# PULL-DRIVEN CONSTRUCTION OF HIGH-RISE APARTMENT BUILDINGS

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## ABSTRACT

Construction of high-rise apartment buildings is made complex by the myriad possibilities for clients to adapt their apartments to suit their individual needs and preferences; traditional construction planning practice of progressing upwards from floor to floor breaks down in the face of the arbitrary sequence in which clients finalize their decisions. The results are long cycle times for delivery of completed apartments and corollary high levels of work in progress (WIP), budget and schedule overruns, and general dissatisfaction with the process on the part of the contractors, subcontractors and the clients. This paper presents a management model that applies lean thinking to this problem. The model was first formulated in theory, then tested using a management simulation game, and subsequently developed for practical application by a dedicated team composed of university researchers and construction company personnel. It is now being tested in a large construction company.

## KEYWORDS

Pull-driven flow control, High-rise buildings, Residential construction.

## INTRODUCTION

The ability to customize apartments for individual clients is an absolute requirement in any free-market economy where developers compete for clients. In any housing construction project other than single-family dwellings, and particularly in high-rise construction, the building is usually commenced—and often completed—well before the last apartment is sold. Customization demands the ability to respond rapidly to late changes in design, because home-owners' design decisions are only made relatively late in the production process (always after the apartment is sold).

However, traditional construction management scheduling and accounting practices are relatively inflexible. Predetermined and optimized construction schedules and centralized control structures result in significant and inevitable waste. Frustration for all involved is common, with high rates of litigation resulting. The conflict between the need for customized products and rigid approaches to production planning, with resulting inherent waste, is reminiscent of the problems faced by many manufacturing industries that turned to lean principles in search of improved management approaches (Womack and Jones 1998).

Housing forms a major part of the construction industry in most developed economies, and it has been the focus of a number of studies that have adopted a lean perspective. Gann (1996) compared industrialized housing with car manufacture in Japan, highlighting similarities and differences in production and supply chain strategies, although none of the industrialized housing companies investigated constructed high-rise buildings. Bashford et al. (2003) examined the impact of time-gating strategies adopted by US housing developers, exposing very long cycle-times and large inventories of work in progress (WIP) that resulted from extreme optimization of the individual activities for single-family houses. The relationship between cycle time and WIP predicted by

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Little's Law (Hopp and Spearman 1996) has been shown to hold at a macro project level for customized housing projects (Bashford et al. 2005). Naim and Barlow (2003) proposed the application of lean and agile approaches to housing construction in the UK, but focused on supply chains and did not tackle the fundamental construction planning and control practices. Ballard (2001) suggested multi-skilled teams as a key factor in achieving even-flow production for reducing cycle-times and enhancing stability for construction of single family houses.

In this project, a holistic lean construction management strategy based on pull flow scheduling was developed for high-rise customized apartment buildings. It is fundamentally different to the traditional strategy common in most companies active in this sector. A set of tools, techniques and technological changes was then developed by a collaborative academic and industry team in order to apply the strategy in practice. In this paper we analyze the traditional approach and its problems in terms of lean principles, and present the alternative strategy. A management game was used to illustrate the problems, and it is presented briefly. Key components of the implementation plan are also presented.

## A LEAN ANALYSIS OF TRADITIONAL PRACTICE

The main source of conflict and waste in traditional high-rise residential construction arises 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. This is comparable to the desire to process large batches on machines with setup times in manufacturing settings.

However, apartments are not sold in the sequence of their location, and therefore the flow of information from client is out of sync with the needs of the construction process. 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.

Client-initiated changes are therefore executed largely as change-orders. Change-orders have been shown to have a strong negative impact on labor productivity (Moselhi et al. 2005), result in wasted materials. As a result, changes are invariably priced to clients at rates significantly higher than standard construction costs (Rosenfeld and Paciuk 2000). In one reported case, a company charged clients a demolition fee for partitions that appeared on the standard plan even if the partitions were not yet erected! Where changes are significant and disrupt the standard process, clients are dissuaded from making them irrespective of the price; this represents a lose-lose situation. Overall, clients' perceptions are negative—they are not receiving value.

