'WORKMANAGER' - AN ONLINE INTERFACE FOR LEAN FLOW CONTROL IN APARTMENT BUILDING CONSTRUCTION

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ABSTRACT

Waste is rife in building construction, both in the process and in the product. In apartment construction, where clients' design changes are often delivered late in the process, traditional project management methods are inadequate. Lean construction research has pointed to numerous ways in which waste can be reduced. Many of them, such as pull flow and in-process quality control, require effective and timely flows of information both to and from the workface. Dynamic pull of work teams and materials to the correct locations requires direct communication with and between work teams; workflow must be made clearly visible to all. Traditional methods of document and drawing delivery to work teams are inadequate in terms of their cycle time and content. Similarly, process and quality monitoring information must be provided to all immediately. In response to this need, a workflow control system for apartment building construction was detailed and developed. The user interfaces were specifically tailored for site supervisors and team leaders. The system uses 3G cellular communication technology to link all participants online with tablet PCs. Its innovation lies not in the technology, but in the way that the system specifically supports the lean construction project management approach. A prototype system has been implemented and is undergoing pilot trials at three building construction projects.

KEY WORDS

Building construction, user interfaces, production control, pull flow, site computing.

INTRODUCTION

Waste is rife in building construction, both in the process and in the product. Process waste includes time spent waiting for information, materials or completion of preceding tasks; excessive inventory buffers of work spaces that accumulate behind teams with high production rates; rework to correct work done with outdated information; and unnecessary movement of workers and equipment when workflow is interrupted (Koskela 1992). Product waste includes quality defects that remain part of the completed building and material waste.

Effective flow of information both to and from the work face is a powerful instrument for improving the process and the quality of the finished product. The lean production principle of pull flow control has been shown to be highly effective in reducing process waste, but its

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implementation in building construction requires frequent, effective and transparent communication between site production management (engineers and supervisors) and subcontractors (Ballard 2000). Similarly, checking for and correcting defects at every step of production, rather than allowing them to propagate as construction proceeds, reduces product waste, but it too requires detailed and frequent reporting. Ideally, pull flow control and in-process quality management should be integrated in a single construction production management system with graphic interfaces for subcontractors and site management (Sacks and Goldin 2005).

The need for ubiquitous computing solutions to support construction personnel has been recognized and explored by numerous researchers (Pena-Mora and Dwivedi 2002; Williams 2003). An extensive survey of research and development in the field of computing for construction management, reported by Christiansson et al. (2002) revealed that support of site managers with wireless/portable technology was focused on resource use and control (Chrysostomou 2003), progress monitoring (Repass et al. 2000), and work inspection/quality control. None enabled dynamic flow control.

A number of software systems have been developed specifically to support quality work package assignments on the basis of the Last Planner™ methodology (Ballard 2000). Among them are Workplan (Choo et al. 1999), WorkMovePlan (Choo and Tommelein 2000), Integrated Production Scheduler (Chua and Shen 2001) and LEWIS (Sriprasert and Dawood 2002). All aided site engineers in assessing and resolving the various constraints that limit the ultimate assignment of work packages to crews. LEWIS linked upstream design and project management systems with downstream production planning. However, like its predecessors, it functioned at a level of complexity unsuitable for everyday use by site supervisors at the workface.

In summarizing the goals for the IT community in civil engineering at a recent IT in CE symposium, participants called for "better, more task appropriate views of complex project information, that involve different interfaces for viewing data; different views such as time, process, output, and resources; and different usage contexts such as in the office and at the workface" (Garrett et al. 2004). The capital projects technology roadmap developed by FIATECH (a US consortium of owners, vendors, government researchers, and academics) (FIATECH 2006) describes the input to an intelligent construction job site as "Detailed work packages/command and control instructions". However, the lean approach for short-term planning at the job-site places emphasis on *communication between project participants* (work team leaders) rather than on command from above (Ballard 2000).

Thus the need for workface pull flow control to be integrated with the other information needs in a single information interface specifically designed for use by site supervisors and subcontractors is apparent; the 'Workmanager' interfaces, as described in this paper, attempt to meet that need. The following section details the information requirements. The subsequent section describes the prototype that was implemented and is being tested in a large general contracting company active in high-rise housing construction.

