EFFECTIVENESS OF LEAN PRINCIPLES IN CONSTRUCTION

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ABSTRACT

This paper analyses the experiences of 16 companies who utilized lean construction principles, during the 1990 to 2003 period. A total of 41 lean principles were applied, and a total of 29 benefits were realised. Eliminating those principles that were used less than average times resulted in 11 major lean construction principles, and 6 major benefits. The two most applied lean principles included: 'Percent Plan Complete' (PPC), used on 10 projects; and 'Lookahead plan', used on 8 projects. The 6 major benefits included: (i) Cost savings, (ii) Less management cost, (iii) Project time reduction, (iv) PPC increase, (v) Less inventory, and (vi) Less rework.

An analysis of the 11x6 lean principles vs. benefits table revealed that the most effective lean principle was the 'Percent Plan Complete (PPC)', seventy percent (70%) of the projects, who monitored PPC, experienced cost savings, and 60% experienced time reductions. 'All parties involved in design' principle was also very effective, reducing project times on 100% of the projects. This paper relates the major lean principles to their benefits. The experience of 16 construction companies presented in this paper will guide the future lean construction managers in selecting the most effective principles.

KEY WORDS

Effectiveness, Principles, Benefits

INTRODUCTION

In the last decade, several construction companies have applied lean principles, and some of them have published their experiences. Limited valid data is now available for evaluating the effectiveness of each of the lean principles, for the guidance of future users. This paper includes the experiences of 16 companies who utilized lean construction principles, during the 1990 to 2003 period.

Analysis of data extracted from the various publications, that included descriptions of the projects, listed a total of 41 lean principles that were applied, and a total of 29 benefits that were realized. A cross-classification arrangement of the 41 x 29 lean principles-benefits was used to narrow down the list of lean principles and benefits to include more frequently used principles. The two major attributes, that had less than average frequencies in their classes, were dropped. This exercise resulted in 11 major lean construction principles, and six major benefits. The 11 major lean principles included: (i) 'Identify customer needs in design', used on 2 projects; (ii) 'All parties involved in design', used on 6 projects; (iii) 'Pull scheduling', used on 3 projects; (iv) 'Look ahead planning', used on 8 projects; (v) 'Just-in-time' (JIT) delivery, used on 4 projects; (vi) 'Employee training', used on 4 projects; (vii) 'Weekly meetings', and (viii) 'Weekly planner', each used on 6 projects; (ix) 'Percent plan complete' (PPC), used on 10 projects; (x) 'Reasons for non conference (RNC), used on 3 projects; and (xi) 'Last planner' used on 3 projects.

The 6 major benefits included: (i) Cost savings, (ii) Less management cost, (iii) Project time reduction, (iv) PPC increase, (v) Less inventory, and (vi) Less rework.

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The project descriptions mentioned the following benefits, realized by lean construction: (i) increase in PPC, ranging from 32% to 50%; (ii) cost savings of 11% to 42%, one electrical contractor saved $3.9 million in one year; (iii) time savings of 5 weeks to 18 weeks; (iv) less rework, the expansion of AWWA headquarters in Colorado had zero rework; (v) less inventory at site was reported by 8 of the 16 companies; and (vi) fewer change orders, less overheads, shorter punch list, increased worker motivation, fewer accidents, and lesser waste on site. This paper has tabulated the lean principles used by each of the 16 companies, and the benefits realized by each company.

ANALYSIS OF DATA OF 16 CONSTRUCTION PROJECTS

Published descriptions of sixteen (16) construction projects, that used lean principles, from 1990 to 2003, were studied and analysed. Table 1 includes summary of the lean principles applied on each of the 16 projects, and the benefits realized on each project. The lean principles applied and their direct benefits were mentioned in the descriptions of the projects.

All of the lean principles that were applied on the 16 construction projects are listed in Table 2. The lean principles totaled 41, which have been grouped into 8 categories, often used in project management. The frequencies in Table 2 give the distribution of each of the lean principles used on the 16 projects. Figure 1 shows the relative distribution of the top 16 of the 41 lean principles.

The frequencies in Table 2, sum to 92, which means that a total of 92 applications were made on the 16 construction projects using 41 lean principles, each principle applied one or more times. As shown in the table , 34 of the 92 applications, 37% of the total, were used for Project Monitoring and Control, 17 (18%) for Time Scheduling, 12 (13%) for Personnel Management, and 8 (9%) each for Design, and Materials Management. Out of the 41 lean principles applied, *Percent Plan Complete* (PPC) was used most, on 10 of the 16 projects; followed by *Lookahead Plan,* on 8 projects. The other more applied lean principles included: *Weekly Meetings*, *Weekly Planner*, and *All Parties Involved in Design* principles, which were used on 6 projects. *Just-in-Time Materials Deliver (JIT)*, *More Employee Involvement*, and *Employee Training*, was each applied on 4 projects.

