A simulation-based approach to accounting for uncertainty and variability in look-ahead planning

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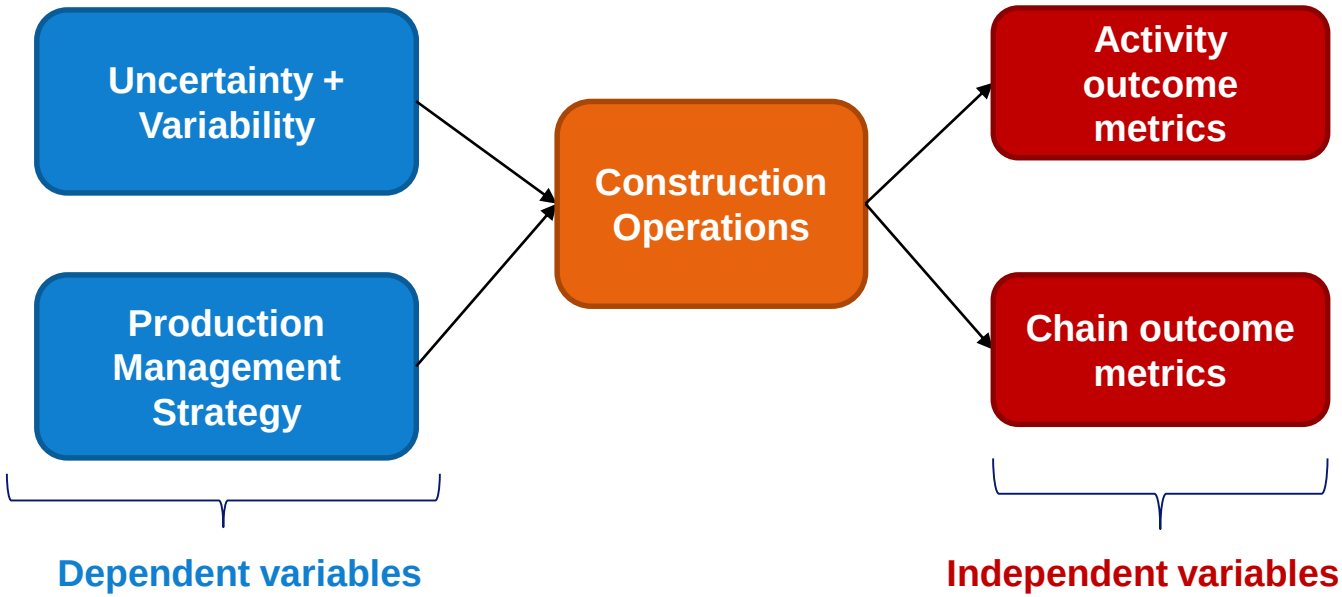
The big idea

We propose to develop a Simulation-based look-ahead planning method that considers the most frequent sources of variability formally to combine the knowledge of construction managers with a more formal method.



Motivating Problem

Uncertainty affects activities in a construction site

Tie rebar activity

Uncertainty:

- **Labor:**
  - *Availability, skill*
- **Tools & Equipment:**
  - *Availability, working*
- **Information/plans**
  - *Updated, clarity*
- **Materials:**
  - *Availability, quality*
- **Previous work:**
  - *Completed, quality*
- **External:**
  - *Weather*

Motivating Problem

Uncertainty can lead to variability in activity execution

Tie rebar activity

Uncertainty:

- **Labor:**
  - *Availability, skill*
- **Tools & Equipment:**
  - *Availability, working*
- **Information/plans**
  - *Updated, clarity*
- **Materials:**
  - *Availability, quality*
- **Previous work:**
  - *Completed, quality*
- **External:**
  - *Weather*

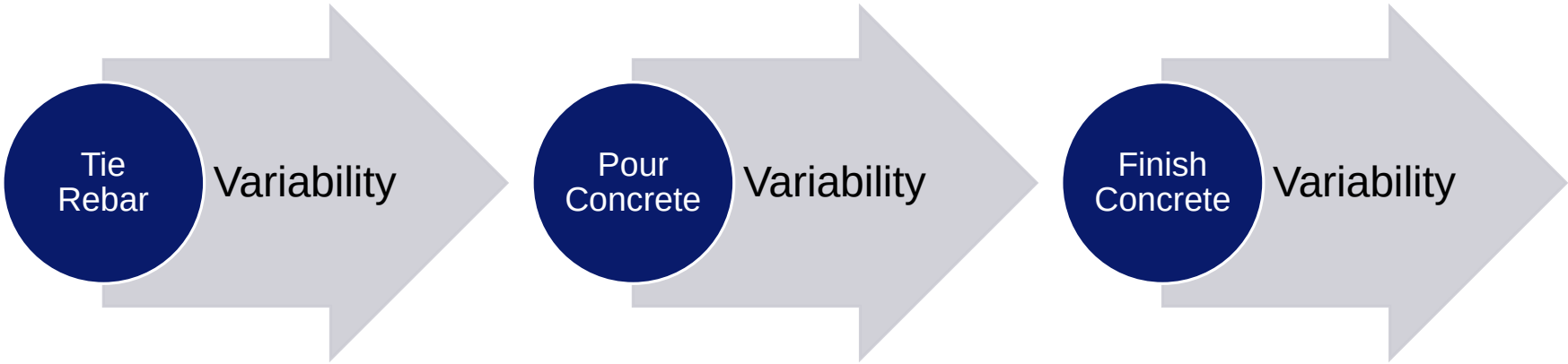
Variability in execution:

- Productivity rates
- Activity duration
- Activity cost
- Quality
- Rework
- Safety

Motivating Problem

Why is this an issue?

- Construction activities are tightly interrelated
- Downstream activities are affected by variability in upstream activities



Managers need to design production systems to minimize the effect of uncertainty and variability while meeting project objectives (cost, schedule, etc.).

