Evaluating the Implementation of Lean Construction into Construction Education

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ABSTRACT

Lean construction is growing in popularity throughout the A/E/C industry. The concepts of lean construction promise to effectively delivering construction projects with ever increasing complexity and ever shrinking resources. As a result, many construction companies are beginning to use lean construction as ‘standard operating procedure’ on their projects. Despite this trend, the concepts and practices of lean construction are not widely taught in undergraduate construction education programs. In response, one undergraduate construction management program redesigned the required scheduling course utilizing the Last Planner System™ framework to introduce lean construction concepts. The goal of this course redesign was to integrate lean construction principles and practices, while maintaining the traditional learning outcomes for a construction scheduling course. A comparison of course learning outcome assessment results after the redesign validated this approach. Recommendations are presented for implementing lean construction into similar construction education courses.

INTRODUCTION

Lean construction is one of the fastest growing trends in the construction industry (Alves et al. 2010). Construction project owners and contractors are implementing lean practices on more of their projects because of the promise of greater productivity (Sutin 2012). And lean practices applied to the construction industry promise to not only improve productivity, but to also improve the overall project management process (Howell et al. 2011).

Despite the fact that lean construction has gained momentum throughout the construction industry, few construction education programs have integrated this topic into their curriculum. And most lean construction content has been implemented at the graduate level. There are many factors that attribute to this lack of infiltration into construction education including accreditation requirements, instructor expertise, and traditional course learning outcomes. However, because of the proliferation of lean construction, academia is compelled by practitioners to find a way to incorporate this trend into their curriculum. (Johnson and Gunderson 2009)

The Construction Management Program at California State University, Fresno approached this challenge by redesigning the undergraduate construction scheduling course to include lean construction topics. The key principles and practices of lean construction were integrated into the course by using the Last Planner System™ as a framework for the course. The Last Planner System™ (LPS) provides a streamlined
process for incorporating key principles of lean construction, while still utilizing the core scheduling techniques taught in the scheduling course.

However, a significant concern in this redesign was that incorporating additional topics would degrade the students’ ability to achieve the current learning outcomes for the course. After all, when new content is added it typically replaces existing content within the course. Therefore, the challenge was to implement this new content in a meaningful and effective way within these constraints.

Table 1 summarizes the three goals for this course redesign. The primary goal was to incorporate lean principles and practices while teaching scheduling concepts to students. The desired outcome of this redesign was to allow students to learn the scheduling content by using lean construction practices.

<table>
<thead>
<tr>
<th>No.</th>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Use the Last Planner System™ to provide a framework for incorporating lean construction principles and practices into the scheduling course.</td>
</tr>
<tr>
<td>2</td>
<td>Maintain the same student learning outcomes in the course.</td>
</tr>
<tr>
<td>3</td>
<td>Maintain the same level of attainment of student learning outcomes in the course.</td>
</tr>
</tbody>
</table>

BACKGROUND

Lean Construction in the Industry

Lean construction is based upon the principles developed by Toyota and led by Engineer Ohno to increase efficiency in automobile manufacturing (Ohno 1988). The main objective of this ‘lean approach’ was to maximize value and to eliminate waste. The lean approach has proliferated throughout many industries and become a key management practice in nearly every sector (Emiliani 2007). Despite this success in general management circles, lean within the construction industry has only begun to gain momentum within the last ten years (Alves et al. 2010). Thus the definitions and applications of lean principles in construction often vary greatly throughout the industry (Alves et al. 2010).

Though some argue that lean construction has the greatest potential to transform the industry, it has been the slowest of recent emerging trends (BIM, sustainability, etc.) to penetrate the construction market place. This may be due a general lack of understanding of the trend (Alves et al. 2010). Another reason may be that it lacks an accepted lean construction “system” in the industry. Whatever the reason, lean construction has yet to be fully embraced throughout the industry. (Sutin 2012)

The Lean Construction Institute (LCI) provides an association for construction industry stakeholders to share ideas on applying lean construction. LCI lists three linked opportunities that lean construction provides: impeccable coordination, projects as production systems, and projects as collective enterprises (Howell 1999). The founders of LCI also provide a keen focus on using lean principles to improve
production systems on projects. This focus, they argue, provides a unique opportunity to address the lack of productivity improvement in construction.