At the outset of this study, statistics were collected from numerous projects of a large housing contractor (2,300 units annually). The average cycle times for the interior finishing works[4] on individual apartments, listed in Table 1, were found to be very long when compared with the net time required to perform the work (12 weeks). In almost every project, the 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 |

4 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.

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 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.

The state of affairs described above can be characterized in terms of waste, value and flow. Firstly, all of the types of waste defined by Womack and Jones (Womack and Jones 1998) are present, as listed in Table 2.

An extensive survey conducted among clients from the contracting company's previous projects revealed that the existing process is not providing maximum value. The range of changes is restricted, prices for changes are considered to be exorbitant, decisions are demanded too early, multiple design consultations are required at different locations, design choices and changes are not accurately executed, and handover dates are unreliable if changes are made. From the point of view of project developers (the company's immediate clients), value is delivered when the design decisions for unsold apartments are delayed as far as possible, extending the time during which they can sell apartments and offer maximum customization flexibility to potential buyers.

Lastly, in terms of flow, work on apartments is not continuous; WIP levels are high, often reaching the full complement of apartments in a building, and cycle times are up to four times as long as the net continuous work time required for completing the finishing works in apartments.

## PULL SCHEDULING MODEL FOR HIGH-RISE APARTMENTS

The goals of the process change initiative were a) to increase value for the clients by reducing the cost of customization while extending the time during which design decisions could be made and reducing the cycle time for customizing each apartment, and b) to reduce the direct costs and management overheads for the general contracting company. Analysis of the existing management practice led to formulation of the following principles for achieving improved production flow:

- Abandoning conventional push schedules based on progress vertically up the floors of the building in favor of pull scheduling of work teams from apartment to apartment driven by completion of client change decisions,
- Reduction of handovers between work packages[5] and reduction in the number of distinct work packages through increased use of multi-skilled teams and changes to construction methods,
- Restructuring of the work to decouple stable work packages[5] from those dependent on late change information,
- Changes to the client change coordination procedures to improve communication and planning reliability.

Once these principles were crystallized, a management simulation game was devised to test the potential benefits of a management model based on the principles. The game was loosely based on the airplane game (Verma 2003) which explains the impact of one-piece pull flow in a manufacturing setting. The simulation game was later used to aid in presenting the management model to construction industry professionals at all levels. The game and its results are the subject of the following section.

## APARTMENT CONSTRUCTION SIMULATION GAME

The lean apartment construction simulation game simulates construction of an eight story building with four apartments on each floor. Participants are assigned the roles of project manager, a client change manager, a quality controller, a tower crane operator, and four specialty contractors. Their task is to carry out the interior finishing works for all 32 apartments in as short a time as possible. Execution of the finishing works is simulated using assembly of small building models using LEGO® bricks (see Figure 1); they are assembled in four distinct steps, each performed by one of the specialty contractors. Two additional players represent the apartment clients—the first selects design variations from a prede-

5 A work package is defined as an activity performed in a defined area by a distinct work team. A stable work package is one that is not dependent on client preferences, i.e. it cannot be customized.

Table 2: Waste in traditional management of construction of customized high-rise apartment buildings.

| Waste | Observations |
|---|---|
| Undesired products | Apartments built to standard designs are less attractive to potential buyers |
| Rework | Client changes performed as change orders require demolition of work completed earlier; management effort is required to coordinate late change orders and to control their execution |
| Inventories | Inventories of completed (but not yet purchased) apartments are accumulated; |
| Unnecessary activities | Unfinished apartments must be cleaned and repaired after periods during which they are not worked on. |
| Unnecessary movement of workers and/or materials | Work stoppages are frequent when apartments are sold during finishing to allow time for clients to reach design decisions—specialty contractors are forced to move to other apartments and then back again later. |
| Waiting for materials or information | Delays due to unavailable information reduce productivity; |
| Products that do not meet clients' needs | Apartments built to standard designs do not fully meet clients' needs; clients often forego customization where the cost of change-orders is considered prohibitive. |

fined set of seven variations to the basic design, and the second checks completed apartments and pays $1,500 for each one that is free of defects.

