ALLIANCE LEAN DESIGN/CONSTRUCT ON A SMALL HIGH TECH PROJECT

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ABSTRACT

It is the author's conviction that Lean Production will largely influence a lasting Lean change in the construction industry not from the top down, but from the bottom up. It will grow though the proven productivity gains of Lean practitioner firms. It will grow even more dramatically through the formation of informal and formal alliances between individual practitioners of Lean Design and Construction. This paper describes one such example.

A leading international high technology facility design firm2 and a visionary domestic design/construct firm3 joined in an informal alliance and tested their conviction that Lean Design and Construction can lead to world class results on a small, but challenging , high technology facility project. This unlikely relationship itself was largely a result of the two firms' involvement in the Lean Construction Institute of the USA and the Lean Thinking revolution growing in a yet small but expanding part of the industry, internationally.

This project case study showcases the answers to a number of previously untested theses: That the Owner can be convinced to try Lean practice for the first time, based upon the "selling" of the concept by their design and their construction firms. That two firms that had previously never worked together can establish an informal alliance that lasts the testing of a construction project with Lean Thinking as the glue to the relationship. That Lean practice can be performed on a design/construct project using many of the same tools that have previously only been used independently, not across the full project design/construct life. That the Last Planner and production planning can be effectively implemented in the design effort, with a staff that are Lean Thinking novices.

This paper describes the formal contractual relationships, as well as the informal relational "contracts". It presents the "Schematic Design in a Day" process. Training efforts are described. Lean production metrics are defined, and the resultant project data is reported. Lastly, lessons learned are shared and suggested next steps of continuous improvement are presented.

KEY WORDS

Lean design, lean construction, alliance, high tech.

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THE PROJECT

In late 1997, a high technology manufacturing facility owner (hereafter called the customer) identified a need to enlarge, consolidate, and relocate a portion of functions from a manufacturing site on the west coast of the USA to another facility in the Rocky Mountain states region of the country. Industrial Design Corporation (IDC) had prepared a programming report outlining the general objectives of the project earlier in 1997. This was prior to any consideration by the customer of how the design and construction phases would be executed. Included in the program was a schedule for design and construction based on a conventional design/bid/build scenario assuming the design phase would start immediately following programming. Time lapsed while the customer was considering how to procure design and construction services. As a result of the delays, this project and the associated design and construction could not be started until the end of February 1998, with completion of the project needed by the end of July of the same year.

The functional relocation includes the physical relocation of various pieces of equipment from the original site, as well relocation of an existing lab and as the addition of some new equipment. The new location would be within an existing space of around 7000 square feet. The new space would require significant modifications in order to accommodate the technological requirements of the new usage.

Given the late start possible for the project, it was apparent that traditional design-bid-build approaches would not accomplish the goals of the project. In addition, certain individuals within the customer's organization expressed frustration with the conventional design/bid/build process and the inherent 'waste' that it entails. Concern was expressed that "there must be a better way of procuring projects" and that a design/build approach might be worth investigating. The initial thought was to have IDC, The Neenan Company (TNC), and a third firm competitively propose for the project. IDC's strength was in design, knowledge of the customer's requirements through previous programming of similar projects and a long history of working with the customer. TNC's strength was in construction, being located in the same city as the project and a proponent of 'Lean Construction'. Both firms have design/build capabilities. That being the case, the customer wished to pursue some form of design/construct process of delivery. The project design and construction costs were to be fixed costs, established up front.

FORMATION OF THE TEAM

Coincidentally, in December of 1997 IDC hosted the quarterly meeting of the Lean Construction Institute (LCI) in its Portland, Oregon headquarters. The Neenan Company (TNC), which had very recently become familiar with LCI, attended the meeting. IDC and TNC, prior to this project, had limited awareness of the other firm and had never considered working together. Both firms had independently been developing some Lean production techniques within their organizations.

The middle of February, 1998, the customer made the decision that the project was to be performed as a design/build. At the same time they were convinced that new methods were needed to better perform projects. IDC was not currently positioned in the location of the project to take on the construction portion of the project. TNC offered to the customer to perform that function. Within that same week based upon a positive response from IDC and TNC, the customer selected IDC and TNC to function as a design/build team.

IDC and TNC had not previously been associated on a project. However, they quickly found that they had a common ground upon which to base a one-off project relationship: Lean Design and Construction (LD&C). Within that same week, the customer was introduced to LD&C when TNC hosted Jim Womack4 as keynote speaker at their annual industry seminar. The author and the IDC project manager for the project subject of this paper also attended this important conference which also included such Lean notables and Greg Howell and Glen Ballard5. The die was cast, and the IDC/TNC team was given a mandate to perform the project under LD&C practices.

Within the next week, TNC in consultation with the customer, selected their specialty subcontractors for the project. Their selection was based upon previous working relationships, and upon the commitment of the subs to perform under LD&C. They were then brought on-board immediately so as to participate from the very beginning of the project.

IDC would perform the design within their Portland, Oregon offices. TNC would, with their subcontractors, perform construction from their project local offices in Colorado.

FORMAL RELATIONSHIPS

Driven by schedule and a desire to try an alternate method for project delivery, the customer sole-source selected IDC to design the project. Concurrently IDC was introduced to TNC and the two firms were asked to evaluate working together in a design/build relationship utilizing Lean Design/Construct techniques. If IDC and TNC decided that they could work together in this manner, they were to propose for the customer's consideration how they envisioned structuring the relationship, interacting with the customer, performing the work, potential benefits and possible difficulties with the scenario proposed. Thus the customer's challenge to IDC and TNC was to function together and interact with the customer as a single design/build entity utilizing 'Lean' methodology.

This project would thus function as a benchmark trial for evaluating procurement of both design and construction services in a new way. Prime opportunities as perceived by the customer for improvement (eliminating 'waste') over conventional methodology involved lower design and construction costs, a more rapid construction schedule, better project coordination, fewer change orders and minimized need for the customer's project management involvement in the control of the day to day process. Affirmative results from this benchmark evaluation could serve as a model throughout the customer's organization for securing design and construction services.

Although the challenge placed before IDC and TNC was to function together and interact with the customer as a single design/build entity, the contractual relationship for both IDC and TNC with the customer was to be conventional. Both firms had independent contracts with the customer and were not contractually tied in terms of

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4 Jim Womack is one of the pioneer researchers who documented Lean Production's origins in the Japanese auto industry in the early 1980s. He is co-author of the books *The Machine that Changed the World* and *Lean Thinking*.

5 Directors of the Lean Construction Institute of the USA and pioneers in Lean Construction.

rewards for performance. This conventional structure facilitated a more rapid project startup where-in schedule was a primary driver in the customer's decisions regarding delivery of the project. Had the customer required IDC and TNC to formulate a contractual relationship between the two firms and then contract with that new entity, considerable effort and time would have been required before design work could begin.

A significant question to be assessed by the customer through this project involved whether two firms could in fact function as one entity in their relationship with the customer without benefit of a formal legal or contractual structure between the two firms. The customer was also very interested to see if LD&C was real or just another fad. They wanted to see if this new project methodology could deliver the desired improvement in project delivery and to evaluate its future potential.

SCHEMATIC DESIGN IN A DAY (SDIAD)

Out of frustration over the amount of time required for the schematic design phase in a traditional project TNC had previously developed a process called 'Schematic Design In A Day' (SDIAD). In order to effectively utilize the full team assembled for this project (designers, owner, general contractor and subcontractors) a different methodology from the conventional preliminary or schematic design process was required. In response to this need, the SDAID process was identified as a way to bring all members of the team together from project inception to effectively participate and contribute in the design and construction process.

The essence of SDIAD is to eliminate waste by bringing *all* project participants together so that maximum design and construction information is leveraged at the beginning of the project. It is a day of highly concentrated design effort, the purpose of which is to establish all parameters for design, pricing, scheduling and construction of the project. Participants required for SDIAD include everyone, from customer's representatives to those responsible for executing the actual construction. Through this concentrated schematic design effort 'waste' is eliminated by reducing project duration, establishing a knowledge base for all subsequent design and construction efforts and reducing the need for a later value engineering process.

For this project, customer participants in SDIAD included the project manager, facility engineers for each utility system, security, communications and user representatives. IDC participants included the project manager and seven leads representing each architectural and engineering discipline required for the project. TNC participants included the project manager, superintendent, estimator and SDIAD facilitator. Each subcontractor provided a superintendent and estimator. Over forty people participated in the SDIAD event.

Typically a one day event, SDIAD for this project was modified to a two day process to respond to the project's complex technical nature. The time was organized into a series of one hour meetings beginning the first day with a review and discussion of the owner's conditions of satisfaction (COS) for this particular project. Individual work groups then broke up to discuss and develop each system or discipline required for the project (architectural floor plans and code issues, mechanical, electrical, chemical, tool install, telecom, etc.). Representatives from each entity involved in the project participated in the work groups. Work groups interacted with each other to share information and get decisions that each needed to proceed with their work. Periodically each group briefly reported out to the entire team on what decisions have been reached. Critical to the success of SDIAD is that *all* participants are expected to contribute toward developing the most effective and efficient design for the project. As the requirements for systems are developed, pricing and availability of components are checked with suppliers. Construction methods and sequencing are also considered. Final definition for each system is then based not only on design requirements but also cost, availability, schedule and constructability.

