Introduction to Lean Construction: Work Structuring and Production Control

Presented by the Lean Construction Institute

Glenn Ballard & Greg Howell

Presented at

Cincinnati, Ohio
April 20-21, 2006

www.leanconstruction.org
What has changed Manufacturing, and sharply pushed up productivity, are new concepts. Information and automation are less important than new theories of manufacturing, which are an advance comparable to the arrival of mass production 80 years ago. Indeed, some of these theories, such as Toyota’s “lean manufacturing”, do away with robots, computers and automation.

Objectives of LCI

• To develop theory and tools for understanding and managing the way work is done throughout the project delivery process, and
• To support implementation and dissemination.
Seminar Objectives

• Understand the theoretical basis of the Lean Project Delivery System.
• Understand its language, essential features, principles, tools and techniques.
• Make clear the primary differences between the Lean Project Delivery System and current practice.
• Encourage you to take action.
What is this thing called “LEAN”?

• Not mass, not craft. A third form of production system design.
• The Lean Ideal
  – Meet requirements of a unique customer
  – Deliver it instantly
  – Maintain no inventory

• “Give customers what they want, deliver it instantly, with no waste.”
Lean Production Goals

Deliver the product, while...

maximizing value *(give the customer what they need when they need it)* and

minimizing waste *(eliminate anything not needed for delivering value)*, and

pursuing perfection *(never stop striving to better achieve the lean ideal)*
Range of Projects & LCI

Stodgy

Understand the “Physics” of the Task

Design Systems to Support Lean Ideal

Conform Organization and Contracts

Dynamic
How do we manage projects now?

• Determine client requirements including quality, time and budget limits and design to meet them.
• Break project into activities, estimating duration and resource requirements for each activity and placing them in a logical order with CPM
• Assign or contract each activity, give start notice and monitor safety, quality, time and cost standards. Act on negative variance from standards
• Coordinate with master schedule and weekly meetings
  – reduce cost by productivity improvement
  – reduce duration by speeding each piece or changing logic.
  – improve quality and safety with inspection and enforcement
## Agenda

- **Start up**
- **Work Structuring/Production System Design**
  - Airplane Simulation
  - Case Studies in Design of Fabrication Systems: Malling and SpanCrete
  - Case Studies in Design of Site Installation Systems: Brazil (Pereira)
  - Case Study in Design of Supply Systems: Hollow Metal Doors (Boldt)
- **The Physics of Production-Work Flow**
  - The Parade of Trades Simulation
- **The Physics of Coordination**
  - Workflow loop
- **Production System Control using the Last Planner® System**
  - Pull scheduling
  - Lookahead planning
  - Reliable promising
  - Learning
- **More about Lean Project Delivery (if time available)**
- **Implementation/Organization Structuring**
- **Research directions**
- **Wrap up**
The Airplane Game

An exercise in production system design
The Airplane Game

At your table, discuss and answer the following questions and have a spokesperson report for your group. You have 15 minutes.

1. What are the key points or lessons for you?
2. How might these apply to designing and building?
• Release work (materials or information) from one workstation (specialist) to the next by pull versus push
• Minimize batch sizes to reduce cycle time.
• Make everyone responsible for product quality
• Balance the workload at connected workstations
• Encourage and enable specialists to help one another as needed to maintain steady work flow (multiskilling)
More Lean Production Techniques

1. Stop the line rather than release bad product to your ‘customer’.
2. Minimize changeover ("setup") time to allow one piece flow.
3. Make the process transparent so the state of the system can be seen by anyone from anywhere.
Goals for Production System Design

- Match throughput rate (TH) to demand rate
- Minimize cycle time
- Reduce WIP to the minimum needed to maintain throughput
- Minimize resources required
Production Systems in Construction

• The physical characteristics of production tend to be ignored.

• Variability in production systems is not taken into account.

• Production is largely uncontrolled.

• Lack technical knowledge about production; e.g., work flow reliability, defect rates, process and operation designs.

• There is no systematic process for learning from experience.

• Extreme fragmentation, even within single companies.

• Central control fantasy—push system.
Ohno’s 7 Types of Waste

- Defects in products
- Overproduction of goods not needed
- Inventories of goods awaiting processing or consumption
- Unnecessary processing
- Unnecessary movement of people
- Unnecessary transport of goods
- Waiting by employees for process equipment to finish work or for an upstream activity to complete.
Key Terms

- **Work Flow** - the movement of information and materials through networks of interdependent specialists.
- **Release of work** - making work available to the next specialist.
- **Dependence** - waiting on release of work.
- **Variation** - the range of work completed each day or week.
- **Buffer** - a verb: “to isolate one activity from the next.”
- **WIP** - Work in process.
- **Point Speed** - how fast each assignment or activity is completed.
- **Throughput** - the amount of the project completed each period.
- **Capacity** - amount of work that can be done by the specialist, related to productivity.
- **Push** - Advancing work based on central schedule
- **Pull** - Signaling for components of work to arrive when they will be required.
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XYZ Production Cell: Shear Walls
Process Chart

Suppliers → Precast Concrete Factory → Customers

Stores → Prep. → Tie rebar mats & close mould ends → Place mat in mould & prepare for pouring → Pour → Cure → Strike stone & clean mould → Load & Deliver
XYZ Production Cell: Shear Walls
Process Chart

Suppliers → Precast Concrete Factory → Customers

Build up of inventories and cycle time in push systems
Production System Design
Exercise: How apply pull, one piece flow, etc.? 

How would you improve a process for fabricating precast concrete shear walls from 3.2 walls average per day to match a demand rate of 9 walls per day, without changing technology or manning? How would you match production sequence and rate to customer demand? How would you assure availability of information and materials needed to support the production plan?
Fabricating precast concrete shear walls: process as found

- Foreman receives drawings and collects materials
- Foreman gets rebar cut and bent at rebar department
- Foreman has ironworkers tie rebar cages
- Foreman has carpenter shop make end pieces for form from wood
- Laborers place cage in form and install embeds.
- Foreman has carpenter come close ends of form
- Laborers seal form
- Foreman orders concrete from batch plant
- Laborers place concrete in form
- After concrete has cured, laborers strike the form and load the wall section onto trailer
- 7 laborers and 1 foreman are assigned to shear walls, plus part time from carpenter, et al., amounting to 12 worker days per day
- Average production rate is 3.2 shear walls per day
Shear Walls: Removing Obstacles to Better Performance

• Refurbished cut and bend plant to make them self-sufficient
• Moved materials to the workplace to reduce unnecessary movement
• Got them trailers to move stones out
• Cleared work area
• Played Airplane Game with work force and adapted lessons
• Got additional chains for crane
• Set up carpenter in cell location
<table>
<thead>
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<th>3</th>
<th>Night</th>
<th>Early Shift</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Night</th>
<th>Early Shift</th>
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<tr>
<td>Cut &amp; bend steel bars &amp; make mould ends</td>
<td>AB</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
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<td>Fix rebar cage</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
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<tr>
<td>Place cage &amp; pour</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>F</td>
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<tr>
<td>Cure</td>
<td>A,B,C</td>
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<td>A,B,C</td>
<td>D,E,F</td>
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<tr>
<td>Strike &amp; clean mould</td>
<td>A,B,C</td>
<td></td>
<td></td>
<td>A,B,C</td>
<td>D,E,F</td>
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XYZ Production Cell: Shear Walls
Process Flow Chart

- **Rebar Supplier**
- **Lumber Supplier**
- **Lumber**
- **Couplers & Rebar**
- **Make couplers**
  - Dylan does next day's couplers the previous afternoon
- **Cut & Bend Steel**
- **Do carpentry work on moulds**
  - 1 Chippie 9/day
- **Place cage in mould & prepare for pouring**
  - 3 2-person teams 9/day total
- **Pour**
  - 2 person Striking Gang 9/day
- **Cure**
  - 24 hrs. (approx. 12 hrs if heated)
- **Strike & Clean Moulds**
  - 2 person Striking Gang 9/day
- **Load & Deliver**
  - Moulds