In the first round of play, which lasts 11 minutes, the project manager is provided with a suggested construction plan which calls for the specialty contractors to progress up the building floor by floor, one after the other, in logical sequence according to the technological dependences of their work type. The batch size is four—only one contractor may work on a floor at a time. At set time intervals during construction, the clients select design variations by pulling apartment numbers and variation codes at random from a hat and deliver them to the 'company'. Design variations received before work on an apartment is commenced are easily executed, although they do disrupt steady flow because they require more time. Apartments for which design variations are received after work has begun but before the apartment has been delivered to the client, must be changed. The project manager must decide whether to withdraw specialty contractors from the floors they are working on and send them to make local changes, or to delay the changes. The driving factor is that the company is only paid for completed apartments, while they must invest working capital ($1,000) for any incomplete apartment. Play is stopped after 11 minutes, and the team's performance is assessed in terms of apartments delivered, quantity of WIP, cash flow, defective apartments, and the time required to deliver the first non-standard apartment. The results measured through distinct executions of the game with seven different groups are provided in Table 3.

In the second round, the following changes are made:

- pull scheduling replaces push scheduling—the work sequence is changed to match the sequence in which design variations are selected to be pulled by the clients' selections of design variations (work is only begun on apartments once the design variations are selected),
- the four specialty contractors are replaced with four multi-skilled apartment finishing teams that can perform all of the activity types.

All other conditions remain as before. Typical results for this round, obtained by the same seven groups, are listed in Table 4. As can be seen, productivity is approximately doubled, WIP is drastically reduced (as in all pull systems, it is explicitly controlled) as is cycle time, and as a result, cash flow turns from negative to positive.

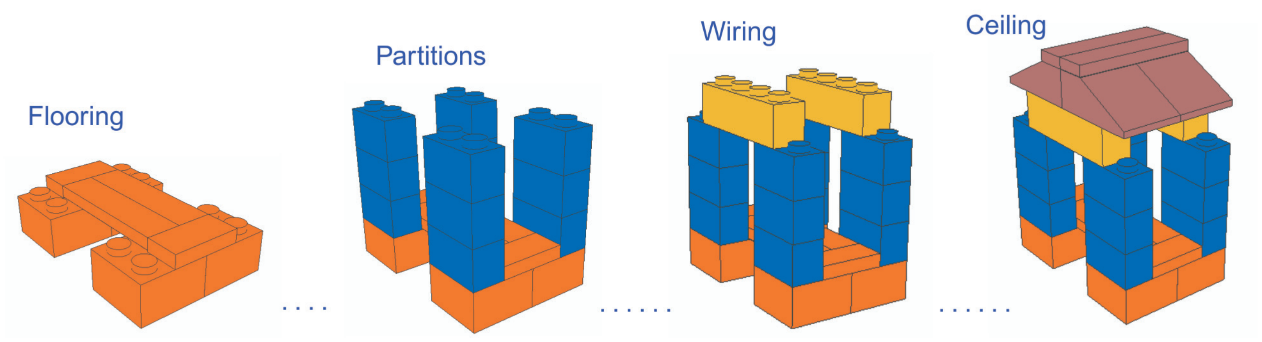


Figure 1: A standard apartment.
Assembly steps represent flooring (orange), partitions (blue), electrical wiring (yellow) and acoustic ceilings (brown).