The benefits realized in using lean principles, on each of the 16 projects, are listed in column 3 of Table 1. All of these benefits are compiled and listed in Table 3. The benefits total 29, and have been organized into 8 major categories as shown in bold, in Table 3.

CORRELATION BETWEEN THE LEAN PRINCIPLES USED AND THEIR RELATED BENEFITS

To correlate each of the lean principles to its corresponding benefit(s), a cross- classification table was developed. This table included all of the 41 lean principles in column 1. All of the 29 benefits, grouped in 8 major categories, as in Table 3, were then listed, on top, across the cross- classification table, from columns 2-30. Each benefit of each of the lean principles was then marked in the corresponding cell of the table by a number '1', as a unit counter. After inserting the unit counters for all of the benefits, each lean principle accounted from zero to more than one unit counters in the corresponding benefit cells. A 41x29 table showing the number of unit counters in each of the cells against each of the lean principles resulted from this exercise. The numbers in the cells represented the number of times that benefit was realized due to using the corresponding lean principle, on one or more of the 16 construction projects.

The unit counters in the 29 cells of each row were summed up, and then these 41 sums were totaled. The total of all rows came to 344 unit counters. Each row's total of unit counters was then assigned a percentage of the total of 344. For 41 lean principles, an average percentage of 2.44 (100/41) was expected, if each of the lean principles realized equal benefits. This, however, did not occur. The row percentages ranged from 0.58% to 11.92%. To focus on the more effective lean principles, those that had less than the average percentage, i.e. 2.44%, were deleted. Table 4 includes those 11 of the 41 lean principles that had a total row benefit of more than 2.44 %. To easily reference the lean principles, and the benefits, the numbering for each of them given in Tables 2 and 3, has been maintained throughout the paper.

Table 1: Lean Construction Case Studies

Project Description	Lean Principles Applied	Benefits Realized
1. Linbeck Construction Remodeling of university building. Time: 12 month. Cost: $28.5M; 1990*.	• Coordination between contrs • Weekly meetings at site, • Just-in-time (JIT) delivery • PPC calculations, • Weekly planner	• Less rework • Less idle time • PPC increased by 38% • Cost savings: $1 million. • Project time reduced.
2. Construtora Reynold, Brazil. Construction of library in 1997. Time: 18 months; 1998.	• Look ahead schedules • Daily plans, • PPC calculations. • Physical site layout, • Workers assigned to foreman	• Site personnel reduced, 11 to 7 • Cost savings of 42% • Brick laying cost decreased 23%. • No excess materials on site. • PPC close to 1.0. • No budget overruns.
3. Neenan Company. A small high tech project - design and construction, implemented in 1997. Time: 16 weeks; 1998.	• Identify customer needs, • Sch. Desn in A Day (SDIAD), • Look-ahead schedules, • Weekly planner, • PPC calculations, • RNC calculations, • Last Planner • All parties involved in design	• Fewer change orders. • Less than 3% cost added due to change orders. • Saved 5 weeks on schedule. • Labor budget decreased by 7%. • PPC averaged 75% in design and 60% in construction.
4. Verticon Construca Empreendimentos Ltd McDonald's restau rant in Rio de Janeiro. Time: 90 days; 1999.	• Look ahead plan, • Daily plan, • Physical site layout, • All parties involved in design, • PPC calculated.	• Decrease in time, 90 to 83 days • No excess material on site. • Less rework. • Reduced 25% of management cost in last two weeks.
5. Five Storey office building, Finland Time: 12 mo, 1995.	• Fast-track methods, • Use of previous designs, • Constructability analysis.	• Reduced 56 days in schedule. • Protection of finished spaces.
6. Indianapolis Electric. Supply-chain process of an Electrical Contractor; 1999.	• Look-ahead plan, • Strict criteria for selection of contractors, • Just-in-Time (JIT) delivery, • Personnel responsible for proc. • Material list standardized.	• Reduced internal overheads • Inventory was reduced. • Procurement process reduced from 90 to 63 days in a year. • Cost savings of $3,887,000 in a year.
7. Expansion of Toy 'R' Us, New Jersey, in 2001. Time: 107 days; 2002.	• Fast-track methods, • All parties involved in design, • Just-in-Time delivery, • Daily meetings, • Weekly meetings, • Look-ahead schedule.	• Rework minimized. • Hauling and staging costs reduced. • Punch-list was shortened. • Project completed well ahead of • Under budget.
8. City of Los Angeles, Bureau of Engineering. Design and construction; 1998.	• Change organization structure • Training programs, • Flow chart prioritization. • Decision making groups, • Performance measures • Projects needing immediate attention given importance	• Environment of coordination and commitment. • Decreased cost on some projects.