REQUIREMENTS DEFINITION

PROBLEMS IN TRADITIONAL PRACTICE

The main sources of conflict and waste in traditional high-rise residential construction arise from the need to customize the apartments to the specific design specifications of each home-owner (Rosenfeld and Paciuk 2000). Traditional construction schedules call for progress of trades through a building in a vertical ascending direction, closely following the erection of the structure itself. Conventional wisdom also dictates that, in order to optimize productivity, all of the work of any particular processing step on a floor should be completed as a single work package.

However, apartments are not sold in the sequence of their location, and therefore the flow of information from clients is out of sync with the needs of the construction process (Sacks et al. 2005a). Most companies deal with this situation by attempting to coerce clients to make design decisions regarding location of partitions, selection of finishes of various types, etc., in accordance with the overall construction schedule. When design decision information is delayed or unavailable, assumptions must be made for work to continue. This is of course inevitable where apartments are not sold ahead of construction. The magnitude of the impact is greatest for high-end apartments, where the degree of freedom for customization is greatest.

Statistics collected from numerous projects of a large housing contractor (2,300 units annually) showed that the average cycle times for the interior finishing works[3] on individual apartments, listed in Table 1, were very long when compared with the net time required to perform the work (12 weeks). In almost every project, the quantity of work in progress (WIP) was 100% of the total production for a significant period of the project's life, i.e. all of the apartments were worked on simultaneously. Batch size in every project was determined by the full number of apartments on each floor, commonly 4.

Table 1. Average cycle times for individual apartments measured in high-rise housing projects.

Cycle-time Measure	Average (weeks)	Standard Deviation (weeks)
Start of finishing works to handover	49.1	8.4
First client change meeting to handover	50.4	12.0
Last client change meeting to handover	24.9	15.4
Duration of change definition process - first to last client change meetings	25.5	17.5

Project managers on high-end projects reported spending up to 60% of their time managing client changes and the resulting complexity of instructions to specialty contractors. As changes became delayed due to late change orders, management teams lost control of the flow of work; contractors, always searching for high rates of productivity (Sacks 2004), continually

[3] Interior finishing works include, amongst others, acoustic insulation, flooring, electrical, plumbing and HVAC systems, gypsum board partitions and ceilings, waterproofing, painting, kitchens, ceramic tiling, and installation of doors.

redirected their efforts to those apartments in which larger quantities of work were available, leaving many minor details unfinished in incomplete apartments. This appeared to be a major source of high WIP, as apartments with little work left were simply not completed. Push scheduling was another important cause of high WIP, since work was begun in apartments that either had not been sold or where client changes had not been confirmed, with the result that stoppages in their execution were inevitable. In the latter stages of projects, contractors reduced the sizes of their teams as instability and unpredictability in their workloads increased.

In this environment of frequent change, in-process quality control is essential. Checklists must be tailored to the specific work methods required in each apartment. Practical experience in construction has shown that effective use of checklists is problematic where it is difficult to monitor their use, as is the case in any paper-based system.

LEAN PROCESS IMPROVEMENTS

Analysis of the existing management practice led to formulation of a number of principles for achieving improved production flow (Sacks and Goldin 2005). Among them, four are relevant in the context of the information flows:

- Abandoning conventional push schedules based on progress vertically up the floors of the building in favor of pull scheduling of work start for any apartment driven by the maturity of design information (i.e. completion of client change decisions),
- Pull flow control to guide work teams through the building (a form of electronic 'Kanban' card system) (Womack and Jones 2003),
- On demand delivery of up-to-date design information to the work face, to ensure that the right work is done,
- Effective in-process quality control to ensure smooth handovers between work packages[4] and to reduce rework to a minimum.

INFORMATION FLOWS AND SYSTEM OBJECTIVES

A major difference between construction and manufacturing in terms of pull flow control is that pull signals are not visible in construction in the way that they are in manufacturing. This is because in construction, the 'products' (beams, slabs, walls, floors, etc.) do not move along a production line, but rather the work teams move from product to product. Not only must the amount of WIP between any two work teams be communicated to the teams explicitly, but also its *location*. Teams must be directed to progress through a building in the sequence of the pull signals. Flow control of this kind is 'mission critical' for an effective lean construction production system.

