Use the right tool for the job:
The case for more fundamental construction models

Martin Fischer, Stanford University
100% funded by industry
- Building owners
- Design and construction companies
- Software and hardware vendors

1988-2000 BIM
2000-2010 VDC
2010+ Optimize Facility Performance
"You are an idiot if you are not using the best tool possible"
Manfred Fischer, 1972
Frustrating  First attempt  Inspiring
Vision –
A future I would like to make happen

Every workhour builds the right product safely and productively

Definition of Vision by Robert Burgelman, GSB, Stanford
Is every work hour building the right building?
"This brings up another related problem. Few of even those who claim to be "CPM experts" fully appreciate the fact that in a resource-restrained schedule the concept of float breaks down and quite often the concept of a critical path breaks down. Since almost all construction projects are resource-restrained, at least to some extent, this becomes a source of major problems."
Precedence diagram

Spatial Requirements

Gantt chart

Work by René Morkos
Creating a short schedule requires playing space chess

The term “space chess” was mentioned to me by Phil Bernstein.
Considering 64 Million schedules in an afternoon to find the schedule with a short duration and high flexibility
Are we really using every work hour well?
How far can activity-based models get us?

Work by Nelly Garcia-Lopez

- Last Planner System implementation
- Hospital project (2.5 years)
- 30,005 activity entries

**Objective:** How to help field managers understand and prevent variations?

**Only one strong relationship found:** If the total variability of the predecessor is high, the variability of the activity start is high.

(Original graph showing the relationship between activity start variability and predecessor total variability, with annotations: What factor caused delay? Why did activities start on time?)

(Garcia-Lopez & Fischer 2016)
Activities require a set of flows to be executed (Koskela 1999)

Façade brick construction (Frederikskaj project)

- Labor
- Materials
- Precedence
- Workspace
- Equipment
- Information
- External

2m around building perimeter
Upstream activities release flows to downstream activities

Photos from the Equilibrium project

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Activity-Flow Model (AFM) helps field managers

- Formally manage activities and flows
- Make data-driven decisions e.g., Resource and buffer sizing
- Predict delays in downstream activities
Current models do not represent all the flows

1. Build deck form Area 1
2. Install slab rebar Area 1
3. Pour slab Area 1
4. Build deck form Area 2
5. Install slab rebar Area 2
6. Pour slab Area 2
Activity-Flow Model

1 activity $\rightarrow$ 3.5 flows

Typical 4-week look-ahead = 250 activities
$\approx$ 850 flows

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### Snapshot of Activity-Flow App

#### Table View

<table>
<thead>
<tr>
<th>Activity name</th>
<th>Status</th>
<th>Planned start/finish</th>
<th>Actual start/finish</th>
<th>Area</th>
<th>Reason for variability</th>
<th>DS</th>
<th>DD</th>
<th>DF</th>
<th>Activity Type</th>
<th>Sub</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>2M ST 2 - FLOOR RADIANT HEAT</td>
<td>EXECUTING OF</td>
<td>11/09/2016</td>
<td>11/14/2016</td>
<td>11/17/2016</td>
<td>2M ST 2</td>
<td>PREDECESSOR</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>FLOOR RADIANT HEAT</td>
<td>FLOORING SUB</td>
</tr>
<tr>
<td>2N ST - ELECTRICAL FLOOR</td>
<td>EXECUTING OF</td>
<td>11/10/2016</td>
<td>11/11/2016</td>
<td>11/17/2016</td>
<td>2N ST</td>
<td>PREDECESSOR</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>ELECTRICAL FLOOR</td>
<td>ELECTRICAL SUB</td>
</tr>
<tr>
<td>4G ST - CYPRESS</td>
<td>EXECUTING OF</td>
<td>11/11/2016</td>
<td>11/14/2016</td>
<td>11/16/2016</td>
<td>4G ST</td>
<td>SLOWER THAN ANTICIPATED</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>CYPRESS</td>
<td>CARPENTER SUB</td>
</tr>
<tr>
<td>2N 1 - ELECTRICAL FLOOR</td>
<td>EXECUTING OF</td>
<td>11/14/2016</td>
<td>11/15/2016</td>
<td>11/18/2016</td>
<td>2N 1</td>
<td>PREDECESSOR</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>ELECTRICAL FLOOR</td>
<td>ELECTRICAL SUB</td>
</tr>
</tbody>
</table>

#### Diagram

- **Activities**
- **Activity name**
- **Status**
- **Planned start/finish**
- **Actual start/finish**
- **Area**
- **Reason for variability**
- **Variation metrics**
- **Act. Type**
- **Sub.**
- **Activity risk**
**Snapshot of Activity-Flow App: Flow detail view**

<table>
<thead>
<tr>
<th>Activity info</th>
<th>Flow info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow type</td>
<td>Flow name</td>
</tr>
<tr>
<td></td>
<td>Flow predecessors</td>
</tr>
<tr>
<td></td>
<td>Flow status</td>
</tr>
<tr>
<td></td>
<td>Due date</td>
</tr>
<tr>
<td></td>
<td>Flow risk</td>
</tr>
</tbody>
</table>

**Activity info**

- **Activity name**: 2N1 - ELECTRICAL FLOOR
- **Activity Type**: ELECTRICAL FLOOR
- **Activity Parent**
- **Activity status**: EXECUTING DF
- **Activity update reason**: PREDECESSOR