Table 3: Lean apartment simulation game results—round 1.

| Group | Apartments completed | Defective apartments | Time to first apartment (min.) | W.I.P. | Throughput (units/min) | Cash flow | Cycle time (min.) |
|---|---|---|---|---|---|---|---|
| **A** | 8 | 0 | 5:15 | 22 | 0.84 | ($18,000) | 5:30 |
| **B** | 6 | 0 | 7:30 | 14 | 0.80 | ($11,000) | 6:15 |
| **C** | 12 | 2 | 6:00 | 12 | 2.00 | ($6,000) | 4:00 |
| **D** | 7 | 1 | 7:30 | 10 | 0.86 | ($6,500) | 7:30 |
| **E** | 7 | 1 | 5:50 | 12 | 0.55 | ($8,500) | 5:50 |
| **F** | 8 | 0 | 8:00 | 13 | 2.00 | ($9,000) | 7:00 |
| **G** | 8 | 0 | 6:00 | 11 | 0.80 | ($7,000) | 6:00 |
| **Average** | 8.0 | 0.57 | 6:35 | 13.4 | 1.12 | ($9,429) | 6:00 |

Table 4: Lean apartment simulation game results—round 2.

| Group | Apartments completed | Defective apartments | Time to first apartment (min.) | W.I.P. | Throughput (units/min) | Cash flow | Cycle time (min.) |
|---|---|---|---|---|---|---|---|
| **A** | 12 | 0 | 4:15 | 2 | 2.32 | $4,000 | 2:00 |
| **B** | 18 | 0 | 4:00 | 4 | 3.58 | $5,000 | 1:00 |
| **C** | 17 | 0 | 2:00 | 2 | 2.29 | $6,500 | 1:00 |
| **D** | 15 | 0 | 2:30 | 3 | 1.87 | $4,500 | 1:30 |
| **E** | 14 | 0 | 2:00 | 1 | 1.63 | $6,000 | 1:00 |
| **F** | 16 | 0 | 2:30 | 2 | 2.31 | $6,000 | 1:30 |
| **G** | 17 | 0 | 2:30 | 2 | 2.13 | $6,500 | 1:30 |
| **Average** | 15.6 | 0.00 | 2:49 | 2.3 | 2.30 | $5,500 | 1:21 |

## DEVELOPMENT OF AN IMPLEMENTATION PLAN

In this phase, the researchers were joined by construction company representatives to form a task group charged with formulating specific steps for implementation, first in a pilot project and later for all similar projects. The task group included three university researchers, the company vice-president for control systems and information technologies, a senior company engineer, the head of the client change service department, a client change representative, and the pilot project site staff—project manager, construction engineer and the senior works supervisor. The team met weekly over an extended period to propose, evaluate and develop the implementation. The key features of the implementation decided upon are explained in the following sections.

### SEPARATION OF FIXED WORK PACKAGES FROM THOSE SUBJECT TO CHANGES

The first step is separation and disconnection of work packages with high degrees of certainty (structure, public areas and building facade) from those susceptible to change (partitions, systems and finishes within apartments). This required changes to basic features of building design, such as removal of all water and electrical conduits from flooring layers to walls and suspended ceiling systems, so that they could be installed as late as possible in the process. In some cases, making these changes demanded cooperation of the developer and the design team. The developer's cooperation was obtained in return for relaxation of the contract requirement that the developer provide design decisions as construction progresses up the building regardless of whether apartments were sold or not (this requirement is standard practice under traditional contracts for high-rise apartment construction). The potential of technological changes to increase flexibility, through delayed dependence of the production process on informa-

