Flow-based Construction Site Management: 4D visualization of activity flows and enhanced data analytics

Martin Fischer
Nelly Garcia-Lopez
Motivating case: curtain wall installation

Field managers were concerned about the installation crew outpacing the fabrication crew.
Actual fabrication rate was 20% slower than planned.

Planned production rate: 12 units/day
Actual production rate: 9.6 units/day

What decisions should the field managers make to minimize the impact on downstream activities?
Field managers can shield activities from variability by implementing buffers.

**Types of buffers**

- **Inventory**
- **Capacity**
- **Time**

**Type of flow**

- Material flow
- Workspace flow
- Information flow
- Resource flows (Labor, equipment)
- All flows

---

# Crews

# Equipment available

Fabricate curtain wall

Install curtain wall
Visualizing and tracking flows is important for managing variability and choosing buffers.

1. Flow rate 20% slower than planned
2. Planned buffer (120 units) insufficient to shield variability
3. Late release of flows affects downstream activities
4. Place targeted buffers to shield activity e.g., workspace handoffs
5. Visualize & quantify unplanned buffers: e.g., redirect resources

Legend:
- Flow queues
- Late release of flows
- Buffers set by field managers

PS: Planned Start, AS: Actual Start, PF: Planned Finish, AF: Actual Finish
Without visualizing and tracking flows, it is difficult to choose and size the buffers.

Transformation view

Flow view

Existing models do not formally represent, track, and quantify the activity flows.
Construction workflow model

Last year, we proposed to develop a construction workflow model to make the execution of activities more reliable.
We developed an app implementing the model.
App follows the Last Planner System + information about the activity flows

App flow diagram Look-ahead + Commitment planning process

**Look-ahead**

**Start look-ahead**

Add look-ahead activities

For each activity in the look-ahead

Identify activity flows:
- Materials
- Labor
- Equipment
- Materials
- Information
- Workspace
- External

Flow information:
- Flow name
- Responsible stakeholder
- Where the flows come from: (predecessor activity or external)

Track W0 activity flows:
- Flow status
- Flow mgt.
- Flow reason for variability

Track W0 activity execution:
- Actual Start
- Actual Finish
- Reasons for variability

Field planners

+ 1 week
Weekly data collected by the app

Aggregate metrics
- WIP
- Aggregate activity statuses
- 10 variables

Activity metrics
- Activity info
- Activity execution variability
- 17 variables

Flow metrics
- Flow info
- Flow execution variability
- 24 variables

High level of detail data about the plan, its execution, and reasons for variability
We tested the app at a construction jobsite

Project info:
• Graña y Montero jobsite in Peru
• 11 basements + 21 floors
• 4-week period
• Structural phase

Objectives:
1. Can the flow-based model represent the look-ahead plan? ✔
2. Is the information needed for the model easy to obtain? ✔
3. Can the model support field planning and control? ±
In a nutshell

• **Problem:** The lack of visualization of the activity flows and data analytics hinder the applicability of the flow-based model for field planning

• **Solution:** Develop a 4D method for visualizing the activity flows and data analytics that leverage the flow-based workflow model to generate insights for field managers

• **Research Approach:** Carry out field test to validate 4D representation and data analytics
Outline

1. Observed problem
2. Points of departure
3. Research methods
4. Expected results
5. Industry Involvement
6. Milestones and risk
Activity flows are difficult to visualize using Gantt Charts

1) **Complexity**
90 activities/week x 3 flows/activity = 270 flows/week
Activity flows are difficult to visualize using Gantt Charts

2) **No spatial representation:**
Workspace releases are hard to visualize
How do resources move between workspaces?
Are there any flow conflicts?

Pour slab
Workspace

L8 zone 3
Scaffold
Lack of methods for analyzing data from flow-based model

Data collected by the app every week contains a high level of detail record of the plan, how it was executed, and the reasons for variation

- 24 variables/flow x 270 flows/week = 6,480 flow data points/week
- Test Project (6-week period): over 66,000 data points

How can we take advantage of this data to generate insights for field managers?
Flow-based Site Management

Outline

1. Observed problem
2. Points of departure
3. Research methods
4. Expected results
5. Industry Involvement
6. Milestones and risk
Definition of workflow variability

Workflow variability:

A departure from the baseline (or the plan) in the quality or quantity of the flows (information, materials, resources, or workspaces) necessary to perform a sequence of construction activities.