The site works management function was identified as the focal point for the information flows. Figure 1 shows the various participants and flows. This is the group of individuals responsible for determining the sequence of work for each team on a day to day basis, often called the 'last planners' (Ballard 2000). In most cases this group is led by the general contractor's site works manager and/or project manager and include the supervisors of each

[4] A work package is defined as an activity performed in a defined area by a distinct work team.

(internal or subcontracted) work team. The specific information flows that are required to support the process improvements contemplated are detailed in Table 2.

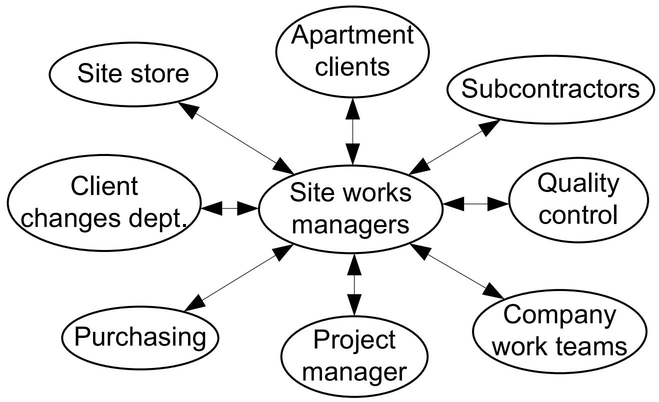

Figure 1: Site works managers' view of information flows.

Table 2. Information flows to and from site works managers.

Information Flow originator/recipient	To site managers	From site managers
Apartment clients	Submit supplement verbal requests Coordinate meetings on-site	Ask for clarification/final approvals
Site storeroom	Report delivery status of apartment accessories	Order to pull accessories for apartment
Client change department	Drawings Work orders	Report progress Ask for intervention in case of discrepancies
Purchasing	Lists of client's chosen accessories	Issue demands for standard accessories
Project manager	Apartments to start – pull signals.	Report progress Report defects
Company work teams	Report progress Call for inspection	Plan assignments and activities Signal process flow (pull signals)
Quality control	QA sheets and check lists for inspections (ISO 9000 forms)	Submit QA forms
Sub-contractors	Report progress Call for inspection	Signal process flow (pull signals) Handover QA check list for corrections

In qualitative terms, the objectives for the proposed 'WORKMANAGER' system were defined as follows:

- Achieve efficient flow in the production process.
- Improve service to apartment clients.
- Enable remote monitoring of construction progress.
- Provide effective information flow between site supervisors, subcontractors and head office.
- Improve construction quality.
- Enhance the image of the site supervisor.
- Achieve a positive return on investment.

IMPLEMENTATION

The system was implemented as a front end to existing company-wide information systems (client change management, project monitoring and control, supply logistics and quality control). The interface is provided to end-users online at the construction site using a 3G cellular network. Designated rugged-casing outdoor tablet PCs were chosen for the site supervisors' use due to their wide screen and mode of operation. To cope with potentially unreliable cellular communication within buildings under construction, the system supports working off-line for short periods with automatic synchronization on reconnect. Figure 2 depicts the network system and the hardware configuration.

