CYCLE-TIME CONTRIBUTIONS OF HYPER-SPECIALIZATION AND TIME-GATING STRATEGIES IN US RESIDENTIAL CONSTRUCTION

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ABSTRACT

High-volume home building (those homes built in large subdivisions by large homebuilders) in the United States has undergone a gradual increase in construction cycle time from start to closing over the last two decades. Part of the increase may be attributable to a concomitant increase in the size and complexity of the typical production home. Cycle times on the order of 2 months were common 20 to 30 years ago in the industry, whereas 6 to 8 months is more common at present; this dramatic increase cannot be explained by differences in the size and specification of the homes being built alone.

Most large production homebuilders in the United States have discontinued the practice of self-performing work on their projects, and instead rely upon a network of highly specialized subcontractors organized by trade or activity. This change was motivated by the search for efficiency and cost reduction at the individual task level. In the present production system, 30 to 40 individual subcontractors must be coordinated to complete 100 to 150 separate activities at the home site. Typical value-stream maps of portions of the residential process are presented, illustrating the large number of interfaces or handoffs between organizations which result in the production system. Substantial quantities of wasted time are documented in the production process based on field observation. Much of the wasted time can be attributed to the large number of interfaces and the time-gating strategy of turning over each home to each trade in one day increments. The implications are demonstrated conceptually and quantitative results are derived from process simulation. The paper provides suggested modifications to the production system to reduce cycle time, even assuming existing production methods (at the activity level) are maintained.

KEY WORDS

Residential construction, production systems, process mapping.

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INTRODUCTION

The residential construction industry constitutes an extremely large industry sector with significant economic importance. Estimates suggest that there are more than 3.5 million US workers in the industry, who collectively produce approximately 1.5 million new homes (NAHB 2001), worth about $225 billion, every year. Housing investment and consumption contribute one-fifth of the US gross domestic product (JCHS 2002) and the US housing stock has developed into the nation's largest single assets with a total value that exceeds that of the US equity markets. The industry sits somewhat apart from the rest of the construction industry, however. Its product is perhaps the most like mass-production of all the construction industry sectors, and in fact a significant use of factory-built component exists in the US and worldwide.

In the United States, this factor has created pressure for consolidation in the sector over perhaps the last decade, giving rise to "high-volume builders" who may construct several thousand housing units each year (Taylor and Björnsson 2002, Walsh et al. 2002). This consolidation was motivated by the cost efficiencies which arise from demand pooling, and also provide a critical mass of units to attempt to employ mass production principles similar to those in common use in manufacturing (Bashford et al. 2003b). Key characteristics of high-volume builders in this context include the following (Walsh et al. 2002):

- The large size and capitalization of high-volume builders allows them to obtain large tracts of land.
- These large tracts are typically developed as thematically connected subdivisions for particular target markets. A small number of floorplans (perhaps 4 to 8) with different front elevations and a fairly small number of options are constructed repeatedly in the tract (perhaps 100 to 400 lots).
- A sales office and a model of each (or most) available floorplan is constructed at the subdivision.
- Site superintendents employed by the homebuilder manage construction of the homes, which are built entirely by a network of trade contractors with the homebuilder typically self-performing no work.

The network of trade contractors required to complete the home has been conceptualized as a linear progression of key activities. Bashford et al. (2003a) described an analysis of various production management strategies using a simulation involving a simplified process including 10 linear steps, modeled generally on the parade of trades concept (Tommelein et al. 1999).

A very similar process for new home construction has actually existed in the US for some time, with an emphasis on lumber for the exterior envelope. Prior to the consolidation described previously, homebuilders tended to operate in individual markets of regions, and self-performed much more of the work. Cycle times on the order of 2 to 3 months for new home construction were common in this era, perhaps 20 to 30 years ago. Over the intervening time, homes have become somewhat larger, and some increased complexity has accrued to the building services. In particular, higher standards are commonly employed for the energy performance of homes, and communication systems are certainly more complex. Lifestyle options such as central vacuum systems are also more common in the current market. All of these systems are entangled into the structural frame, which undoubtedly increases the complexity and duration of the construction effort (Kendall 1994). At present, construction cycle times (measured from start to closing) on the order of 6 to 8 months are common in the United States (Bashford et al. 2003c), an increase which cannot be explained by the changes in the product previously described. Paradoxically, the assembly line process adopted by high-volume homebuilders, instead of reducing cycle times, seems to be associated with dramatic *increases* in construction cycle time. In this paper, the production process will be examined in more detail in order to understand this paradox.

HOUSING PRODUCTION SYSTEM

The production system currently used by high-volume homebuilders has been previously described as a linear parade of trade contractors. Figure 1 presents a simplified view of the process, breaking the house production into a series of 10 principal phases.