Building: Savyonei Ramat Aviv 2 **Status report** 31/03/05

| Apt # | Owner's Name | Structure | Layout | Kitchen plan | Plumbing consultant | Electricity consultant | HVAC consultant | Door selection | Flooring selection | Finish materials available | Partition plan finalized | Task completion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | TS | 100% | Complete 19/02/05 | | Complete 19/02/05 | | Complete 19/02/05 | Complete 12/03/05 | Complete 19/02/05 | Complete 12/03/05 | | 88% |
| 10 | | 100% | | | | | | | | | | 0% |
| 11 | CO | 100% | Complete 15/01/05 | Complete 15/01/05 | Complete 15/01/05 | Complete 15/01/05 | Complete 15/01/05 | Complete 26/02/05 | Complete 26/02/05 | Complete 26/02/05 | Complete 26/02/05 | 100% |
| 12 | SH | 100% | Complete 20/02/05 | | Complete 20/02/05 | Complete 20/02/05 | | | | Complete 7/03/05 | Complete 7/03/05 | 50% |
| 13 | | 100% | | | | | | | | | | 0% |
| 14 | OF | 100% | Complete 26/02/05 | | | Complete 26/02/05 | Complete 26/02/05 | | | | | 30% |

Figure 2: An excerpt from a weekly apartment file status report.

tion, is measured with a simple 'rigidity index'. The index is calculated using the formula:

$$RI = \sum_{i=1}^{n} (N - j_i) D_i$$

where $i$ = client design decision index;
*n = number of client design decisions;*
$ji$ = serial number of work package by which design decision $i$ must be made;
$N$ = total number of work packages;
$Di$ = relative impact of design decision $i$. A reduction of the RI indicates that a process has been made more flexible. A hypothetical process with maximum flexibility (i.e. all design decisions can be made at the time of the last finishing work package would have $RI = 0$; a process that demanded all design decisions before its start would have $RI = \sum_{i=1}^{n} ND_i$. In the pilot project, the RI was decreased from 1258 to 979.

## PULL SCHEDULING

The second step entails strict pull scheduling of change-susceptible work packages, controlled using completed client change files as 'Kanban' cards. A set of criteria were established for assessment of the 'maturity' of the apartment files, including the degree of certainty that the client changes were final, a check of the availability of all the materials selected, completeness of the building frame, and availability of the trades needed. Apartments are released for construction in order of their degree of maturity. The client-change representative was given the task of making apartments ready by sorting clients into 'decisive' and 'indecisive' groups, and scheduling their milestones for making product selections accordingly. The degree of maturity of each apartment was assessed in weekly meetings of the site management together with the client-change representative (and specialty contractor representatives where necessary), and the highest ranking apartments were selected for work to start. Figure 2 shows an excerpt of a status report that was implemented. It draws data from the company's existing client changes, project control and purchasing software systems.

The TAKT time and the rate of release of apartments for finishing works depend on the quantity of apartments sold at any point in time. The basic requirement is that all apartments sold should be available for occupation at the time that the building as a whole receives a certificate of completion from the local building authority. Unsold apartments could be completed after that time (see below). The initial start date for the interior finishing works and the desired TAKT time are interdependent. The starting rate for the pilot project was initially set at 2 apartments per week, based on the need to deliver 40 of the 52 apartments in the project within 32 weeks, with a cycle time of 12 weeks.

## CHANGES TO THE PRIME CONTRACT

The construction contracts between the developer and the general contractor (GC) were amended to incorporate pull flow driven by client changes. The team determined that value to the developer could be increased by allowing design decisions for unsold apartments to be postponed as far as possible. In traditional construction, developers were required to make decisions in time for apartments to be completed and the building handed over as a whole. In the lean implementation, where apartment finishing sequence is no longer constrained to vertical progression of work teams, finishing of unsold apartments could be delayed beyond initial occupation of the building. Con-