- **Concrete Batch Plant**
  - Cement, Aggregate, Admixtures, etc.
- **Cement and Aggregate Suppliers**
- **Pull to Cement & Aggregate Suppliers**
- **Release the next 3 drawings**
- **Release the next 9 drawings**
- **Release the next 3 drawings**
- **Release the next 3 drawings**
- **Pull**

- **Cell Production Control**
- **Factory Production Control**
- **Next day's drawings**
- **Project Schedules**
- **Revised Schedules**
- **Call Outs**

- **Customers**

- **Moving to blanket purchase orders with standard releases modified as needed to match changes in work mix to Cement & Aggregate Suppliers**

- **Work is made ready based on project schedules, but released for production based on call outs. Malling is working on improving the detail and accuracy of call outs, and working to gain customer confidence in their ability to deliver, so the customers won't order so much ahead and in such large batches.**

- **Now weekly deliveries. Starting twice daily milk runs.**
- **When materials are available, fixers fix cages as needed to maintain a buffer of 3 ready for the 3 placing teams.**
- **Normally stones are loaded onto trailers and delivered directly to site, but big batches are sometimes needed to support erection rates greater than fabrication rates.**
Moving Towards Self Managing Production Cells: Guidelines

• Follow the sequence.
• Inspect your own work.
• Don’t get more than one step ahead of your ‘customer’— do one at a time.
• Help others maintain work flow.
• Make suggestions to improve safety, product quality, productivity, or quality of work life.
Implemented Suggestions from the Work Force

• Simplified bearers
• Poly vs steel boxes
• Truck mixer
• Reallocated tasks from striking crew so they could hit their 30 minute window
• Reassignments: Medium experienced operative placed 3 cages per day with minimal supervision
• Cell meetings and clearly assigned responsibilities
• Workers self initiated area cleanup
Improvement in Throughput & Productivity

- Shear Walls
- T's

Graph showing performance metrics for Shear Walls and T's over time, comparing old output, first week, and current performance.
Product Mix

**Process Pattern**
- One of a Kind or Few
- Low Volumes: many products
- High Volumes: several major products
- Very High Volumes: Standard product (Commodity)

**Management Challenges**
- Scheduling; materials handling; shifting bottlenecks
- Worker motivation; balance; maintaining enough flexibility
- Capital expenses for big chunk capacity; technological change, materials mgmt; vertical integration

**Management Challenges**
- Bidding; delivery; product design flexibility
- Quality (Product Differentiation); flexibility in output volumes
- Price

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Spancrete’s Lean Approach to Manufacturing (SLAM)

<table>
<thead>
<tr>
<th>Work Group</th>
<th>Status</th>
<th>Results</th>
<th>Focus</th>
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</thead>
<tbody>
<tr>
<td>Waukesha Wet Cast</td>
<td>Launched (now on 6th improvement cycle)</td>
<td>27% cost reduction; 67% increase in productivity</td>
<td>5S in shop; TPM; cycle time reduction in shop from pull techniques, pouring concrete asap. Now working on yard operations</td>
</tr>
<tr>
<td>Valders Wet Cast</td>
<td>Launched (on 5th cycle)</td>
<td>100% increase in tees, from pours every 2 days to daily pours</td>
<td>5S in shop; cycle time reduction. Current goal: turn 2 beds of insulated plank/day.</td>
</tr>
<tr>
<td>Crystal Lake Plank</td>
<td>Launched (on 4th cycle)</td>
<td>18% increase in productivity, greater flexibility to changes in demand</td>
<td>Changed from stack casting to single piece flow. Now working to reduce changeover time from 8-inch to 10-inch plank.</td>
</tr>
<tr>
<td>American Concrete Pipe Specialty</td>
<td>Launched (on 3rd cycle)</td>
<td>82% reduction in finished goods inventory</td>
<td>5S and pull techniques on outside operations; now implementing 5S on inside operations</td>
</tr>
<tr>
<td>Drafting &amp; Engineering</td>
<td>Current</td>
<td></td>
<td>Admin 5S, info transfer from Sales, materials ordering</td>
</tr>
</tbody>
</table>
SLAM Accomplishments

• Throughput increased from 565,898 cu. ft. to 1,134,966 cu. ft.
• Direct labor hours per unit of output decreased from .174 to .162
• Raw material inventory turns increased from 17.14 to 25.15
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Terra Brasilis
23 floors

Vila do Sol
23 floors

Opening: Jun/2005

Lean w/o Autonomation

Lean w/ Autonomation
Vila do sol – Table for the customer to define his options
Like a puzzle

Competitive advantage
© 2006 Lean Construction Institute
Section of Vila do Sol with an annotation of the model for each apartment. (April / 04)
A1, A2, A3, A4, B1, B3, B2, B4, B5, B6, B7, C, C1, C3, C4, C5, D1, D2, E1, F, F3, F4, G, G2, G3, G7, G8, G9, G10, G11, G13, G14, G15, (Total 33/92)
Objective: Best quality, Least Cost, and Shortest Lead Time

Just in Time
- Takt time planning
- Continuous Flow
- Pull System
- Quick changeover
- Integrated logistics

Autonomic - Jidoka
- Automatic stops
- Andon
- Person-machine separation
- Error proofing
- In-station quality control
- Solve root cause of problems

Heijunka
- Leveled Production

Visual Management

Kaizen Improvement

Stability and standardization

TOYOTA WAY
Two Pillars that support the Toyota Production System

1. Just-in-time
2. Autonomation, or "automation with a human touch"

".. autonomic means making judgements autonomously at the lowest possible level; for example, when to stop production, what sequence to follow in making parts, or when overtime is required to produce the required amount."


"Autonomic" Self regulating, functionally independent. Webster’s on-line dictionary
**SEQUENCE AND FLOW - How is the dog running?**

<table>
<thead>
<tr>
<th><strong>Stair cell</strong></th>
<th><strong>Villa do Sol</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>M Informática</strong></td>
<td><strong>Vila do Sol</strong></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Limpeza de teto</th>
<th>Limpeza de teto</th>
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<table>
<thead>
<tr>
<th><strong>CRONOGRAMA</strong></th>
<th><strong>ESCALA - POÇO - SHAFT - PAVIMENTO</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vila do Sol</strong></td>
<td><strong>28°</strong></td>
</tr>
</tbody>
</table>
The foreman was sitting when I arrived at the Vila do Sol site. I asked how the tasks were going and he said:

If somebody looked at this site, they would never have a clue that we have 150 workers and all the tasks are going smoothly.

(And the foreman was SITTING – This is not my experience with construction projects.)

Foreman: Jose Maria
2 of september 2004 16:30 pm
Vila do Sol
Fortaleza- Ceará
Obs: Autonomation
Cell 1 Phase Plan

1ª Etapa da Obra

PREVISTO ATUALIZADO
REALIZADO
PREVISTO INICIAL

© 2006 Lean Construction Institute
Comparing cell 1 performance between buildings
KANBAN CARDS

Quantities established to support standard production rates
Response time and quantities established for transport cell to support standard production rates.
Eng. Pedro Eduardo Pereira
Vila do Sol

3 buttons

- **Normal Operation**
- **We will stop in less than one hour**
- **Work Stopped**

**Signal Station on each Floor**

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3 buttons

LIGHT PANEL FOR ANDON SIGNALS FOR EACH FLOOR

Secretary Maruska Gomes Arruda

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Learnings (Kaizen)

Before
- Normal Operation
- We need help.
- Work Stopped

After
- Normal Operation
- We will stop in less than one hour
- Work Stopped

• At first, ANDON lights were a dangerous idea - inviting management to the work
  (Ohno’s great idea of a Pull system for a manager cell).