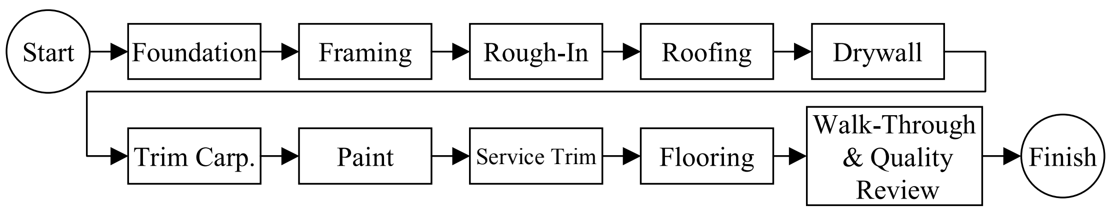

Figure 1: Production Scheme Illustrated By a Simplified Work Packaging Schema (after (Bashford et al. 2003a))

This simplification is useful for high-level analysis of the residential production system, but cannot successfully explain the cycle time changes previously described. The activities included in the figure were developed from discussions with Phoenix area homebuilders, who described a sequence of "key" trade contractors in essentially this way. For example, taking any individual activity in Figure 1, one might reasonably expect that the application of manufacturing system design principles to make the activity more efficient should have reduced the duration of that activity. With so few activities present in the production process, one might further expect the compounding effect of these efficiencies to be a shorter overall cycle time (or perhaps the performance increases previously noted in something like the same cycle time). Believing that the answer to the increased cycle time lay hidden inside the individual activities, the authors undertook a more detailed process mapping effort.

Figure 2 presents an example process map for the foundation activity. The process maps were developed using the cross-functional style in order to provide attribution of the activities to the agent responsible (Damelio 1996). Figure 2 highlights the manner in which the drive for efficiency and cost reduction at the activity level has played out in practice in this industry. The foundation activity is subcontracted to the concrete trade contractor, who in turn subcontracts portions of the work (bedding and shading subfloor utilities, termite pre-treatment) to more specialized trade contractors. Furthermore, the several activities indicated in the row for the concrete trade contractor on Figure 2 are actually conducted by very specialized crews. In addition to increased efficiency of this specialization, many trade contractors have responded to a shortage of skilled labor by breaking up their activities into very small pieces, so that low-skilled labor can be trained to conduct these activities easily.