SDIAD concluded with summary report outs from each work group. Floor plans, elevations, concept details and perspective drawings were presented. Each system was defined noting system diagrams, quantities, requirements, materials, selected manufactures, methods of construction and utilities routing. Long lead items were identified and schedule impacts noted. System shutdowns, sequencing and testing requirements were also identified. Following the work groups the general contractor reported on the overall project including schedule, coordination, access, storage, etc. A list of outstanding issues to be resolved was kept throughout the SDIAD process as well as a list of 'Not Now, Not Yet' items that would be resolved at a later stage in the project. All COS, drawings, work group issues and resolutions, budgets, schedules and lists were documented and distributed to all attendees the following day to form the basis for detailed design of the project.

The TNC SDIAD process was not foreign to IDC as it is similar to the "working group" approach of multifunctional task force pre-planning (Miles 1995) utilized by TDC6. Therefore, it was easy for the IDC staff to adapt to the approach. However, this was the first time IDC had seen this approach fully applied when there was no contractual relationship between the design and construction firms. The following diagram (Figure 1) represents the IDC approach and is consistent with the TNC SDIAD.

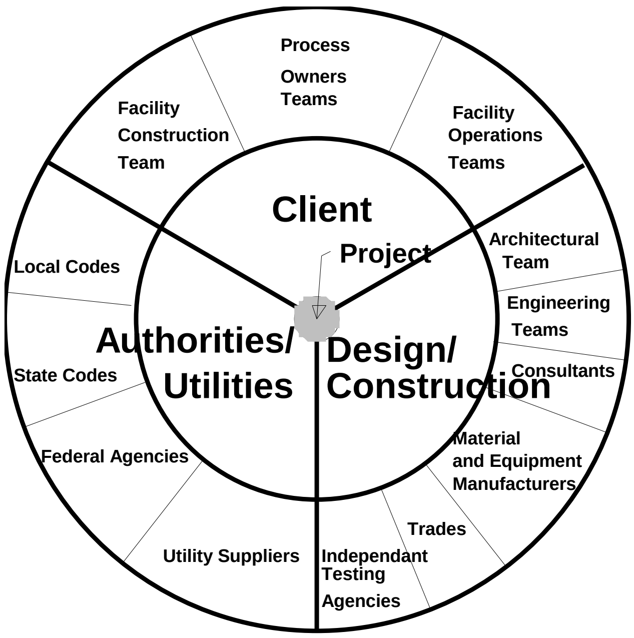


Figure 1: IDC's Approach Towards SDIAD

6 Technology Design and Construction (TDC) is an IDC company that performs design/build.

DESIGN AND CONSTRUCTION LEAN PLANNING PROCESS

TNC and IDC agreed that LD&C planning processes would be implemented and utilized throughout the duration of design and construction. The customer was is concurrence. It was further agreed that the same tools and techniques would be used by both firms in order to form a seamless execution stream. The basis of the process was that developed over the last five to six years within the International Group for Lean Construction (IGLC), and the newly formed Lean Construction Institute of the USA (LCI).

Figure 2 exhibits the fundamental concept of an integrated planning system that is focused on true management of productivity, and on continuous learning7. The general principle is "that which cannot or is not measured cannot be controlled; that which cannot or is not controlled cannot be improved." It is imperative that the systems not only provide a structured systematic method of planning, but that they continuously provide valid metrics which enable real-time learning and continuous improvement.

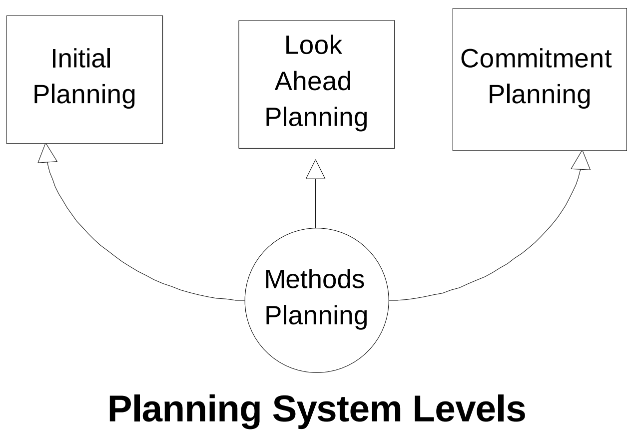


Figure 2: Planning System Levels

INITIAL PLANNING

Initial planning started within the SDIAD session. As described above the budgets, schedule (in the form of simple bar charts), and key milestones were established. Initial information needs lists were started. These needs would later be integrated into the lookahead and weekly work plans. It was not found to be necessary to develop complex schedules such as CPM or PERT. The size, and duration of the project, and the intent to implement PULL production control was felt to dictate a simpler initial planning method.

The initial plans were updated as needed to reflect new knowledge and changes. This level of planning served as the starting point for the lookahead plans.

LOOKAHEAD PLANNING

Lookahead duration was set at five weeks. This duration was chosen based upon the work of Ballard and Howell that indicated that looking forward farther than five weeks put the planner in a period that was simply too uncertain for effective planning. Looking ahead

7 The integrated planning concept and diagram was developed by Howell and Ballard (op cit. Footnote 2).

less than five weeks was too short a time to allow for effective “make ready” work and assignment screening. Experience in design and construction application in this project confirmed that this was an appropriate lookahead period.

Lookahead planning was performed utilizing a simple format spreadsheet (Figure 3). Each sheet in the spreadsheet workbook file represented a project work week.

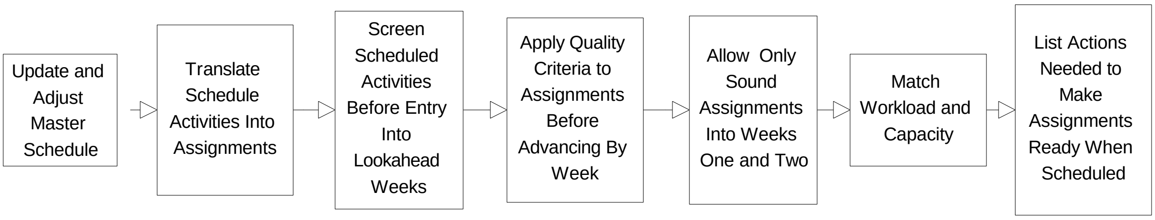
5 Week Lookahead Plan

Project: HP Ft. Collins - Lab Relocation
Discipline: Process
Planner: Genevieve Phillips
Checked By; x
Prep. Dt: 3/13/98

Activity	Week Ending: 3/27/98							Week Ending: 4/3/98							Week Ending: 4/10/98							Week Ending: 4/17/98							OUTSTANDING NEEDS
	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	
Provide construction support (q & a)			x	x	x			x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			Need questions from subs.
Review submittal(s)								x	x																				Need submittals from sub.
Aid with tool install dsgn effort.		x	x	x	x			x	x	x	x	x			x	x	x	x	x			x	x	x	x	x			Frozen layout, pkg 1 dwgs.
Design drains from tools to tunnel tie-ins.			x	x	x																								Frozen layout, input from tool install on installation preferences
Help layout people complete a layout that will work well with tool install routing and drains into the tunnel.	x	x																											Correct tool list.
Complete Pkg 2 specifications									x	x	x	x			x														Final equipment and material usage from mech. and tool install.
Create work plans					x							x							x							x			
Send package to QA/QC reviewer for drain design review																							x	x					Final design dwgs for drains; plot time
Start/complete QA/QC review																									x	x			Set of Package 2 review docs, dwgs

Figure 3: Example Lookahead Plan

In the case of the design team, these were completed and maintained directly on the discipline lead’s computers. In the case of construction, it was more expeditious to print the blank forms and fill them in by hand. The lookahead plans were currently not electronically tied together or to the weekly work plans, so hand generation by construction was not seen as a great disadvantage.



Lookahead Planning Process

Figure 4: Lookahead Planning Process

The team leads were instructed in the development of the lookahead plans in accordance with principles of Assignment Screening as represented in Figure 4 (adapted from Ballard 1997). Assignments were not to be progressed closer in time on the lookaheads, unless the planner was sure that they could be performed when so scheduled. This meant validating them against the outstanding needs related to the assignment. No assignments were to be progressed into weeks one or two of the lookahead unless they were convinced that they could be moved onto the respective weekly work plan when scheduled. Needs lists were therefore to be aggressively worked so that assignments could be "made ready" and progressed as needed to meet the overall project schedule and milestone dates established in the initial planning. In addition, parallel tasks that could be performed early were identified and placed on the "workable backlog" list for inclusion on the weekly work plans.

WEEKLY WORK PLANNING

Again, weekly work planning was performed utilizing electronic spreadsheets. However, in this case the individual design discipline and craft planning files (each containing sheets for each work week) contained automated calculations of key metrics and graphical output over time. Also, the individual files were linked to a master project roll-up file that automatically generated overall project summary data of the key metrics.

Metrics

Metrics were established for the purpose of continuous measurement and feedback for learning and improvement within the project and for future projects. Following is a definition of the metrics.

Percent Planned Complete (PPC):

Planner records percent complete of all activities on the *weekly work plan* at the end of each planning week. They also record ***Reason*** for non-conformance to the plan (100% completion). Only activities that are 100% completed on plan are considered *complete* for PPC purposes. Data is used to measure planning methods effectiveness *(flow)* and focus continuously improvement efforts.

Reasons for non-conformance to plan (RNC):

(see PPC). Logs, charts, and trends reasons that assignments were not completed when planned. Targets *reasons* with highest number of occurrences for continuous improvement of both planning effectiveness *(flow)* and activity execution efficiency *(conversion)*. As current most prevalent reasons are reduced, re-target the new highest occurrence reasons.