• ANDON lights became a very good idea when management began to solve problems. Workers made more money. (New good problem is how to change the price)

• And so the lights’ definition of use were adjusted to provide a warning for managers before a stop.
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The DNA of Toyota

1. All work shall be highly specified as to content, sequence, timing and outcome
2. Every customer-supplier interface must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses
3. The pathway for every product and service must be simple and direct
4. Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest level possible in the organization.
Work structuring is planning, aka process design. Planning starts with the design of the entire production system and goes all the way down to the design of individual operations. Process design changes to generate product-based value. Product design changes to generate process-based value and to eliminate waste.
Products of Work Structuring

- Global sequencing
- Project Organizational/Contractual Structure
- Supply Chain Configurations (how the project hooks to external production systems)
- Master Schedule & Phase Schedules
- Rough Cut Operations Designs; e.g., decision to cast-in-place vs precast, or use a tower crane vs rolling stock
- Detailed Operations Designs; e.g., how to form-rebar-pour basement walls
Work Structuring and Operations

The extent of choices on the design of operations

Phase 1: Work Structuring and design activities

Phase 2: Last Planner

Time

Extent of remaining choices
Discussion questions

• Why did they do it the way they did? (What “organizing principle” was applied?)
• How would you do it if you were doing it right? Identify the new “organizing principle”.
Building a Cell - The Big Steps

Foundation → Precast → Top Slab → Doors → Paint
3D View of Door Frame and Wall Panel

- **OUTSIDE EDGE OF CONCRETE PANEL**
- **GROUT**
- **LATEX CAULKING**
- **SECURITY CAULKING**
- **ANCHOR BOLT**
- **INSIDE EDGE OF CONCRETE PANEL**
- **DOOR FRAME**
Door Installation: The Little Steps

Ready to Install
Laying out
Drilling
Shimming
Trimming the Shim
Backer Rods

As shown on submittals

As provided
Caulking Outside
Feathering Caulk
Keeping the Grout In

- U-shaped plywood
- Plywood C-clamps
- Wooden shims
Door Inventory
Supply and Contractual Relationships

Case Study for Work Structuring: Installation of Metal Door Frames
Cynthia C.Y. Tsao et al., IGLC 2000

Legend

State Prison Authority
Architect
Design Build Contractor
Installation Subcontractor
Precast Subcontractor
Door Subcontractor
Caulking Subcontractor

Identify Enclosure Criteria
Design Walls & Rough Opening
Approve Precast Concrete Panel Shop Drawings
Design Doors, Make Bid Package
Approve Door Bid
Install Door Frames
Install Plywood Fix
Specify Caulk
Specify Grout

Develop Shop Drawings
Cast Concrete Panels
Door Supply Bid
Fabricate Doors
Deliver Panels to Site
Deliver Doors to Site
Caulk

Fix Damaged Caulk

Transport to Site
Product Flow
Contractual Relationship
Discussion

• Why did they do it the way they did? (What “organizing principle” was applied?)

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Work Structuring as Design

• Lean Work Structuring IS PROCESS DESIGN
• As in product design, options must be considered and these may reveal different dimensions of the problem.
• Expect iteration between consideration of the design of “What” is to be built, and “How” to build it.
• Since work structuring recurs, early decisions as to “What” must fully consider “How” or leave adequate room for later decisions.
• “Change” often is the result of over-specifying “What” while not considering “How.”
Lean Work Structuring

• In what chunks will work be assigned to specialists?
• How will work chunks be sequenced?
• How will work be released from one production unit to the next?
• Will consecutive production units execute work in a continuous flow process or will their work be de-coupled?
• Where will de-coupling buffers be needed and how should they be sized?
• How will tolerances be managed?
• When will different chunks of work be done?
• The objective of WBS is to assure that all scopes of work are assigned and that none overlap.
• Lean Work Structuring (LWS) strives for the best approximation of the lean ideal.
• LWS “chunks” work so that it
  1) can be produced rapidly and for a low cost,
  2) supports optimizing at the project level, and
  3) delivers value to the customer and producer.
What are your takeaways?
What questions have been provoked?
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## Week 1

Concrete

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<th>Capacity (Rolled)</th>
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<th>Lost Capacity</th>
<th>Remaining Incoming Inventory (Backlog)</th>
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### Week 2

#### Mason

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<td>Number on Dice</td>
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<td>Available-Used = Remaining</td>
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<tr>
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#### Concrete

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<th>Remaining Incoming Inventory (Backlog)</th>
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<th>Available-Used = Remaining</th>
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<td>Available-Used = Remaining</td>
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### Mason

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<th>Remaining Inventory (Backlog)</th>
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</thead>
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<td>Moved Chips</td>
<td>Capacity-Passed=</td>
<td>Available-Used = Remaining</td>
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<td>1</td>
<td>1</td>
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Physics of Production

Load on Resources

Delivery Time

Capacity Utilization (one factor in Productivity)

100%
Time Cost Revisited

(1) – Reduce cycle time, maintain productivity
(2) – Increase productivity, maintain cycle time
(3) – Increase productivity, AND reduce cycle time
Key Points

- Reducing workflow variability
  - Improves total system performance
  - Makes project outcomes more predictable
  - Simplifies coordination
  - Reveals new opportunities for improvement

- Point speed and productivity don’t matter – throughput does.

- Strategy: Reduce variation then go for speed to increase throughput.
Question for Discussion

What would be the specific advantages of improved work flow reliability on your projects?
Agenda

• **Start up**
• **Work Structuring/Production System Design**
  – Airplane Simulation
  – Case Studies in Design of Fabrication Systems: Malling and SpanCrete
  – Case Studies in Design of Site Installation Systems: Brazil (Pereira)
  – Case Study in Design of Supply Systems: Hollow Metal Doors (Boldt)
• **The Physics of Production-Work Flow**
  – The Parade of Trades Simulation
• **The Physics of Coordination**
  – Workflow loop
• **Production System Control using the Last Planner® System**
  – Pull scheduling
  – Lookahead planning
  – Reliable promising
  – Learning
• **More about Lean Project Delivery (if time available)**
• **Implementation/Organization Structuring**
• **Research directions**
• **Wrap up**
Planning IS Conversation

• Always has been.
• The key to coordinate actions if...
• You talk about the right things, and
• Create coherent commitments linking client value to the work of specialists, and coordinates that to their action.
The “Physics” of Coordination

1. Request
   “Will You?”

2. COMMIT
   “I Promise I WILL”

3. Declare Complete
   “I’m Done”

4. Declare Satisfaction
   “Thank you”

Conditions of Satisfaction & Completion Date

CUSTOMER

PROVIDER
Reliable Promises - 5 test questions

1. Am I competent to perform or do I have access to competence?
2. Have I estimated the amount of time (hands-on) required for this work?
3. Do I have the capacity available & allocated?
4. Am I having a private unspoken conversation in conflict with promise?
5. Will I be responsible?
Problems with Current Practice

- Activity Focus ignores value creation and the flow of work.
  - Collaboration in design is limited
  - Fails to produce predictable work flow
- Command and Control planning cannot coordinate the arrival of the wherewithal or work of specialists.
  - Opportunities for trading ponies for horses are lost
  - Push systems are commitment free zones.
- Control begins with tracking cost and schedule.
  - Efforts to improve productivity leads to Unreliable Work Flow further reducing project performance.
  - Protecting activities leads to adversarial relations.
Project Based Production

- Structure work to maximize value and throughput and control work flow while minimizing idle inventory and resources.
- Make work ready and release it at the right time and in the right sequence.
- Plan and coordinate action through reliable promising.
- Learn from failures and take advantage of the opportunities it creates.
- Maximize performance at the project level, continue to learn.
## Agenda

- **Start up**
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- **Research directions**
- **Wrap up**
A Traditional (Push) Planning System

- Project Objectives
- Planning the Work
- Inputs
- Executing the Plan
- Should
- Did

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## Construction Weekly Work Plan

