Production Management Experiences and Research at CIFE

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Introduction – CIFE

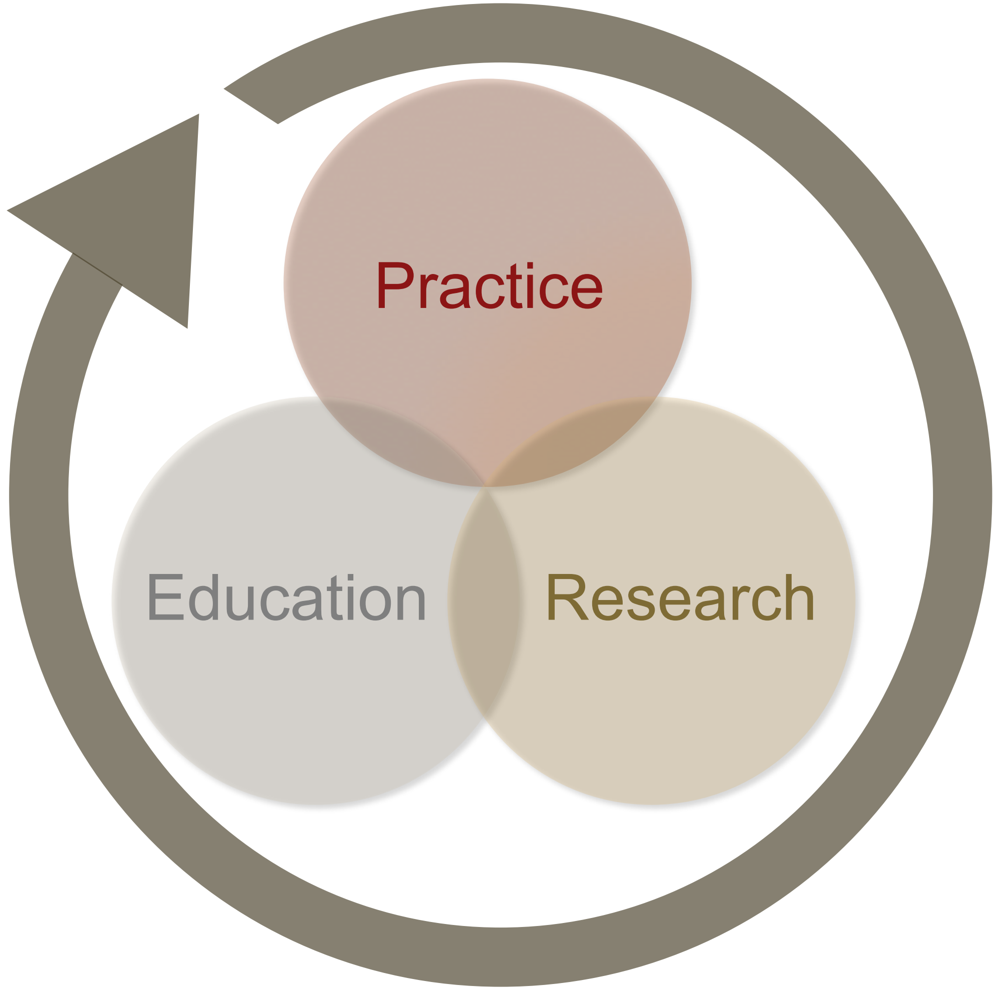
100% funded by A/E/C industries

- Building owners and developers
- Design and construction companies
- Software and hardware vendors

Timeline

- 1988 - 2000 | Building Information Modeling (BIM)
- 2001 - 2010 | Virtual Design and Construction (VDC)
- 2011 - pres | Facility Performance Optimization

The CIFE community invents the future construction practice



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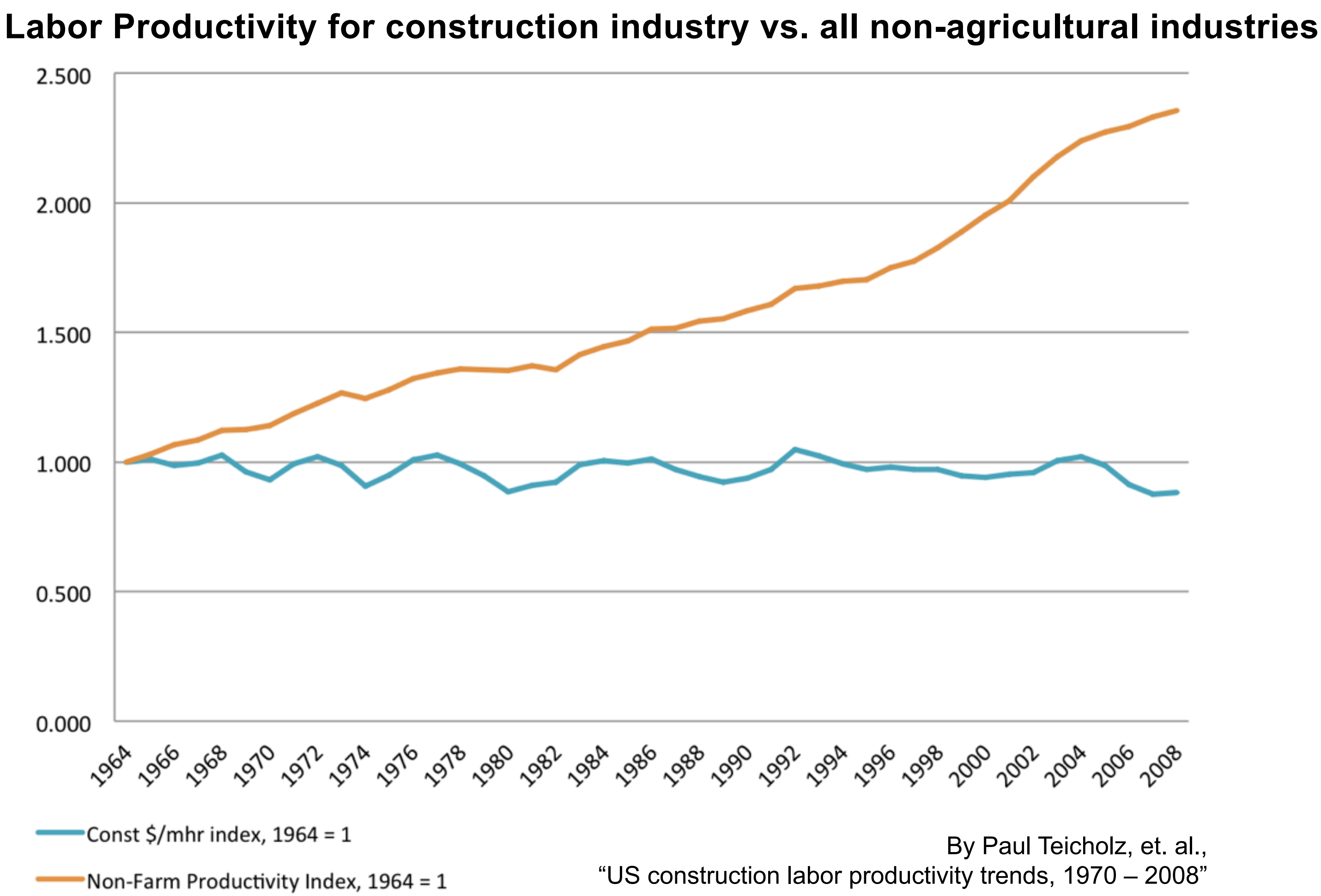
CONSTRUCTION
CREATES
SOCIETY'S FIXED
PHYSICAL WEALTH

CIFE Stanford | Engineering

Other industries making "things" have increased the value added per work hour by 250% over the construction industry since 1964



By Paul Teicholz, et. al.,
"US construction labor productivity trends, 1970 – 2008"

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Virtual Design and Construction (VDC)

Client/Business Objectives

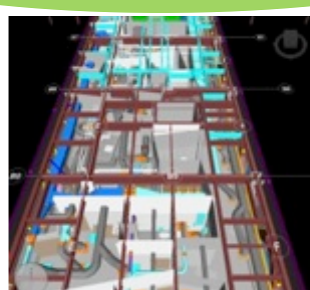
↑

Project Objectives

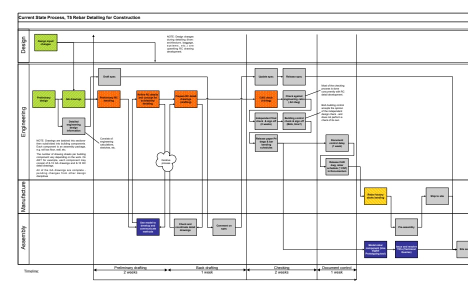
↑

Integrated Concurrent Engineering (ICE)

Product Modeling (BIM+)



