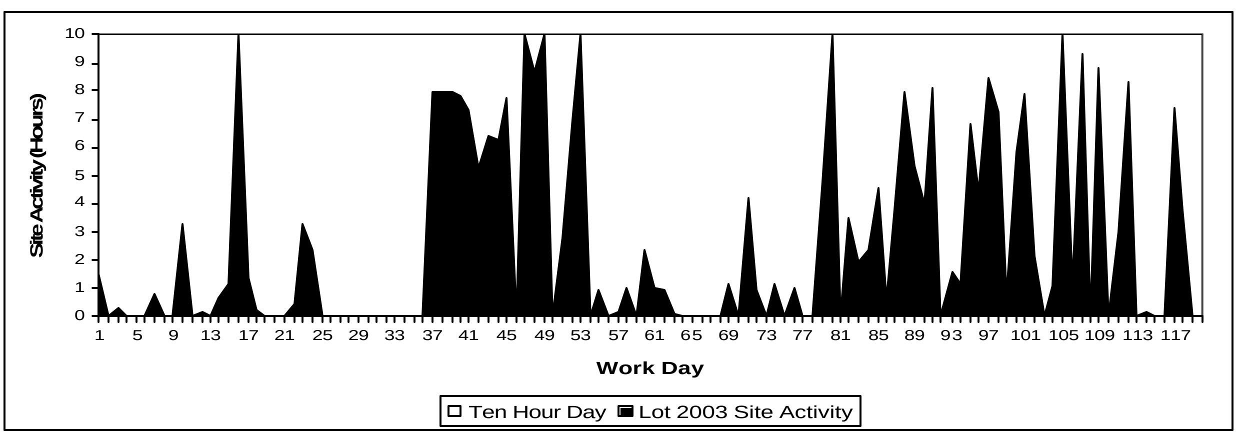

Figure 5. Lot 2003 site activity by work day.

The results shown in Table 2 for the row labeled “Total Site Activity Hours” are the sums of the site activity durations listed on figures 3, 4 and 5. The total days without any site activity show lot 2001 with 48 days of no activity, lot 2002 with 50 days of no activity, and lot 2003 with 50 days of no activity.

Table 2
Site activity results by lot.

	Lot 2001	Lot 2002	Lot 2003
Work Days (Cycle Time in Days)	121	120	120
Site hours per day	10	10	10
Total Site Hours	1210	1200	1200
Total Site Activity Hours	325.93	277.48	310.02
Percentage of Site Activity	26.9%	23.1%	25.8%

Improvement Opportunities
Koskela (1992) suggests that improvements in a production environment may be realized by reducing any of the four following areas: processing time, inspection time, waiting time, and move time. The largest area for improvement suggested by the data in this study is to reduce the amount of idle time, or wait time, involved in the production process.
K. Hovnanian, a home building company, took a challenge in 1999 to see just how quick a home could be built. The company started with a slab and completed a 2,000 square foot home in Lakewood N.J. in 4 days 5 hours and 27 minutes, working from 7 a.m. to 5 p.m. It is clearly possible to drastically increase efficiency by eliminating idle time. "We did it just to prove it to ourselves that it could be done" (Sawyer, 2006).

The standard management model may account for the lack of fluidity in the construction process of the observed residential homes. "The current and most prevalent model comes from Frederick W. Taylor, the 'father of scientific management' "(Bashford, et. al., 2005). The theory behind this model is that by breaking the task down into separate pieces and improving the efficiency of each piece the project as a whole will be more efficient. The data suggests that tasks done in a shorter amount of time does not address the inefficiencies of idle time between tasks. Hence, there is evidence showing that focusing on the efficiency of tasks does not guarantee efficiency for the process as a whole.

Reasons Why Homes are Not Built Faster
There are many reasons why homes are not built faster. "Scheduling is listed as one of the major reasons by K. Hovnanian why homes are not constructed more quickly. Scheduling across a large number of home construction jobs also causes a problem" (Sawyer, 2006).
One of the limitations in the current management model is the lack of attention given to the interrelated characteristics of the production system (Bashford et. al., 2005). The system model tends to take a limited project view rather than an enterprise view. These important, neglected characteristics include the amount of work in process in the production system, the throughput of the system, the integration of the related supply chains, and utilization of resources. Behavioral differences of those involved in scheduling increase the variability, reducing reliability of the schedule.

Conclusions and Recommendations

The large amount of idle time identified in this study leads to the conclusion that there is substantial time that is currently wasted where production activities could take place. The claim is not made in this instance that, as Koskela (1992) suggests, all waste or idle time should be removed from the production system. A reasonable amount of buffer is necessary to ensure that trade contractors have enough time and space to complete their respective tasks in an orderly fashion. They then can move on without interfering with subsequent trade contractors.

Substantial opportunity exists to reduce the overall cycle time observed in this study. Doing so will result in more operating capital for the home builder. It will also reduce the amount of time it takes to deliver a finished product to the customer. It is thought that this effort will be accomplished through increased accuracy of scheduling, resulting in better coordination and execution of work performed by trade contractors.

Further Study

In order for the findings of this study to be generalized to a larger population it is imperative that the sample size be greater. By increasing the sample size and randomly selecting houses the results can be generalized to a larger population. According to Olomolaiye (1998), for the timing of an operation to be effective it must be coupled with a rating. Thus, utilizing a rating system to quantify the efficiency of activities will shed light on the interaction between task efficiency and cycle time.

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Appendix A

Process Flow Diagram