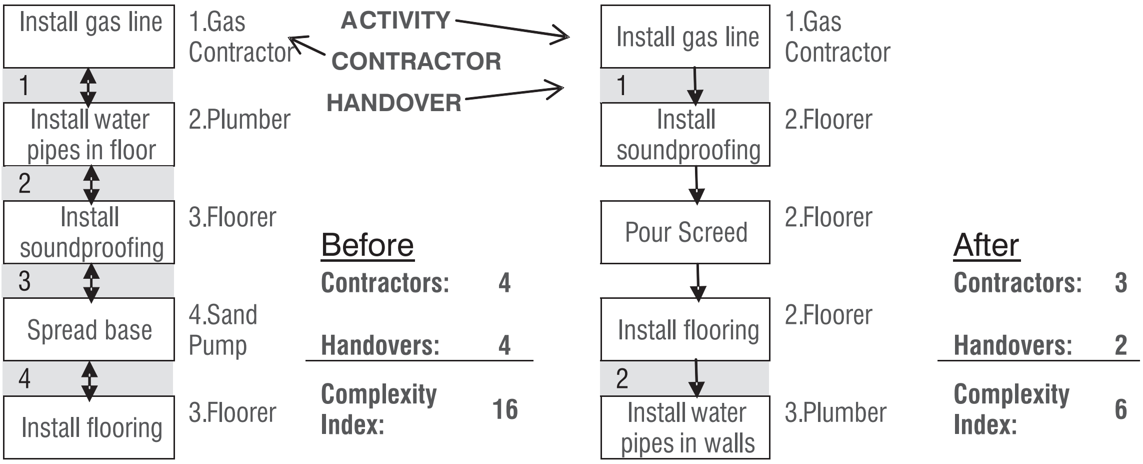


Figure 3: Construction method 'Complexity Index'.

struction methods that required fewer bulk materials caused little noise, generated minimal material waste, and required minimal material deliveries, were identified. The GC obtained the developer's agreement to cover additional costs for these methods in return for the marketing flexibility it provided. Provisions were also made for the GC's release from obligation to complete interior finishes for apartments whose completion the developer preferred to postpone beyond the end of the major works.

**WORK RESTRUCTURING**

Both before project start and during execution, finishing works are restructured to enhance flow, though intrinsic improvement of the production process itself. Changes in technology and/or work methods aim to reduce the number of subcontractors and the number of handover points between them. A 'complexity index' was devised to enable comparison of alternative process improvement strategies. The measure is calculated as the product of the number of distinct work teams multiplied by the number of interfaces between work teams. Figure 3 illustrates the concept with a simple example extracted from a full construction process analysis, in which two alternatives for the process of flooring are compared. The lower the index, the more streamlined the workflow.

**REDEFINING MANAGEMENT ROLES**

The role of the company's 'client-change representatives' is upgraded to that of 'interior-finish manager', which requires their relocation from company headquarters to the construction site, retraining, and results in their becoming an integral part of the site management team. They carry responsibility for final construction coordination and provide a direct link for information flow between the clients and the specialty contractors, and play a key role in making apartment files ready. The project manager is relieved as far as possible from dealing with client changes and interior work, allowing him or her to concentrate on managing the project as a whole.

**PULL-DRIVEN FLOW CONTROL**

Once apartments have been introduced into the production system, flow is controlled using a publicly displayed electronic workflow progress chart to pull work teams (mostly specialty contractors) to the appropriate work packages, to prevent execution of work out of sequence, and to prevent commencement of work that was not ready for release. A portion of the chart, termed the Pull Flow Control (PFC) chart, is shown in Figure 4. It shows the activities on the vertical axis; the activities are drawn directly from an MsProject plan compiled for each apartment. As apartments are selected for execution, they are added to the horizontal axis. The state of each work package is evaluated and published using an appropriate symbol. The chart has a number of benefits that aid the work teams and the project managers to maintain steady flow:

- The path of the work teams through the building, determined by the pull of 'mature' client files, is clearly visible, as is the status of work in every apartment.
- Bottlenecks can be identified easily—they are activities behind which numerous 'green light' (ready for execution) activities accumulate horizontally.
- Work teams can clearly see the buffer of work being made available to them, as each work package ahead has its status clearly indicated, and so they can adjust their resource assignments to the project appropriately in advance and with a high degree of certainty.
- Work teams are prevented from entering apartments before approval of completion of