Process Modeling



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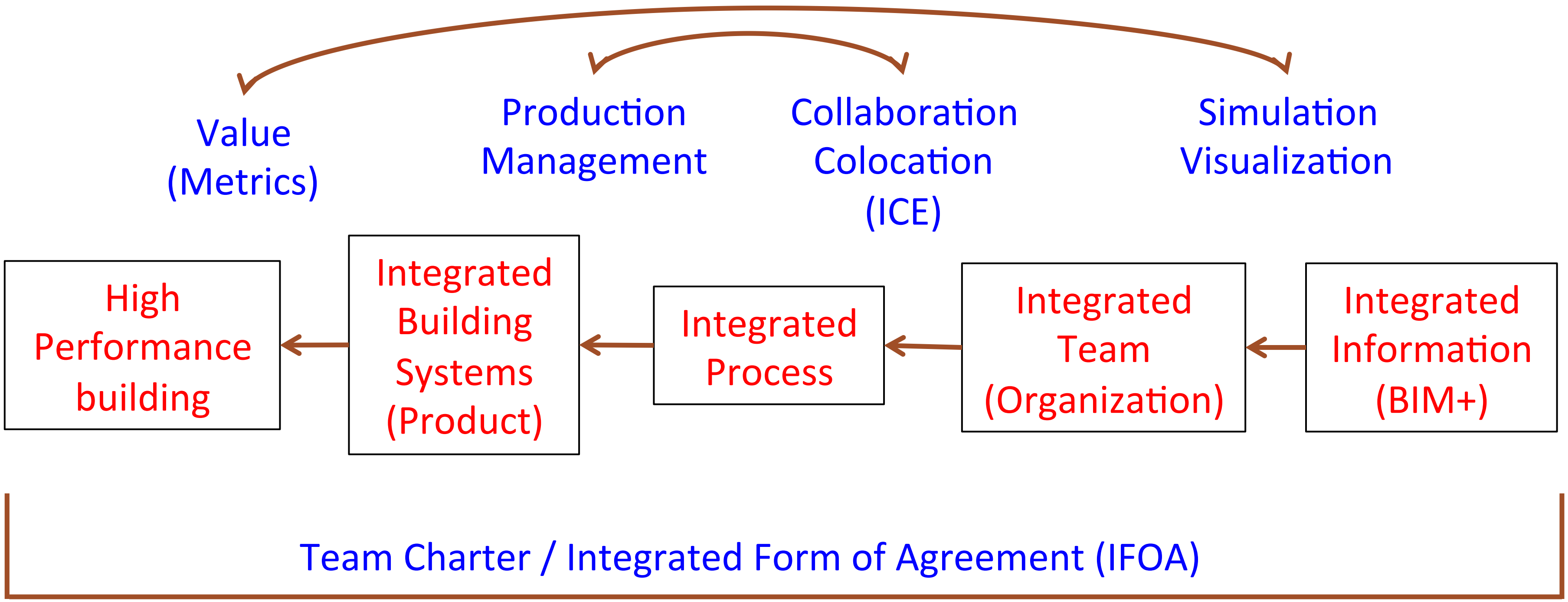
To achieve high-performance facilities, we need a strategy and methods for integration

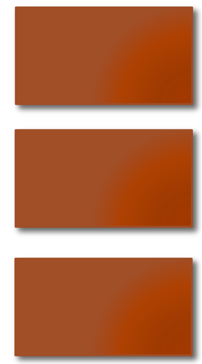


Pay for integration now or pay for it later.

Developed with Khanzode, Reed, and Ashcraft.

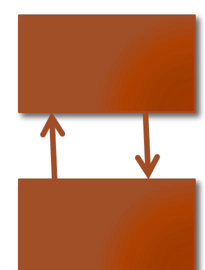
There are 3 types of work interdependencies:

Pooled (independent)



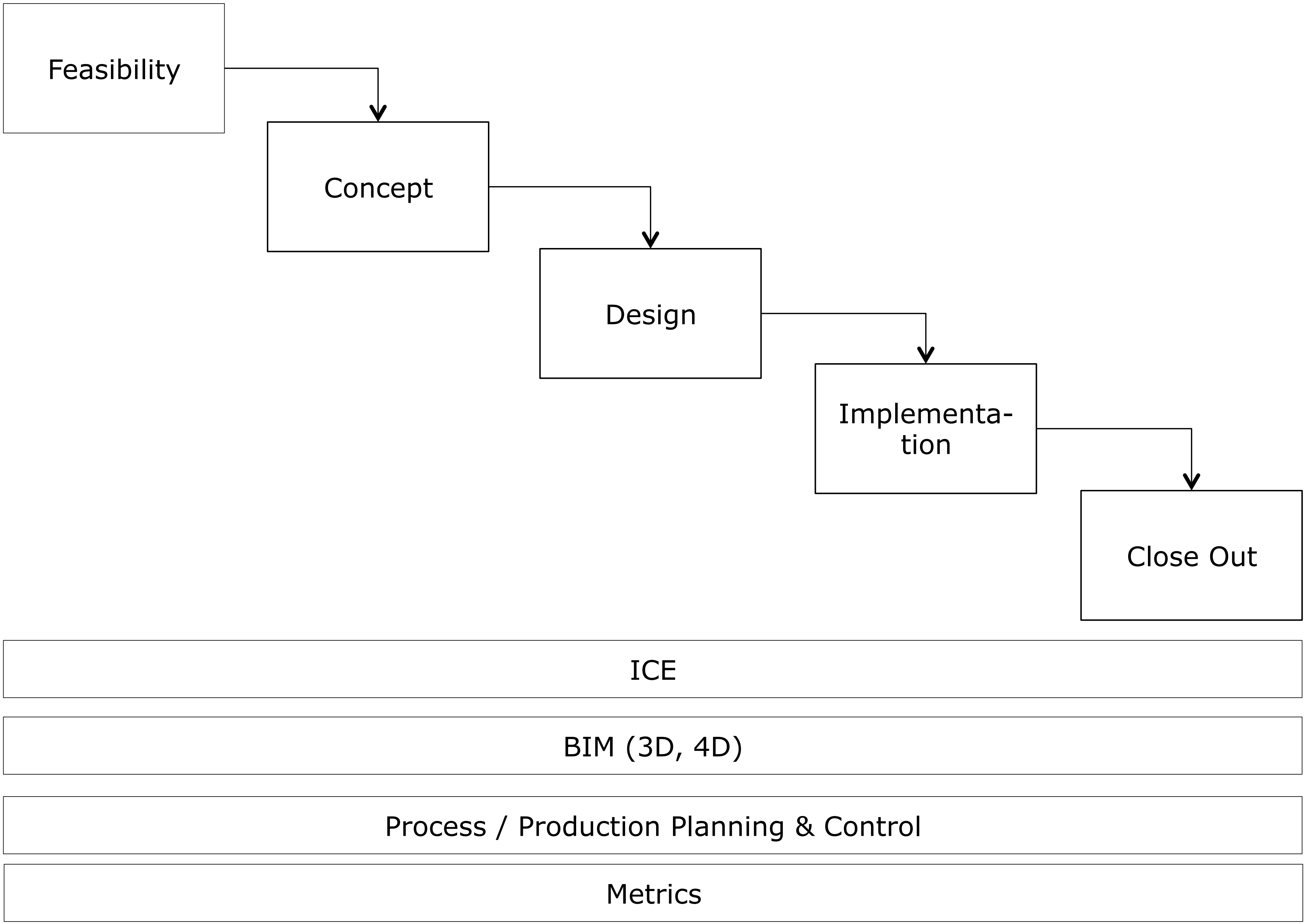
Sequential (dependent)