**1 WEEK PLAN**

**PROJECT:** Pilot  
**FOREMAN:** PHILLIP  
**DATE:** 9/20/96

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>Est</th>
<th>Act</th>
<th>Mon</th>
<th>Tu</th>
<th>Wed</th>
<th>Thurs</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
<th>PPC</th>
<th>REASON FOR VARIANCES</th>
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<tr>
<td>Gas/F.O. hangers O/H &quot;K&quot; (48 hangers)</td>
<td>xxxx</td>
<td>xxxx</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No</td>
<td>Owner stopped work (changing elevations)</td>
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<td>Gas/F.O. risers to O/H &quot;K&quot; (3 risers)</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
<td></td>
<td></td>
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<td></td>
<td>No</td>
<td>Same as above-worked on backlog &amp; boiler blowdown</td>
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<tr>
<td>36&quot; cond water &quot;K&quot; 42' 2-45 deg 1-90 deg</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
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<td>Yes</td>
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<td>Chiller risers (2 chillers wk.)</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
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<td>No</td>
<td>Matl from shop rcvd late Thurs. Grooved couplings shipped late.</td>
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<tr>
<td>Hang H/W O/H &quot;J&quot; (240'-14&quot;)</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
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<tr>
<td>Cooling Tower 10&quot; tie-ins (steel) (2 towers per day)</td>
<td>xxxx</td>
<td>xxxx</td>
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<tr>
<td>Weld out CHW pump headers &quot;J&quot; mezz. (18)</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
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<tr>
<td>Weld out cooling towers (12 towers)</td>
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<td>No</td>
<td>Eye injury. Lost 2 days welding time</td>
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<tr>
<td>F.R.P. tie-in to E.T. (9 towers) 50%</td>
<td>xxxx</td>
<td>xxxx</td>
<td>xxxx</td>
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**WORKABLE BACKLOG**  
Boiler blowdown-gas vents -rupture disks
## Traditional Management Increases Variability: Plan Reliability Data

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Variability</th>
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<tbody>
<tr>
<td>Contractor 1</td>
<td>33 %</td>
</tr>
<tr>
<td>Contractor 2</td>
<td>52 %</td>
</tr>
<tr>
<td>Contractor 3</td>
<td>61 %</td>
</tr>
<tr>
<td>Contractor 4</td>
<td>70 %</td>
</tr>
<tr>
<td>Contractor 5</td>
<td>64 %</td>
</tr>
<tr>
<td>Contractor 6</td>
<td>57 %</td>
</tr>
<tr>
<td><strong>Contractor 7</strong></td>
<td><strong>45 %</strong></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>54 %</strong></td>
</tr>
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</table>
Helmuth von Moltke
Head of the Prussian & German Staff 1858-1888

- No plan of operations extends with certainty beyond the first encounter with the enemy’s main strength. Only the layman sees in the course of a campaign a consistent execution of preconceived and highly detailed original concept pursued consistently to the end.

- Certainly the commander and chief will keep his great objective continuously in mind, undisturbed by the vicissitudes of events. But the path on which he hopes to reach it can never be firmly established in advance.

- Throughout the campaign he must make a series of decisions on the basis of conditions that cannot be foreseen. The successive acts of war are thus not premeditated designs, but on the contrary are spontaneous acts guided by military measures.

- Everything depends on penetrating the uncertainty of veiled situations to evaluate the facts, to clarify the unknown, to make decisions rapidly, and then to carry them out with strength and constancy.
The Last Planner® System of Production Control

**SHOULD**
- Master Scheduling: Set milestones
- Pull Scheduling: Specify handoffs

**CAN**
- Lookahead Planning: Make ready & Launch replanning when needed

**WILL**
- Weekly Work Planning: Promise

**DID**
- Learning: Measure PPC & Act on reasons for failure to keep promises
Who is the Last Planner®?

- The person or team that gives assignments (makes requests for commitments) to production units such as design squads or construction crews.
# Master Schedule-1

## Approval Process
- **1000** Submit Proposal to DFD: 002FEB00
- **1010** DFD Authorization to Proceed: 02FEB00, 02MAR00
- **1030** Site Permit Review: 02MAR00, 03MAR00
- **1050** Prisoner Housing Permit Review: 03MAR00, 03MAR00

## Design Phase
- **1080** Site Development & Utilities: 08MAR00, 11APR00
- **1105** MEP - Building Underground: 12APR00, 09MAY00
- **1085** Footings & Foundation Package: 26APR00, 06JUN00
- **1115** MEP - Structural: 10MAY00, 06JUN00
- **1090** Building - Structural & Enclosure: 17MAY00, 12JUL00
- **1095** MEP Package: 07JUN00, 15AUG00
- **1098** Building - Finishes: 28JUN00, 23AUG00

## Bid Packages
- **1240** Site Development & Utilities Bid Package: 09MAY00
- **1250** Footing & Foundation Bid Package: 09MAY00
- **1270** Building Enclosure Bid Package: 09AUG00
- **1260** MEP Bid Package: 17AUG00, 13SEP00
- **1470** Building Finishes Bid Package: 24AUG00, 20SEP00
Functions of Master Schedules

- Demonstrate the feasibility of completing the work within the available time.
- Develop and display execution strategies.
- Determine when long lead items will be needed.
- Identify milestones important to client or stakeholders.
Linking Scheduling & Production Control

Proposed schema for work structures:

- **Projects** consist of phases.
- **Phases** (site prep., substructure, superstructure,….) consist of processes.
- **Processes** (w/in substructure: layout, excavate, shore, place drilled caissons,….) consist of operations.
- **Operations** (w/in place drilled caissons: fabricate cage, drill hole, place cage, pour concrete) consist of steps.
- **Steps** (w/in fabricate cage: acquire materials, place straight bar in jig, weld coiled bar helically around cylinder, fit & tack lifting bands, weld out lifting bands) consist of motions.

Today’s **assignment** for X: Perform welding steps in the operation Fabricate Cage. Fabricate cages 101, 102 and 103 in that order.

The goal of control is the handoffs between work groups performing different processes within phases.
Fabricate cage
Place cage in hole
Drill hole
Excavate Place drilled caissons
Shore
Substructure
MEP rough-in

Project: 101 Calhoun

Phase: Substructure

Process: Place drilled caissons

Operation: Fabricate cage

Step n: Place straight bars in cage jig
Step n+1: Weld helical coil to straight bar while rotating jig
Step n+2: Fit & tack lifting bands

Motion Analysis of Steps into Therbligs
Pull Scheduling: Designing the Network of Commitments

- Produce the best possible plan by involving all with relevant expertise and by planning near action.
- Assure that everyone in a phase understands and supports the plan by developing the schedule as a team.
- Assure the selection of value adding tasks that release other work by working backwards from the target completion date to produce a pull schedule.
- Publicly determine the amount of time available for ‘contingency’ and decide as a group how to spend it.
The Last Planner® System of Production Control

**SHOULD**
- Master Scheduling: Set milestones
- Pull Scheduling: Specify handoffs

**CAN**
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**WILL**
- Weekly Work Planning: Promise

**DID**
- Learning: Measure PPC & Act on reasons for failure to keep promises

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# Look Ahead Plan

**Milestone = RTT1B**

## Project Information
- **Group**: MHM
- **Program**: Delta
- **Project**: Women's Center
- **Project Number**: 02074639
- **Responsible Individual**: Bill Ortiz

## Look Ahead Plan

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</tr>
<tr>
<td>Backing</td>
<td>Brian</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Rock One Side</td>
<td>Brian</td>
<td>X</td>
<td>X</td>
<td></td>
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<td><strong>Area 1B2 Walls</strong></td>
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</tr>
<tr>
<td>Framing</td>
<td>Brian</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Wall Electrical</td>
<td>Dave</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Wall Controls</td>
<td>DDC</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Backing</td>
<td>Brian</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rock One Side</td>
<td>Brian</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Notes
- **RFI or Constraint #**: 23-Aug-04
# LOOKAHEAD SCHEDULE