Motivating Problem

Production Management Strategies to minimize impact of variability

1. Implement buffers:

Tradeoff between cost and duration.

Buffer	Impact on project objective	
	Cost	Duration
Capacity	↑	
Inventory	↑	
Time		↑

2. Implement variability reduction strategies:

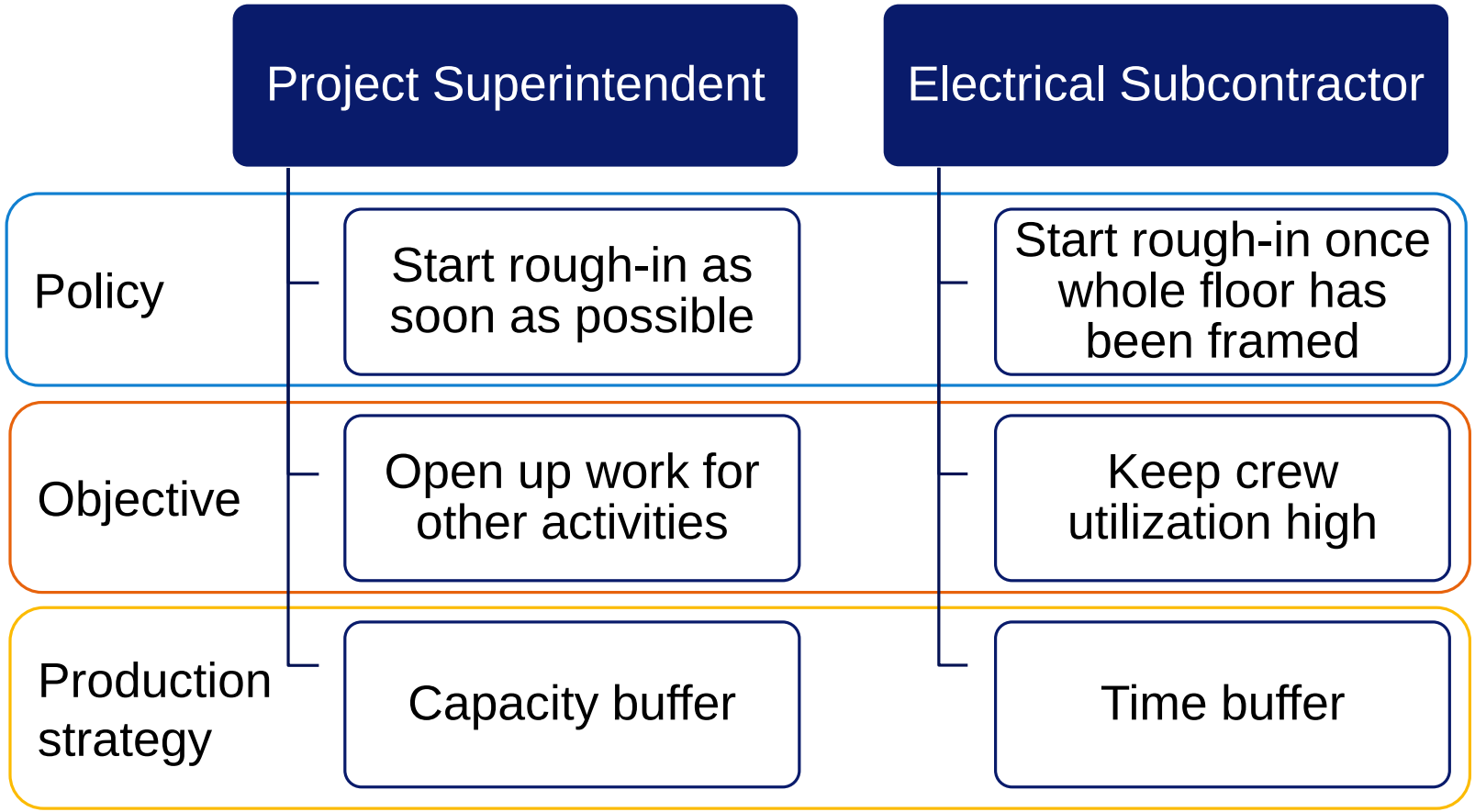
- E.g. Standardization, last planner, takt time.

Issues:

- Require coordination among various players.
- Difficult to implement a short term.