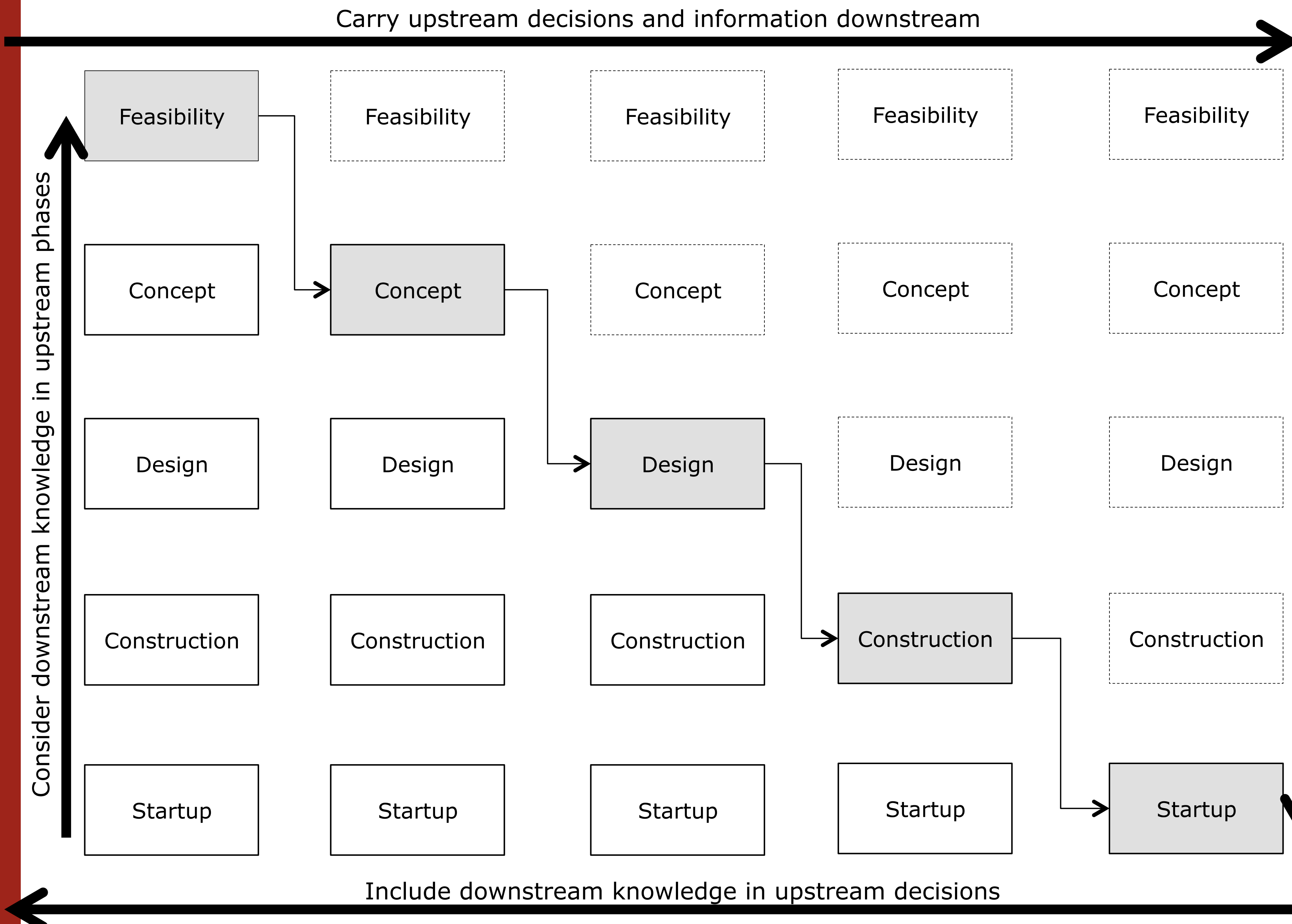
Reciprocal (interdependent)



From: Thompson, Organizations in Action, 1967

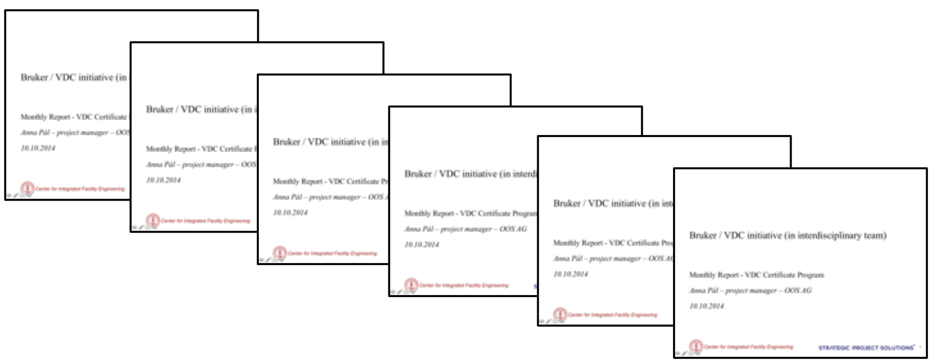
CIFE-SPS VDC Course at NCC, Helsinki Aug. 20-23, 2013


Feasibility
Concept
Design
Implementa-
tion
Close Out
ICE
BIM (3D, 4D)
Process / Production Planning & Control
Metrics



Carry upstream decisions and information downstream
Feasibility
Feasibility
Feasibility
Feasibility
Feasibility
Concept
Concept
Concept
Concept
Concept
Design
Design
Design
Design
Design
Construction
Construction
Construction
Construction
Construction
Startup
Startup
Startup
Startup
Startup
Consider downstream knowledge in upstream phases
Consider upstream information in downstream phases
Include downstream knowledge in upstream decisions

VDC	BIM	Prod Mgt	Metric s	VDC Plan
BIM	ICE	Prod Mgt	VDC	VDC Plan



Learning from Implementation	What's next?

1-week intro

↓

6-month implementation

↓

2-day integration

Clark Pacific

Don Clark (President, Owner):

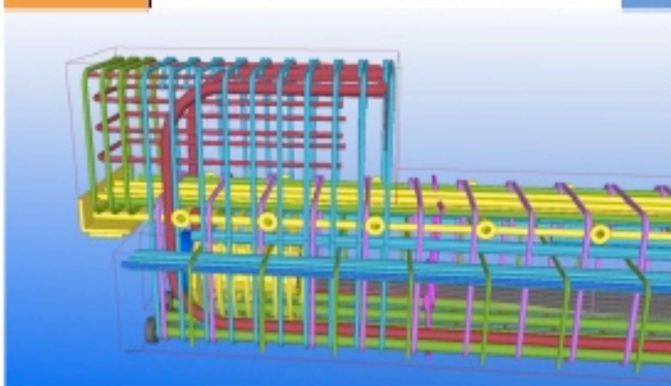
"By digitally modeling all the parts a worker touches during fabrication and erection and rethinking the production process, we were able to

- increase rebar productivity by 40%,
- cut tolerance in half,
- reduce rebar waste to 2%, and
- decrease inventory to 3 days."

Rebar

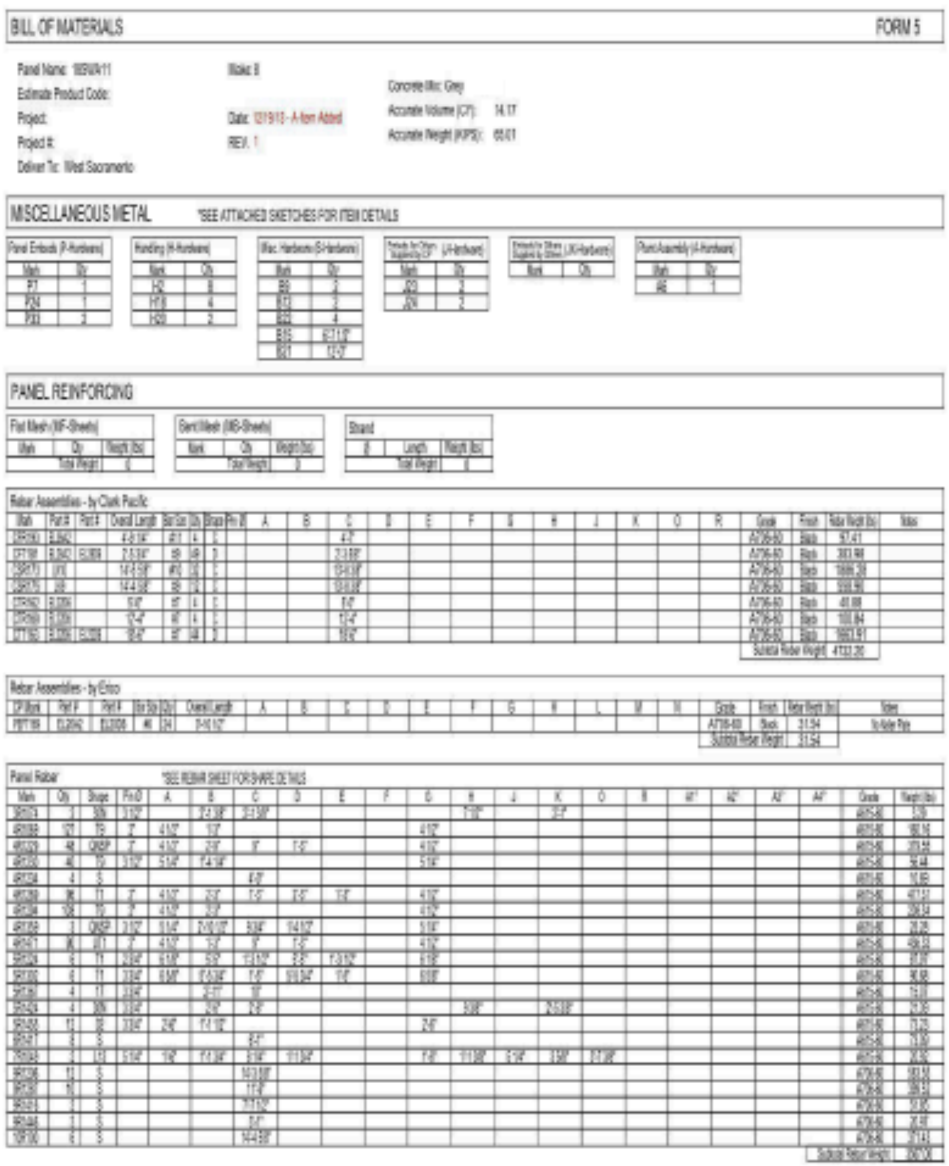
Panel Rebar *SEE REBAR SHEET FOR SHAPE DETAILS