Table 1: Lean Construction Case Studies

9. Last Planner System applied to a housing project in Ecuador. Time: 6.5 months, Cost: $860,000; 2002.	• Look ahead schedule, • Weekly work plans, • PPC calculation, • RNC calculation, • Performance measure, • Weekly meetings, • Training of employees. • Kept current activities linked to master schedule.	• PPC value between 41% and 91%. • Increased motivation to workers.
10. American Water Works Association (AWWA) expansion of the headquarters in Colorado; 1999.	• Customer needs identified, • All parties involved in design, • PPC calculated, • Just-in-time (JIT) delivery, • 'Last Planner'	• Saved six weeks in schedule. • 11% cost savings. • PPC averaged 70% • Eliminated rework. • Design took only 2 weeks.
11. Construtora Hernandez. 18-storey residential building, with a built up area of 14230 m2.	• PPC calculated, • Weekly plans, • Weekly meetings, • 'Pull' scheduling, • All parties involved in design	• PPC increased, 50% to 82% • Reduction of team by 30%. • Schedule reduced by 2 months • 11% cost savings. • Reduced inventory.
12. MT Hojgaard. A study of a company in Denmark, which uses lean construction in its projects; 2003.	• Weekly work plans, • PPC calculations, • RNC calculations • Look ahead plan, • Training of employees • Last Planner.	• Lower degree of disruption of activities. • Lesser inventory on site. • Lesser accidents. • Subcontractor gained more profit.
13. Office development project in the UK. Cost: £25 million.	• Training of employees, • All parties involved in design, • Last Planner, • PPC calculations, • Weekly meetings, • Look Ahead plan.	• Less rework. • Reduced 'over run' time. • Forced management to analyze reasons for non conformance.
14. Malling Precast Products Ltd,. Precast concrete fabrication in the UK; 2002.	• 'Pull' scheduling, • Decoupling buffer, • Weekly work plans, • PPC calculated, • More employee involvement.	• Productivity increases of walls, • Reduced inventory on site. • Lead time reduced. • Throughput doubled from £130,000 to £260,000.
15. An $840 million Pentagon renovation project. Time: 10 years; 2002.	• Resource variation, • Weekly progress reviews, • Short Interval Production Scheduling (SIPS), • All parties in making schedule, • Foremen involved in decisions	• Schedule reduced by 18 weeks for one of the wedges. • Flow and continuity achieved. • Ensured that work for that week was completed.
16. Neo Corporation. Construction of 30–storey condominium apartments in Singapore Time: 100 weeks; 2000.	• Elimination of waste • 'Pull' system • Uninterrupted work flow • Employee involvement. • Total quality control • ISO 9002 Certified • Continuous improvement.	• Decrease amount of waste on site. • Saves site storage space. • Less management costs • No hold ups.

Table 2: Frequency Distribution of Lean Principles Used on 16 Construction Projects

Lean Principle Used	Freq.
1. Subcontractor Selection	**2**
1.1 Strict criteria for subcontractor selection	1
1.2 ISO 9002 certified subcontractors	1
2. Design	**11**
2.1 Identify customer needs	2
2.2 All parties involved in design	6
2.3 Use of previous designs	1
2.4 Schematic Design In A Day (SDIAD)	1
2.5 Constructability analysis	1
3. Bidding	**2**
3.1 Electronic quoting	1
3.2 Flow chart prioritization	1
4. Time Scheduling	**17**
4.1 'Pull' Scheduling	3
4.2 Lookahead plan	8
4.3 Short Interval Production Scheduling (SIPS)	1
4.4 All project participants involved in making of schedule	1
4.5 Fast-track methods	2
4.6 Uninterrupted work flow	1
4.7 Keep current activities linked to master schedule	1
5. Materials Management	**8**
5.1 Just-in-Time (JIT) materials delivery	4
5.2 Materials list standardization	1
5.3 Physical site layout	2
5.4 Decoupling buffer	1
6. Personnel Management	**12**
6.1 More employee involvement	4
6.2 Employee training	4
6.3 Workers assigned to foreman	2
6.4 Personnel responsible for procurement	1
6.5 Change in organization structure	1
7. Project Monitoring and Control	**34**
7.1 Daily meetings	1
7.2 Daily plans	2
7.3 Weekly meetings, progress reviews	6
7.4 Weekly planner	6
7.5 Percent Plan Complete (PPC)	10
7.6 Reasons for Non-Conformance (RNC)	3
7.7 Last planner	3
7.8 Quality control	1
7.9 Performance measures	1
7.10 Foremen directly involved with decisions	1
8. Miscellaneous Lean Principles	**6**
8.1 Coordination between contractors	1
8.2 Elimination of waste	1
8.3 Resources variations	1
8.4 Decision making groups	1
8.5 Project needing immediate attention given more importance	1
8.6 Continuous improvement	1
Total	**92**

