

Linbeck Construction used the Last Planner system of production control on a \$22 million remodel of the Chemistry Building at Rice University. This was one of four innovative practices was described by Michael Pappas, P.E, in his thesis for a Master's of Civil Engineering at the University of Texas. The research was funded and supported by the Construction Industry Institute.

The following is extracted from "Evaluating Innovative Construction Management Methods through the Assessment of Intermediate Impacts" A thesis by Michael Pappas for a "Master of Science in Engineering", University of Texas at Austin, 1990. A complete report is available through The Department of Architectural and Civil Engineering - ECJ 5.200, University of Texas, Austin, Texas 78731.

The project

"The project was a complete demo-to-structure renovation of a university chemistry building originally built in 1925. The project was located in the southwestern United States. The general contractor studied was a merit shop contractor who specializes in commercial and building construction. Approximately 90% of the work on this project was subcontracted; both union and merit shop subcontractors were involved. The construction contract was \$22 million. The entire project, including assessment and design, was \$28.5 million. The construction duration was 12 months.

The contractor was responsible for all material procurement, including laboratory equipment. The owner procured the furniture. The project was approximately 85% complete at the time of the site visit. Project staffing included 1 project manager, 2 project engineers, 1 superintendent, 1 assistant superintendent, 15 foremen (9 from subcontractors), and 78 craftsmen (65 from subcontractors).

The construction contract was a negotiated, Cost Plus Fixed Fee/Guaranteed Maximum Price contract with graded incentive bonuses. The five major subcontractors were also under the same contract arrangement. The incentive bonuses were based primarily on the cost performance of the project.

The implementation of Lean Construction principles on this project required the use of outside consultants to provide training for key players and assistance in developing the project milestone pull schedule.

Some unique features of this project include:

The owner and the general contractor interviewed potential major subcontractors during the negotiation process, and full implementation of Lean Construction was a prerequisite for selection as a major subcontractor.

The contract's incentive bonus was structured to align all the parties on the overall project goals.

The owner, general contractor, and subcontractors developed the construction schedule as a team, as opposed to the general contractor pushing the overall construction schedule to the subcontractors.

The Innovation

The innovative management method implemented on this project is called “Lean Construction.” Lean Construction applies the concepts of lean production to the construction project. The Lean Construction Institute defines “control” as “causing events to conform to plan” as opposed to the current construction definition of “monitoring” against schedule and budget projections.”

Another important concept is the optimization of the entire project as opposed to a specific activity. This requires a different paradigm from a scheduling viewpoint – the “pulling” of work through the schedule. In other words, a work activity is scheduled based on when its completion is required by a successor activity. Traditional construction schedules “push” work by emphasizing required start dates for activities. This can lead to performing work before it is needed, which can cause problems such as using resources on some activities that would be better spent on other activities, overcrowding, rework due to subsequent changes, etc. Lean Construction schedules employ the “pull” concept, which basically states that an activity is not done until it is needed to facilitate a subsequent activity.

Lean Construction also addresses the subject of buffers and emphasizes the reliability of the work flow. Buffers are normally a defensive measure created to protect against uncertainty in the work flow. In construction, buffers are commonly manifested in ordering bulk materials and storing them on site, increased lead times in scheduling, increased levels of manpower, etc...

Lean Construction employs a three-level hierarchy of schedules and planning tools, which are described in the following paragraphs. These tools look similar to others commonly used in the industry, but the planning system identifies what is to be done at finer levels of detail than is typically seen, and focuses on reducing uncertainty in proportion to that level of detail. Lower-level schedules are developed in progressively greater detail, using higher-level schedules as “outlines.” Each schedule contains only the degree of detail appropriate for the length of time it represents. This scheduling and planning system, when implemented effectively, enhances communication and coordination among project participants. While a detailed critical path schedule is usually developed early in a project in order to identify dependencies and key milestones, a Lean Construction project does not use an activity-level critical path network schedule as the primary management tool during the project.

The milestone pull schedule or master pull schedule is the overall project schedule. It contains major milestones only. Milestone dates are determined by using the “pull” process from successor milestones, beginning with the project completion date and working backwards to the beginning of the project. On some complex projects, intermediate phase schedules are maintained in critical path format to identify and coordinate the activities needed to support milestone completion.