The Last Planner™ system (LPS) was developed to provide the framework for focusing on production planning and management for construction projects. LPS has become a popular management process on many construction projects (Sutin 2012). Prior research provides evidence that LPS increases the reliability of project planning, increases production performance, and improves workflow in design and construction operations (Ballard and Howell 2004).

**Lean Construction in Education**

As with the construction industry, lean construction has the least amount of focus of recent emerging trends within undergraduate construction education programs. Not surprisingly, a recent study of programs found that less than half include lean construction within their curriculum (Johnson and Gunderson 2009). This lack of focus provides a significant challenge for faculty members because until recently there has been minimal course materials’ pertaining to lean construction available for instructors. Even more problematic is the lack of resources for undergraduate courses. Lean construction has typically been taught in graduate level courses and short courses (Tsao et al. 2012). However, there has been an increasing interest in teaching lean construction at the undergraduate level (Tsao et al. 2012; Leathem and Cosper 2013).

The most significant concern with bringing lean construction to the undergraduate level is the question of where and how to incorporate the topics. It is generally noted that adding new technologies and trends into any undergraduate curriculum is challenging for a multitude of reasons. First, some undergraduate construction education programs are required to include minimum topics for accreditation purposes. Additionally, construction education programs often lack the expertise to quickly and efficiently implement emerging trends within the construction industry. Finally, finding the ‘right place’ for new content is another significant challenge for programs. (Johnson and Gunderson 2009)

**COURSE REDESIGN APPROACH**

In the summer of 2009, faculty at the Construction Management Program at California State University, Fresno redesigned the undergraduate construction scheduling course (CM 116) with the goal of incorporating lean principles and practices into the course. The course is a second semester, junior level course that focuses on teaching students how to effectively plan and schedule a construction project. It was selected because much of lean construction deals with planning, scheduling, and management. Thus, despite the inherent challenges with curricular additions, lean seemed the ‘best’ fit in this course.

A core focus of any lean approach is to maximize value and to minimize waster. In order to accomplish this goal, there are two core principles of a lean approach: (1) respect for others and (2) continuous improvement (Emiliani 2007). These principles form the basis for all other lean construction concepts and practices. Therefore, the redesign was based upon these two key principles. First, the instructor strove to redesign in a manner that respected the students’ time commitment for the
course. The instructor was very cognizant of increasing student workload by adding content. Second, the instructor wanted to make sure that there was a continuous improvement process in place to evaluate the impact of the additional content on achieving learning outcomes. The instructor addressed these principles by reviewing existing course learning outcomes, validating the assessment methods, and continually assessing student achievement of outcomes each semester.

Scheduling in Construction Education

Initially, the instructor reviewed the current topical content within the scheduling course to ensure that it was still relevant. Literature review found that many undergraduate scheduling courses focus on teaching construction planning and an introduction to types of schedules. Types of schedule included bar charts (or Gantt charts), critical path method (CPM), short interval processes (SIP’s) and line of basis (LOB) schedules. (Galloway 2006; Hinze 2011; Newitt 2008)

Additionally, some construction education programs formally or informally follow the scheduling processes outlined by the Project Management Institute. These processes include: activity definition, activity sequencing, activity resource estimating, activity duration estimating, schedule development, and schedule control. (Galloway 2006; PMI 2013)

Course Learning Outcomes

Based upon this initial analysis of scheduling courses, the existing learning outcomes of the course were validated and retained for the course redesign (Table 2). The course learning outcomes provide a basis for use in future courses.

<table>
<thead>
<tr>
<th>CLO</th>
<th>Learning Outcome Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Create a bar chart for a simple construction project</td>
</tr>
<tr>
<td>2</td>
<td>Develop a project plan for a construction project</td>
</tr>
<tr>
<td>3</td>
<td>Analyze the activities that make up a project plan</td>
</tr>
<tr>
<td>4</td>
<td>Create a Critical Path Method (CPM) schedule</td>
</tr>
<tr>
<td>5</td>
<td>Load and level various resources in a construction project</td>
</tr>
<tr>
<td>6</td>
<td>Evaluate an updated schedule</td>
</tr>
</tbody>
</table>

Assessing Course Learning Outcomes

Course learning outcomes can be assessed using various direct and indirect methods. Some literature on assessing learning outcomes recommends that direct methods target specific skills, knowledge, and/or values (Diamond 2008). Skills and knowledge can be the easiest to assess since they typical produce concrete results. For this study, all of the learning outcomes require students to demonstrate skills.