Mark	Qty	Shape	Pin Ø	A	B	C	D	E	F	G	H	J	K	O	R	A1"	A2"	A3"	A4"	Grade	Weight (lbs)
[illegible]	2	XON	3 1/2"		2'-1 3/8"	2'-1 3/8"					7 1/2"		2'-1"							A615-60	[illegible]
[illegible]	121	T9	2"	4 1/2"	1'-3"					4 1/2"										A615-60	[illegible]
[illegible]	48	CNSP	2"	4 1/2"	2'-8"	9"	1'-3"			4 1/2"										A615-60	[illegible]
[illegible]	40	T9	3 1/2"	3 1/4"	1'-4 1/4"					5 1/4"										A615-60	[illegible]
[illegible]	4	S				4'-8"														A615-60	[illegible]
[illegible]	36	T1	2"	4 1/2"	2'-3"	1'-3"	2'-3"	1'-3"		4 1/2"										A615-60	[illegible]
[illegible]	128	T9	2"	4 1/2"	2'-3"					4 1/2"										A615-60	[illegible]
[illegible]	3	CNSP	3 1/2"	3 1/4"	2'-10 1/2"	9 3/4"	1'-4 1/2"			5 1/4"										A615-60	[illegible]
[illegible]	90	U11	2"	4 1/2"	1'-3"	9"	1'-3"			4 1/2"										A615-60	[illegible]
[illegible]	6	T1	2 3/4"	6 1/8"	3'-5"	1'-5 1/2"	3'-5"	1'-5 1/2"		6 1/8"										A615-60	[illegible]
[illegible]	6	T1	3 3/4"	6 5/8"	[illegible]	1'-5"	[illegible]	1'-5"		6 5/8"										A615-60	[illegible]
[illegible]	4	17	3 3/4"		2'-11"	10"														A615-60	[illegible]
[illegible]	4	XON	3 3/4"		2'-6"	2'-6"					9 3/8"		2'-5 3/8"							A615-60	[illegible]
[illegible]	12	02	3 3/4"	2'-6"	1'-5 1/2"					2'-6"										A615-60	[illegible]
[illegible]	8	S				8'-1"														A615-60	[illegible]
[illegible]	2	L15	5 1/4"	1'-2"	1'-1 3/4"	8 1/4"	1'-1 3/4"			1'-2"	1'-1 3/8"	5 1/4"	3 5/8"	3'-7 3/8"						A615-60	[illegible]
[illegible]	12	S				16'-3 5/8"														A706-60	[illegible]
[illegible]	10	S				11'-9"														A706-60	[illegible]
[illegible]	2	S				7'-1 1/2"														A706-60	[illegible]
[illegible]	2	S				3'-1"														A706-60	[illegible]
10R180	6	S				16'-4 5/8"														A706-60	[illegible]
																				Subtotal Rebar Weight	[illegible]



<Grade>A706-60</Grade>
<Coating>Black</Coating>
<Size>#9</Size>
<Quantity>10</Quantity>
<TotalLength>11' 9"</TotalLength>
<CutLength />
<LineType>H</LineType>
<Part />
<Bend>S</Bend>
<SectionRemark />
<Mark>9R1287</Mark>
</Detail>
<Detail>
<BendingDimensions>
<BendingDimension>
<Name>DIM_A</Name>
<Value> 5" 5/ 8</Value>
<Hold>false</Hold>
</BendingDimension>
<BendingDimension>
<Name>DIM_B</Name>
<Value>1' 4" 1/ 2</Value>
<Hold>false</Hold>
</BendingDimension>
<BendingDimension>
<Name>DIM_C</Name>
<Value>2' 10" 1/ 2</Value>
<Hold>false</Hold>
</BendingDimension>
<BendingDimension>
<Name>DIM_D</Name>
<Value>2' 4" 1/ 2</Value>
<Hold>false</Hold>
</BendingDimension>
<BendingDimension>
<Name>DIM_E</Name>
<Value>1' 4" 1/ 2</Value>

Cast Unit Bill of Materials (BOM)



BILL OF MATERIALS FORM 5

Panel Name: 18SWA11
Make: 8
Estimate Product Code:
Project:
Date: 12/19/13 - A-Item Added
Project #:
REV. 1
Deliver To: West Sacramento
Concrete Mix: Grey
Accurate Volume (CF): 14.17
Accurate Weight (KIPS): 65.01

MISCELLANEOUS METAL *SEE ATTACHED SKETCHES FOR ITEM DETAILS

Panel Embeds (P-Hardware)

Mark	Qty
P7	1
P24	1
P33	2

Handling (H-Hardware)

Mark	Qty
H2	8
H18	4
H20	2

Misc. Hardware (S-Hardware)

Mark	Qty
B9	2
B13	2
B22	4
B35	67.1/2'
B21	12/2'

Embeds for Others Supplied by CP (J-Hardware)

Mark	Qty
J23	2
J24	2

Embeds for Others Supplied by Others (JX-Hardware)

Mark	Qty

Panel Assembly (A-Hardware)

Mark	Qty
A6	1

PANEL REINFORCING

Flat Mesh (MF-Sheets)

Mark	Qty	Weight (lbs)
	Total Weight	0

Bent Mesh (MB-Sheets)

Mark	Qty	Weight (lbs)
	Total Weight	0

Strand

Ø	Length	Weight (lbs)
	Total Weight	0

Rebar Assemblies - by Clark Pacific

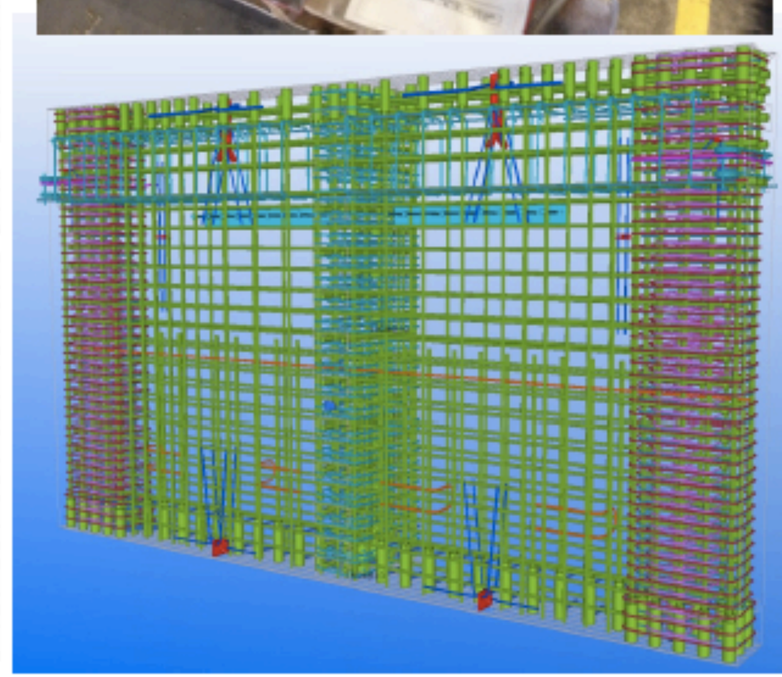
Mark	Part #	Part #	Overall Length	Bar Size	Qty	Shape	Pin Ø	A	B	C	D	E	F	G	H	J	K	O	R	Grade	Finish	Rebar Weight (lbs)	Notes
[illegible]	[illegible]		4'-6 1/4"	#11	4	C				4'-7"										A706-60	Black	97.41	
[illegible]	[illegible]	[illegible]	7'-5 3/4"	#8	48	D				2'-3 5/8"										A706-60	Black	383.98	
[illegible]	[illegible]		14'-6 5/8"	#10	[illegible]	C				13'-6 3/8"										A706-60	Black	1886.28	
[illegible]	[illegible]		14'-4 5/8"	#8	[illegible]	C				13'-8 3/8"										A706-60	Black	938.90	
[illegible]	[illegible]		5'-6"	#7	4	C				5'-6"										A706-60	Black	40.88	
[illegible]	[illegible]		12'-4"	#7	4	C				12'-4"										A706-60	Black	100.84	
[illegible]	[illegible]	[illegible]	18'-6"	#7	44	D				18'-6"										A706-60	Black	1683.91	
																				Subtotal Rebar Weight		4132.20	

Rebar Assemblies - by Erico

CP Mark	Part #	Part #	Bar Size	Qty	Overall Length	A	B	C	D	E	F	G	H	L	M	N	Grade	Finish	Rebar Weight (lbs)	Notes
[illegible]	[illegible]	[illegible]	#6	24	[illegible]												A706-60	Black	31.54	[illegible]
																	Subtotal Rebar Weight		31.54	