## Six Week Lookahead / Constraints Analysis

### Activity

<table>
<thead>
<tr>
<th>#</th>
<th>Activity</th>
<th>Responsible Party</th>
<th>Comments / Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Build mock-up of room 11</td>
<td>Boldt</td>
<td>Millwork &amp; mirror</td>
</tr>
<tr>
<td>1</td>
<td>Microscope vibration study</td>
<td>Langer</td>
<td>CD's will be issued prior to this info; Isolation system will come as addendum</td>
</tr>
<tr>
<td>1</td>
<td>Bid &amp; award bid pack 3</td>
<td>Boldt</td>
<td>Review with Brad</td>
</tr>
<tr>
<td>1</td>
<td>Release updated constr docs</td>
<td>ARC</td>
<td>Additional submittals required</td>
</tr>
<tr>
<td>1</td>
<td>Demolition</td>
<td>Boldt</td>
<td>Coordinate with Ring &amp; Du</td>
</tr>
<tr>
<td>1</td>
<td>Pour roof</td>
<td>Boldt</td>
<td>Stone was ordered 10-19-00</td>
</tr>
<tr>
<td>1</td>
<td>Expedite stone production</td>
<td>BDI</td>
<td>5-6 week lead time - Ordered 10-19-00</td>
</tr>
<tr>
<td>1</td>
<td>Steel Shops: Curtainwall Support</td>
<td>Duwe</td>
<td>Shopping 11-3; Besam header to Dickert</td>
</tr>
<tr>
<td>1</td>
<td>Roof detailing</td>
<td>Duwe</td>
<td>Millwork; Mirror</td>
</tr>
<tr>
<td>1</td>
<td>Phase 3 Millwork Shop Drwngs</td>
<td>Precision</td>
<td>Waiting for framing materials-by October</td>
</tr>
<tr>
<td>1</td>
<td>Fabricate louvers</td>
<td>Air Flow</td>
<td>Roger needs to confirm if brick is in</td>
</tr>
<tr>
<td>1</td>
<td>Fabricate auto entrance doors</td>
<td>Besam</td>
<td>Boldt to confirm placement of AHU's</td>
</tr>
<tr>
<td>1</td>
<td>Fabricate curtainwall</td>
<td>Klein Dickert</td>
<td>Award contracts</td>
</tr>
<tr>
<td>2</td>
<td>Mock-up review</td>
<td>SLMC</td>
<td>Need to coordinate with Jan Keepers</td>
</tr>
<tr>
<td>2</td>
<td>Masonry Work</td>
<td>BDI</td>
<td>Shipping: 11-13-00</td>
</tr>
<tr>
<td>2</td>
<td>Penthouse framing &amp; decking</td>
<td>Duwe</td>
<td>Delivery: 11-6-00</td>
</tr>
<tr>
<td>2</td>
<td>Bid Pack 3 Submittals</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Start work on patient rooms 3847 -49</td>
<td>TBD</td>
<td></td>
</tr>
</tbody>
</table>

## Workable Backlog

- **Fabricate AHU's / ACCU**: Trane
- **Med Gas Equip. Lead-Time**: Squires
- **Demo shades at main entrance**: TBD
- **Review room numbering**: ARC / Lakes
Functions of the Lookahead Process

- Shape work flow sequence and rate
- Match work flow and capacity
- Maintain a backlog of ready work
- Develop detailed plans for how work is to be done
  - Safety, environmental, quality issues
Mapping Language: Activity Definition Model

- Prerequisite Work
- Directives
- Process
- Resources
- Output

Meets Criteria?
## Constraints Analysis: Design

### Project: Mega Bldg
Report Date: 3 Nov

<table>
<thead>
<tr>
<th>Activity</th>
<th>Responsible Party</th>
<th>Scheduled Duration</th>
<th>Directives</th>
<th>Pre-requisites</th>
<th>Resources</th>
<th>Comments</th>
<th>Ready?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design slab</td>
<td>Structural Engineer</td>
<td>15 Nov to 27 Nov</td>
<td>Code 98 Finish?</td>
<td>Soils report</td>
<td>10 hours labor, 1 hr plotter</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Get info. from client re floor finish &amp; level</td>
<td>Structural Engineer’ s gofer</td>
<td>3 Nov to 9 Nov</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Get soils report from Civil</td>
<td>Structural Engineer</td>
<td>By 9 Nov</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Layout for tool install</td>
<td>Mechanical Engineer</td>
<td>15 Nov to 27 Nov</td>
<td>OK</td>
<td>Tool configurations from mfger</td>
<td>OK</td>
<td>May need to coord. w/ HVAC</td>
<td>No</td>
</tr>
</tbody>
</table>
How is the lookahead within Last Planner® different from traditional lookahead schedules?

• Traditional lookahead schedules are used to provide advance notice of activity starts in the service of sticking to a usually quite detailed master schedule.

• Traditional lookahead schedules do not:
  – Shape work flow sequence and rate
  – Match work flow and capacity
  – Maintain a backlog of ready work
  – Develop detailed plans for how work is to be done
Steps in the Lookahead Process

- **Explode** scheduled activities into assignment-level detail, using the Activity Definition Model and First Run Studies.
- **Screen** the constraints on each assigned task within the lookahead window.
- **Make** assigned tasks **ready** by removing constraints.
- **Balance** load and capacity by advancing/retarding scheduled work, increasing/decreasing capacity, or deciding how to invest excess capacity.
- **Adjust** phase or master schedules as needed.
- **Learn**: measure and improve performance.
First Run Studies

• An explicit, detailed plan for an operation developed prior to starting work. Includes consideration of safety, operation design including timing and location of activities, work flow, crew balance, tools, release of work downstream, etc.

• The plan is developed with those involved in doing the work, tested and improved.

• The actual process is recorded, analyzed to identify improvements.
PDCA Cycle

**PLAN**
1. Select work processes to study.
2. Before the first run of each process, assemble people with input or impact.
3. Chart the work process steps.
4. Brainstorm how to eliminate, reduce or overlap process steps.
5. Check process designs for safety; anticipate hazards and specify preventions.
6. From past experience, list probable errors and specify preventions. Plan for feedback and learning by identifying key variables to observe or data to collect.
7. Assign optimum labor, tool and equipment resources.

**DO**
8. Carry out the plan on the first run.

**CHECK**
9. Describe and measure what actually happens:
   - process steps, sequences and durations
   - interactions with other operations or crews
   - errors, omissions and rework
   - accidents, near misses and hazards
   - resources used (labor, tools, equipment, support crafts, etc)
   - outputs

**ACT**
10. Reconvene the team, including those who actually did the work, review data and share ideas. Continue until opportunity for improvement is exhausted.
The Last Planner® System of Production Control

- **Master Scheduling**: Set milestones
- **Pull Scheduling**: Specify handoffs
- **Lookahead Planning**: Make ready & Launch replanning when needed
- **Weekly Work Planning**: Promise
- **Learning**: Measure PPC & Act on reasons for failure to keep promises

**SHOULD**

**CAN**

**WILL**

**DID**
Forming the Commitment Plan

- **CAN**
  - Possible
  - Workable
  - Backlog

- **SHOULD**
  - These tasks need to be made ready

- **WILL**
  - Eligible
  - For
### Weekly Plan & PPC

**Week of 10/16/00**

**PPC = 69%**

<table>
<thead>
<tr>
<th>Assignment Description</th>
<th>Responsible Party</th>
<th>M</th>
<th>T</th>
<th>W</th>
<th>T</th>
<th>F</th>
<th>S</th>
<th>Y</th>
<th>N</th>
<th>Reasons For Variance / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remember the Five Criteria for Release of Assignments Defided - Sound - Proper Sequence - Right Size - Able to Learn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review mock-up drywall dimensions</td>
<td>Randy</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Y</td>
<td></td>
<td>Wardrobe dimensions changed</td>
</tr>
<tr>
<td>Review microscope vibration Study</td>
<td>David</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>Will award next week.</td>
</tr>
<tr>
<td>Review bids - Bid Pack 3</td>
<td>Dena/ Brad</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
<td>Week 1 of 2</td>
</tr>
<tr>
<td>Review roofing shops</td>
<td>Jose’</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete concrete haunches</td>
<td>Randy</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Release order on limestone</td>
<td>Dena</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Re-submit curtainwall support shops</td>
<td>Dick</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>N</td>
<td></td>
<td>Waiting for curtainwall shop drwg.</td>
</tr>
<tr>
<td>Roof framing: 75% complete</td>
<td>Bob Brue</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>Submit Phase 2 Millwork Shops</td>
<td>Precision</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fabricate mock-up millwork</td>
<td>Precision</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td>Week 2 of 3</td>
</tr>
<tr>
<td>Re-submit curtainwall shops &amp; structural calcs</td>
<td>Jim Leicht</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>Middle of next week</td>
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<tr>
<td>Finalize review of louver shops</td>
<td>Tony/ David</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>Y</td>
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<td></td>
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<tr>
<td>Review GL-1 and GL-2</td>
<td>ARC/Jim Leight</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
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</tr>
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</table>
Quality Characteristics of Weekly Work Plans