Actual to Planned Labor Ratio (APLR):

Documents planned labor to complete each activity on the *weekly work plan*. Records actual expended labor per activity. Calculates APLR. Data used to validate manpower estimating and to trend improvement in the efficiency of the assignment execution *(conversion)* processes.

1. Lookahead Planning Performance Measurement:
2. Measurement of the extent to which weekly work plan assignments previously appeared on lookahead plans—*Lookahead Assignments Anticipated Ratio (LAAR).*
3. Measurement of the extent to which assignments that appeared on lookahead plans appeared on weekly work plans when scheduled—*Lookahead Assignments Made Ready Ratio (LAMRR).*

WEEKLY PLAN—ANNOTATED

To assist the team in usage, an annotated sample version of the weekly work plan as shown in Figure 5 was prepared and distributed.

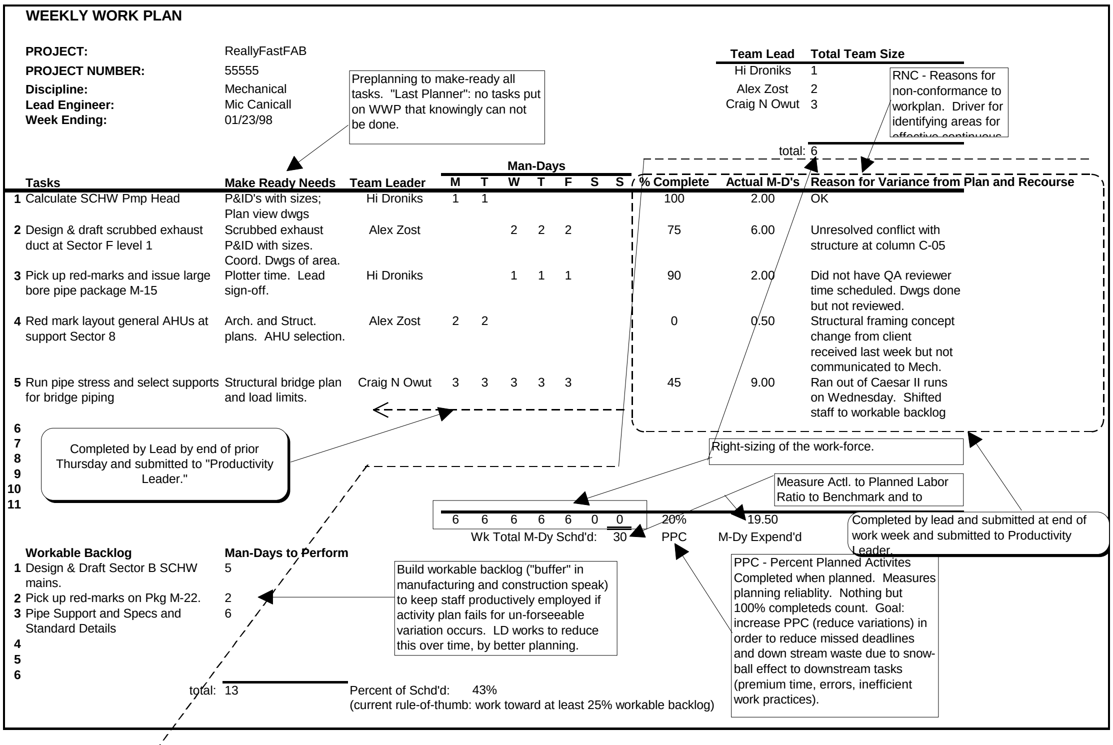


Figure 5: Annotated Weekly Work Plan

Lookahead plans were the basis of preparation of the weekly work plans. The principle of "shielding" was employed to assure that only workable assignments were placed on the weekly plan. This process is represented in Figure 6 (adapted from Ballard and Howell 1994-2).

IMPLEMENTATION

In addition to the initial and formal training discussed above, it was necessary to continually monitor and support the planning efforts. The LD&C facilitator conducted an initial briefing, then two two-hour formal training sessions. Subsequently the facilitator coached each planner as needed. A previous experiment in applying the planning to a design project was unsuccessful at least partly due to failure to provide sufficient initial

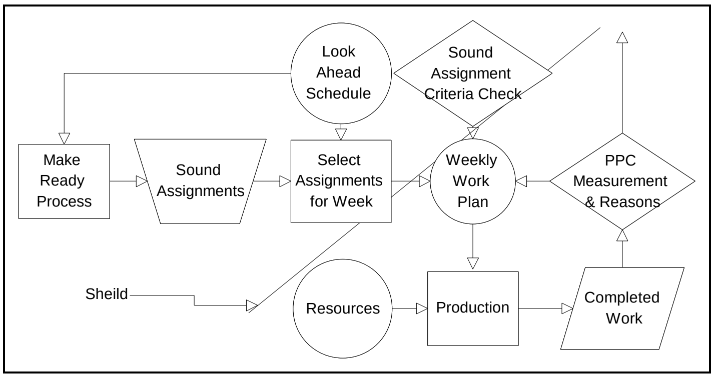


Figure 6: Shielding of Assignments

training and continual coaching. This lesson learned was valuable in supporting the need for the larger effort for this project.

Each Friday the respective planner would electronically submit the current lookahead plan and weekly work plan files to the author who acted as project LD&C facilitator and coach. They would have prepared the lookahead plan, as-done status of the past week's weekly plan, and prepared the planned portion of the following week's weekly work plan. These would be rolled up to the overall project level by the LC&D facilitator by mid-day the next Monday. Copies of the summary individual reports were distributed to the planners, and a roll-up report (annotated with the facilitator's comments and suggestions) was delivered to the project manager. Necessary coaching with the individual planners facilitated improvement in their respective planning efforts.

LAST PLANNER AND WEEKLY WORK PLANS

The *Last Planner* (Ballard 1994, Figure 7) is the party who makes the final assignment of tasks to be performed. They are the end of the planning process and the initiator of the work execution (*conversion*). In the case of design this was the discipline lead; for construction this was the craft superintendent.

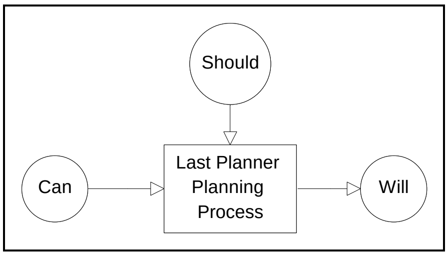


Figure 7: Last Planner Planning Process

In principle the Last Planner has the responsibility and is authorized to say "no" to the performance of a task that clearly cannot be performed in accordance with the *Quality Selection Criteria.* The Last planner is responsible to perform the following:

- Shield Production from Uncertainty in order to Increase Conversion Efficiency
- Select from Workable Backlog

- Make Only Assignments that meet the Quality Selection Criteria (Shielding)
- Assure that Work Is In The Correct Sequence (Should)
- Assure that Work Is the Right Amount (How Much)
- Assure that Work Is Practical (Can)

Figure 8 shows the weekly work planning and execution flows. The diagonal line represents the *Shielding* as assignments are moved into the weekly plans (Ballard and Howell, 1994-2).

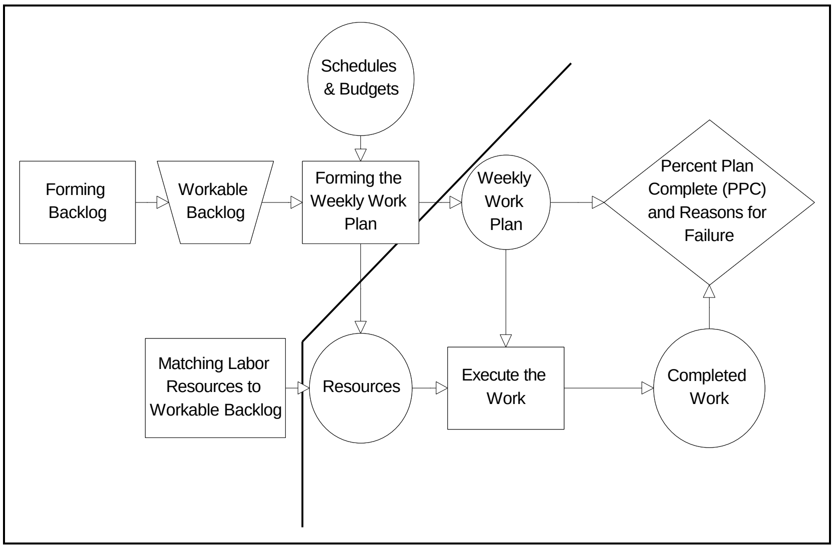


Figure 8: Weekly Work Planning and Execution Flows

DESIGN EXECUTION

PROJECT WEEK ONE—DEFINITION AND ORIENTATION

The week following selection of the team by the customer was designated project Week One for purpose of the planning systems to be implemented. During this week TNC selected their subcontractors, in order to assemble the entire first tier supply chain. At the same time, IDC's team was beginning to quickly lay the foundation for daily operations and to document the value definition of the customer for the project.

IDC's project manager and TNC's project manager and superintendent met with the customer's project manager and key stakeholders to jointly develop a list of eighteen Conditions of Satisfaction (COS) for the project. This list represented the customer's best expectations as to the end results of the project. All of the COS had to be met in order for value to be maximized in the customer's perception.

During this first project week the design team received orientation, organization, and planning information. It was at this point that the design team was introduced to the basic principles of LD&C. They received initial training in the implementation of Five Week Lookahead Planning, Weekly Work Planning, and implementation of the Last Planner practice for the design process. TNC emphasized that the key to reducing waste and adding value for the customer was to perform the following when beginning any task:

> Ask yourself: “If the customer were looking over my shoulder, would they say that what I was doing was something they were willing to pay me to do.”