Motivating Problem

Alignment between production strategy and objectives



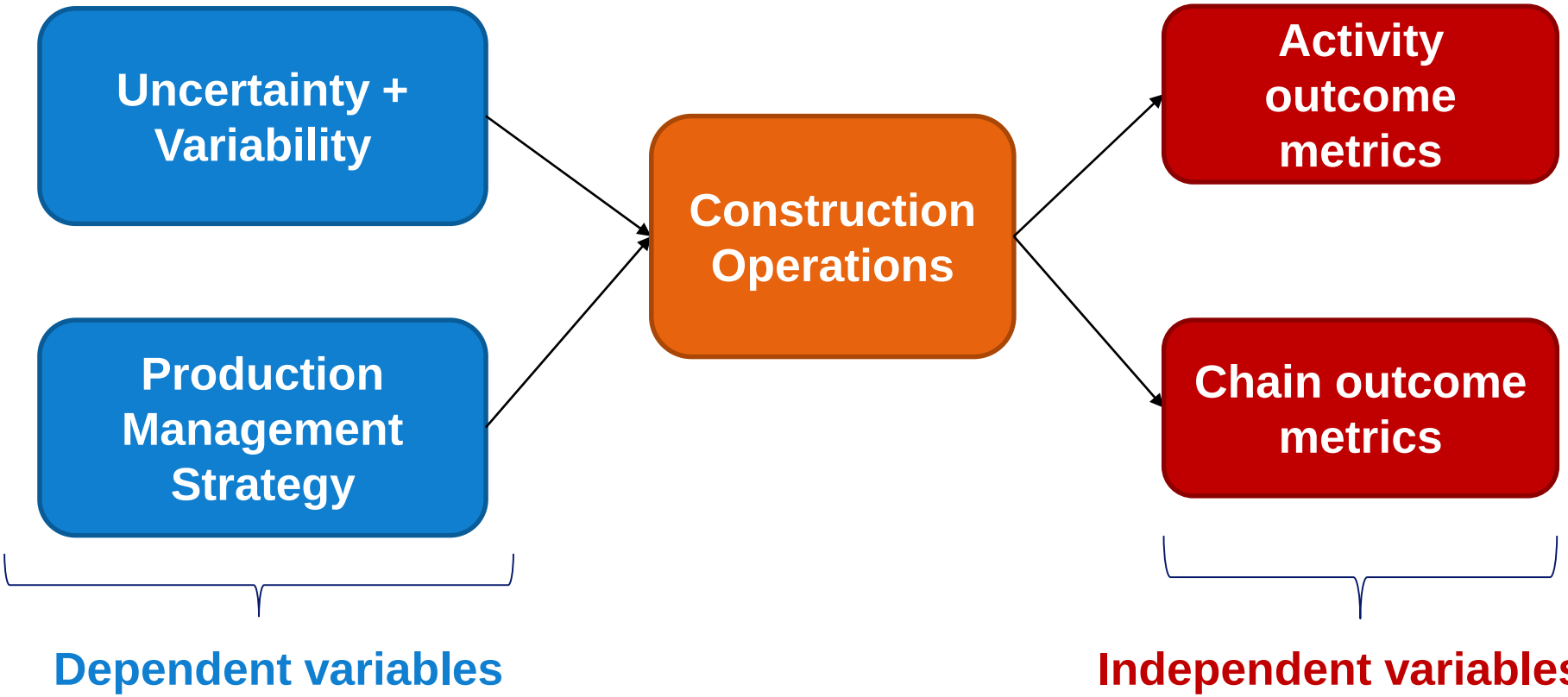
What production strategy is better?

Intuition

- Develop a method to **simulate the effects of uncertainty and variability** and evaluate how they **impact the project at an activity level and a chain level**.
- Assess the effect of implementing different **production management strategies** on the metrics at the activity level and the chain level.

Intuition

Model Conceptualization

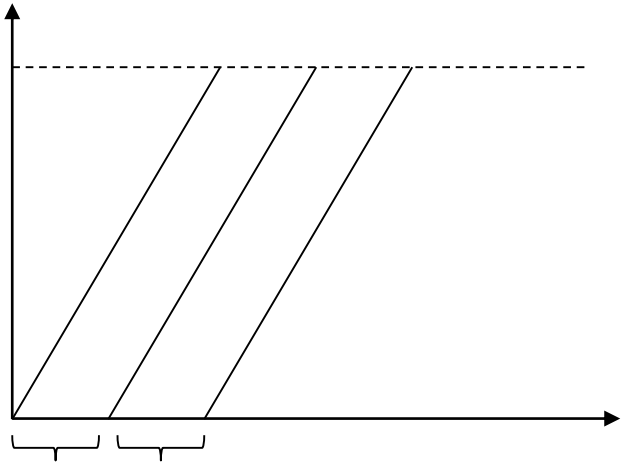


Intuition

Example: Wall chain of activities

Productivity rate [LF/day]	80	80	80

Traditional planning:



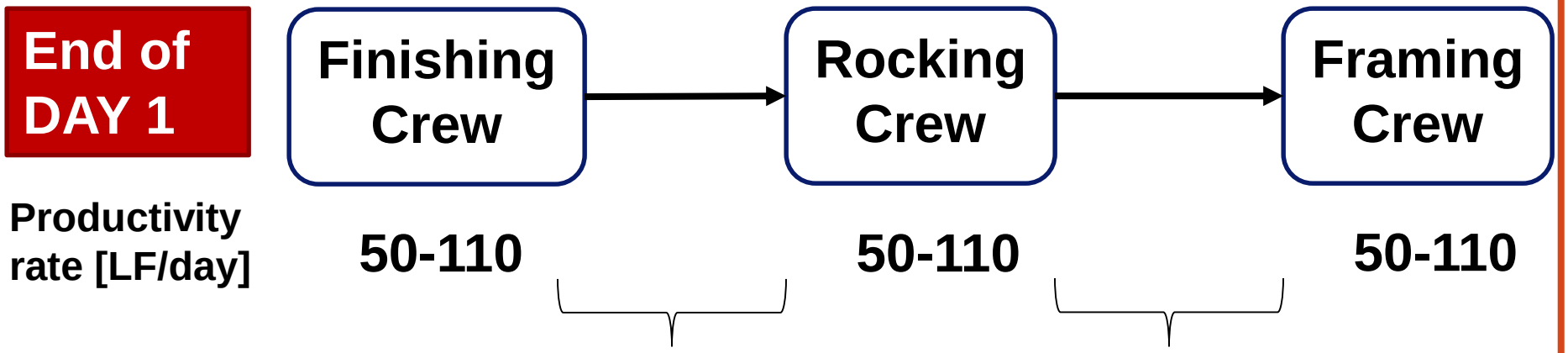
Assumptions:

- No variability
- No loss in productivity

Lags between activities are defined based on intuition and past experience.