The look-ahead schedule represents an intermediate level of planning. This schedule contains major work items that must be completed in order to meet the milestone dates in the master pull schedule. Major activities and their completion dates are “pulled” from the master schedule, broken into more detail, and “screened” prior to entry in the look-ahead schedule. Screening essentially means that all the constraints preventing the execution of the activity have been identified, and enough time remains prior to the activity’s scheduled start date to eliminate those constraints. This schedule typically looks ahead six to eight weeks. The exact duration of the look-ahead window is determined on a case-by-case basis by the lead time required to eliminate constraints. Management continues to break activities into more detail and screen the resulting smaller activities throughout the look-ahead window, until the activities are essentially assignment-level tasks.

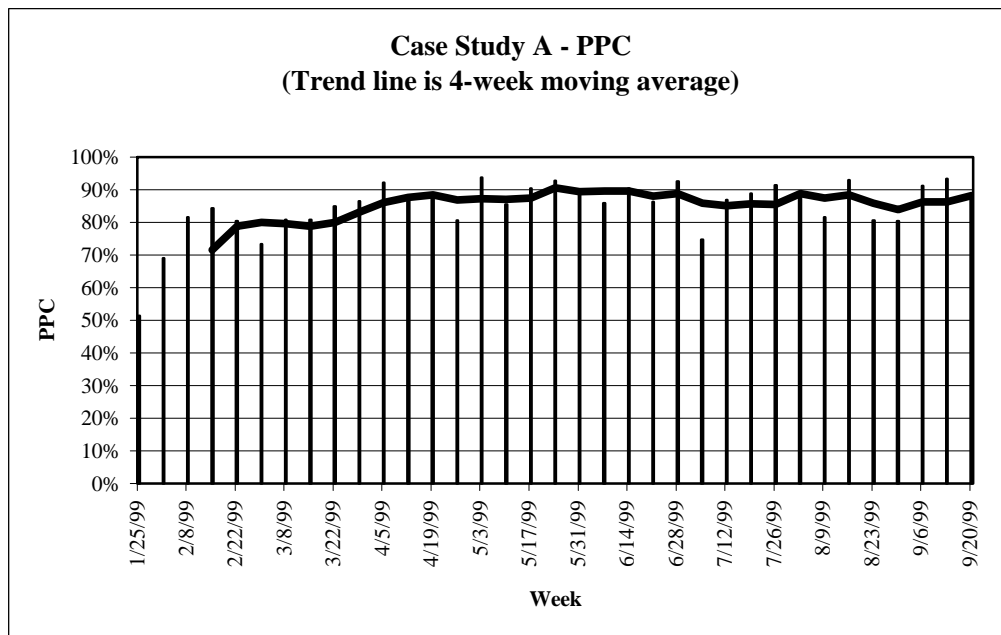
The weekly planner is an assignment-level schedule, one week in duration. This schedule includes all assignments or work activities that are required to be started that week in order to maintain the completion dates in the look-ahead schedule. Work assignments are “pulled” from the look-ahead schedule onto the weekly work plan. The weekly work plan is “shielded” from poor quality assignments, however. Shielding means that an assignment must be ready to start prior to its inclusion in the weekly work plan – all constraints, including prerequisite work, have been completed, and resources are available and have been assigned to do the work. Shielding the weekly work plan increases its reliability, and, as a result, the production crews are “shielded” from uncertainties in the work flow. The “Last Planner” is the person who makes task assignments to the people who execute the work, and who develops the weekly work plan. This is most often the foreman in a construction organization. The Last Planner considers productivity targets and crew size when determining how much work to include in the weekly work plan. The weekly work plan also includes some future work items that are ready to be started (all constraints removed), but not required to be started through the pull process. These items are called “workable backlog,” which is a ready buffer of work activities that the crew can easily shift to if an assignment on the work plan is delayed, or if all assignments on the plan are completed.

Improving the reliability of the work flow is a major element of Lean Construction. The reliability of the weekly work plan is measured by “Percent Planned, Complete” or PPC. This is simply the percentage of those assignments on the weekly work plan that are completed that week. For those assignments that are planned but not completed, root causes are determined and actions are taken to prevent recurrence. Additional metrics are being developed to measure the reliability of look-ahead schedules and other aspects of work flow reliability.

Observations

Overall, the jobsite was organized, clean, and uncluttered. The building was originally constructed with 13 feet between floors, which created tight work spaces in the ceilings. The ceiling spaces were full of piping, ductwork, and wiring, but it was organized and neatly installed.

Percent Planned, Complete (PPC) is measured and tracked as the main performance metric on this project. The contractor began measuring PPC approximately 7 weeks into the project. PPC was 51% at that point – barely half of the assignments on that week’s work plan were completed. The contractor had measured PPC for a total of 35 weeks at the time of the site visit, and it had averaged 87.5% over the previous 20 weeks. PPC data were collected during the interviews. A graph of PPC, including the four-week moving average, is provided as Figure 3.