- Definition
- Soundness
- Sequence
- Size
- Learning
Percent Plan Complete (PPC) Chart

Rasacaven: Electrical Power Distribution
Reasons for Plan Failure

Total Planned Activities in Study = 625
Activities That Could Not Be Completed When Planned = 227
Average for 5 Projects = 36.3% Activities Supervisors Could Not Complete as Scheduled.
Design PPC: Nokia Project

REALIZATION % OF ASSIGNED DESIGN TASKS

VTT Building Technology 1997, VPT
PPC & Productivity

- Crews with PPC >50%:
  - 1.15 times budget

- Crews with PPC <50%:
  - 0.85 times budget
Evolution of PPC

- Avg. PPC before LPSI
- Avg. PPC after LPSI
- Direction of PPC before LPSI
- Last Planner® System Implemented (LPSI)
Productivity Evolution

Below Budget (Making $$)

At Budget

Over Budget (Losing $$)

Average Productivity before LPSI

86%

65%

Last Planner® System Implemented; PPC increasing

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Uncertainty and Variability Can Be Managed

• Reduce variability then go for speed.
• The place to start is by shielding production from flow variability by making only ‘quality’ assignments.
• Managing the remaining variability involves thoughtful location and sizing of inventory and capacity buffers.
• Every ‘workstation’ must make work ready in the right sequence and rate for reliable release to their ‘customer’
The Place To Start

1. Project Objectives
   - Work Structuring
     - Master or Phase Schedule
       - Lookahead Planning
         - Should
           - Make Ready Process
             - Can
               - Last Planning Process
                 - Will
                   - Production
                     - Did

- Defined
- Sound
- Sequenced
- Sized

Shield
Summary Recommendations for Production Control

• Limit master schedules to milestones and long lead items.

• Produce phase schedules with the team that will do the work, using a backward pass, and making slack explicit.

• Drop activities from the phase schedule into a 6 week lookahead, screen for constraints, and advance only if constraints can be removed in time.

• Learn to make reliable promises.

• Track PPC and act on reasons for failure to keep promises.
Project and Production Controls

Project Objectives

- Work Structuring

Master or Phase Schedule

- Lookahead Planning

SHOULD

- Can

Last Planning Process

WILL

- Production

On Budget & Schedule?

AA

AMR

PPC

DID
What have you heard so far?
What questions do you have?
## Agenda

- **Start up**
- **Work Structuring/Production System Design**
  - Airplane Simulation
  - Case Studies in Design of Fabrication Systems: Malling and SpanCrete
  - Case Studies in Design of Site Installation Systems: Brazil (Pereira)
  - Case Study in Design of Supply Systems: Hollow Metal Doors (Boldt)
- **The Physics of Production-Work Flow**
  - The Parade of Trades Simulation
- **The Physics of Coordination**
  - Workflow loop
- **Production System Control using the Last Planner® System**
  - Pull scheduling
  - Lookahead planning
  - Reliable promising
  - Learning
- **More about Lean Project Delivery (if time available)**
- **Implementation/Organization Structuring**
- **Research directions**
- **Wrap up**
## LC and Safety - Results

<table>
<thead>
<tr>
<th></th>
<th>2001 all year</th>
<th>2002 1. half-year</th>
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<tr>
<td>LC</td>
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<td>Working hours</td>
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<td>146460</td>
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<td>Projects</td>
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<td>Accidents causing absence</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Days of absence due to accidents</td>
<td>-</td>
<td>37</td>
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<tr>
<td>Incident rate (accidents per 200000 w.hours)</td>
<td>5,8</td>
<td>6,8</td>
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<td>Absence rate (preliminary results)</td>
<td>-</td>
<td>1,9</td>
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<td>Ordinary</td>
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<td>Working hours</td>
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<td>Accidents causing absence</td>
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<tr>
<td>Days of absence due to accidents</td>
<td>-</td>
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<td>Incident rate (accidents per 200000 w.hours)</td>
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<td>20,0</td>
</tr>
<tr>
<td>Absence rate (preliminary results)</td>
<td>-</td>
<td>5,4</td>
</tr>
</tbody>
</table>

**P=1.3%**  
**P=2.9%**

The results are significant!
A new approach to safety

Irreversible loss of Control Boundary

Organizational Boundary to Economic Failure

Boundary of unconditionally Safe Behavior

Loss of Control Zone

Hazard Zone

Safe Zone

Workload Gradient

Cost Gradient

Individual Boundary to Unacceptable Workload

Increasing Risk

Irreversible loss of Control Boundary

Boundary of unconditionally Safe Behavior

Organizational Boundary to Economic Failure
Project Definition Process (setting the target)

What’s Wanted (Ends) ➔ What Provides (Means)

- Purposes
  - Values
  - Design Criteria
- Funds, Time, Location, Regulations
- Operation Design
- Facility Design(s)

Constraints
Project Definition Process

Affiliate has idea

Affiliate, FPD & Industry Advisors declare project feasible at face value

FPD forms project delivery team/holds kickoff workshop

Values Workshop

Design Workshop

Constraints Workshop

Workshop to identify misalignments between values, designs and constraints

Workshop to align values, designs and constraints

FPD submits project to Sutter Health board for funding approval

OK?

Set target cost below approved budget

Launch Design Phase

Notes:
1. All workshops are one day or less in duration.
2. Preparation occurs between workshops and other process steps.
3. Multiple workshops may be required to achieve alignment.
## Lean Design: An Overview

| Organize in Cross Functional Teams | * Involve downstream players in upstream decisions  
* Alternate between all-group meetings and task force activities  
* Create and exploit opportunities to increase value in every phase of the project |
|------------------------------------|--------------------------------------------------------------------------------------------------|
| Pursue a set based strategy | * Select from alternatives at the last responsible moment  
* Share incomplete information  
* Share ranges of acceptable solutions |
| Structure design work to approach the lean ideal | * Simultaneous design of product and process  
* Consider decommissioning, commissioning, assembly, fabrication, purchasing, logistics, detailed engineering, and design  
* Shift detailed design to fabricators and installers |
| Minimize Negative Iteration | * Pull scheduling  
* Design Structure Matrix  
* Strategies for managing irreducible loops |
| Use Last Planner System of Production Control | * Try to make only quality assignment  
* Make work ready within a lookahead period  
* Measure PPC  
* Identify and act on reasons for plan failure |
| Use technologies that facilitate lean design | * Shared geometry; single model  
* Web based interface |
Lean Supply To Do’s

- Reduce the number of suppliers and engage them in pursuit of the lean ideal.
- Shift detailed engineering to fabricators and installers.
- Integrate detailed engineering from multiple specialists in 3D models.
- Drive fabricating equipment with model data.
- Reduce lead times so more materials can be pulled to site from further back in supply chains.
- Structure logistics so materials can be pulled to site in small batches.
- Monitor and improve the quality and timeliness of supplier deliveries
Lean Assembly To Do’s

• Simplify site installation to final assembly and test
• Strive for one-touch material handling
• Pull from off-site suppliers
• Structure work in continuous flow processes
• Minimize total head count of site personnel
• Use in-process inspection
• Strive for zero defects through progressive completion and rapid learning
Traditional versus Lean