As required to meet the project objectives, the delivery form would be fast-track, multi-work-package design delivery. Execution would be by concurrent engineering execution. The design leads were to work with their construction counterparts in structuring the content of the two work packages. The first work package would include required pre-work to establish utility services for the new functional location, and for purchase of long lead time equipment and materials. The second would contain the remaining design-for-construction documentation. In all cases, the construction team was to provide input related to the design in order to optimize the cost, schedule, and quality of the construction work.

The design team discipline leads were also charged with working directly with related customer staff in both the current location of the functions being relocated, and those in the new location. They were to identify and coordinate all functional requirements for the successful operation of the equipment and work flow in the new facility location. This included site visits (along with their construction counterparts) to both the current and the new facility locations.

WORK WEEK TWO—SCHEMATIC DESIGN IN A DAY (SDIAD)

Consistent with Lean practice, the organization of the project was based upon multifunctional teams. The design discipline leads would provide leadership of these teams during design, with transition to leadership by the trade construction superintendents during construction. It would be the roll of construction to provide support and input to design. This would include: constructabilty, materials availability, construction sequence and schedule impact, and total construction cost impact of all design elements. In turn, design provided support to construction as the effort shifted to them. This included the typical review of procurement items as well as one day response to requests for information or clarification of the design documents. The team key membership largely remained constant during the full project duration.

The process would begin by performance of Schematic Design (SD) in a joint design and construction effort in true concurrent fashion. This is why it was essential that the construction team was on-board from the beginning of the project. The process was performed utilizing the process developed by TNC called SDIAD described above (and very similar to similar processes used by IDC on past fast-track projects (Miles 1995)).

WORK WEEKS THREE THROUGH FIVE—DESIGN OF WORK PACKAGE ONE

Design work related to utilities and long lead purchase items was substantially completed by the end of work week four. The documents were sent to the customer for their pre-review prior to a formal review session on week five via teleconference. The final package was issued to construction at the end of week five.

WORK WEEK SIX THROUGH NINE—DESIGN OF WORK PACKAGE TWO

During week six, a formal Lean Design and Construction orientation class was conducted for the design team. The author conducted this class in two sessions on two contiguous days, each about two hours long. The intent was to give the design team a more solid background in the origins, theory and practice of Lean Production. The production training game called "The Airplane Game" was played during the first session. The remaining parts of the training utilized the lessons learned in the game as the basis of imparting a greater understanding, and more importantly an emotional and logical buy in by the team.

The role of construction began to ramp up during week six as well, as they began utility preparation, and pre-purchase of long lead items. The design documents issued in work package one were utilized seamlessly into the generation of work package two. The goal was to waste no documentation. During this period the design team took on the dual roll of progressing the design through package two, as well as supporting the early construction effort by reviewing shop drawings of pre-purchase materials and answering construction questions. The trade subcontractors and the respective design discipline leads directly communicated in this effort. Communications were not strained through the typical wasteful levels and paths.

In week eight package two was issued to the customer for review, with the same teleconference adjudication of comments process by teleconference in week nine. The package was issued for construction and permitting at the end of week nine, and construction of the major building effort commenced on week ten with planning and site staging. This was one week ahead of the already very aggressive design schedule.

During the design process there were some late deliveries of information and changes required of the design team. These were incorporated with no time extension. The impact of these will be further discussed below in the context of the LD&C planning process and execution.

CONSTRUCTION EXECUTION

Substantial construction commenced in work week thirteen and completed on work week twenty. This period would be followed by about four weeks of final tool install and clean up work that went beyond the period when this paper was required to be completed.

The implementation of the planning methods and the use of the software tools was more problematic on the construction side. There were a number of reasons for this that are discussed below as related by the TNC project LC facilitator.

NOTES FROM TNC'S LC FACILITATOR

The specialty subcontractors (subs) were instructed not to advance work into week two of the lookahead plan without good assurance of make-ready work to be done, and onto the weekly work plan (WWP) without very good assurance of make-ready work to be done. Two primary subs still moved things forward, a construction industry mental model, and as a result had low PPC averages. Often the reasons for non-compliance were their own material procurement failures.

The process piping sub performed extremely well on the project, meeting commitments and getting the manpower there when needed. It was their first opportunity to work with the customer. They were familiar with LD&C before this project. At the very beginning when reviewing what we would be doing, they had requested a copy of the program developed by Miles and used the five week look ahead and the WWP fully. They clearly recognized the system as the effective planning tool it can be, if used as intended. Significantly, they had extremely high PPC averages.

The electrical and HVAC subs did their WWP and to an inconsistent degree their five week look ahead. Both had low PPC averages, often working from workable backlog. The electrical sub was not able to complete the lookahead plans beyond week three due to lack of planning skills. There is clearly a need for them to implement training in this skill.

The TNC superintendent operated as the last planner for the carpentry, drywall and painting crews. These crews were not full time on the job site but critical to the success of the project. He was appropriately the last planner for the carpentry but not the others. The drywall company laid off five staff one week and the following week had no available staff to do key work onsite to maintain flow, it actually took them two more weeks to get this key work done. In researching this, it became apparent if they had been their own last planner they would not have laid off some of these workers and completed this work as needed.

Only the piping sub directly used the planning software and a computer to perform the planning task. I (an architect with no job site management experience) entered all the data for every sub except the piping sub. As discussed below, this is an area that needs to be addressed in future implementations.

Four weeks into the construction, my assessment was that the piping sub was doing great and not a concern, the HVAC sub had a major problem with his own shop in getting ductwork there when needed and was behind, and the electrical sub's foreman was struggling with his management and planning skills and was a concern as well. I propose that the HVAC fabrication shop should also be using Last Planner in lieu of whatever communication system they were using and planning training was needed with the electrical foreman. I shared these assessments with the TNC superintendent and he totally agreed. As a result, I maintain that the LC planning methods are an excellent way for even non field-trained personnel to make accurate assessments of the project situation and to take proper and effective action.

The most effective use of this system was via the direct use of the computer. Therefore, successful implementation was limited by the lack of computer skill of all but one of the subs. A manual and visible system that the job site foremen would have in front of them each day and could easily be used to get the feedback would have greatly improved their ownership and utilization of the concept. [author's note: an alternative might be training and availability of job site computers or hand-held's with download to the LC PM.] The process of manual planning on hard copy led to the perception by many in the field that this was an administrative tool more than something that was theirs to use to improve their performance.

DESIGN RESULTS

As of the time of publication of this paper the design is complete, excepting continuing support for the remainder of the construction efforts. The use of the planning tools was discontinued in design at the end of work week eleven. The following presents the output of the planning process, and then provides some commentary on how the process enabled the Lean performance efforts.

The design was completed one week early. The design labor budget was under-run by approximately seven percent, resulting in a significant gain over planned profit margin.

PPC was tracked graphically, along with the respective number of assignments for comparison. Figure 9 is an example of an individual discipline graph for the duration of the major design work (through work week 11). This particular discipline was the best PPC performer. This planner was also the most effective lookahead planner—a direct correlation that supports the principle of screening and make-ready of assignments.

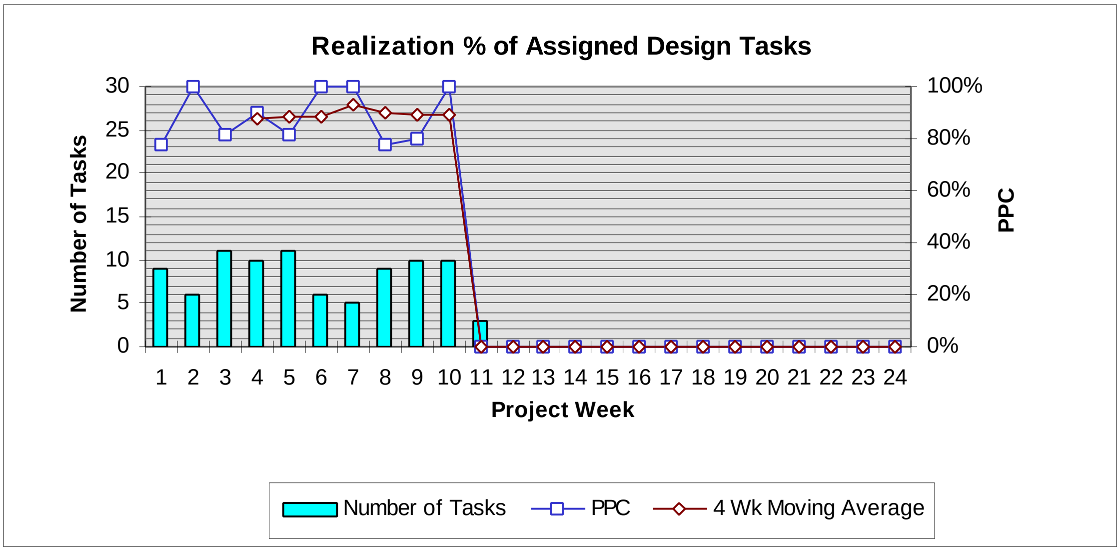


Figure 9: Realization % of Assigned Design Tasks

Figure 10 is the overall project chart, showing the summary average PPC for of all design disciplines.