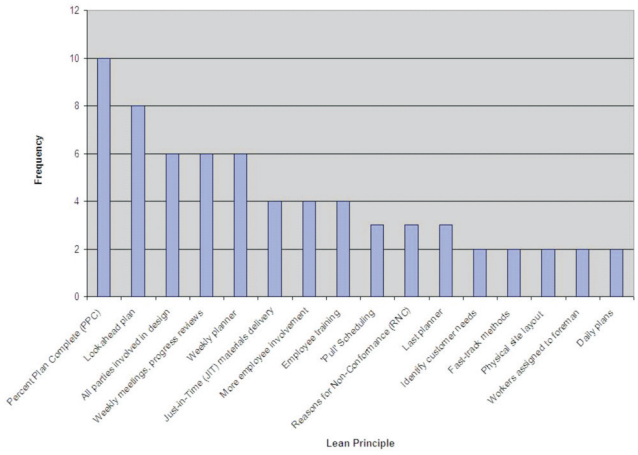

Figure 1: Major Lean Principles used on 16 Construction Projects

Next, the unit counters for each of the 29 benefits realized were totaled, and those benefits that calculated 3.45% or less were deleted, 3.45% being the average over 29 benefits. This deletion left 6 benefits. The resulting 11x6 cross-classification table including 6 of the 29 benefits and 11 of the 41 lean principles, is shown in Table 4.

Table 4 also ranks the 6 major benefits. Eleven major lean principles were applied on 16 construction projects, for a total of 143 times. Consequently, cost savings were realized 38 (26.6%) times, project time was reduced 34 (23.8%) times, PPC increased 30 (21%) times, less rework occurred 21 (14.7%) times, and less inventory was measured at site 16 (11.2%) times. Less management cost was reported only 4 of the 143 times.

Table 4 thus represents the cross-classification between the lean principles that experienced above average benefits, and their above average benefits as realized and documented on 16 construction projects. Table 4 includes 11 lean principles that were used 143 times against a total use frequency of 344 (Table 2), calculating to 42% of the total. Out of the 29 benefits documented on the 16 projects, these benefit numbers represent 42% of the total benefit counts. Several simple correlations are very obvious in the principle-benefit Table 4, and can be summarized as below, showing the effectiveness of each of the major 11 lean principles, in construction.

Table 3: Benefits Realized by Lean Principles Used on 16 Construction Projects

Benefits Achieved
1. Cost Savings
1.1 Cost Savings
1.2 Less management costs
1.3 Less internal overhead costs
2. Time Savings
2.1 Project time reduced
2.2 Less design time
2.3 Less procurement process time
2.4 Less lead time
2.5 PPC increased
3. Materials Management Efficiency
3.1 Less inventory
3.2 No excess material on site
3.3 Less waste on site
3.4 Saving in site storage space
3.5 Holding and storage costs reduced
4. Productivity Gains
4.1 Higher productivity
4.2 Less rework
4.3 Shorter punch list
4.4 Less idle time
4.5 No hold ups
4.6 Increased worker motivation
4.7 Flow and continuity achieved
5. Personnel Efficiency
5.1 Site personnel reduced
6. Worksite Safety
6.1 Lesser accidents
7. Project Variations
7.1 Fewer change orders
7.2 Change orders costs reduced
7.3 Lower degree of disruption of activities
8. Other Benefits
8.1 Management forced to analyze reasons for non conformance (RNC)
8.2 Environment of coordination and commitment created
8.3 Finished spaces protected (in multi-storied construction)

DESIGN

Identify Customer Needs

Identify Customer Needs principle resulted in cost savings, reduced project time, increased percent plan complete (PPC), and reduced rework. Each of the above benefits was realized by one of those 16 companies who identified customer needs at the design stage. Two of the 16 projects used this lean principle. Combined, this principle contributed 2.8% of the total benefits.