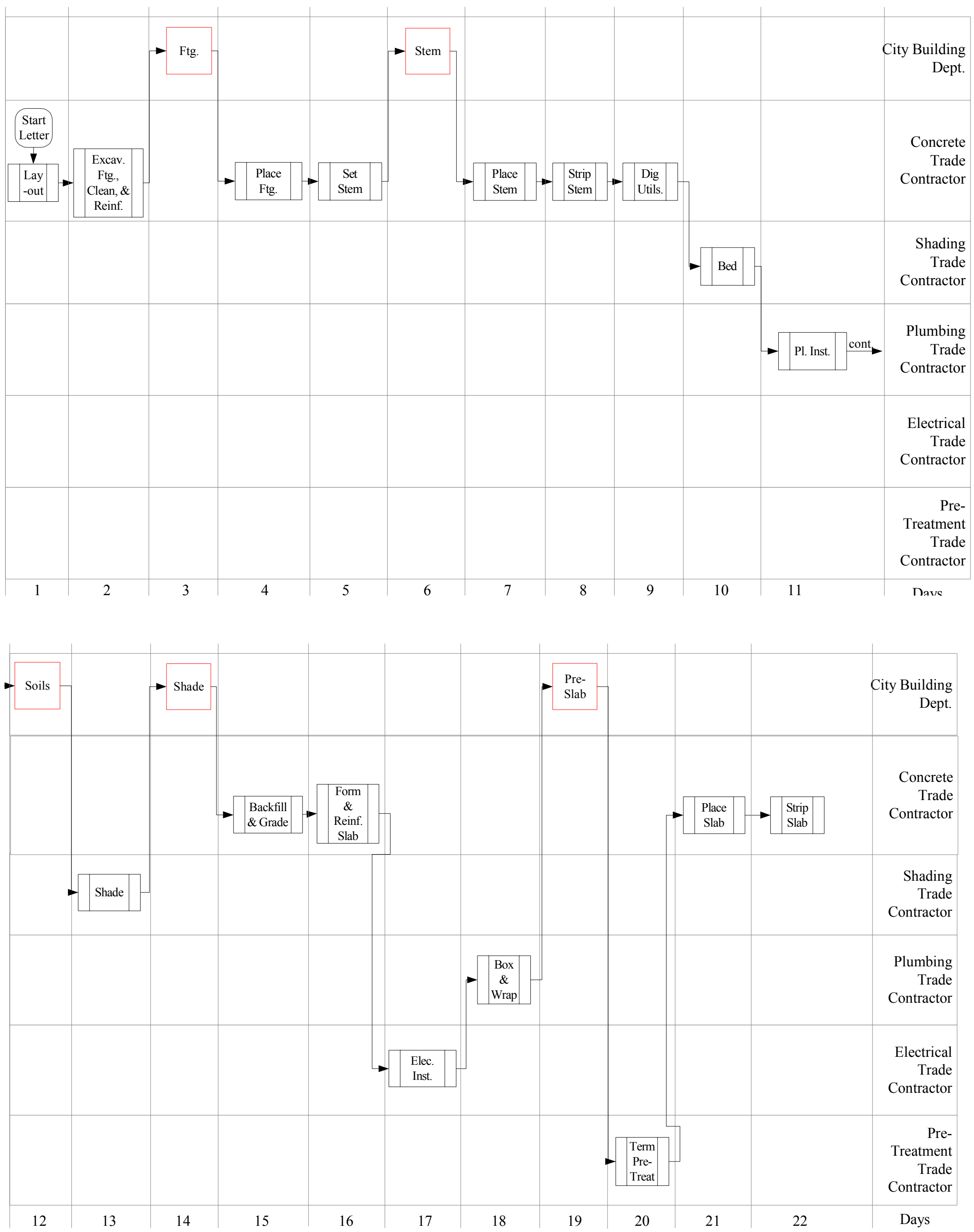

Figure 2: Expanded Process Map for the Foundation Activity (after (Bashford et al. 2002))

The process map presented in Figure 2 was developed through a structured interview process with several Phoenix-area homebuilders, requiring several iterations. The final map was subsequently checked against reality with the aid of time-lapse photographic studies of field activity. These studies were very helpful in verifying the order of activities presented on the process maps. However, they also revealed a somewhat surprising finding: value-added time for the homes studied was very low. With the exception of the framing activity (which is essentially a single-crew, multi-day activity), during other activities the most common event observed in photographs was no activity at all, indicating that the house spent most of its time waiting for something to happen. Because of its visibility, the best data relates to the foundation activity, wherein we observed that only about 25% of elapsed work time was value added time, with the remaining 75% constituting wait time between activities (Bashford et al. 2002). Subsequent analysis and observation has led to the conclusion that this low intensity of value added can be largely attributed to the combined effects of hyper-specialization of labor and the time-gates used for conducting handoffs in the process.

FACTORS INFLUENCING VALUE-ADDED TIME

HYPER-SPECIALIZATION

Figure 2 presents a generally sequential construction process for the foundation activity. Other portions of the work could be expanded similarly, but in the interest of space only the foundation activity is presented at this level of detail. As was previously pointed out, similar issues exist for the remaining activities in Figure 1, with the possible exception of the framing activity. The crews conducting the activities shown on the detailed process map (Figure 2) tend to conduct only a single activity at many locations where the trade contractor has work. So, for example, there are crews that simply deliver and set up forms, separate crews who place the concrete footing, separate crews who strip the forms, and so on.

This focus on a single activity allows individual crews to achieve very high efficiency. Some activities traditionally conducted by the concrete trade contractor have become so specialized that separate trade contractors have grown up to conduct the work. A good example is the bedding and shading activities for subfloor pipes (shaded on Figure 2). Arizona has very rocky soils, which can damage utility pipes when compacted against the pipe material. Furthermore, many soils which are very sensitive to differential settlement upon wetting (collapsible soils) exist as well. In response to the presence of these conditions, many municipalities require that pipes be bedded with fine granular material below the pipe, and then shaded carefully beside and over the top of the pipe with soil free of large, sharp rocks. Several years ago, these processes were conducted by laborers using wheelbarrows and shovels. The activities are somewhat more difficult than it may at first appear, because trenches for footings and subfloor utilities retard circulation to the trenches in need of bedding or shading, with the result that the manual process was fairly slow.

Recently, mechanized equipment has been developed explicitly for this purpose. This equipment allows a single operator to literally throw bedding and shading into the trenches using a joystick-controlled conveyor. Using this equipment, the bedding and shading activities can each be completed in less than an hour. Because the equipment required is somewhat expensive, concrete trade contractors do not maintain it (at least so far), but subcontract that portion of the work to a small contractor with the equipment. There is little question that the management decision to adopt very specialized crew assignments has been very effective in lowering training requirements for labor and in increasing the speed at which the individual assignments are completed.