The instructor tracked achievement of each learning outcome by determining the overall average grade of the assessment method assigned to that outcome (Table 3). The minimum standard was set at 75% for each learning outcomes. This minimum standard was based on the historical average score for all deliverables in the course. It also represents a close approximation of the minimum passing score for all of the
formative assessments in the course. This standard provides a basis for comparing learning outcome achievement across semesters.

Table 3. Assessment Summary

<table>
<thead>
<tr>
<th>CLO</th>
<th>Brief Description</th>
<th>Assessment Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bar chart creation</td>
<td>Bar chart (rubric)</td>
</tr>
<tr>
<td>2</td>
<td>Project plan development</td>
<td>Project plan (rubric)</td>
</tr>
<tr>
<td>3</td>
<td>Project activity analysis</td>
<td>Exam/Quiz questions</td>
</tr>
<tr>
<td>4</td>
<td>CPM schedule creation</td>
<td>Exam questions</td>
</tr>
<tr>
<td>5</td>
<td>Resources loading and leveling</td>
<td>Exam questions</td>
</tr>
<tr>
<td>6</td>
<td>Schedule updating and evaluation</td>
<td>Schedule update (rubric)</td>
</tr>
</tbody>
</table>

Lean Construction Principles

It was critical that the course redesign also include key concepts of lean construction. Recent literature describes key lean construction concepts as: (1) stability and learning, (2) systematic planning and control of weekly assignments, (3) focus on value creation, (4) flow of resources, and (5) reduction of variability in the system (Alves et al. 2010). The Lean Construction Institute applies these concepts within the LPS system. The LPS system ultimately provides three opportunities on a project: (1) impeccable coordination, (2) projects as production systems, and (3) projects as collective enterprises (Howell 1999).

These core concepts are integrated into the redesigned course through several steps. First, the students are introduced to these concepts by reading contemporary journal articles related to the lean construction. These articles are primarily resources from the Lean Construction Institute website (www.leanconstruction.org/training/readings). Second, using simulations and/or class activities reinforces these concepts. These activities help students to assimilate the concepts into a realistic context. Finally, students are asked to apply these concepts to construction related deliverables for the course. These deliverables are closely related to ‘real life’ construction planning and scheduling requirements. They are also some of the methods used to assess learning outcomes.

Lean Construction Course Framework

The framework of the Last Planner™ system (LPS) was chosen because it provided a well-defined process for planning, scheduling, and managing a construction project (Hamzeh and Bergstrom 2009). The goal of the system is to allow the project team to design effective production systems throughout entire construction process. LPS also provided the advantage of utilizing typical scheduling techniques throughout the four phases of the system. The four LPS phases are: Master Scheduling, Phase Scheduling, Look Ahead Planning, and Commitment Planning.

The instructor used this framework for course organization. As such, each course module aligned with a LPS phase. The sections below describe each of the LPS phases and how they were applied to the course modules.
Phase 1: Master Scheduling

This phase creates a master schedule for the project. It lists the milestone dates of the project based upon the front-end planning activities of the project team (Ballard 1997).

The first module in the revised course utilizes this phase to introduce students to project planning. Within the module, each student is tasked with creating a ‘master’ bar chart schedule for a given project (CLO-1). Additionally, students are expected to identify, sequence, and estimate the duration of the milestone activities for this master schedule. This assignment provides foundation for future project phases in the course. Students are also required to complete a general plan for the project that includes identification of ‘conditions of satisfaction’, safety, site logistics, and a general project approach (CLO-2).

Phase 2: Phase Scheduling

This phase creates a more detailed schedule for each project phase. Construction project phases may include foundations, structural framing, core/shell, interior finishes, and/or tenant improvements. The key aspect of this phase is the use of a collaborative planning effort where key project participants (specifically specialty contractors) identify “handoffs” between each participant in order to best achieve milestones set in the master schedule. This effort uses a “pull” scheduling method that employs reverse phase scheduling (Ballard and Howell 2004).

The second course module focuses on using CPM schedules to develop good phase schedules (CLO-4). A key activity in this module is the ‘team scheduling exercise’. Previously this was taught as the ‘Gilbane Method’ (Newitt 2008). However, this was modified to match the pull planning method recommended as a phase scheduling tool in LPS. To add more realism to this phase scheduling exercise, students are assigned specific scopes of work within the phase. Students are required to research the means and methods of their scope of work prior to the exercise. This allows the student to analyze specific activities within the phase schedule (CLO-3).