Intuition

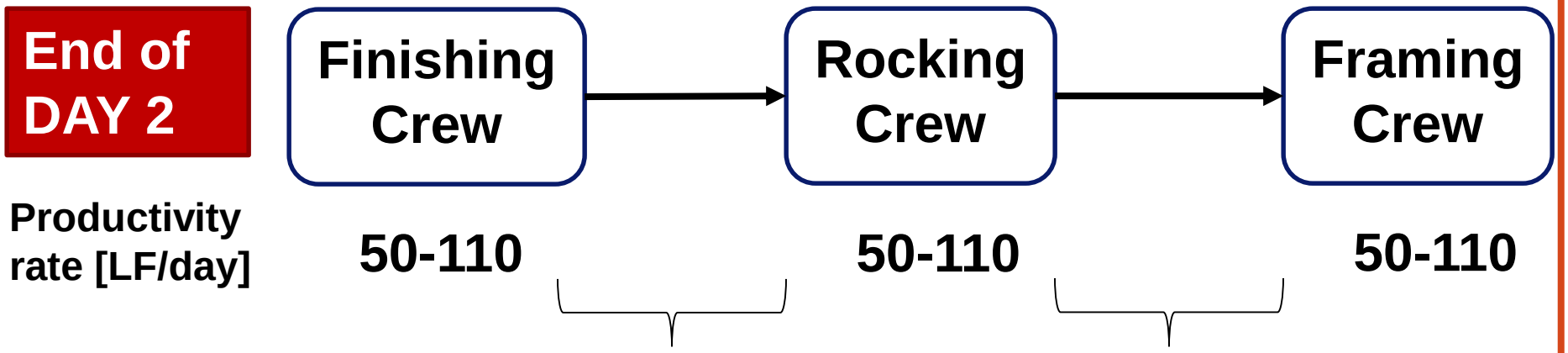
Example: Simulation of wall chain of activities



WIP [LF]	-	75	
Pot. Output	-	-	
Act. Output	-	-	75
Lost Prod	-	-	
Cum. Lost Prod	-	-	

Intuition

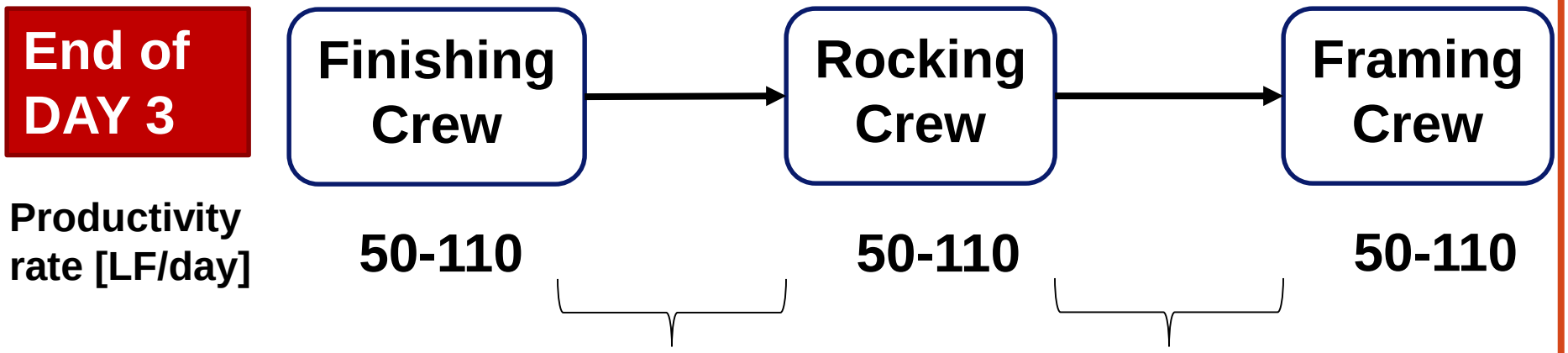
Example: Simulation of wall chain of activities



WIP [LF]	-	56	
Pot. Output	-	100	
Act. Output	-	100	81
Lost Prod	-	0	
Cum. Lost Prod	-	0	

Intuition

Example: Simulation of wall chain of activities



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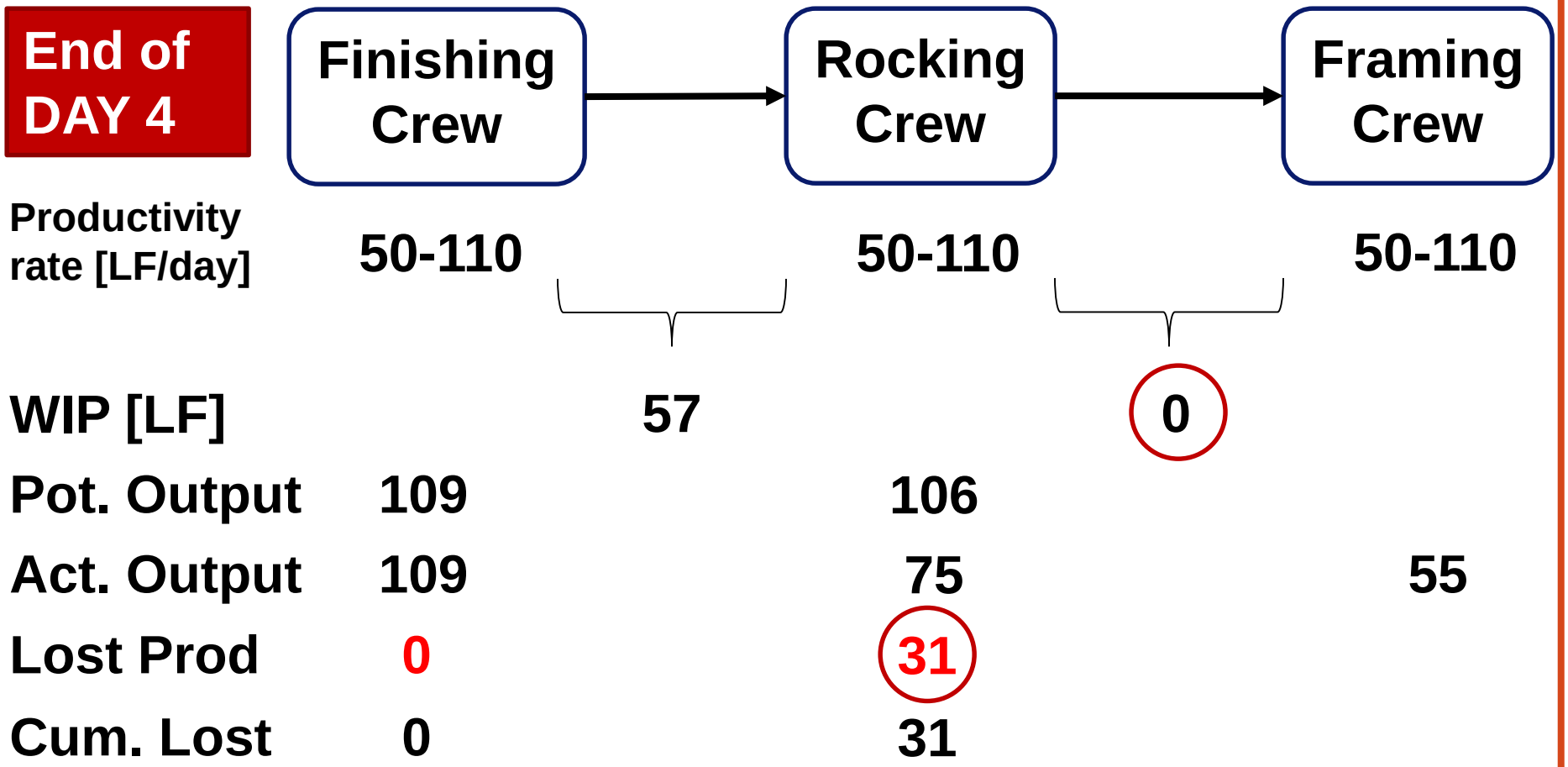