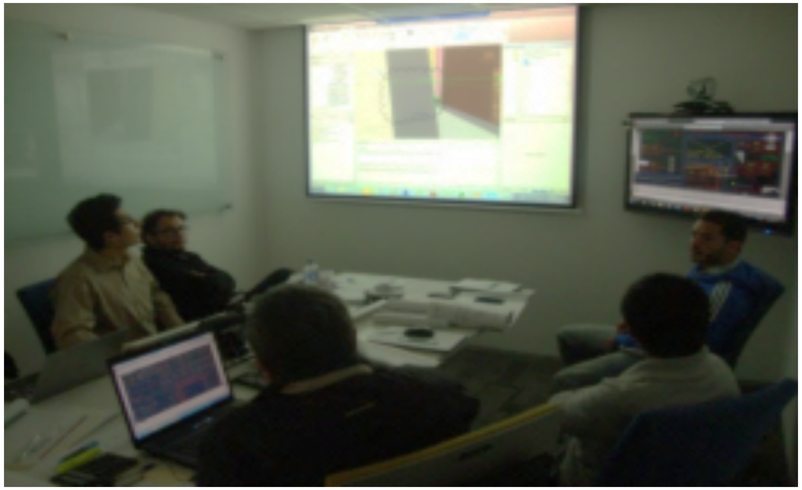
Panel Rebar *SEE REBAR SHEET FOR SHAPE DETAILS

Mark	Qty	Shape	Pin Ø	A	B	C	D	E	F	G	H	J	K	O	R	A1	A2	A3	A4	Grade	Weight (lbs)
[illegible]																					

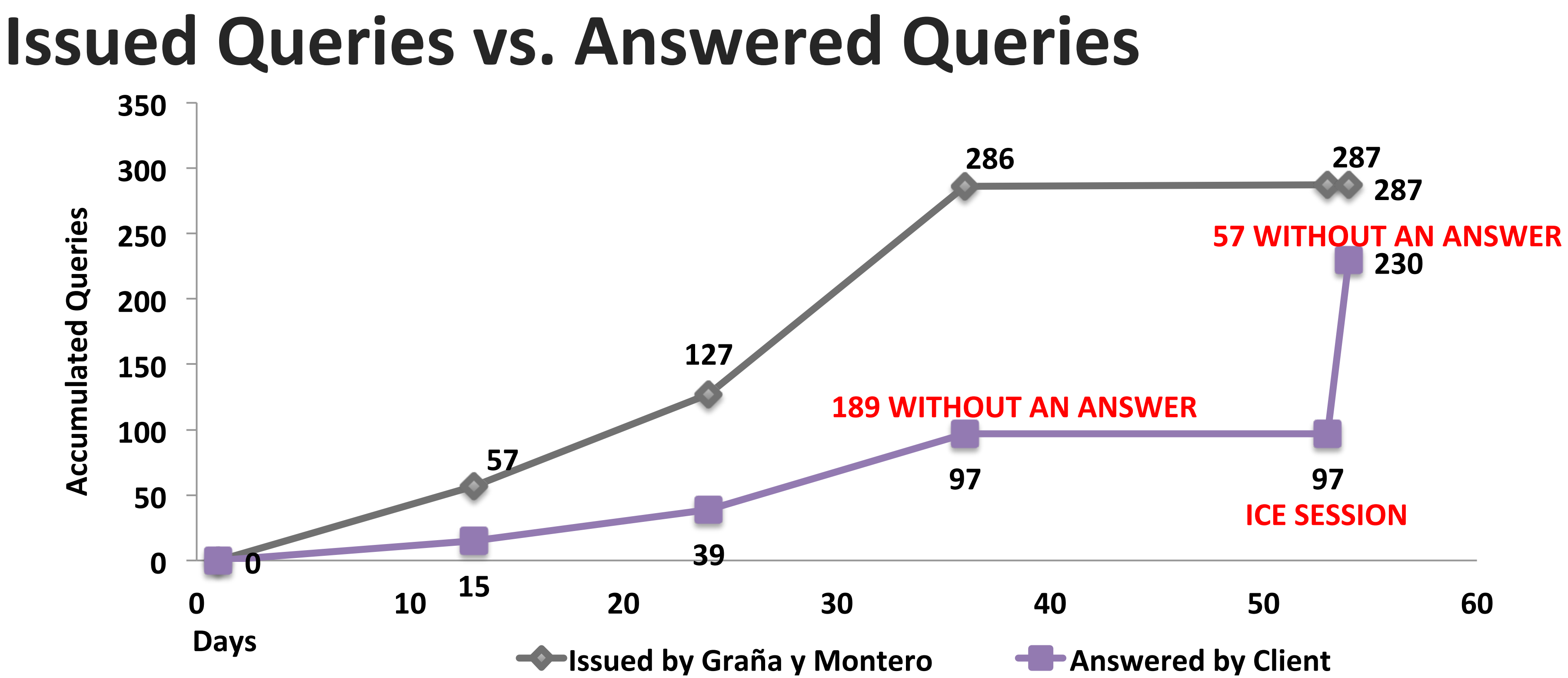


Diagrammatic

First ICE Session at Graña y Montero in Lima, Peru



ICE Session resulted in 80x increase in answers to queries

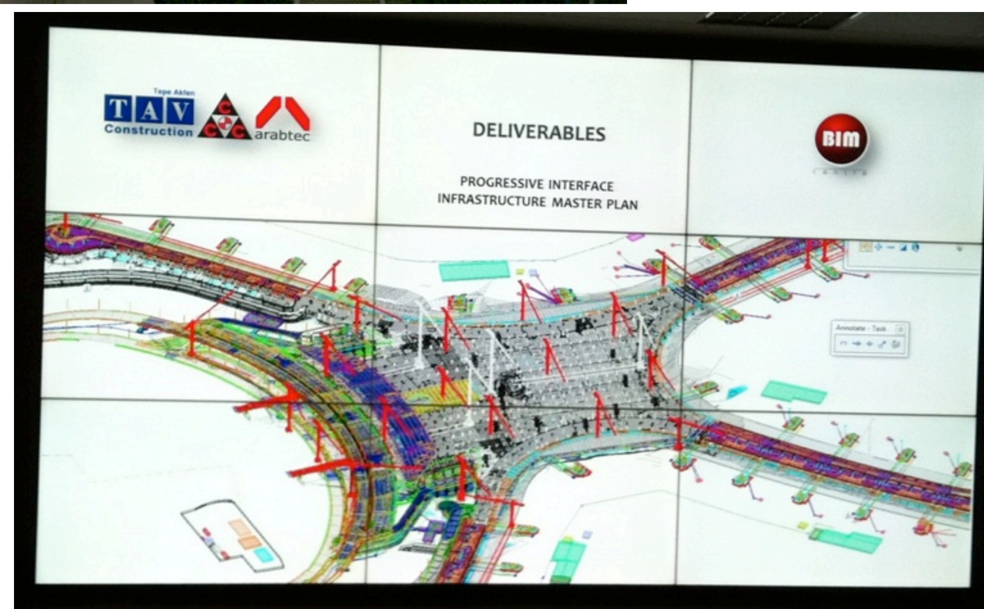


Without ICE Session: 97 queries answered in 36 days = 0.11 queries/hr

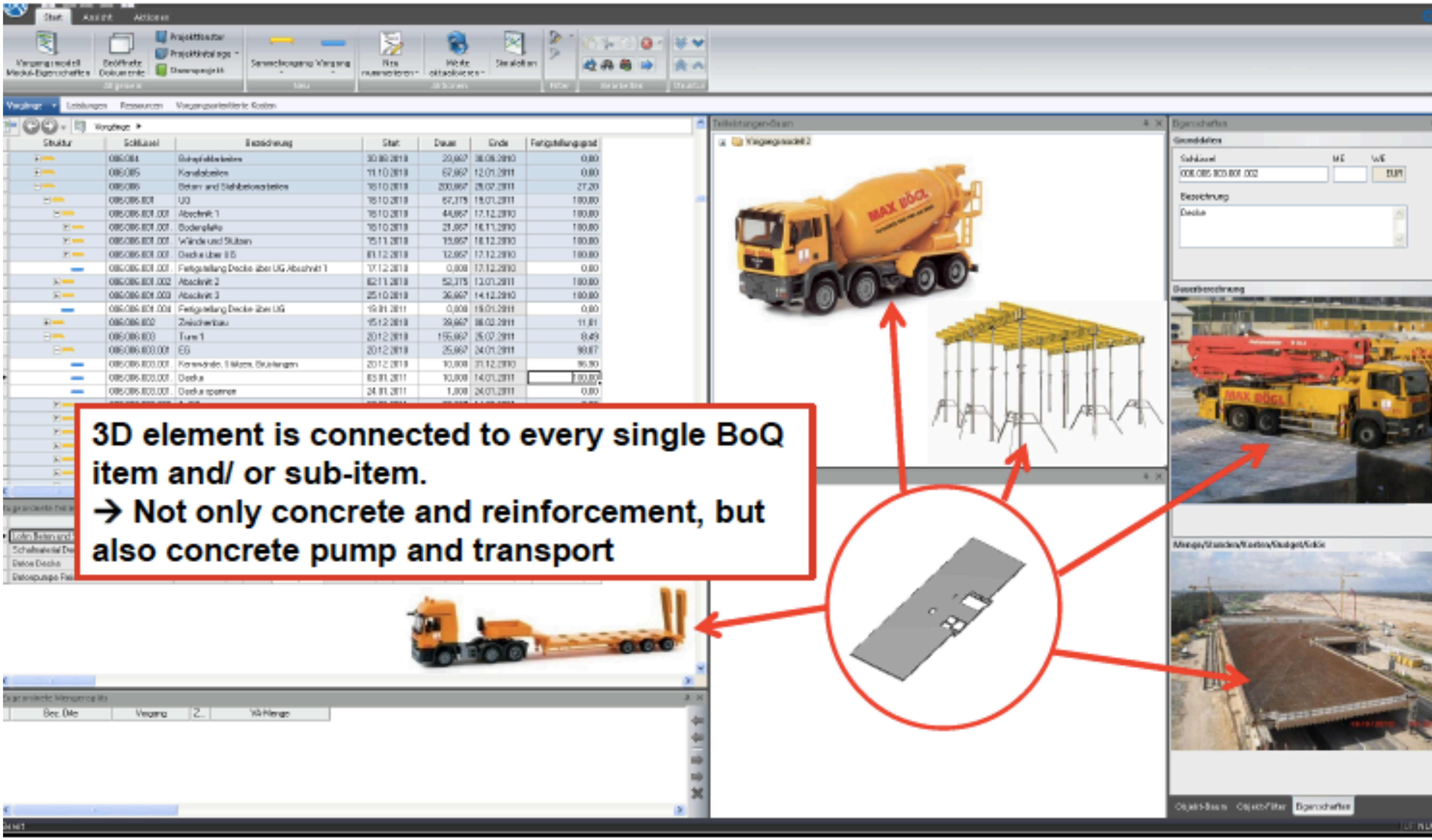
ICE Session: 66 queries answered in 8.5 hours = 7.76 queries/hr (1 query every 8 min)