Productivity was not measured on this project; the only metric measured by site management was PPC. By Lean Construction theory, productivity factors are considered in developing the weekly work plans, so that if all assignments on the weekly work plan are completed, the incorporated productivity factor is met by design. The collection, analysis, and comparison of PPC and productivity data on the same project would provide an interesting comparison.

Feedback from Interviews

The research team interviewed six subcontractor foremen and one prime contractor foreman. The foremen stated that this project had an entirely different atmosphere than others they had worked on – the subcontractors communicated among themselves and coordinated their work. On a typical project, they were not concerned with other subcontractors – they installed their work as quickly as possible and submitted their invoices, regardless of whether or not it interfered with future work by others.

All major subcontractors participated in the Lean Construction effort. The subcontractors knew the general contractor was serious about implementing Lean Construction when project management made a subcontractor stop and remove some work that it had started out of sequence. At the beginning of the project there was the typical amount of conflict between the subcontractors, but this greatly declined in the middle of the project. It increased a little bit at the end of the project, due to new subcontractors coming in who were not familiar with the concepts of Lean Construction. All project personnel interviewed agreed that the designer needed to be more involved in the Lean Construction process.

The foremen interviewed stated that this project experienced less rework due to better coordination between subcontractors. It took active participation by all parties to make the process work smoothly, though – poor planning by one subcontractor could affect all the others. This most often happened with inaccurate information about when prerequisite work would be completed. The accuracy and reliability of schedules and plans were very important. Increased communication resulted in more of a team concept than the typical situation where each

subcontractor looked out for its own interests – both at the foreman and craft levels. The contract incentive bonus was a motivating factor that encouraged teamwork. Crew morale was excellent on the project.

The foremen admitted that they initially thought the meetings held at the beginning of the project to build the master pull schedule were a waste of time, but once they saw the system work, they all agreed that it was a valuable experience. This was their first project where subcontractors had been involved in developing the overall project schedule.

The foremen said that they knew this project better than others they had worked on because they were given planning time and were required to plan the work in detail. Due to the amount of planning required, especially at the beginning of the project, they felt that a good field foreman was essential to keep the work running smoothly in the field. Foremen stated that the weekly planning meetings were extremely valuable, because they were forced to plan their work in detail, and the meetings provided regular opportunities to coordinate with other crafts. The crews knew, based on the weekly work plans, what needed to be done by the end of the week. One foreman gained his crew's commitment to the weekly work plan prior to submitting it to the project superintendent. Foremen felt that the productivity on the project was very good. The workable backlog helped to ensure that there was plenty of work each week.

The planning process helped the foremen maintain a good steady flow of work with a reasonably constant number of people. The plumbing foreman said his crews finished their work more quickly and with less manpower (13 craftsmen vs. 20+) than they typically would on a project of this size. The foremen generally stated that they did not see anything new in Lean Construction, but it provided a structured way to plan the work. Everybody reported schedules and progress in the same format, and that was a significant benefit.

The majority of the construction materials were delivered in a just-in-time manner. The electrical subcontractor was the only one to store bulk materials. There was very little room for material storage at the jobsite, so materials were stored in trailers off the jobsite. The drywall and plumbing subcontractors ordered material in 3-day increments, and received deliveries twice a week. In this way, they did not store or move much material around on the site, which saved a significant amount of labor and schedule time. The mechanical subcontractor would likely have had similar results, were it not for vendor problems. The foremen said purchasing materials in this manner cost more due to the smaller quantities and increased number of deliveries, but the labor cost saved by not having materials in the way was significantly more than the increase in material prices.

Three foremen said they had very good support from their home offices toward implementing Lean Construction on this project. One foreman said his home office took a “wait and see” approach. Two of the foremen had already trained other foremen in their companies on the Lean Construction process. All foremen interviewed stated that they would personally use Lean Construction principles on future projects.

Two foremen said that their companies considered adopting Lean Construction as a standard operating procedure. One said his company had already started using it on other projects. They felt that the principles would help their companies, even if they were the only ones on the project using them. They knew how to better load manpower, schedule their work, and schedule material deliveries so they did not have to relocate material.

The owner representatives attributed the increased communication and coordination on this project to two main factors – the people and the process. They were very pleased with the general

contractor, who assembled good subcontractors, and assigned people to the project who worked well together. The Lean Construction process provided the emphasis on planning, realistic schedules, and coordination between all parties.