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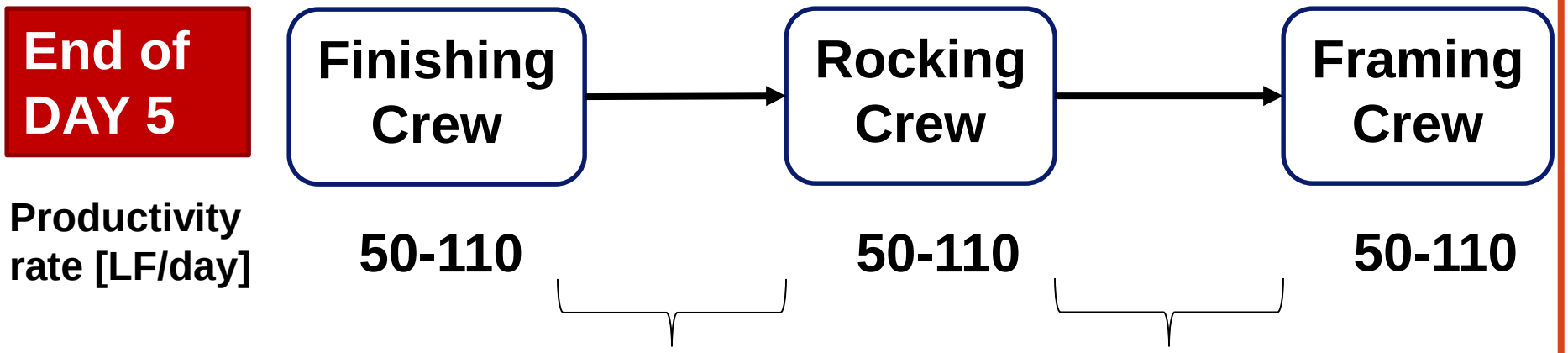

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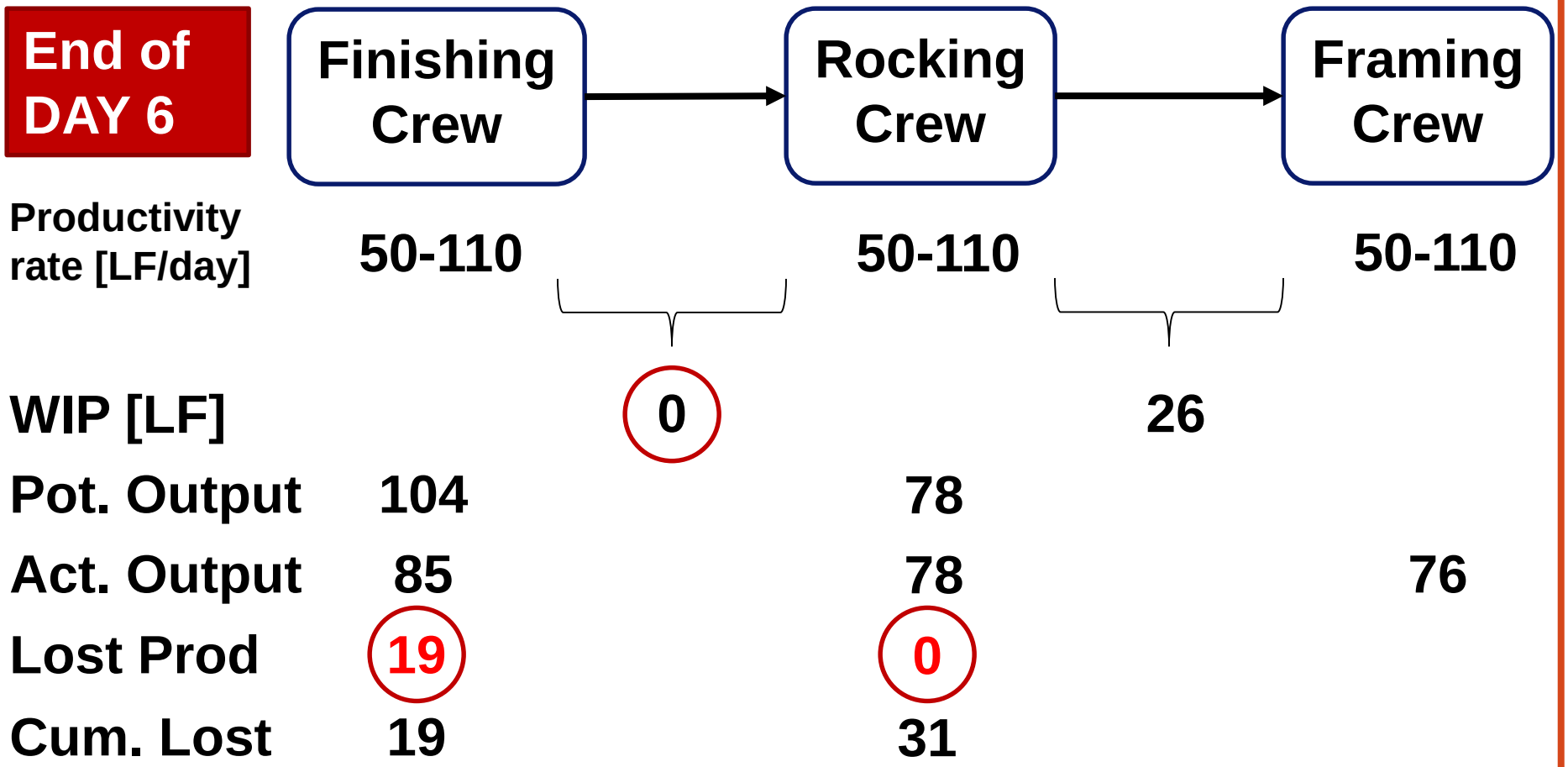