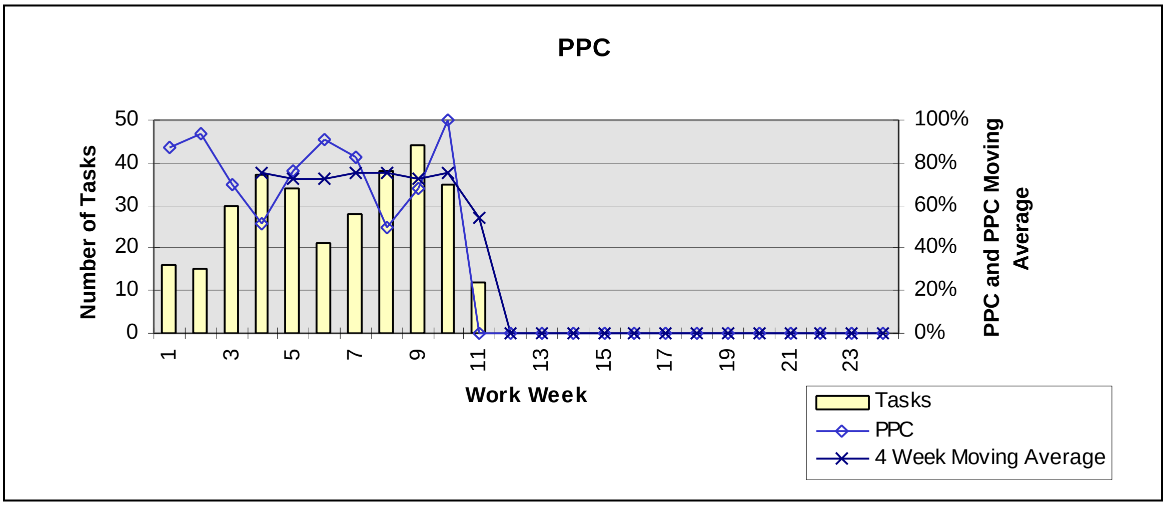


Figure 10: PPC in Design

It can be seen that the overall PPC averaged around 75%, but notably well below the best performer which was at an average of about 90%. It should be noted that given the novice level of the design leads in the LD&C planning process, the performance was well above that anticipated. Previous studies of PPC in construction application have shown that PPC for projects not utilizing effective planning systems run around 40% (Ballard and Howell, 1994). The only documented application in design is a case study which showed an increase in PPC over the project duration from about 55% rising to about 65% (Koskela,, Ballard, and Tanhuanpaa 1997)

Of particular note are the two dips, at weeks four and eight. These are directly related to incidents that impacted the design team's productivity. The early recognition of these problem areas led to quick recovery in both cases. The next-working-day reporting to the project manager therefore enabled true proactive productivity management, rather than the typical "management by looking in the rear-view mirror." Instrumental in this was the RNC metric, along with PPC and APLR. As can be seen in Figure 11, RNC was rolled up on an overall project level and updated weekly for the project manager.

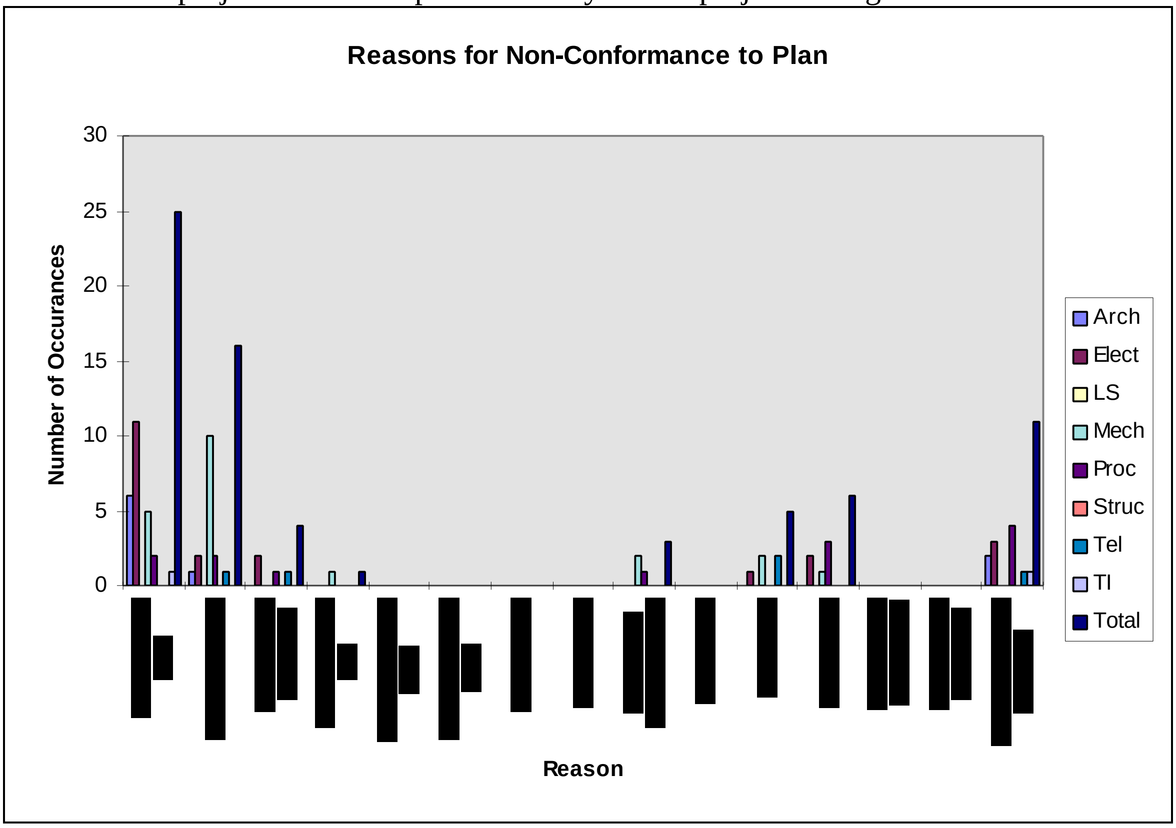


Figure 11: Reasons for Non-Conformance to Plan in Design

It is typical of design organizations to consider the greatest impacts on their productivity to be that generated externally and therefore "uncontrollable." This project's RNC metrics says otherwise. Of all Reasons, those within internal control exceed those external impacts by a factor of 2.4:1. Following, in order of diminishing occurrence, is a listing of the top five RNC.

1. Underestimation of the effort required to perform the assignment.
2. Missing client data required to complete the assignment.
3. Failure to anticipate a prerequisite task.
4. Internally generated changes impacting the performance of the assignment.
5. Changes in scope or criteria generated by the customer.

Of these top five, internal impacts still exceeded external by a factor of 2:1. This continuous learning information was both used to correct productivity impact on the current project, as well as for improvement on future projects. The failure to properly understand the effort required for the assignment was an "eye opener" for management, and should drive some efforts to better assess and plan project design assignment effort.

Another important metric is APLR. By tracking APLR and PPC on the same graph it is possible to measure the effectiveness of implementation of the Last Planner technique.

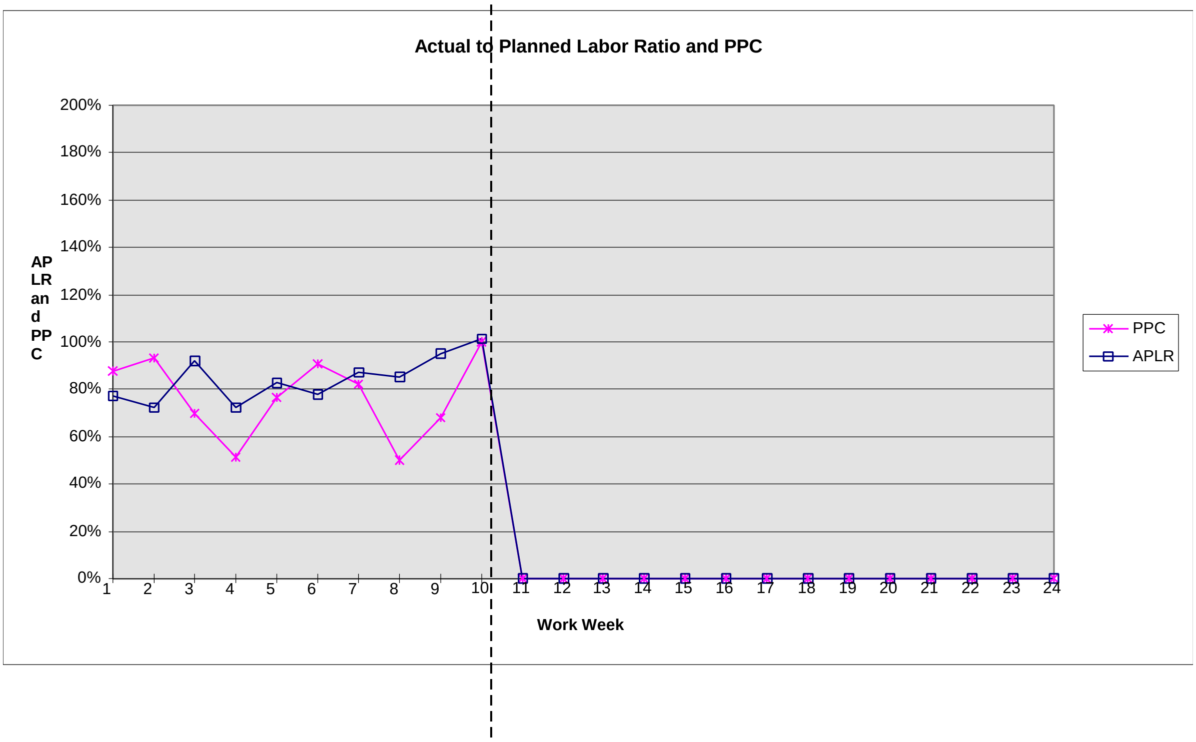


Figure 12: Actual to Planned Labor Ratio and PPC in Design

As can be seen in Figure 12, there are occurrences when PPC is low and APLR is simultaneously high—a cross over of the APRL line to above the PPC line. These are cases where excess effort was being employed with low assignment completion. In some cases, individual design disciplines actually recorded APLR's in excess of 100% indicating expenditure in excess of plan. These cases corresponded directly with that of low PPC and are related to variation hitting the project, classic instances where the Last Planner technique and effective use of workable backlog needed to be better effected. It proved difficult (particularly on a short project) to break the old habit of "staying busy" and simply "working harder" when in fact the assignments simply could not be done in the week scheduled.