All Parties Involved in Design

All Parties Involved In Design principle was responsible for 14.0% of the total benefits. Six of the projects were completed in less time; four experienced less rework, four saw cost savings, and four increased their percent plan complete (PPC) numbers. Six of the 16 projects used this principle.

TIME SCHEDULING

Pull Scheduling

'Pull scheduling' was used on 3 of the 16 projects, and contributed to 4.9% of the benefits. This principle effected cost savings on 2 projects, and caused less inventory on 2 projects. It also reduced management cost, and project time, each on one of the projects. 'Pull scheduling' also increased PPC on one project.

The Pull Scheduling technique requires working backwards from the completion date. It limits the completion of the previous activity to just before the successor is ready to start. This system enforces JIT materials delivery and thus saves on (i) site storage, (ii) material holding costs, and (iii) idle person and equipment hours.

Figure 2 illustrates the 'pull' scheduling concept. In Figure 2(a), the dotted line boxes show the float of activity 'A'.

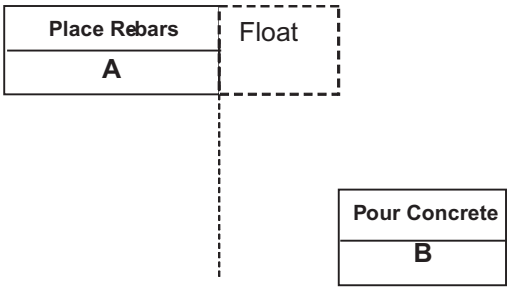

Figure 2(a): Traditional Scheduling

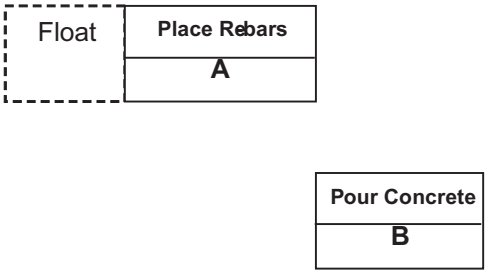

Figure 2(b): Pull Scheduling Concept

TABLE 4: Benefits Realized by Lean Principle

		Major Benefits of Lean Principles							
Lean Principle Used	**Use Frequency**	**1.1 Cost Savings**	**1.2 Less management cost**	**2.1 Project time reduced**	**2.5 PPC increased**	**3.1 Less inventory**	**4.2 Less rework**	**Total Benefit unit measures**	**Percent Benefits**
2. Design									
2.1 Identify customer needs	**2**	1*		1	1		1	**4**	**2.8**
2.2 All parties involved in design	**6**	4	1	6	4	1	4	**20**	**14**
4. Time Scheduling									
4.1 'Pull' Scheduling	**3**	2	1	1	1	2		**7**	**4.9**
4.2 Lookahead plan	**8**	5	1	4	3	2	3	**18**	**12.6**
5. Materials Management									
5.1 Just-in-Time (JIT) materials delivery	**4**	4		3	2	1	3	**13**	**9.1**
6. Personnel Management									
6.2 Employee training	**4**	2		1	1	1	1	**6**	**4.2**
7. Project Monitoring and Control									
7.3 Weekly meetings, progress reviews	**6**	3		5	4	1	3	**16**	**11.2**
7.4 Weekly planner	**6**	5		3	4	3	1	**16**	**11.2**
7.5 Percent Plan Complete (PPC)	**10**	7	1	6	6	3	3	**26**	**18.2**
7.6 Reasons for Non-Conformance (RNC)	**3**	2		1	2	1		**6**	**4.2**
7.7 Last planner	**3**	3		3	2	1	2	**11**	**7.7**
Total	**55**	**38**	**4**	**34**	**30**	**16**	**21**	**143**	

**Numbers in each cell represent the number of projects that realized the benefit related to that cell.*

Lookahead Plan

Lookahead plan was used on 8 of the projects and contributed to 12.6% of the benefits. Five projects realized cost savings, 4 had less project completion time, three projects reduced rework, and three projects increased PPC. Two projects had less inventory at site. Less management cost was realized on one project.

A 6 to 8 week work flow is created from the master schedule, which is updated in the weekly meetings. Weekly plans are extracted from the Lookahead plan. The Lookahead plan is directed towards developing detailed work methods; material, equipment and labor needs; and specific work assignments to each of the foremen.