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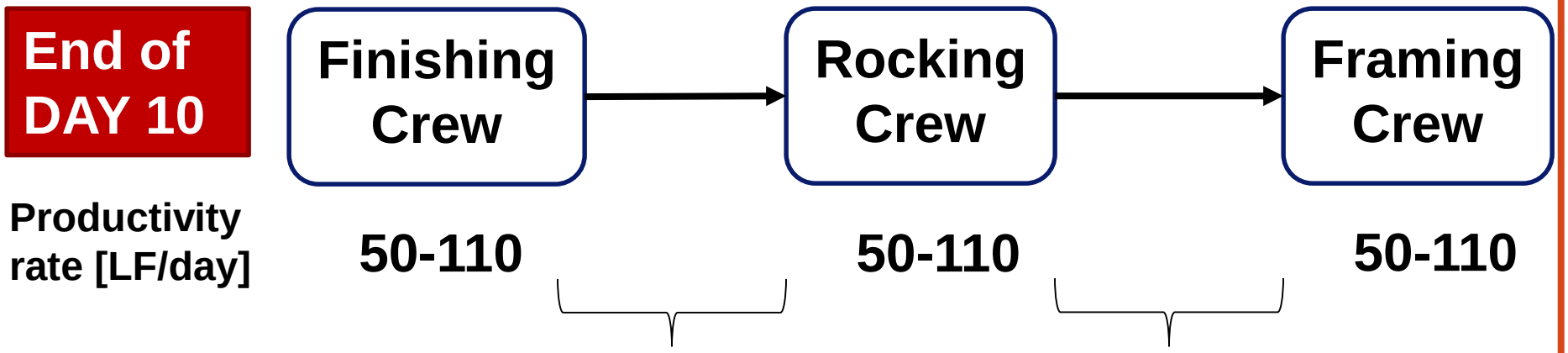

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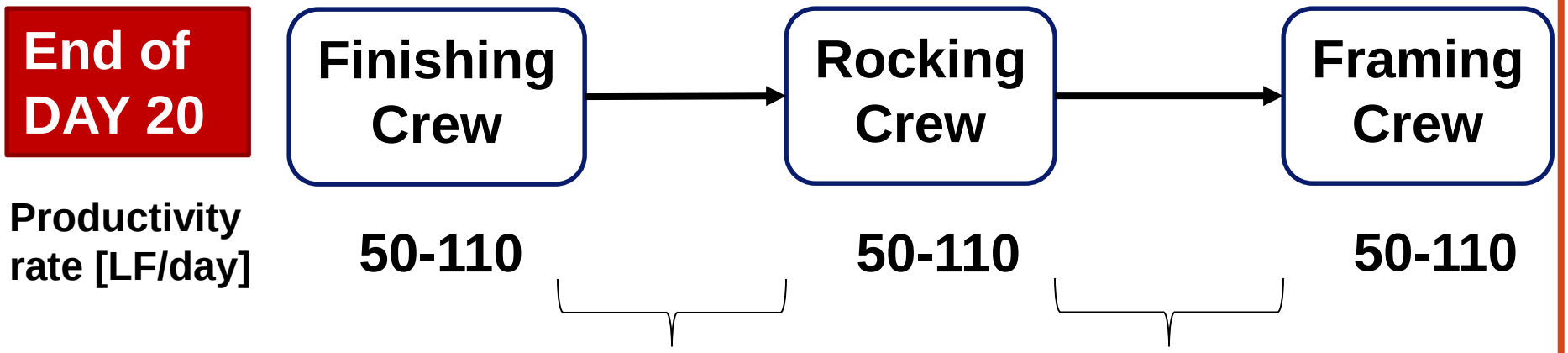