In order to measure the effectiveness of the lookahead planning system, the metrics of LAAR and LAMRR were tracked weekly by discipline as shown in Figures 13 and 14.

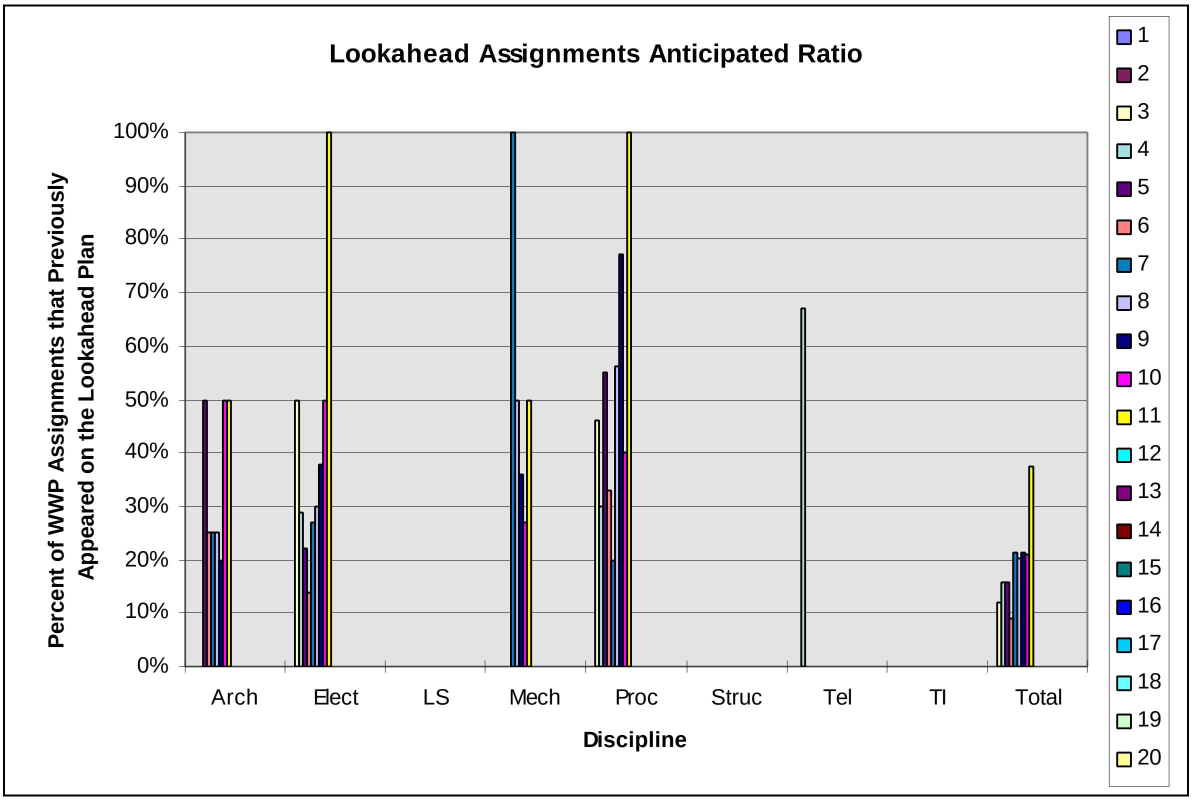


Figure 13: Lookahead Assignments Anticipated Ratio in Design

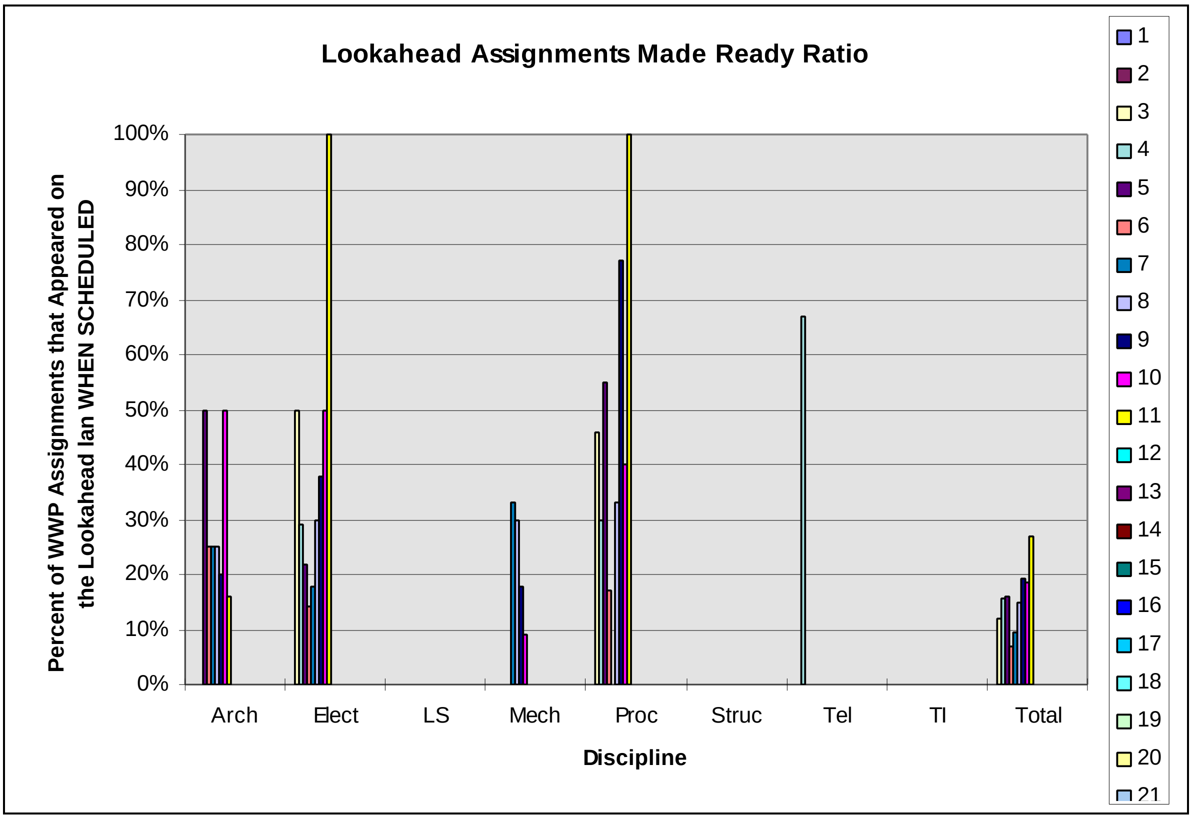


Figure 14: Lookahead Assignments Made Ready Ratio in Design

Of particular note is that the discipline with the best lookahead planning accuracy was also that with the highest PPC and lowest under-run on their respective design budget. On an overall basis, the project design team improved in their skill at lookahead planning over the duration of the heavy design portion of the project. This was partly due to practice, but likely also influenced by the easier predictability due to the approach of the end of the heavy design effort for the project. A future implementation on a project with a longer duration would produce more definitive understanding of the effect of practice, versus that of approaching completion.

CONSTRUCTION RESULTS

Due to the reasons related above in the Construction Execution section, the data reportable through the planning software is not as complete or reliable as that for design. As can be seen, the actual performance data is only partial. This considered, there are still some interesting results that can be seen in the graphical results.

As shown in Figure 15, average PPC for construction was around 60%, with a trend upward. This average was heavily influenced by the high PPC performance of the piping subcontractor who's average PPC was about 95%. As related above, this contractor was the most effective at implementation of the LC planning. With the exception of the carpentry trade (at about 100% PPC), all other trades were well below 50% PPC.

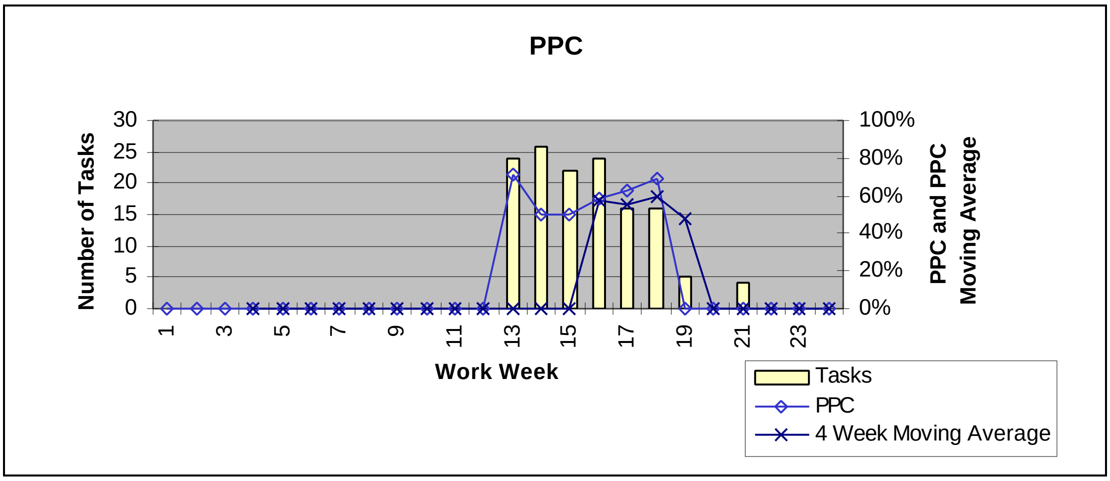


Figure 15: PPC for Construction

Reasons for non-conformance to plan are shown in Figure 16. Far and away the highest recorded RNC relates to failure of materials being on hand for use. This is followed by prerequisite work being incomplete. A focus on materials management on future projects would clearly improve performance.