TIME GATES

The term "time gate" describes the timing of handoffs at the interface between successive activities. If no time gate is present, a given activity will begin immediately upon completion of the preceding activity, assuming resources are present. In high-volume building, a "next day" time gate is used, as previously described. A number of other options could be used. A half-day time gate would delay the start of the next activity until after noon no matter when the predecessor activity was completed in the morning, and until the next morning no matter when the predecessor was completed in the afternoon. A "next hour" gate could be used to delay the successor activity until the next whole hour.

The next day time gate robs the overall process of the gains implied by the specialization described above. The bottom of Figure 2 represents a rough time scale for the foundation process. Note that some 19 days are indicated for the completion of this stage of the work. This duration seems to be about average based on the observations and interviews conducted by the writers, at least in the Phoenix metropolitan area. It is noteworthy that each activity is shown with its own day, regardless of duration. The bedding and shading activities, previously indicated as activities requiring less than an hour each, each receive their own day, as does the activity "place slab," which typically requires some 6 to 8 hours of onsite work.

In fact, direct observation and interviews with builders confirms this scheduling heuristic. With very rare exceptions, each house is scheduled for an activity to be conducted by a crew, and allotted at least one entire day, regardless of the actual duration of the work allotted. The clearest example is shown in the top row of Figure 2, where inspections are indicated. Each of these inspections will be conducted in a matter of minutes, but no other activities will be scheduled (or conducted in all likelihood) on the same day as an inspection.

Inspections present an interesting challenge, because in some cases the inspection fails. In this case, the builder must identify the failure, determine the reason for the failure, and contact the relevant trade contractor(s) for corrective action. Next day time gates still apply, however, so that extensive delays can be introduced in the correction and re-inspection cycle.

The reason for the next day time gate is fairly simple: the builder cannot know in advance what time of day the indicated activity will occur. The trade contractor base is generally active in a number of subdivisions at once, and may have responsibility to conduct work at a large number of houses on a given day. A single HVAC supplier/installer in Phoenix installs approximately 25,000 units each year, for example. As a consequence, crew scheduling tends to be based on the work load and routing needs of the trade contractor, and not on the "convenience" of the homebuilder to maintain production. The inspections, previously indicated as the shortest of the listed activities, are also the least susceptible to expediting on the part of the builder.

PROCESS SIMULATION

In order to evaluate the effect of changes in the gating systems used for the various handoffs, a simulation of the foundation activity was developed using the Process 2000 Simulation software produced by iGrafx. Process 2000 is a simple user-friendly process mapping software with a built in discrete event simulation engine. It provides an effective and logical approach to mapping processes, especially one that involve the participation of a number of stakeholders. Once a process has been mapped the Process 2000 simulation engine allows the user to perform simple "what-if" scenarios thereby providing a dynamic view to the static model.

For the validation of the main hypothesis of this work Process 2000 was used for process modeling and simulation. The base model presented in figure 2 was developed in Process 2000 and was then modified to develop 4 different scenarios. These scenarios were then simulated and results compared with the base scenario in Process 2000. A summary of results are presented in Table 1.

Table 1: Summary of Simulation Results with Changes in Time Gates

Simulation Scenario	Description	Total Duration	Value-Added Time
I	Overnight time gates on all activities	22 days	25%
II	Overnight time gates removed for 3 activities	18 days	30%
III	Overnight time gates removed for 6 activities	16 days	36%
IV	Overnight time gates removed for all activities but strip slab and strip slab	11 days	50%

CONCLUSIONS

Consolidation in the housing industry in the US has been motivated largely by demand pooling, risk pooling, and the need to develop economies of scale for application of manufacturing process design principles to the industry. Very specialized crew assignments, often supported by the development of specialized equipment, have resulted. However, the trade contractor routing and scheduling decisions are made by the individual trade contractors, for the convenience and productivity of the trade contractors, not for the convenience and productivity of the homebuilders. Currently, an entire day must be allotted to each specialized activity. As a result, gains in efficiency or productivity in the individual tasks are more than offset by time wasted waiting for the next activity to start.

Simulation was used to confirm the intuitive result: reduction of the time gate delay would have significant, positive impacts on the overall construction cycle time for housing.

Unfortunately, changes to the time gate are easier to suggest than to accomplish. Experience in Phoenix shows that the increased management attention required to support even a half-day gating structure was not sustainable in the long run in actual application. Increased management attention included additional phone calls to obtain commitments for the half-days, and checking the homes more frequently to make sure the activities were completed on time. Given the workload of site management personnel in high-volume subdivisions, and the largely paper-based systems available for managing workflow, such increased attention could only be maintained for short bursts. Interestingly, it appears that this approach may often be employed when a site superintendent works to "catch up" on a tardy home.

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