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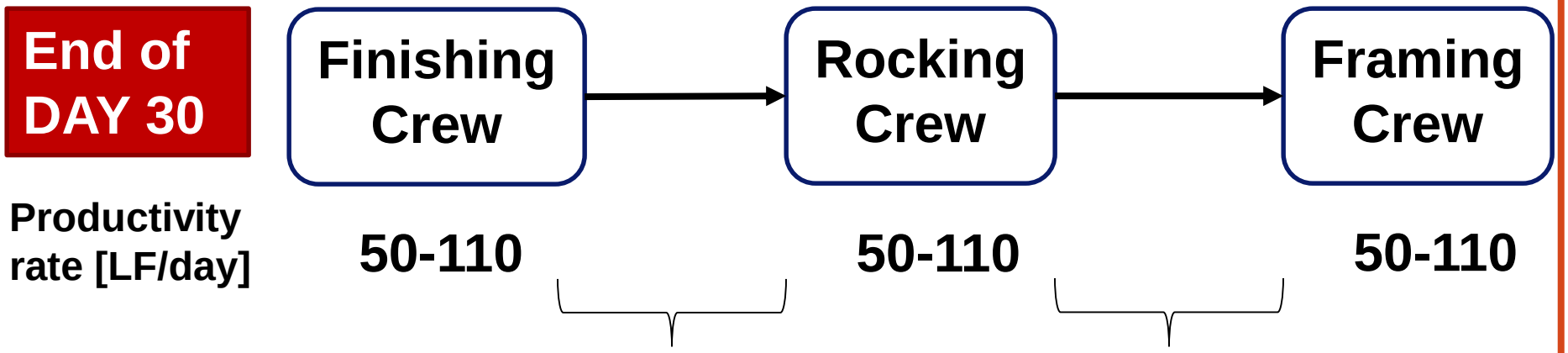
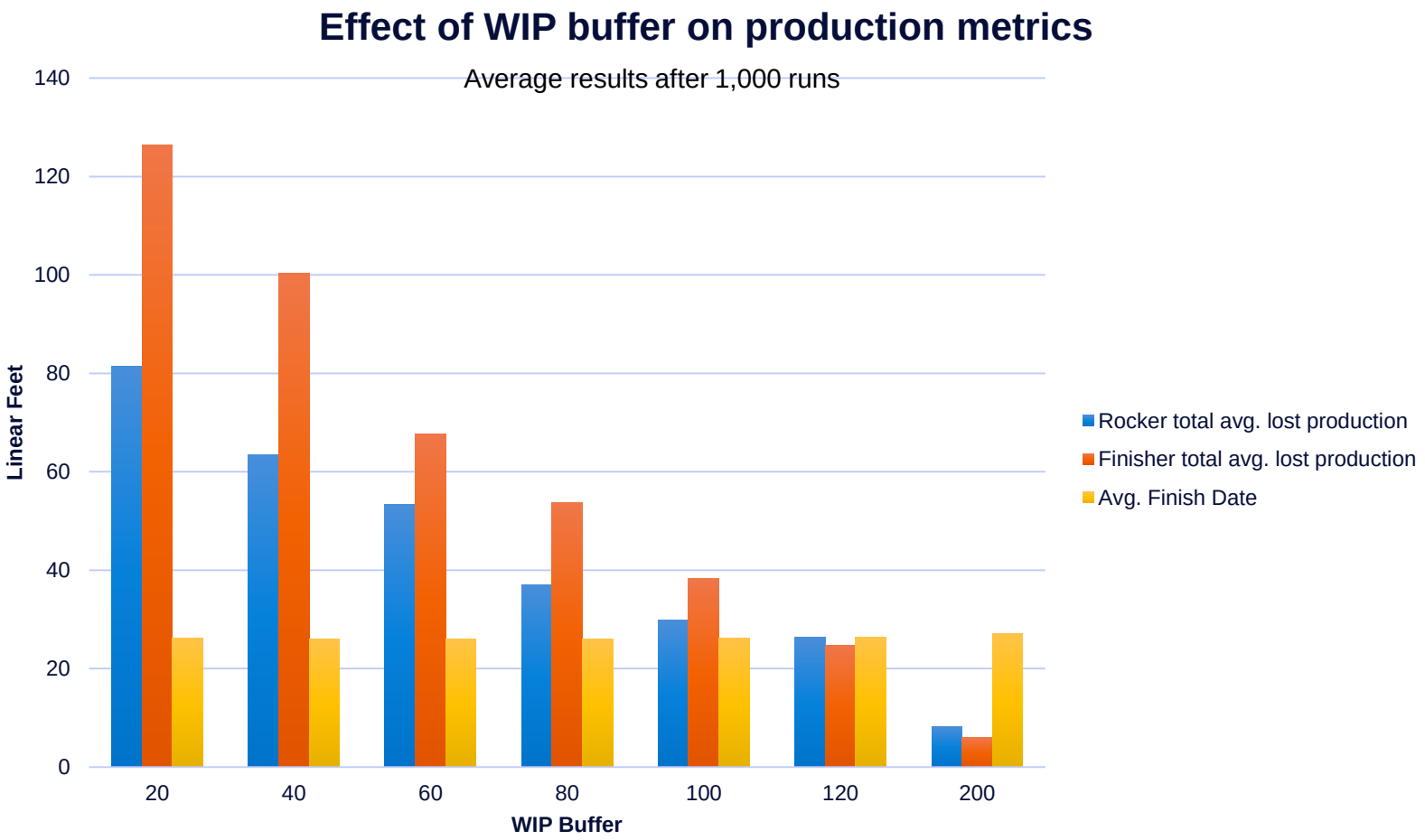


Intuition

Analysis of WIP Buffer sizing vs. Production metrics



Points of Departure

1. Uncertainty and Variability

- Environmental uncertainty (Downey et al. 1975)
- Project uncertainty management (Ward & Chapman 2003)
- Lean Construction (Ballard & Howell 1998)

2. Workflow

- "Flow View" of Production (Koskela 1992)
- "Parades of Trades" (Tommelein et al. 1998)

3. Simulation

- Model interactions and random events (Law 2014)
- Worklow modeling (Tommelein 1998)
- WIP buffers (Gonzalez et al. 2008, 2011)

4. VDC

- Multi-disciplinary performance models (Kunz & Fischer 2009)
- 4D Modeling (Aalami 1998, McKinney & Fischer 1998)
- IT in construction (Fischer & Kunz 2004)

Gaps Identified

1. Current approaches do not capture effects of **local optimization** by subcontractors, which have been observed in practice.