**Flow info**

- **Flow type**: LABOR
- **Flow name**: Flow name (resources) - ELECTRICAL FLOOR CREW
- **Company name**: LINDPRO
- **Qty.**: 1
- **Flow description**: 2N ST - ELECTRICAL FLOOR
- **Flow status**: FAILED
- **Flow mgt action**: Flow management action
- **Flow reason for var**: Flow reason f...
- **Due date**: Date in mm/dd/yy

- **Flow type**: WORKSP...
- **Flow name**: Flow name (workspaces) - 2N1
- **Flow description**: 2N1 - CLEAN BRICK + CLOSE S
- **Flow status**: READY
- **Flow mgt action**: Flow management action
- **Flow reason for var**: Flow reason f...
- **Due date**: Date in mm/dd/yy

**Note**

- 18 ducts in. 21-cable started.
Project set-up + Weekly planning and control

- **Project set-up**
  - Understand planned activities + flows
  - Transform schedule into Activity-Flow representation

- **Weekly planning and control**
  - Update look-ahead and weekly plan
  - Carry out daily tracking
  - Present analytics in weekly planning meeting

- Set-up meeting on Fredrikskaj project
- Collaborative look-ahead update on Equilibrium project
- Tracking using mobile device on Fredrikskaj project
- Weekly planning meeting on Ichma project
Activity-Flow Model = Lots of **structured** data

**Activity-level data**
- Activity type
- Activity status
- Activity variability
- ...

**Flow-level data**
- Flow type
- Flow name
- Flow status
- Flow variability
- ...

53 variables/activity

47 variables/flow

+ 23,000 data points per week
### Tested Activity-Flow Model in 3 building projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Ichma</th>
<th>Equilibrium</th>
<th>Frederikskaj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Peru</td>
<td>Colombia</td>
<td>Denmark</td>
</tr>
<tr>
<td>Building type</td>
<td>Office</td>
<td>Residential</td>
<td>Residential</td>
</tr>
<tr>
<td>Project phase</td>
<td>Structural</td>
<td>Foundations</td>
<td>Finishes</td>
</tr>
<tr>
<td>Planning method</td>
<td>CPM + Last Planner System</td>
<td>CPM + weekly planning</td>
<td>Location-based scheduling</td>
</tr>
<tr>
<td>Test period</td>
<td>18 weeks</td>
<td>4 weeks</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>

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If Flow delay > Buffer → Activity start delay

“We thought that the main problem in the jobsite was the lack of manpower for the structural activities... with the app we were able to show this to the subcontractor using actual data and metrics. The app gives us stronger arguments to back our requests to the subcontractor.”

Project Manager Equilibrium project
More complete models = better predictions

<table>
<thead>
<tr>
<th>Variables represented</th>
<th>RCPM</th>
<th>LBMS</th>
<th>AFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # predictive variables / activity</td>
<td>45</td>
<td>104</td>
<td>234</td>
</tr>
<tr>
<td>Activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precedence flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workspace flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information flow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External flow</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: RCPM = Resource-loaded CPM (Fondahl 1961), LBMS = Location-based Management System (Kenley & Seppänen 2006)

Predictions of activity start delay using machine learning model

<table>
<thead>
<tr>
<th>RCPM</th>
<th>LBMS</th>
<th>AFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Variation Explained</td>
<td>38.85</td>
<td>43.11</td>
</tr>
<tr>
<td>RMSE</td>
<td>2.31</td>
<td>2.15</td>
</tr>
</tbody>
</table>

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Every workhour builds the right product safely and productively
Tracking of material stacks/pallets on a floor—over a period of 15 days

- Out of 28 stacks, 22 stacks relocated at least 1 time (i.e., 78.5% relocated)
- 6 stacks didn’t relocate, 10 stacks relocated 1 time, 9 stacks relocated 2 times, 3 stacks relocated 3 times
- In total, stacks were relocated 37 times
Collection and study of 831 sample daily work orders: 71% of the daily work orders (related to MTS) need LOD 400 for rapid generation of BOM.

UK Chartered Quantity Surveyor

Generating BOM

~2 Hours for 19 Cards

5~10 Seconds for 1 Card

Database

MTS

ETD
Making sure each crew has the right material every day

Combine the knowledge of the field manager with a visualization of the work completed and the work to be done.
Every workhour builds the **right** product safely and productively
The Simple Framework for IPD

- Measurable Value
- Production Management
- Collaboration
- Simulation Visualization

- High Performing Building
- Integrated Systems
- Process Integration
- Integrated Organization
- Integrated Information

Agreement/Framework
The Business Perspective
“The automated execution of processes changes everything.”
(Alan Perlis, 1961)

The Scientific Perspective
“Science is knowledge which we understand so well that we can teach it to a computer; and if we don't fully understand something, it is an art to deal with it. Since the notion of an algorithm or a computer program provides us with an extremely useful test for the depth of our knowledge about any given subject, the process of going from an art to a science means that we learn how to automate something.”
(Donald Knuth, Computer Programming as an Art, CACM, Dec. 1974)
The noblest of pleasures is the joy of understanding. Leonardo da Vinci

Glory if fleeting, obscurity is forever. Napoleon