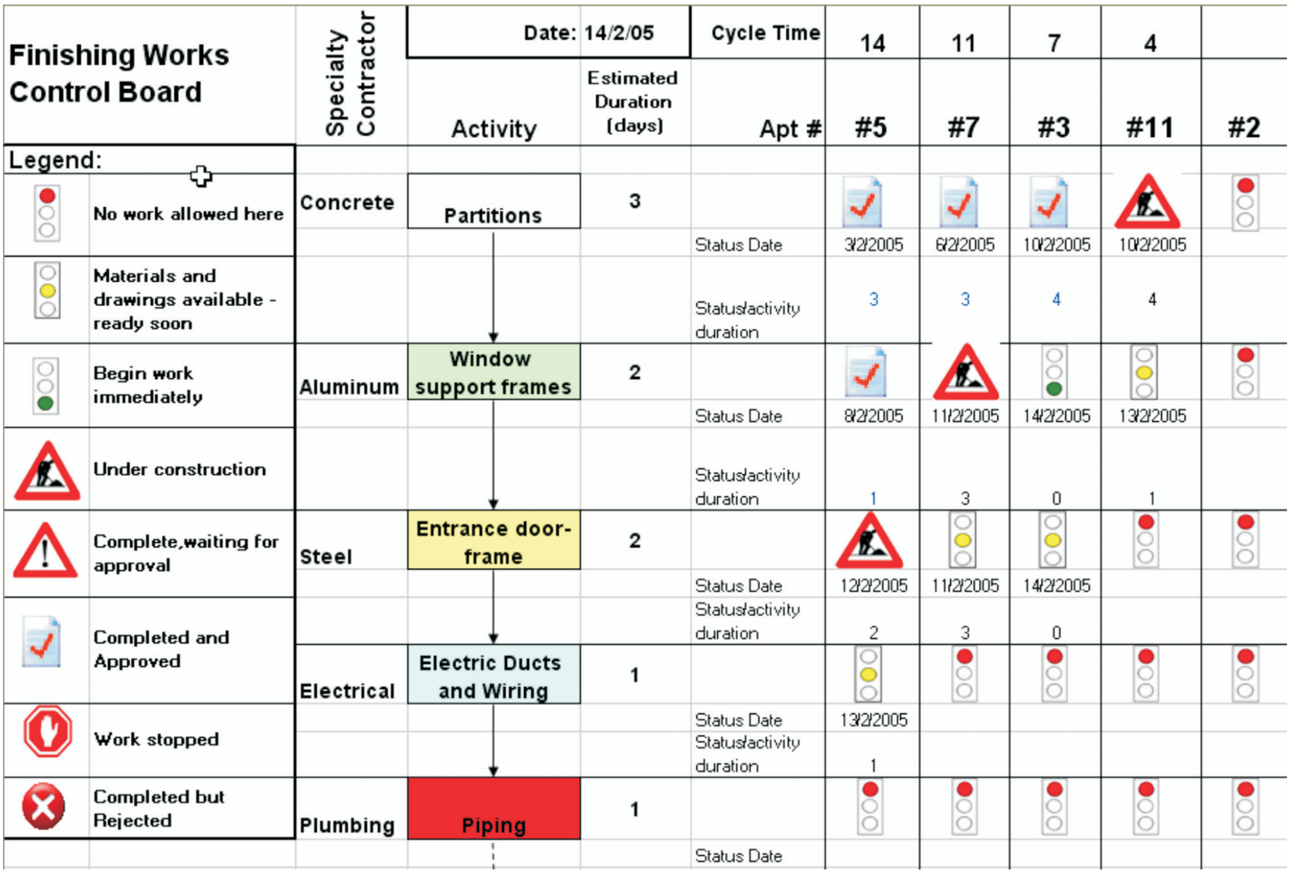


Figure 4: Electronic Pull Flow Control (PFC) chart.

the previous stage and before official 're-lease' of the work by the 'last-planning' team. This prevents 'making-do' (negative buffering) (Koskela 2004) and enables maintenance of single piece batch flow.