How can we visually represent workflow variability?
4D modelling to support field planning

• VDC: Multi-disciplinary models to support business objectives - Kunz and Fischer (2009)

• 4D models:
  – Currently integrate the Product + Process
  – Help anticipate time-space conflicts (Koo and Fischer 2000)
  – Support planning and coordination at a production level of detail (Garcia-Lopez and Fischer 2014)

• Challenges:
  – Integrating Product + Process + Organization
  – Visualizing workspace handoffs between trades
  – Automating the generation of production 4D models
Machine learning predictive models for generating insights for field managers

“The process of developing a mathematical tool or model that generates an accurate prediction” (Kuhn & Johnson 2012)

• Predictive models are used in a variety of fields:
  – Fraud detection, predict purchases, predict unrest

• Types of predictive models:
  – Regression: Numeric/continuous output
    • E.g., time buffer between two activities
  – Classification: Output classified into groups
    • E.g., flow will fail/not fail
Outline

- Observed problem
- Points of departure
- Research methods
- Expected results
- Industry Involvement
- Milestones and risk
Improve visualization of the activity flows

1. Develop 4D visualization of activity flows
   - Develop methods for linking the activity flows (workspaces + resources) with the BIM
   - Integrate the 4D visualization into the workflow during look-ahead and commitment planning

2. Validate 4D visualization
   - Implement 4D visualization at a jobsite during look-ahead planning
   - Obtain feedback from field managers
Flow-based 4D mockup
Develop an analytics engine to support decision making

• Generate insights for field managers based on:
  – Flow-based representation of look-ahead
  – Project’s past performance
  – Data analysis + machine learning methods
Build and test predictive model

1st Data-set
- Flow-based model
- Activity + flow variation data

Generate feature vectors

Select machine learning model type
- E.g. Regression trees, support vector machines, partial least squares, linear regression

Split data
- Chronologic split 80/20%

Training data
- Train model
  - Fit model with different parameters

Model selection
- Perform cross validation, choose model with lowest RMSE

Testing data
- Model test
  - Compare prediction with actual output
  - Report error metric

Model test on new data set

(Rajagopal 2014)
Example of insights that could be generated

| Activities with flow: carpenter crew have started late 70% of the time - manpower availability |
| Rebar crew released late, time buffer insufficient |
| Material delivery – buffer alert Supplier has missed 85% of deliveries by 2+days |
| RFI created on 9/9 Avg. lead time for response: 8 days |

Validation:
- Retrospective: check predictions vs. actual data
- Prospective: apply at jobsite, feedback from field managers
Flow-based Site Management

Outline

- Observed problem
- Points of departure
- Research methods
- Expected results
- Industry Involvement
- Milestones and risk
Expected results, and contributions

1. Method for generating 4D visualization of activity flows

2. Analytics engine that leverages data from the flow-based model to help field managers during look-ahead planning
Impact

• Help field managers generate conflict-free plans

• Help field managers anticipate problems during look-ahead planning

• Better schedule and cost conformance
Outline

- Observed problem
- Points of departure
- Research methods
- Expected results
- Industry Involvement
- Milestones and risk
Industry involvement

1. **Access to project data**
   - Historical data of projects implementing the Last Planner System

2. **Access to projects**
   - Allow researcher to collect data at a jobsite
   - Access to: planning documents, planning meetings, and planning staff.

3. **Field study**
   - Allow researcher to introduce the results of the analytics engine and 4D during the planning meetings
   - Interview field managers at the end of field study
Outline

- Observed problem
- Points of departure
- Research methods
- Expected results
- Industry Involvement
- Milestones and risk
Research milestones and risks

Milestones:
• December 2016: Develop and test analytics engine
• January 2017: Prospective validation of analytics engine
• May 2017: Integrate activity flows to 4D model
• June 2017: Complete project, submit report

Risks:
• Access to projects for validation
• Difficulty validating model using project data alone (retrospective validation)