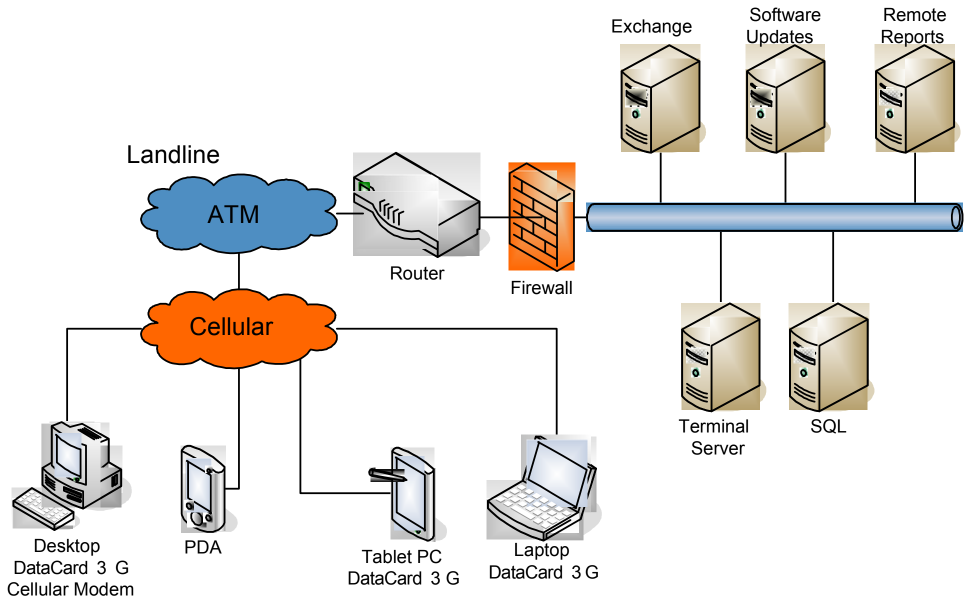

Figure 2: Network system and hardware.

The primary interface is the Pull Flow Control chart (PFC), which shows the apartments that have been introduced into the production process along the horizontal axis and the possible work packages on the vertical axis (see Figure 3). A set of 'status signals' (Figure 4) are used to indicate the progress of each specialty contractor's work packages in each apartment. Some signals can be selected and set by the general contractor's site supervisor, while other are set by the trade team's supervisors.

The 'green light' is the main pull signal; it sets the path of the work teams through the building, determined by the pull of 'mature' apartment design files. The 'red light' signal prevents the start of work packages that are not ready, which is a basic departure from traditional practice (in which teams are pushed to work in any location that becomes physically available). Work teams are prevented from entering apartments before approval of completion of the previous stage and before official 'release' of the work by the 'last-planners'. This prevents 'making-do' (negative buffering) (Koskela 2004) and enables maintenance of flow with the batch size selected by the planners. The numbers in the top row indicate the total cycle time (time since start of production) for each apartment; cycle time is an important measure of a lean construction system.