Project Control Room by TAV-CCC-Arabtec JV on Midfield Terminal Project at Abu Dhabi Intl Airport

6 BIM engineers manage all quantities (vs. 52 quantity surveyors)



Progress reporting



3D element is connected to every single BoQ item and/ or sub-item.
→ Not only concrete and reinforcement, but also concrete pump and transport

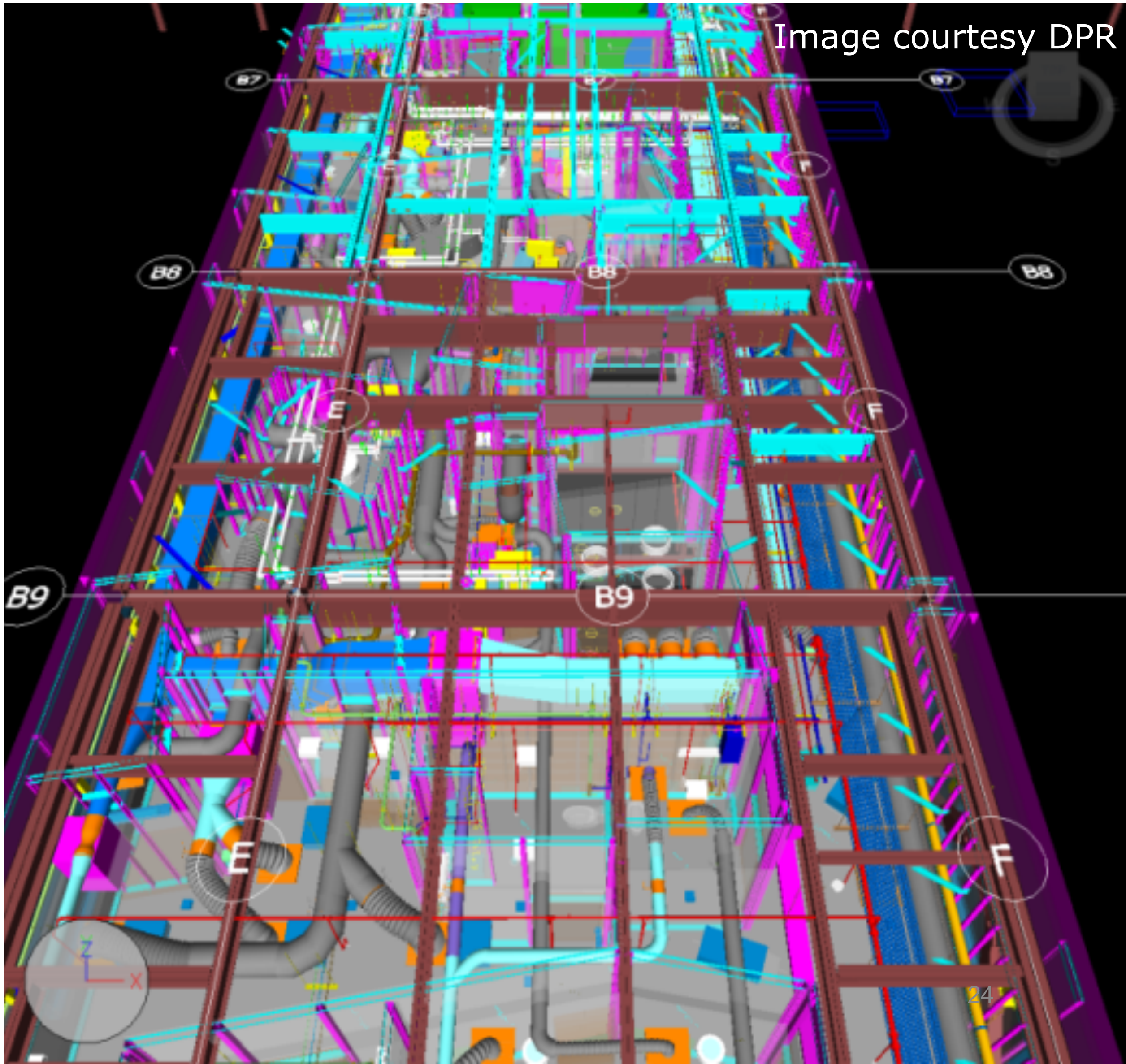
Recommendation

Don't treat BIM as an isolated add-on

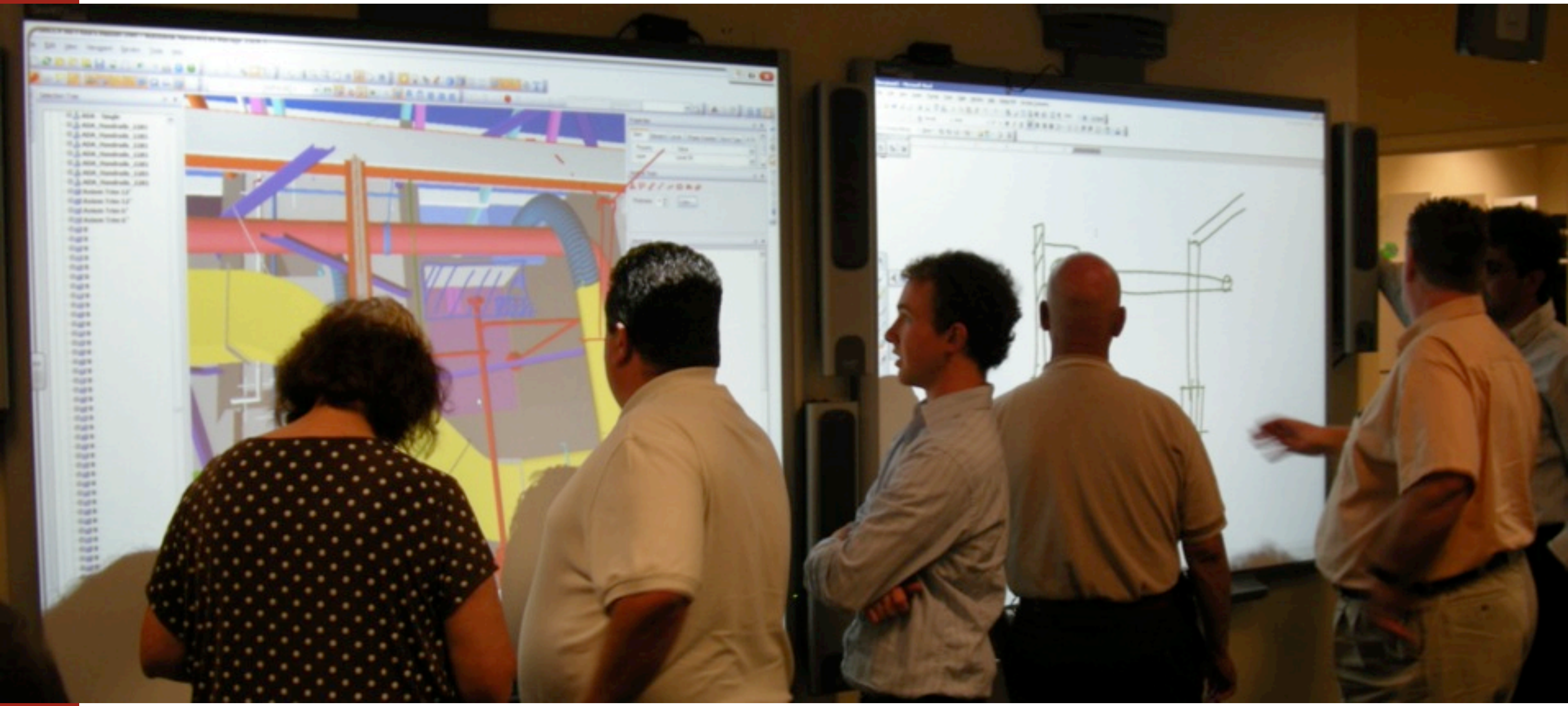
→ Create VDC methods for your work, including