The owner held weekly on-site meetings with the designer and the contractors. This is a routine practice for the owner, who finds it to be very effective in solving design information and clarification problems. The owner normally hires local architects, which makes such meetings feasible. The foremen agreed that these meetings were very effective – most questions were answered in the meetings, thus saving a great deal of time and paperwork. Foremen said there were fewer RFIs on this project than is typical.

Traditionally, contractors submit updated schedules to the owner on a periodic basis. In this case, with the milestone pull schedule, the owner's representative met with the contractor's project manager weekly to review the schedule from a strategic viewpoint. The owner tracked milestone dates from the master schedule, but was comfortable that the contractor had thought through the process in detail and was updating the detailed schedules weekly through the Lean Construction process.

At the time of the site visit, the project was projected to finish approximately \$1 million (4.5%) below budget. The owner evaluates projects on a "value" basis, using metrics such as design fee per square foot, construction cost per square foot, and total project cost per square foot. The owner has completed five building projects in the last ten years; the last three finished slightly over their budgeted costs. The budget for this project was essentially equal to a comparable project completed two years earlier. The owner's goal is to get the best value, and felt that Lean Construction contributes to improved cost performance by reducing waste.

This was the owner representative's first project using Lean Construction concepts. The owner's project management staff was planning to adopt it for all future projects, because it worked so well on this project.

4.1.5 Likelihood of Replication

This was the first Lean Construction project for all project participants. A Lean Construction Institute consultant provided one day of introductory theory training for key participants, and another spent one day helping the project team develop the milestone pull schedule. This is considered a key factor for successful implementation of this program. The owner, designer, general contractor, and major subcontractors were all involved in developing the milestone pull schedule.

It took a great deal of effort initially to get the subcontractors to work together (for example, coordination of plumbing and duct work). Cooperation significantly improved over the course of the project. Some changes within individual company policies were required as well. For example, some subcontractor foremen were initially unsure how readily their supervisors would accept project data reported in the Lean Construction format as opposed to their traditional company formats.

A learning curve related to the Lean Construction planning and scheduling process was evident. Foremen stated that at the beginning of the project, it took them approximately 4 to 6 hours to develop a look-ahead schedule, but by the middle of the project it took less than 1 hour per week to update the look-ahead schedules. They said that the initial training was essential to properly implementing the concepts on the project.

Lean Construction methods were fully embraced by the owner, general contractor, and all major subcontractors. There was obviously a great deal of coordination and communication; contractors worked together, instead of at each other's expense. This level of commitment was critical to the success of the project. The designer was willing to implement Lean Construction as long as it received some benefit, but did not fully embrace the program. This had detrimental effects on the timely completion of the design documents, which negatively impacted the start of the construction schedule. The construction permits were obtained individually for each floor as parts of the design were completed, in order to mitigate some of these delays.

The general contractor performs only negotiated contracts where it is involved early enough in the pre-project planning phase to provide constructability input and participate in similar effective practices. This selectivity undoubtedly contributes to the success of its projects. In the future, it plans to start the Lean Construction process earlier in the project, and obtain the full commitment of the designer. The composition of the project team, both companies and personnel, is vital to the success of Lean Construction. The general contractor stated that it would use these same subcontractors on future projects.

The general contractor has used Lean Construction principles in the preliminary planning phase of a separate venture. At the time of the site visit, the owner and the general contractor were negotiating another building renovation and expansion project, with the plan of fully implementing Lean Construction principles with all project participants, including the designer.

This project team, particularly the owner and the general contractor, effectively built an environment that facilitated the acceptance of Lean Construction principles, and as a result enhanced the probability of a successful project. A project team could achieve positive results by creating a similar environment, implementing the Lean Construction process early in the pre-project planning phase, and obtaining full commitment from all participants.

4.1.6 Summary

The renovation of a 70-year old building is a challenging task. Add to this the fact that the work was 90% subcontracted, and the project appeared to be a prime candidate for major coordination problems. The Lean Construction approach clearly had a positive impact on the project. Foreman delay survey data showed that delays due to common problems with tools, information, and materials were a fraction of what is experienced on most projects. This indicates that the planning process was very effective toward improving field productivity. The increased planning, communication, and coordination among project participants allowed the work to progress smoothly, without major conflicts between contractors. This degree of cooperation indicated that the project team accepted the concept of optimizing the project as a whole, as opposed to optimizing individual activities or optimizing the work of individual companies.