MATERIALS MANAGEMENT

Just-in-time (JIT) Material Delivery

This lean principle was utilized on 4 of the 16 projects. All of the projects experienced cost savings, three reduced their project times, and three had less rework. Two of the projects increased PPC, and one of the projects reduced its inventory on site.

PERSONAL MANAGEMENT

Employee Training

Employee Training was practiced on 4 of the 16 projects, and contributed 4.2% of the benefits. Cost savings were realized on 2 projects, project time saving was realized on one project, PPC

increased on one project, less inventory on one project, and less rework on one of the projects that did employee training.

PROJECT MONITORING AND CONTROL

Weekly Meetings

Weekly meetings were held on 6 projects, and contributed to 11.2% of the total benefits. This principle ranked 4th in achieving benefits after PPC calculations, 'All parties involved in design', and 'Lookahead plans'. Using this lean principle, five of the six projects reduced completion time, 4 increased their PPC, 3 experienced cost savings, 3 had less rework, and one had less inventory.

Weekly Planner

Weekly planner was also used on 6 of the 16 projects, and contributed 11.2% of the benefits. Cost savings were realized on 5 projects, increase in PPC on 4 projects, project time reduction on 3 projects and less inventory on 3 projects. Less rework was realized on one project.

Percent Plan Completion (PPC)

Percent Plan Completion (PPC) calculations were monitored on 10 of the 16 projects surveyed in this research. PPC calculations resulted in 18.2% of the total benefits, the highest percent of benefits by one lean principle. Using this lean principle, 7 of the 10 projects realized cost savings, 6 realized project time reductions, 6 realized PPC increases, 3 saw less inventory, 3 reported less rework, and one had less management costs.

Reasons for Non-Conformance (RNC)

Reasons for Non-Conformance (RNC) were analysed on 3 of the 16 projects, and 4.2% of the benefits were contributed by this lean principle. Two of the projects had cost savings, 2 saw PPC increase, one had their project time reduced, and one had less inventory at site.

Last Planner

Although this lean principle is commonly used in manufacturing, only 3 of the 16 construction projects used this principle. All of the 3 projects had shorter project completion times and cost savings. Two projects had their PPC increased, two had less rework, and one project had less inventory. This lean principle contributed to 7.7% of the total benefits.

The 'Last Planner' is the person who creates the weekly work plans from the Lookahead schedule. He is the person who decides what work can be done, and how much can be done. He then evaluates each week's performance through the Percent Plan Complete (PPC), and Reasons for Non-conformance (RNC).

CONCLUSIONS

Using real data from 16 lean construction projects, the research presented in this paper has demonstrated that lean construction principles do work. However, the degree of effectiveness of each lean principle varies. Analysis of data listed a total of 41 lean principles that were applied, and a total of 29 benefits that were realized. Eliminating those principles that were used less than average times resulted in 11 major lean construction principles, and 6 major benefits. The 11 major lean principles included: (i) 'Identify customer needs in design', used on 2 projects; (ii) 'All parties involved in design', used on 6 projects; (iii) 'Pull scheduling', used on 3 projects; (iv) 'Look ahead planning', used on 8 projects; (v) 'Just-in-time' (JIT) delivery, used on 4 projects; (vi) 'Employee training', used on 4 projects; (vii) 'Weekly meetings', and (viii) 'Weekly planner', each used on 6 projects; (ix) 'Percent plan complete' (PPC), used on 10 projects; (x) 'Reasons for non conference (RNC), used on 3 projects; and (xi) 'Last planner' used on 3 projects.

The 6 major benefits included: (i) Cost savings, (ii) Less management cost, (iii) Project time reduction, (iv) PPC increase, (v) Less inventory, and (vi) Less rework.

A study of the 11x6 lean principles—benefits table revealed that the most effective lean principle was the 'Percent Plan Complete (PPC)', seventy percent (70%) of the projects, who monitored PPC, experienced cost savings, and 60% experienced time reductions. 'All parties involved in design' principle was also very effective, reducing project times on 100% of the projects. 27% of the 11 lean principles achieved 'cost savings', 24% experienced 'time reductions', and 21% increased PPC. 'Less rework', was achieved by 15%, and 'less inventory', by 11% of the lean construction principles. This paper has related the major lean principles to their benefits. The experiences of 16 construction companies presented in this paper will guide the future lean construction managers in selecting the most effective principles on their projects.

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