An additional benefit of the PFC chart reported by the company was that the 'red light' was effective in helping implement in-process quality control.

## DISCUSSION AND CONCLUSIONS

Analysis of current construction management practice for high-rise apartment buildings in a major Israeli construction company under the microscope of lean thinking revealed significant waste, client dissatisfaction with the value provided in both the process and the product, high inventories of WIP and interrupted flow. The conclusions of the analysis are supported by country-wide statistics and previous research that investigated the problems related to customization of apartments. A new, lean construction management model was proposed by the researchers to replace the existing practice. The various features of the model are designed to improve process flow and reduce cycle time. They represent a significantly different approach to scheduling the interior works in high-rise apartment construction than the critical path method based approach. A simulation game was devised to experiment with the proposed method—its results proved that the model had the potential to improve production rates while at the same time delivering customized apartments with no waste and reduced cost. It also indicated that the company's cash flow would be drastically improved.

A joint university-industry team then developed the model for implementation in a pilot project. The key principles adopted in the implementation included pull-driven scheduling of apartment finishing works, technological decoupling of stable work packages from work packages subject to client changes, streamlining of work packages and handovers to improve flow, and redefinition of the role of the company's client change representatives. Not all of the principles of the theoretical model could be implemented; for example, the practice of extensive sub-contracting as much of the construction as possible prevented employment of multi-skilled work teams. The option of performing work using sub-contracted multi-skilled teams was rejected by the company based on the assumption that it would reduce its own profit margin.

Despite initial skepticism at all levels, the personnel involved became committed to the lean model once they had the time to think and reflect on existing conditions. Obstacles to implementation were raised, but creative solutions were often found. For example, the ceiling work crew questioned the practicality of moving their equipment (scaffolding etc.) from apartment to apartment, especially through finished public areas. The solution was to provide two sets of equipment and transport them in specialized containers from balcony to balcony using the tower crane.

Three factors appear to be important in enabling this company to develop and implement a fundamental change in its management practice based on the lean management model proposed by the researchers:

- The specific techniques to be implemented were crystallized over an extended period by a multidisciplinary team composed mainly of company personnel, including the full site management team of the pilot project. Direct participation of company personnel in developing the procedures was essential not only for application of the theoretical model under the constraints of real project conditions, but also to provide the team members themselves with the opportunity for reflection and 'unlearning' of conventional wisdom. They also gradually adopted ownership of the solutions that were reached and developed commitment to their success.
- No 'complete' or packaged solution was offered up front by the research team; rather, a set of principles for change was provided, together with a set of measures that aided prediction of the outcomes of changes that were proposed. The management simulation game proved to be a powerful tool in this regard. The flexibility and complexity indices provide a quick and structured method to determine whether any proposed technical or organizational change is likely to improve process flow.
- The tools for flow control were embedded in the company's computerized information systems. The first tool was a simple but comprehensive summary report on the status of each apartment's 'maturity' for execution, and the second was the pull-flow control chart. Both were provided to all project participants; the company plans to make them available to subcontractors on the project extranet, and to site supervisors on internet-enabled tablet PCs.

Construction of the pilot project building is now under way. The only aspect of the model implemented fully in this project is pull flow control, because detailed design was complete and specialty contracts had already been awarded when the task group finalized its implementation plan. Detailed data are being collected, with the intention of measuring the impacts of the method. Early results suggest that substantial improvement requires holistic implementation, although much work is still necessary to establish which aspects of the model can be implemented in practice, what their impacts are, to what degree they are interdependent, and where the hurdles to change exist.

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