- Performance targets
- BIM
- Revised workflow
- Revised collaboration

BIM offers an integrated information basis



Integrated Concurrent Engineering is a method for collaboration



Rethink your work processes given the combination of collaboration and BIM

1. Develop Strategic Goals and Objectives for MEP Coordination

2. Organize a multi-disciplinary team for coordination

3. Co-develop performance and outcome objectives

4. Co-Develop Technical Logistics to manage coordination

5. Develop Pull Schedule to structure the work based on construction sequence

6. Manage against the performance objectives

The IVL Method by Atul Khanzode, PhD Research advised by Martin Fischer, Glenn Ballard, and others

Set performance targets and track them

Outcome Metrics	Case Study 1:	Case Study 2:
Mechanical Prefabrication %	90%	30%
Plumbing Prefabrication %	90%	0%
Electrical Prefabrication %	40%	25%
RFIs due to Conflicts during Construction	2 of 677	30 of 200
Number of Change Orders due to conflicts during Construction	0 of 311	30 of 230
Minutes per day Superintendent spent resolving issues between MEP trades	20 - 30	180
Average Planned Percent Complete	80%	Did not track
% Rework Hours compared to Total Hours	Less than 1%	20%

The Business Perspective

"Automated execution of processes changes everything."

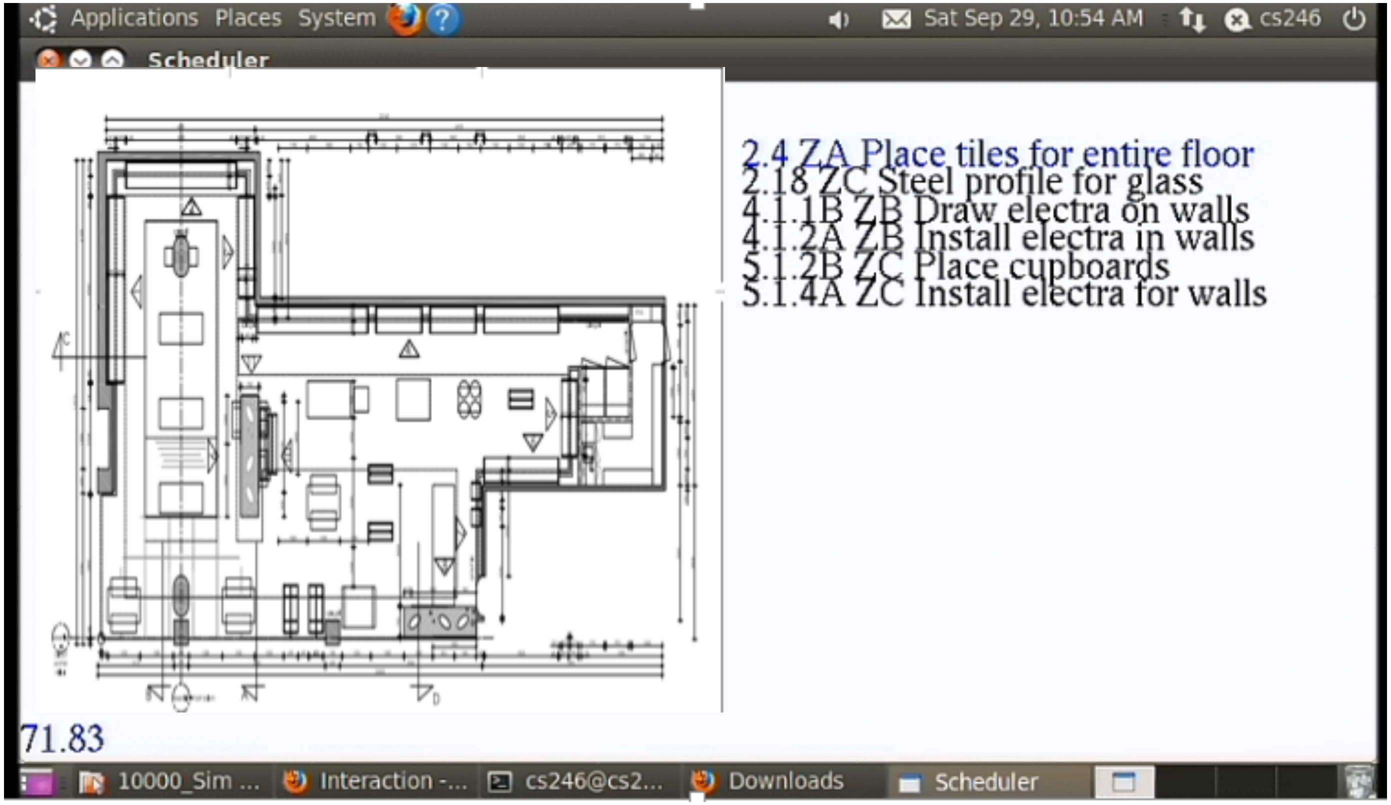
(Alan Perlis, 1961)

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)

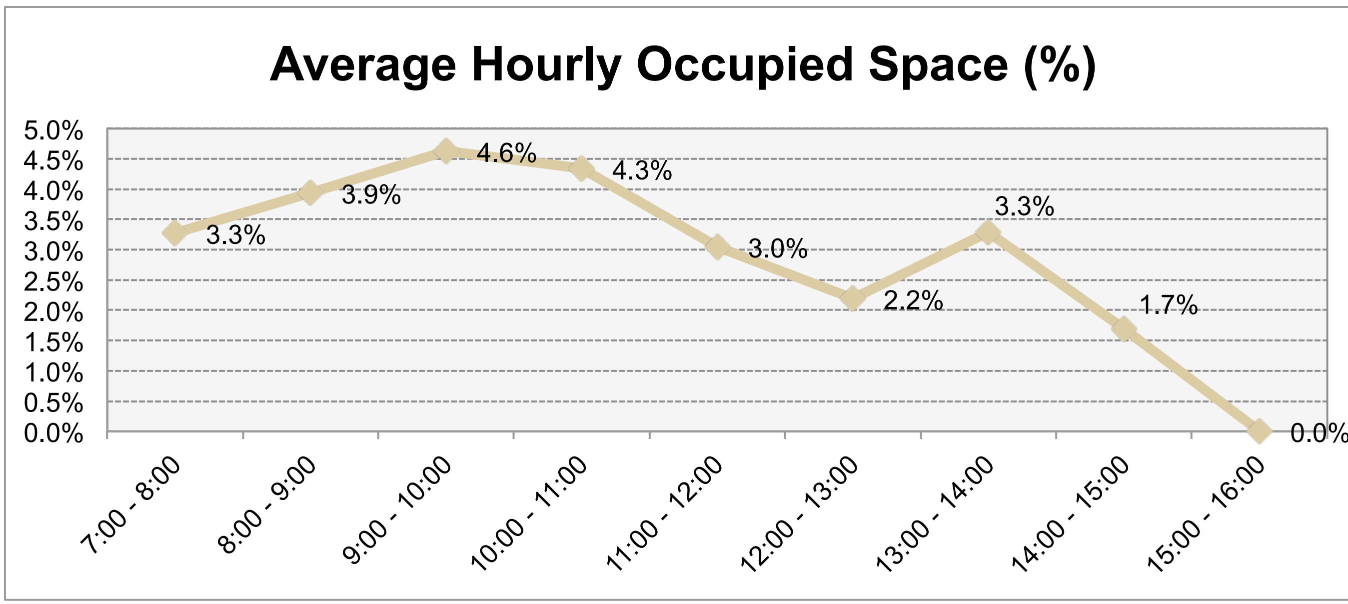
Tri-Constraint Method (work by Rene Morkos)



- Three types of constraints
  - Precedence
  - Discrete (Labor)
  - Disjunctive (Workspace)
- Automated scheduler
- Varies sequence (thousands of viable schedules)