2. Lack of understanding about how sources of uncertainty and variability affect construction operations and how they can be formally introduced into the planning process.

Research Method

Research Questions:

1. What sources of uncertainty affect different construction activities?
2. What production management strategies are implemented by subcontractors and GCs to cope with the different types of uncertainty and variability identified in RQ1?
3. How much more predictive power is gained by incorporating the sources of uncertainty and variability identified in RQ1 and the production management strategies identified in RQ2 in a computational model of the construction chain of activities?
4. What metrics would help managers evaluate the effect of implementing different production strategies, such as buffers or variability reduction, on the construction operations?

Research Method

Research Design:

Part 1: Case studies + Project Data Analysis

- Understand the sources of uncertainty and variability that affect construction chains of activities.
- 3-5 case studies involving managers, subcontractor and workers.
- Data analysis on projects tracking Percent Plan Complete (PPC) and reasons for non-completion to characterize variability sources.

Part 2: Simulation model

- Build simulation model:
  - Chains of construction activities.
  - Uncertainty and variability in activities.
  - Activity outcome metrics: activity cost (versus plan), activity man-hours (versus plan), idle time, activity duration (versus plan).
  - Chain of activity outcome metrics: operation cost (versus plan), total operation man-hours (versus plan), total idle time, total duration (versus plan).
- Verify and validate simulation model with industry experts.

Relationship to CIFE Goals

- Improve construction operations through the innovative integration of:
  - Computer simulation
  - Scheduling and production planning
  - 4D visualization

Industry Involvement

Part 1

- Cary out 3-5 case studies of chains of activities of CIFE member projects.
  - Learn about the system to build an accurate model.
  - Understand sources of uncertainty and variability.
- Data from CIFE member projects tracking PPC and reasons for non-completion.
  - Characterize the probability of occurrence of different sources of variation.

Part 2

- Reach out to CIFE members to review simulation model.
  - Conformance of model to own experience.
  - Feedback and improvements to the model.

Research Plan

Sept-Dec 2014
- Build basic simulation model
- Milestone: Simulation model

Jan-March 2015
- Case studies of chains of activities
- Milestone: Case study reports

March-Jun 2015
- Model uncertainty and variability

Jul-Sept 2015
- Verify and calibrate simulation model
- Milestone: Final CIFE Seed Report

Risks and Mitigation

Inability to validate simulation model	• Overlap modeling and Part 1 to anticipate missing elements/data
Sources of uncertainty/variability cannot be classified and add to much complexity to model	• Focus on identifying a few key drivers instead of an exhaustive list
Subcontractors unwillingness to share local optimization strategies	• Approach subcontractors directly rather than in a project • Triangulate with other sources of data such as observation and interviews with other subcontractors

Expected Contributions

1. **A methodology** for identifying, characterizing, and classifying different **sources of uncertainty and variability** related to construction activities.
2. **A simulation model that enables mangers to virtually experiment with different production management strategies and their effect on the system metrics.** This model takes into account the uncertainty and variability related to construction activities.

Next Steps

The model presented in this research proposal can be extended in two main ways.

1. Incorporate simulation model with 4D model.
2. Extend the simulation model to handle more complex interactions between chains of activities.

Thank you!
Questions? Suggestions?

Motivating Problem

- How do projects account for variability today?

Initial Plan

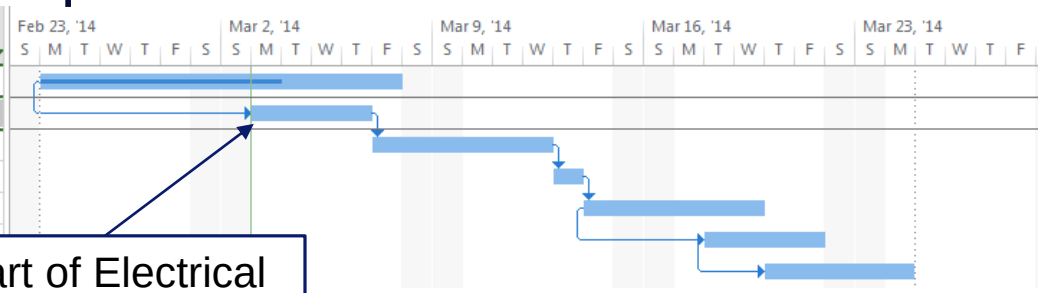
Task Name	Duration	Start	Finish	Predecessors
Install wall studs	10 days	Mon 2/24/14	Fri 3/7/14	
Electrical rough-in	4 days	Fri 2/28/14	Wed 3/5/14	1SS+4 days
Plumbing rough-in	4 days	Thu 3/6/14	Tue 3/11/14	2
Pre-rock inspection	1 day	Wed 3/12/14	Wed 3/12/14	3
Install dry wall	4 days	Thu 3/13/14	Tue 3/18/14	4
Tape and mud	4 days	Mon 3/17/14	Thu 3/20/14	5SS+2 days
Paint	3 days	Wed 3/19/14	Fri 3/21/14	6SS+2 days

Assumptions about downstream activities:

1. Start dates are “pushed”, activities can start on the new date.
2. Lags between activities are sized to account for variability in predecessor activity

Updated Plan

Task Name	Duration	Start	Finish	Predecessors
Install wall studs	10 days	Mon 2/24/14	Fri 3/7/14	
Electrical rough-in	4 days	Mon 3/3/14	Thu 3/6/14	1SS+4 days
Plumbing rough-in	4 days	Fri 3/7/14	Wed 3/12/14	2
Pre-rock inspection	1 day	Thu 3/13/14	Thu 3/13/14	3
Install dry wall	4 days	Fri 3/14/14	Wed 3/19/14	4
Tape and mud	4 days	Tue 3/18/14	Fri 3/21/14	5SS+
Paint	3 days	Thu 3/20/14	Mon 3/24/14	6SS+



Start of Electrical rough-in delayed by 1 day