During the exercise, each student assumes the role of a trade partner in the phase scheduling exercise. The phase scheduling activity reinforces the concept of “pull” scheduling in which participants start with the last activity and then work to the first activity (i.e., backward planning). The other assessment in this module was the allocation of resources to the CPM schedule. In this assignment, students were tasked with allocating and leveling resources (in this case manpower) for the project (CLO-5).

Phase 3: Look Ahead Planning

This phase “signifies the first step of production planning with a time frame usually spanning between two to six weeks. At this stage, activities are broken down into the level of processes/operations, constraints are identified, responsibilities are assigned, and assignments are made ready.” (Hamzeh and Bergstrom 2009)

This module of the course focuses on reinforcing resource allocation and management (CLO-5). Students are also introduced to line of basis schedules during this phase. The primary assignment for this module tasks student with updating an existing schedule and then generating a “4 week look ahead” schedule based upon the
update (CLO-6). Students are also asked to evaluate the current status of the schedule and to generate a brief report summarizing the status of the project. The final aspect of this assignment entailed outlining the responsibilities and resources required to complete the activities shown on the “look ahead” schedule.

**Phase 4: Commitment Planning**

This phase is truly the most important part of the system. It is the basis of the production process. The lead field personnel, or last planners, are required to commit to a weekly list of activities planned for completion. This weekly work plan (WWP) becomes the tool for managing reliability on the project. Reliability is tracked through the percent planned complete (PPC) metric. Percent planned complete measures how many of the activities, in the WWP, were completed versus how many were planned. This provides a means for better understanding how to make reliable promises on the project. (Ballard 2000)

During this last module of the course, a final exercise in class is a “PPC” simulation. This simulation provides students with an opportunity to act out the commitment planning process. This exercise is broken over two lab periods in consecutive weeks. Students create a look-ahead plan (LAP) for a team exercise during the final two lab periods. The activity typically requires the teams to create a virtual mock up and construction schedule for a given set of plans. After the LAP is created, the teams are then tasked with creating a WWP for the first lab. At the completion of the lab, they are required to evaluate the PPC for that day. They do the same steps for the final lab period – update the LAP, create a WWP, do the work, and then evaluate PPC. In the final 30 minutes of the lab period, the instructor guides the students through a continuous improvement session. This session allows students to identify root cause of planning failures in order to create more effective plans for the future.

**RESEARCH METHODOLOGY**

Grading specific assignments, quizzes, or exam questions were the methods used to assess each learning outcome. The instructor identified the specific assessment method at the beginning of this study (Table 3). The assessment data was collected during the course and evaluated at the end of each semester. The assessment results were tabulated each semester and a statistical mean was computed for each assessment method. This statistical mean was compared against the minimum standard to evaluate if the learning outcome was met. This method was also used to evaluate the results of this study.

It is understood that this basic analysis of comparing means only determines if the learning outcomes were met over a specific period of time. This method does not assess if improvement occurred throughout the study.

**RESULTS & RECOMMENDATIONS**

The redesigned course was taught six times over three years. The results from the initial course offerings and the redesigned course offerings are summarized in this section.
Assessing Learning Outcome Achievement

As discussed in the previous section, achievement of learning outcomes for the course was evaluated by assigning specific assessment methods for each outcome. A benchmark (75%) was established for all learning outcomes to evaluate achievement. Assessment data was collected for eight total offerings of the course, two prior to redesign and six after redesign.

Results

The following tables provide a detailed list of the program outcomes for the two semesters before (Table 4) and the six semesters after (Table 5) the implementation of the course redesign. These tables show that the learning outcomes met the minimum standard before and after the course redesign. It should be noted that the mean and standard deviation calculations are based upon student grades for the assigned assessment method across all the semesters.