In general APLR properly appears to have stayed at or below PPC on the weekly chart as shown in Figure 17. As reporting of actual labor effort numbers were reported to be difficult to collect and sometimes reported significantly after the fact, this data is probably not very reliable.

While the planning on the construction effort was more difficult to implement, as reported above and in the Lessons Learned section below, many benefits were still seen. The duration of the project did not allow for any real learning curve in implementation.

Future project implementations, enhanced by the learning of this project, will no doubt improve on the already evident benefits.

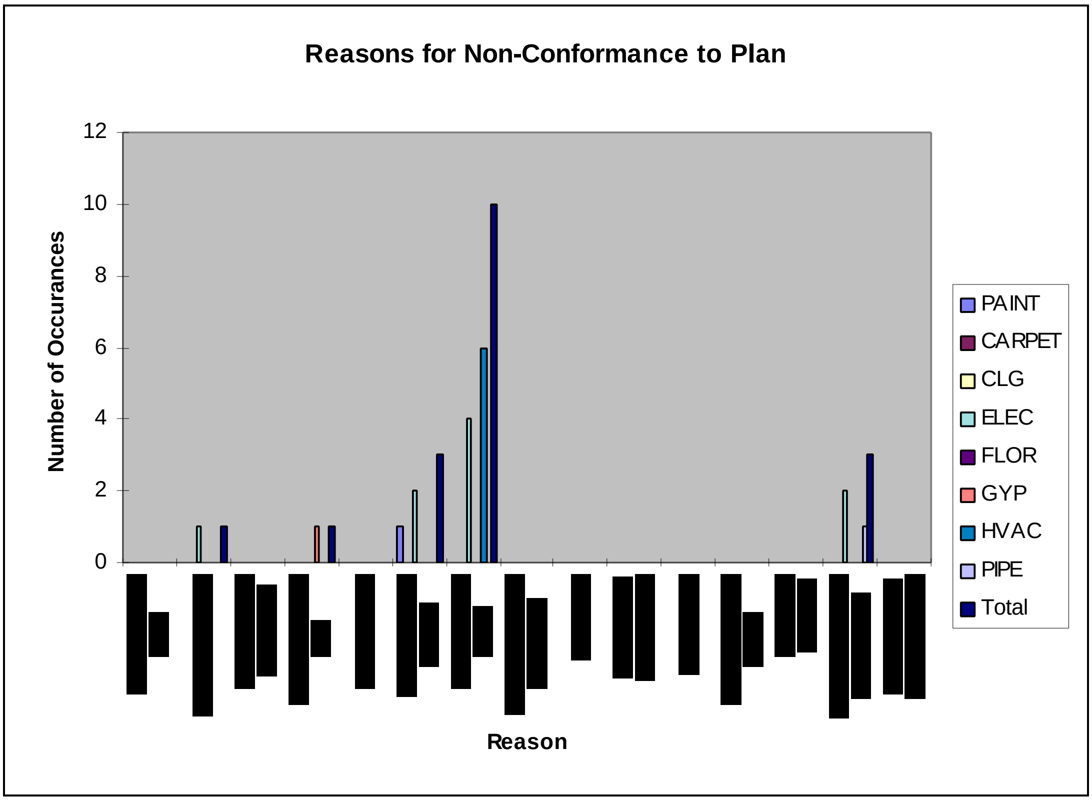


Figure 16: Reasons for Non-Conformance to Plan in Construction

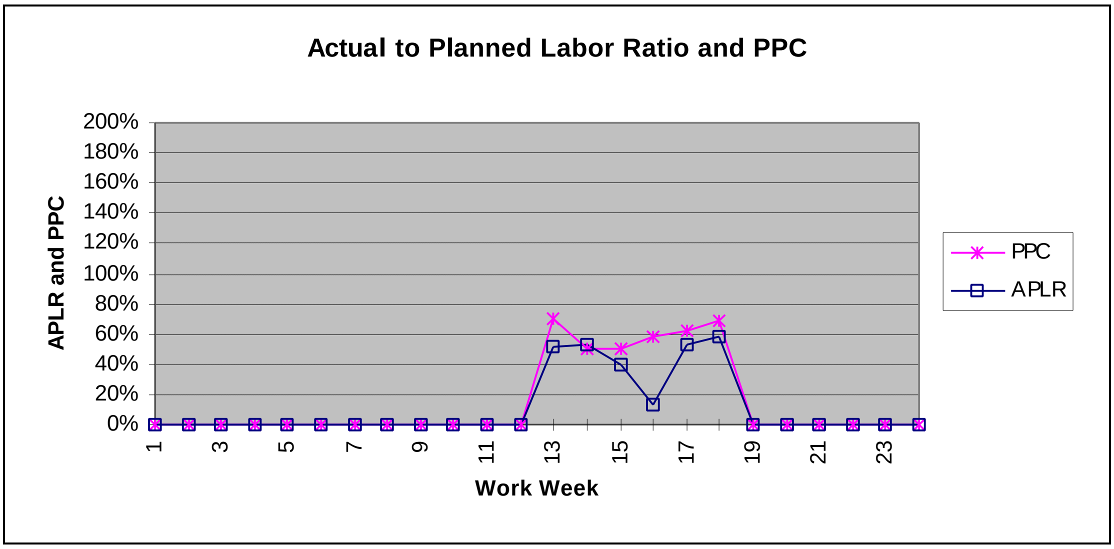


Figure 17: Actual to Planned Labor Ratio and PPC for Construction

LESSONS LEARNED

Listed below are the major lessons learned items identified from the project implementation. While at the time of issuance of the paper, the construction is not quite yet complete these are felt to be relatively comprehensive.

DESIGN

Wins

- The early identification of the customer's Conditions of Satisfaction (COS) established, at the outset of the project, value from the customer's perspective. This presented a clear understanding of where to focus the design effort for each member of the design team.
- The SDIAD was highly successful in focusing the effort of the combined IDC/TNC team. The participation of the owner, design leads, general contractor and all subcontractors resulted in an optimization of the project in all facets. Materials, manufacturers, and methods of construction were identified at the outset of the design effort.
- In addition, the level and content of the design documents was optimized to support construction. The input from construction resulted in the elimination of wasteful design efforts that could not be used later or required rework to support effective and efficient construction.
- The development of the construction budget in the SDIAD provided the basis of design resulting in minimal scope addition items during construction. The traditional wasteful practice of post-design "Value Engineering" and "Constructabilty Review" and the resultant design rework and project delay was eliminated.
- Overall project communications were improved. The entire project staff (the customer staff, design and construction) had a better overall understanding of the entire project. Inclusion of the final facility space users in the communications loops further assured that the final product would meet the customer's needs.
- The design efficiency was improved through use of the LD&C planning methods. This was due to the following:
- Use of a proactive planning tool in place of "rear view mirror management."
- Improved organization of assignments required to complete work in a predictable and trustworthy manner, leading to reduced downstream impacts from upstream variation.
- The use of the planning tool as a vehicle to communicate prerequisite needs between the design disciplines, and with the customer.

- Early (nearly real-time) identification of reasons for assignments not getting done so that timely corrective action could be taken in a positive continuous learning and improvement process.
- The assistance of LD&C planning reporting to the design PM in quantifying true progress.
- The overall process allowed for continuity of participants to the extent that only two formal reviews of the design were performed, and those via teleconference.
- The best utilization of IDC's efforts for the customer's investment. This was the result of:
    - ♦ Designing only to the level of need for the project.
    - ♦ Very few decision reversals or changes.
    - ♦ Design that reflected field conditions and constructabilty input from the construction team.
    - ♦ Early up-front customer decisions allowed use of simplified "outline" specifications.
    - ♦ Elimination of the bidding and bid evaluation, and contractor selection phase present in traditional design—then bid—then build processes.
    - ♦ Seamless transition from design to construction.
- The project processes led to excellent customer relations. There was a notable absence of hidden agendas and wasteful political positioning. The high level of transparency in all parts of the process was key to this situation.

The customer's project manager found that the project ran so smoothly that he was released to work on other projects without concern that this project would get into trouble. He found that (although there was no formal contractual relationship between them) there were no incidents where he had to intercede between IDC and TNC to resolve issues.

The customer developed a confidence that due to everyone's input into the process the decisions reached resulted in the most cost-effective product. The total project construction cost is projected to complete about 20% under the customer's budget.