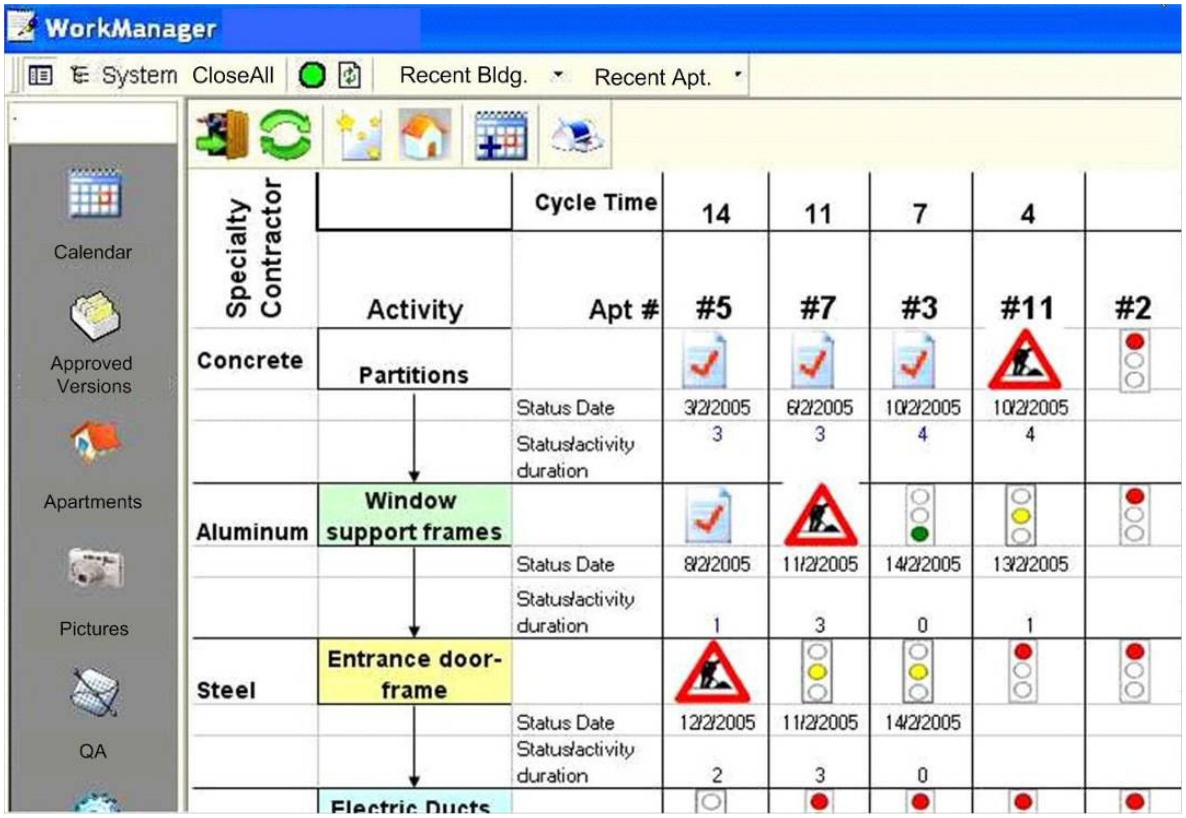

Figure 3. Electronic Pull Flow Control (PFC) chart.

No work allowed here	Completed and Approved	Under construction
Materials and drawings available: ready soon	Checked and Rejected	Complete, awaiting approval
Begin work immediately		Work stopped
Signals set by the general contractor's site supervisor		Signals set by trade teams

Figure 4: Work package status signals.

Plan reliability is a key goal of lean construction production systems. The PFC aims to assist specialty contractors to reliably predict the amount of work that will become available and so be able to size their crews appropriately. To this end, it is accessible for all participants in the process online and updated at all times; each specialty work team can see the progress status of all other teams. The 'amber lights' provide an advance indication of the work that will become available. On the other hand, process bottlenecks can be identified easily – they are activities behind which numerous 'green light' (ready for execution) signals accumulate horizontally. Counting the 'green light' signals in a row provides a visual measure of the quantity of work in progress that has accumulated behind any team.

When specialty contractor teams begin or complete work in a location, they apply the appropriate signal (from the right hand column of Figure 4). They may also alert the management team of problems using the 'stop' signal. All of these provide real-time progress monitoring information, which has hitherto been difficult to obtain (Sacks et al. 2005b).

An additional benefit of the PFC chart reported by the pilot users was that the ‘red light’ was effective in helping implement in-process quality control; work was not released to a specialty contractor team before defects in previously completed apartments were corrected.

The interface enables supervisors to access design change information on demand. Figure 5 shows the graphical component of design change instructions. Text descriptions and specifications can also be accessed. The importance of the on-line availability of this information is that it does not have to be actively dispatched to the recipient, as it must in any off-line or paper system, which would create inventories of information which may become outdated; rather, the users in effect 'pull' the information as needed.

Lastly, quality control checklists are completed online, so that their results are available for analysis at all levels. Although not yet implemented, a set of summary functions are envisaged that would enable participants at all levels a degree of reporting that would enable identification and treatment of systemic problems within short time periods, thus avoiding the long-term waste of late rework to correct defects left untreated while work continues.