### Table 4. Course Learning Outcome Achievement (Prior to Redesign)

<table>
<thead>
<tr>
<th>Term</th>
<th># Students</th>
<th>F09</th>
<th>S10</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min. Std. Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLO-1</td>
<td>24</td>
<td>80</td>
<td>81</td>
<td>80</td>
<td>7.8</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-2</td>
<td>23</td>
<td>92</td>
<td>84</td>
<td>87</td>
<td>10.7</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-3</td>
<td></td>
<td>89</td>
<td>89</td>
<td>89</td>
<td>11.9</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-4</td>
<td></td>
<td>88</td>
<td>86</td>
<td>87</td>
<td>9.8</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-5</td>
<td></td>
<td>83</td>
<td>76</td>
<td>78</td>
<td>11.9</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-6</td>
<td></td>
<td>77</td>
<td>82</td>
<td>79</td>
<td>12.2</td>
<td>Y</td>
</tr>
</tbody>
</table>

### Table 5. Course Learning Outcome Achievement (After Redesign)

<table>
<thead>
<tr>
<th>Term</th>
<th># Students</th>
<th>Su10</th>
<th>S11</th>
<th>F11</th>
<th>S12</th>
<th>F12</th>
<th>S13</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min. Std. Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLO-1</td>
<td>13</td>
<td>89</td>
<td>92</td>
<td>78</td>
<td>86</td>
<td>88</td>
<td>91</td>
<td>88</td>
<td>7.9</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-2</td>
<td>46</td>
<td>76</td>
<td>75</td>
<td>70</td>
<td>79</td>
<td>76</td>
<td>82</td>
<td>77</td>
<td>15.6</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-3</td>
<td></td>
<td>82</td>
<td>79</td>
<td>84</td>
<td>88</td>
<td>87</td>
<td>84</td>
<td>84</td>
<td>8.9</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-4</td>
<td></td>
<td>77</td>
<td>85</td>
<td>81</td>
<td>84</td>
<td>79</td>
<td>83</td>
<td>83</td>
<td>11.4</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-5</td>
<td></td>
<td>83</td>
<td>79</td>
<td>78</td>
<td>79</td>
<td>76</td>
<td>79</td>
<td>80</td>
<td>8.7</td>
<td>Y</td>
</tr>
<tr>
<td>CLO-6</td>
<td></td>
<td>67</td>
<td>84</td>
<td>72</td>
<td>77</td>
<td>81</td>
<td>85</td>
<td>79</td>
<td>14.7</td>
<td>Y</td>
</tr>
</tbody>
</table>

It should be noted that some of the factors contributing to improvement in learning outcome achievement might not be fully attributable to the incorporation of lean construction topics. As stated in the section describing lean, a key lean principle is continuous improvement. Thus, the instructor implemented new teaching methods every semester in an attempt to improve learning outcome achievement.

In summary, though basic statistical methods were used, it can be seen that all of the learning outcomes exceed the minimum standard after the redesign of the
course. Additionally, it is noted that two of the learning outcomes improved after the incorporation of lean into the course. This basic statistical analysis of comparing the mean learning outcome scores provides some validation for the approach utilized for this course redesign.

**Recommendations**

Incorporating new content into any course can be challenging. As previously noted, the topic of lean construction is even more challenging since minimal education content is available for use in undergraduate courses. Therefore, the following recommendations are provided to assist with future courses.

1) Don’t just incorporate lean construction topics. Also incorporate lean principles. Starting with the core concepts of ‘respect for others’ and ‘continuous improvement’ make the transition easier.

2) Make sure to let students know the reason for the addition of lean construction topics. Convincing them that they could use this content on their first job goes a long way to having them accept these ‘new’ topics.

3) Recruit industry members to assist with key lean exercises in the course. The effect of a seasoned industry member speaking into the actual implementation of lean construction on a project cannot be understated. These opportunities greatly enhance the educational opportunity for students.

4) Utilize ‘simulations’ to reinforce core concepts. Though these were not discussed in this study, they are valuable tools for teaching key lean concepts. It should be noted that the Lean Construction Institute provides adequate resources and training for many of these simulations.

**CONCLUSION**

The continuing emergence of lean construction as a key trend within the construction industry makes it an important area for integration within educational programs. This study demonstrates that using the Last Planner System™ as a framework to introduce lean construction concepts into a scheduling course can be done without sacrificing achievement of the traditional learning outcomes. Utilizing LPS as a framework for a scheduling course also provides a formal structure for effectively teaching key construction planning and scheduling topics. The results of the study provide some basic validation for utilizing this system to incorporate lean construction into an undergraduate course. This study provides a basis for continued efforts to integrate lean construction into undergraduate construction education.

**REFERENCES**