Opportunities

A number of areas of opportunity for better future implementation were noted, as follows:

- While in general there was good continuity of staff from the SDIAD forward, there were some notable changes in construction subcontractor key staff on the project. This led to some failures in follow through on actions set forth in the SDIAD.
- The failure to involve a key customer equipment supplier in the early project design process (preferably as early as the SDIAD) resulted in the need for IDC to resolve conflicts between the utility infrastructure design and the equipment. The supplier, while supplied with adequate design documents chose to not coordinate the utility connections on their equipment. In the future, an

expansion of the SDIAD to include all key supply chain companies including equipment manufactures would facilitate avoidance of similar occurrences.

- In some cases the customer failed to meet its commitments in delivery of information required for design. This resulted in design productivity impacts and delays. These showed up immediately in the PPC results, and corrective actions were initiated that resulted in recovery of PPC. This can be seen in the PPC graphics in this paper.
- As related above, it was possible to reduce the content required in the design document specifications. However, IDC did not have an appropriate model outline specification set. This resulted in the need to use existing master specifications and pare them down. The development of a set of appropriate master or model outline specification set would further reduce design effort, cost, and duration.
- While a great deal of unnecessary design drawing effort was eliminated, it was realized in retrospect that under this form of project delivery it is possible to further reduce the overlap and duplication of effort and documentation. Better up front analysis and planning in this regard between the design disciplines is recommended.
- Far and away the number one area for improvement for the planning process was in the tool used to develop and maintain the lookahead and weekly work plans. In the interest of implementing LD&C planning on the project with little lead time, the author developed the spreadsheet tools that were used for planning and documenting the metrics over a weekend. It was admitted from the beginning that the tools were cumbersome and not flexible. The intent for future implementation is to develop a database application that will address these limitations.
- Integration of prerequisite need lists fully into the same planning tool is needed, with the ability for each planner to see the other's prerequisites and import that information into their plans.
- The training and coaching of the design leads seemed adequate. A less formal methodology was employed on the construction with resultant lower performance. It is suggested that the design staff model be used (with some obvious adaptation) for the construction.
- The size and scope of the project dictated that some staff be on the project only part time during the heavy design effort duration. The part time discipline leads found it difficult to integrate fully into the planning methodology. The above software enhancements are anticipated to at least partly correct this deficiency.

CONSTRUCTION

There are many similar issues and overlap related to the design and construction wins and opportunities on the project. The following are the issues that are most relevant to the construction portion of the project as related by the construction project manager:

Wins

- The identification of qualified subcontractors and the decision to have them involved in the very beginning of the design effort yielded several positive results. Introducing the subcontractor project managers and superintendents to all the players from the customer, the owner's internal facility customer and design specialist aided in the exchange of ideas and generated a positive feeling of trust and respect for each others role.
- General contractor and subcontractor involvement in the design discussions helped in providing a better understanding so that more accurate pricing and scheduling could be generated early. In addition, the general and subcontractors could identify long lead delivery items and concentrate on defining them well enough to start the purchase of these items to be delivered in time to support the aggressive construction schedule.
- Because the subcontractors were involved early, many value engineering and constructabilty issues and ideas could be exchanged, discussed and decisions agreed upon. This is not typical in the normal design, bid, build approach that would have these ideas come out after design is complete and often too late to incorporate into the final design and construction.
- The subcontractors, having been chosen and commitments made to them to be a part of the team, could now ready resources such as equipment and personnel for the project and plan how and when they would be needed for project. In times when labor resources are in short supply, this is especially important.
- Involvement of subcontractors familiar with this type of project also helped eliminate the requirement of final, 100% designed drawings. Their involvement up front gave them a familiarization with the project and customer desires so that design intent was very well understood.
- All of the above issues were made more effective due to the customer's involvement in the process as well. This was because the owner's Conditions of Satisfaction were understood clearly in the SDIAD session.
- The project yielded very few change orders that were not related to either additions to scope generated by the customer after the design and construction process had started, or by not having the correct customer personnel at the SDIAD session. This project yielded less than 3% added cost through change orders which are qualified as issues that should have come out through the SDIAD session process.
- Schedule was improved dramatically due to the fast track, design/build approach. It is believed that this saved time in several forms:
  - ♦ It was unnecessary to wait for the project to be fully designed. It is believed that this saved approximately four weeks on the schedule.
  - ♦ It was unnecessary to competitively bid the project, which saved a minimum of two more weeks.

- ♦ Due to the subcontractor's early preparation as mentioned above, additional time in pre-purchasing long lead materials and mobilizing personnel was saved. This may have saved two to six weeks depending on the length of time on pre-purchase of specialty items.

- Having the subcontractors early also helped in execution of the early work to prepare for the main construction of the lab. We were able to take advantage of a customer's planned plant shutdown to complete a large piece of construction. This helped the project go more smoothly during the main construction effort.

Opportunities

- Some of the customer's personnel involved in the project during construction were not involved in the SDIAD session. This resulted in changes that required great effort to execute such that the schedule was not jeopardized. Most of the changes were due to lack of the proper people in the SDIAD session helping to make decisions on scope of work.
- All the foreman that were going to be managing work should have been at the SDIAD session for their input. Both the process piping and HVAC foreman were there, the electrical foreman was not. These people should also have had training in the use of the Last Planner procedures and documentation of their work plans.
- An issue out of the control of any one group is that the project manager for the electrical contractor left their company after the SDIAD session. This did cause a lack of continuity in the understanding of scope.
- Some parts of the specifications were pulled from a standard database and were too stringent or required higher levels of quality than were required for this project. In future projects, such standards should receive more validation early in the design process.
- A number of the key equipment suppliers should have been involved in the SDIAD. There were several issues that came up during the project that could have been avoided if they were involved early in the design process.
- Documentation was produced at the end of the SDIAD session that stated a scope of work and related costs. At the very end of this project it was determined that confusion existed related to another group within the customer's organization thinking that they were doing a portion of finish work connecting equipment. This caused more confusion when they assumed the responsibility, but had difficulty executing the work. In the future, more routine re-validation of the scope of work might help to avert similar misunderstandings.
- The customer decided up front that they alone would hold all contingency funds for changes related to incomplete or inadequate early information, or needed redefinition do to evolving requirements. IDC and TNC felt that some reasonable contingency funding should be held by TNC, so that the "Guaranteed Maximum Price (GMP)" could be held including such minor

> redefinition during the project. As a result, change orders were required for these items, over and above the GMP. This may result at times in the perception that the project "went over budget," when in reality it was on budget as scoped, and below the customer's original budget. This process might lead to the tendency for a constructor to "bury" the contingency funds in the GMP. This is inconsistent with the objective of LD&C for transparency. Some customer re-education from the previous mental models is required in this area.

NOTES ON THE LD&C ALLIANCE

As related in the early part of this paper, a significant question to be assessed by the customer through this project was whether two firms could in fact function as one entity in their relationship with the customer without benefit of a formal legal or contractual structure between the two firms. Results have shown that it is possible to operate very successfully in this manner. The underlying criteria that have made this possible centers around attitude and commitment. From the outset management and team members of both firms have jointly committed themselves to the success of the project. This fundamental value cannot be over stated as a key to project success. Without this commitment the project likely would have quickly fallen into the typical competitive relationship between design and construction, with the owner as mediator.

This fundamental commitment by both firms has actually become in a sense a self-fulfilling prophecy. As issues arose both firms worked together toward mutually beneficial solutions for the customer. As these bridges were crossed both firms developed more trust in the other which in turn strengthened the relationship with the customer. The customer's project manager has stated "there have not been any issues that I have had to resolve between design and construction." He also related that his work was "100 times less" than on a typical project.

It is the conviction of the author that the glue that held the project process together was the common commitment of IDC and TNC to LD&C, and the customer's willingness to give the process and the alliance a fair opportunity to prove itself. "The proof is in the pudding", as the saying goes. IDC and TNC are currently looking forward to three more projects together, two with the same customer as the one described herein. In addition, the customer is entertaining the use of the same processes for the new projects.

This project, while a single test case, has shown that it is possible to both execute one-off projects with a team that has not worked together previously, but also develop ongoing alliance relationships when the players agree to play according to a method that supports the success of all parties involved. While this might connote any form of "agreement" such as traditional design/build and partnering, construction history is strewn with the bodies of those that entered such arrangements with even the best of intentions. This author is convinced that what was missing in these past attempts was a common ground at the most detailed operating level that would not only weather the storms, but result in maximization of the interests of all parties to the project. LD&C has all the earmarks of providing that common ground. It appears from this project case, that a contractual relationship between the designer and constructor is not a requisite when this common ground exists. (see also: Miles, 1997)

Given that LD&C finds its origins in Lean Production (LP), and given the focus in LC on supply chain integration, the above statements should not be considered extraordinary. The LP industrial examples exhibit just such transparent cooperative alliances between manufacturers and their suppliers—many times with no formal contractual or business ownership linkage. In addition, we see very recent “strange” new alliances between past fierce competitors in industry8.

Both IDC and TNC look forward to the future implementation opportunities under LD&C with the full intent to take the lessons learned here as the starting point for the next projects. In addition, it is hoped that the case study results related here will help direct the future work of the LD&C organizations and institutes in the quest for continual improvement and progress in elimination of waste in the construction industry.

ACKNOWLEDGMENTS

The author gratefully acknowledges the contribution of the following project leaders for the case study project, for courage and commitment to a “better way” and for invaluable input into this paper. As IDC LD&C facilitator, it was a pleasure to work with them in this exiting and pioneering experiment.

- Robert Kirkendall, IDC, project manager.
- Jim Bowie, TNC, project manager.
- Michael J. Daily, TNC, architect and project LC facilitator.

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8 Recent examples in the high tech sector include alliances between Toshiba and IBM, and Siemens and Motorola.