- Decisions are made sequentially by specialists and ‘thrown over the wall’
- Product design is completed, then process design begins
- Not all product life cycle stages are considered in design
- Activities are performed as soon as possible

- Downstream players are involved in upstream decisions
- Product and process are designed together
- All product life cycle stages are considered in design
- Activities are performed at the last responsible moment
Traditional versus Lean

- Separate organizations link together through the market, and take what the market offers
- Participants build up large inventories to protect their own interests
- Stakeholder interests are not aligned
- Learning occurs sporadically

- Systematic efforts are made to reduce supply chain lead times
- Buffers are sized and located to perform their function of absorbing system variability
- Stakeholder interests are aligned
- Learning is incorporated into project, firm, and supply chain management
Research Initiative: Target Costing

Glenn Ballard
Project Production Systems Laboratory
University of California, Berkeley
Target Costing

• ...strives to deliver more value for the money to clients and other stakeholders.
• ...strives to reduce the waste and rework in the design-estimate-redesign cycle.
• ...requires a fundamental shift in thinking from 'expected costs' to 'target costs'.
• ...necessarily involves cross functional teams. No one person has all the knowledge.
• ...cries out for an integrated product/process /cost model.
Setting the Target Cost in the Feasibility Study

1. Determine minimum acceptable ROI or maximum available funds (allowable cost from business plan).
2. Select cross functional team.
3. Determine and rank stakeholder values.
4. Scope the facility(s) that will deliver the values.
5. Determine the expected cost if the facility(s) were provided at current best practice.
6. If expected cost > available funds or violates ROI, adjust scope by sacrificing lesser ranking values—until the project delivery team is confident minimum program can be delivered for maximum available funds.
7. Submit project budget to board for approval.
8. Set target cost below budget to drive innovation beyond current best practice.
9. Agree if/how to divide budget underruns between client and project team.

OR
Setting the Target Cost in the Feasibility Study

1. Determine minimum acceptable ROI or maximum available funds (allowable cost from business plan).
2. Select cross functional team.
3. Determine and rank stakeholder values.
4. Scope the facility(s) that will deliver the values.
5. Determine the expected cost if the facility(s) were provided at current best practice.
6. If expected cost > available funds or violates ROI, adjust scope by sacrificing lesser ranking values.
7. Submit project budget to board for approval.
8. Set target scope above minimum program to drive innovation and deliver greater value--specify on ranked list of values.
9. Agree if/how to reward the team for achievement of target value.
Target Costing by Project Phase

- **Project Definition**
  - Set target cost

- **Design**
  - Design to target cost

- **Construction**
  - Build to target cost

Set target cost for project definition, design to target cost, and build to target cost.
### Target Cost Model

#### Legend:
- **Worth (Target) Current Estimate**
- **Const TOTAL per SF** 89.33
- **D-B TOTAL per SF** 94.12

#### SITE WORK
- **Site GC OH&P** 594,500
- **G20 Site Improvements** 373,000
- **G30-40 All Utilities** 75,000
- **G90 Other Site Structures**

#### BUILDING
- **G10 Site Prep., Demo & Excav** 146,500
- **A10 Foundation A20 Basement** 1,006,004
- **B10 Superstructure** 1,218,797
- **B20 Exterior Closure** 2,007,061
- **B30 Roofing** 102,626

#### SHELL
- **A10 Foundation** 4,334,488
- **B10 Superstructure**
  - **C10 Interior Construction** 1,710,386
  - **C20 Stairs** 528,427
  - **C30 Interior Finishes** 1,069,320
  - **D10 Conveying**
- **Total SITE WORK** 8,940,302

#### ESCALATION
- **Escalation**
  - **Construction TOTAL** 10,183,417
  - **Design-Build TOTAL** 10,729,883
  - Incl Design at $504,886+41600

#### INTERIOR
- **D20 Plumbing** 1,111,402
- **D30 HYAC** 85,927
- **D40 Fire Protection** 824,160
- **D10 Conveying**
- **D3030 Security Comm/Data**
- **Total INTERIOR** 50,000

#### MECHANICAL
- **D40 Fire Protection**
- **D5030 Security Comm/Data**
- **D5090 Other Electrical**
- **Total MECHANICAL** 91,575

#### ELECTRICAL
- **D20 Plumbing**
- **D5020 Lighting & Branch Wiring**
- **D5090 Other Electrical**
- **Total ELECTRICAL** 55,500

#### SPECIAL
- **E10 Specialties & Equipment**
- **E20 Furnishings Fixed/Movable**
- **F10 Special Construction**
- **F20 Selective Demolition**
- **Total SPECIAL** 90,808

#### GENERAL
- **E10 Specialties & Equipment**
- **E20 Furnishings Fixed/Movable**
- **F10 Special Construction**
- **F20 Selective Demolition**
- **Total GENERAL** 587,774

### Project Details
- **Project:** Fieldhouse Expansion
- **Location:** St. Olaf College Northfield MN
- **Phase of Design:** Schematic Target
- **Date:** June 21, 2001
- **NOTES:**
  - **Bldg. Type:** Recreational
  - **Target (SQFT):** 114,000
  - **Floors:** Single story plus mezzanines
Applying the Cardinal Rule

- Ensuring that whatever target costs increase somewhere in the facility, costs are reduced elsewhere by an equivalent amount without compromising program and quality.

- Refusing to add scope to a project that will overrun the target cost.

- Managing the transition from design to construction to ensure the target cost is never exceeded.
<table>
<thead>
<tr>
<th></th>
<th>St. Olaf Fieldhouse</th>
<th>Carleton College Recreation Ctr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Date</td>
<td>August 2002</td>
<td>April 2000</td>
</tr>
<tr>
<td>Project Duration</td>
<td>14 months</td>
<td>24 months</td>
</tr>
<tr>
<td>Gross Square Feet</td>
<td>114,000</td>
<td>85,414</td>
</tr>
<tr>
<td>Total Cost (incl. A/E &amp; CM fees)</td>
<td>$11,716,836</td>
<td>$13,533,179</td>
</tr>
<tr>
<td>Cost per square foot</td>
<td>$102.79</td>
<td>$158.44</td>
</tr>
</tbody>
</table>
Sutter Health’s Old Process

1. Business Planning
2. Engage FPD
3. Board Approval
4. SD’s, DD’s, CDs
5. Permit
6. Construction

Flowchart:
- Project Context
- Scope & Budget
- Planning
- 75% DD’s First Est.
- CD Check Est.
- GMP On Approved Docs.
Sutter Health’s New Process

FPD & Business Planning → Feasibility Study → No → Board Approval → SD’s & DD’s → CD’s → Permit → Construct

Project Context Scope, Budget & Business Case

Set Target Detailed Scope & Budget
- Owner
- Arch
- CM/GC
- Estimating Consultant

Target Value Design

Fewer Back Checks Expected

Doc Production & Complete Coordination
Set Based Design Value Focus

Predictable Time & Cost
Increased Value & Less Stress

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Sutter Health’s New Process

FPD & Business Planning

Feasibility Study

Board Approval

SD’s & DD’s

CD’s

Permit

Construct

Fewer Back Checks Expected

Predictable Time & Cost

Increased Value & Less Stress

Set the Target

Design to the Target

Build to the Target

Project Context Scope, Budget & Business Case

Set Target Detailed Scope & Budget
• Owner
• Arch
• CM/GC
• Estimating Consultant

Target Value Design

Doc Production & Complete Coordination

Set Based Design Value Focus
Current Benchmark for Target Value Design

- The client evaluates the business case before deciding if to fund a feasibility study.
- The feasibility study involves all key members of the team that will deliver the project if the study findings are positive.
- The client is an active and permanent member of the project delivery team.
- The feasibility study report includes a detailed budget aligned with scope.
- Cost estimating is done continuously through intimate collaboration between design professionals and cost modelers—‘over the shoulder estimating’.
- All team members understand the business case and stakeholder values.
- The Last Planner system is used to coordinate the actions of team members.
Changes required for the current TVD benchmark

• Clients spend more in the project definition phase of projects than they traditionally have done.
• The major players on the project delivery team are not selected through competitive bidding.
• Architects relinquish their privileged access to clients.
• Design professionals embrace collaboration with suppliers and builders.
• Suppliers and builders understand and respect designers and learn how to contribute and participate in project definition and design processes.
• General contractors allow specialty contractors a seat at the table.
• The incentives of all team members are aligned with pursuit of project objectives.
Special efforts required for implementing the current TVD benchmark

• Clear statements up front, plus frequent reminders about the nature and extent of the changes required in attitudes and behaviors.