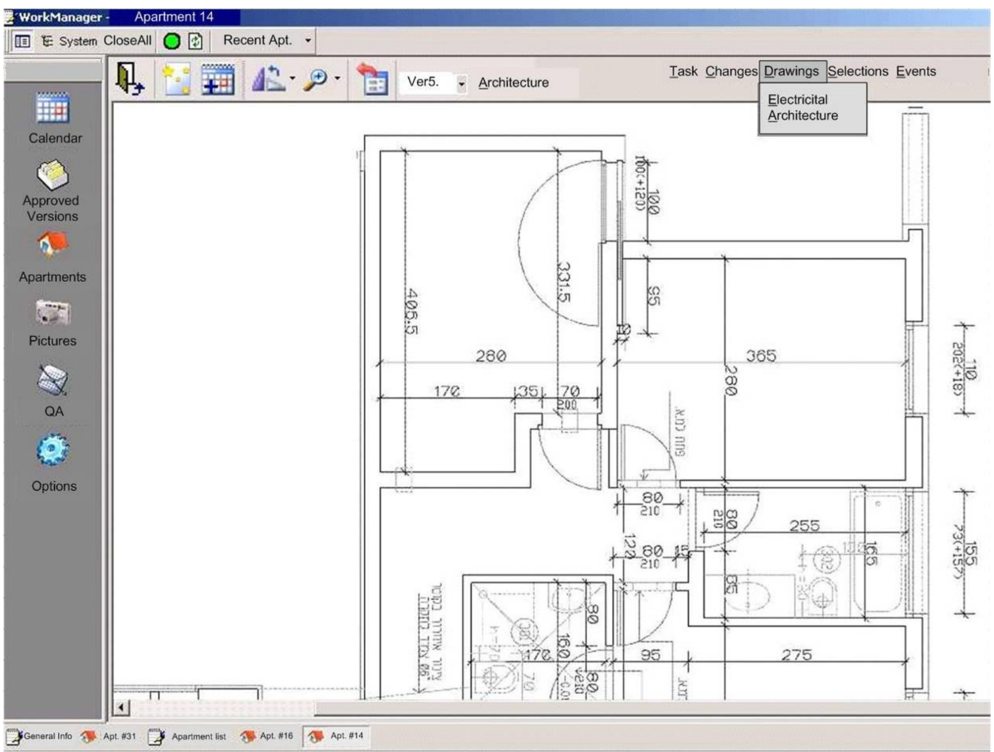

Figure 5: Apartment drawing delivery.

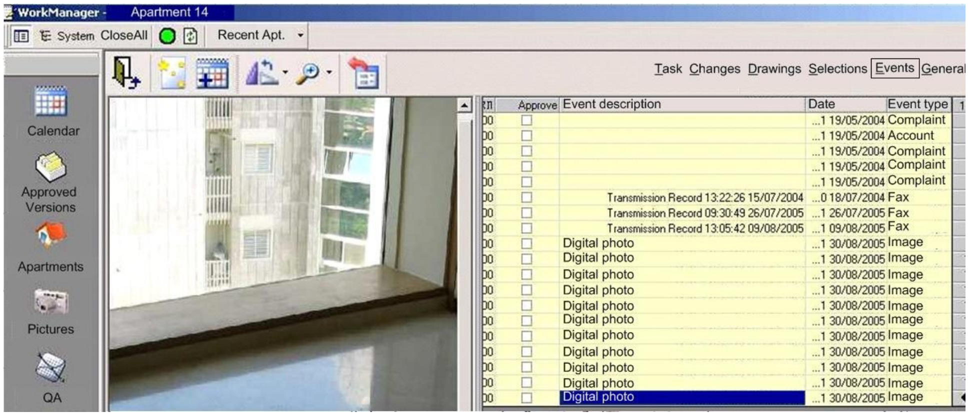

Figure 6: Image support for defect monitoring.

CONCLUSIONS

The 'Workmanager' interface developed in this research has a number of benefits that aid work teams and project managers maintain steady flow. In terms of production flow, it enables pull flow control by providing a clear picture of production progress for subcontractors, including pull signals. Subcontractor managers are able to clearly see which work packages are in progress (their own and those of all other work teams), which work packages are due to become available for them, and what the workable backlog is that is likely to become available over time. Site management can provide signals that show work to be available (pull signals) and to prevent work teams progressing in areas where consecutive work packages are not ready (to prevent accumulation of excessive buffers). Quality is managed by making in-process defect checklist results available immediately for subcontractors and preventing continuation of work in any area before defects are corrected.

It is likely that the interface could be integrated with a production planning system of the kind reported in the literature (such as LEWIS (Sriprasert and Dawood 2002) or the 'Integrated Production Scheduler' (Chua and Shen 2001)), which would enable production planners to effectively evaluate constraints and set the pull flow signals. Similarly, project progress data collected when signals are changed by the specialty contractor teams can be made available immediately to the planning systems (to set the status of work package and location constraints) and to company level project control systems.

To date, the interface has been implemented on top of a company wide production control database system, and provided on tablet PCs using wireless internet on a small number of the company's sites. Initial reaction by site supervisors has been positive. While long-term impact cannot be evaluated yet, anecdotal evidence shows that the interface and approach can enable fundamental change in the way in which production flow in building construction can be managed.

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