• Empowering and requiring team members to declare breakdowns; i.e., to speak up when they perceive that agreed criteria are not being followed, that value is being sacrificed or waste is being generated.

• Including team players in user group meetings and other occasions where they can hear and see for themselves what is of value to the customer.

• Education, coaching and building trust among team members.
Tools and Techniques

• Space planning based on contents and use, not historical standards
• Reverse phase scheduling
• Fixed schedules for user group meetings
• Room data sheets as records of agreements, signed off by users
• Weekly coordinating meetings with strict documentation of commitments
Going Beyond the Current Benchmark

1. How best to assure that the use of the facility is explored and agreed upon before attempting to design the facility itself?

2. Does the investment in upstream processes pay off in a) the avoided costs of bad projects that are not allowed to continue, b) in the increase in value from more effective processes for articulating values and controlling design and construction to the delivery of those values, c) in the reduction in waste from incomplete and inaccurate drawings, from duplicated efforts, from rework, d) from more reliable delivery to quality, time and cost expectations, e) from the ability to respond more quickly to changes and discoveries?

3. How best size and manage contingency to achieve target costs?

4. Is an evergreen, ranked list of stakeholder values beneficial and feasible as a tool for value management?
Going Beyond the Current Benchmark

5. Is co-location of project delivery team members beneficial and feasible? How do we collaborate when team members cannot co-locate regularly?

6. How to improve on current benchmarks as regards the integration of cost modeling and designing?

7. Is it better for specialty contractors to be engaged on a design-assist or a design-build basis?

8. What information technologies can be used to support Target Costing practices; e.g., integrating product, process and cost models?
A clash analysis performed by the I-DEAS software checked 155,961 potential conflicts in minutes; several unanticipated clashes between the electrical and mechanical routing designs were discovered and eliminated prior to the development of construction drawings.
Process Re-engineering

Current

Future

Developed through collaborative workshops

Result:

105 Days  40 Days
Proposal: Sustainability in design can only be achieved through lean project delivery—what the American Institute of Architects is now calling “integrated practice”. The interdependence of properties and the innovation required in solving new problems demands integrated teams without physical or social constraints on collaboration.
Waste reduction in a design office

PRODUCT UNIT ERRORS

% OF WAITING TIME IN PROCESS

% NON VALUE ADDING ACTIVITIES

Before

After

44% Decrease

53% Reduction

31% Decrease

PRODUCTIVITY INCREASE OF 31%
# Profitability Increase

<table>
<thead>
<tr>
<th>Year</th>
<th>% Gross Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>7.0%</td>
</tr>
<tr>
<td>1998</td>
<td>7.2%</td>
</tr>
<tr>
<td>1999</td>
<td>5.7%</td>
</tr>
<tr>
<td>2000</td>
<td>6.9%</td>
</tr>
<tr>
<td>2001</td>
<td>10.3%</td>
</tr>
<tr>
<td>2002</td>
<td>11.2%</td>
</tr>
<tr>
<td>2003</td>
<td>11.9%</td>
</tr>
<tr>
<td>2004</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

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What’s the next step?

• Typical trajectory for builders is from the Last Planner® and reliable workflow into Design and Supply.
• Designers tend to start from Last Planner® and nD modeling.
• Use pilot projects to prove concept and to reveal both larger opportunities and organizational obstacles.
• Build a compelling narrative for change, get the team ready, assure first implementation is done right. Build on success.
• Urgency, Structure, Focus, Discipline, Training, Action and COACHING.
Implementation

- Start with Last Planner®™-moral equivalent in projects of 5S in shops.
- Get early wins.
- Encourage incremental development, but don’t tolerate ‘giving it a try’. Implacable leadership is a necessity.
- Players usually can’t distinguish muscle from fat because of the lack of theory. Need guidance.
## Transformation Matrix (Generic)

<table>
<thead>
<tr>
<th>Description</th>
<th>Who</th>
<th>Phases of Transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tell Compelling Narrative</strong></td>
<td>Key Staff Members</td>
<td></td>
</tr>
<tr>
<td>1. What’s not working &amp; what it will lead to.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. What gives hope that is can get better &amp; why (vision).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. What I (&amp; we) are already doing about it.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Invite their participation in this noble effort.</td>
<td>Document vision (1 page)</td>
<td>Vision evolves as progress is made</td>
</tr>
<tr>
<td></td>
<td>Communicate: @All Hands @Each training event @etc., etc.</td>
<td>Announce anticipation of new behavior</td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Show Behavior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examples &amp; Constitutive Distinctions</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Simulations w/reflection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clinic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implement 1st runs (LPS, MSRP)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consistent demonstration of new behavior</td>
</tr>
<tr>
<td></td>
<td></td>
<td>e.g: collaborate vs order</td>
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<tr>
<td></td>
<td></td>
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<tr>
<td><strong>Coach Behavior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Practice Basics</td>
<td>External Coaching</td>
<td>Peer Coaching</td>
</tr>
<tr>
<td>- Progression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Exceptions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Routine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Inside of Trust Between Parties)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ask different questions of performers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Engaged vs detached</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Produce Alignment (Eliminate Barriers)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Reconcile Disconnects Between New &amp; Old Behavior</td>
<td>Key people on board</td>
<td>Request all Mgrs to learn how to make “lean” work</td>
</tr>
<tr>
<td>- Mitigate Resistance</td>
<td>Influential people not on board</td>
<td></td>
</tr>
<tr>
<td>- Measurement Conflicts</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change metrics e.g: profit speed</td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Continuously Improve</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Positive/Negative Feedback (more positive)</td>
<td>negative E.g.: appropriate categories for variance &amp; constraints</td>
<td>E.g: recording variances, estimatin time</td>
</tr>
<tr>
<td>- Appropriate to Level of Competence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Raise Bar While Expecting to go over more often.</td>
<td>E.g: eliminating a variance, “Lean” the team (Kaizen)</td>
<td></td>
</tr>
</tbody>
</table>
Taking the Initiative

• Owner Lead - BAA, Sutter Health
• Design/Builder - Neenan
• Joint Venture - IPD
• Designer Lead - Burt Hill; IDC
• General Contractor - Boldt, Linbeck, Messer
• Specialty - Enclos, Kinetics, Simpson, Southland
• Consultant - Strategic Project Solutions
What are your takeaways?
What questions have been provoked?
Agenda

• Start up
• Work Structuring/Production System Design
  – Airplane Simulation
  – Case Studies in Design of Fabrication Systems: Malling and SpanCrete
  – Case Studies in Design of Site Installation Systems: Brazil (Pereira)
  – Case Study in Design of Supply Systems: Hollow Metal Doors (Boldt)
• The Physics of Production-Work Flow
  – The Parade of Trades Simulation
• The Physics of Coordination
  – Workflow loop
• Production System Control using the Last Planner® System
  – Pull scheduling
  – Lookahead planning
  – Reliable promising
  – Learning
• More about Lean Project Delivery (if time available)
• Implementation/Organization Structuring
• Research directions
• Wrap up
Seminar Objectives

• Understand the theoretical basis of the Lean Project Delivery System.
• Understand its language, essential features, principles, tools and techniques.
• Make clear the primary differences between the Lean Project Delivery System and current practice.
• Encourage you to take action.