- Maximize space utilization
- Eliminate spatial clashes

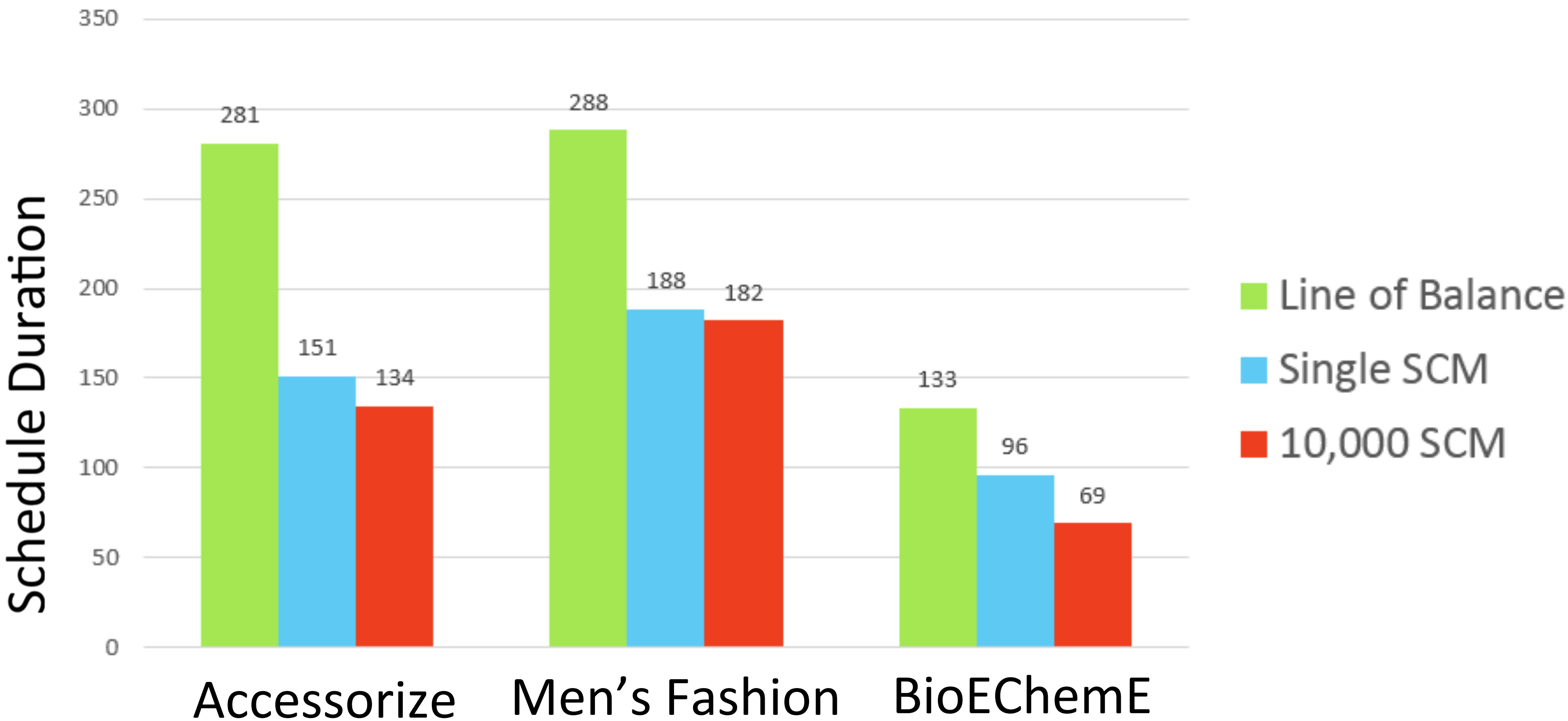
Space is underutilized on some construction sites



Average bay occupancy 3.1%

Need a method to maximize work density

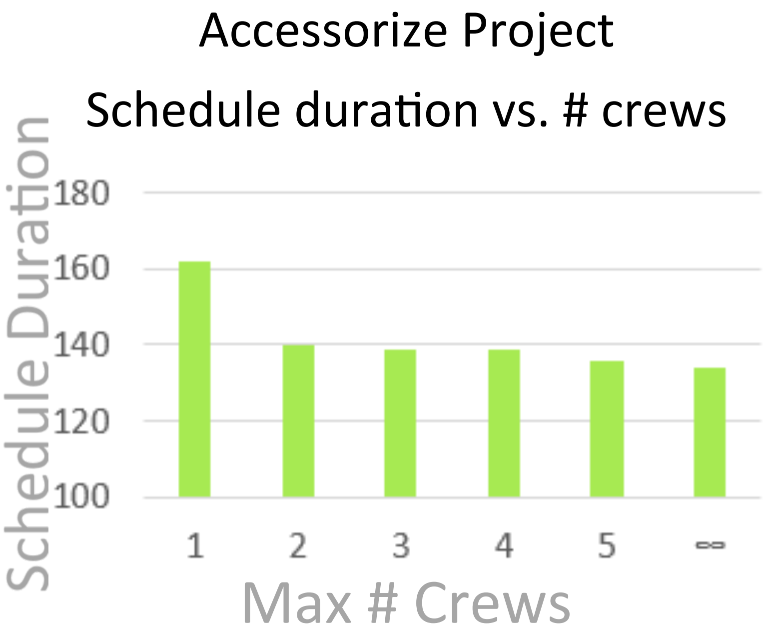
TCM Basic Results

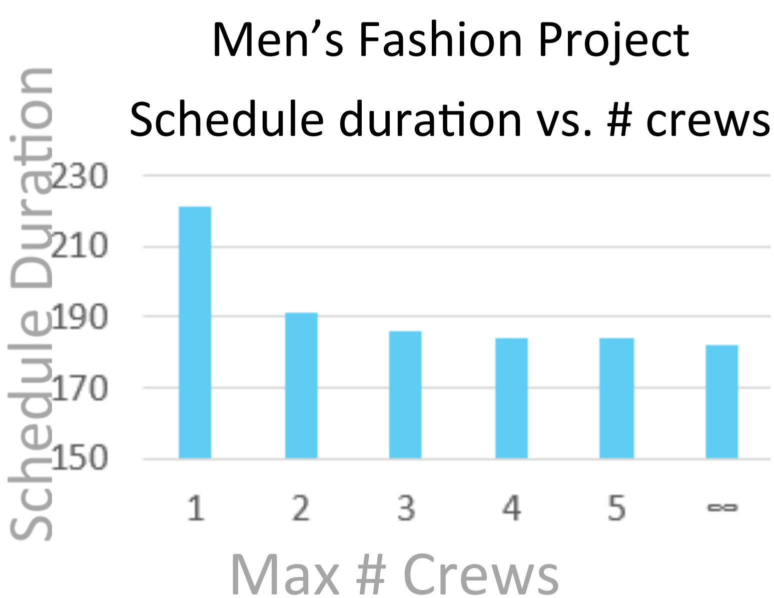


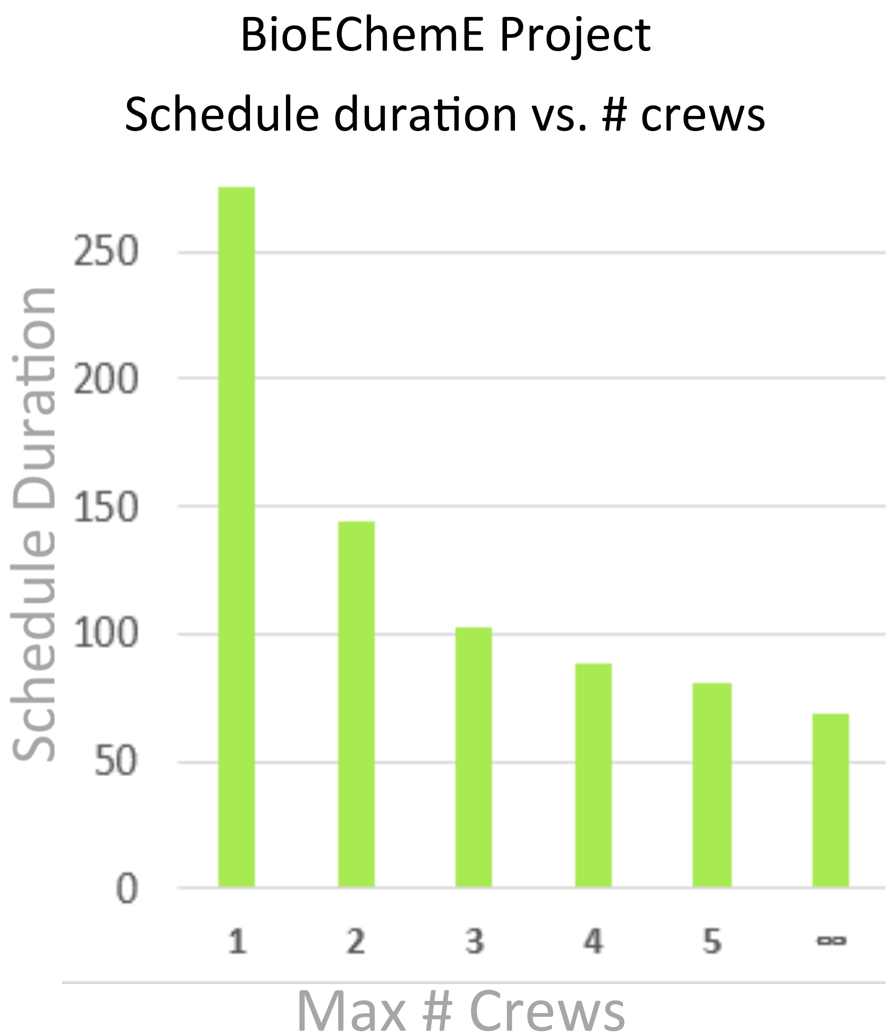


SCM schedule durations on average 47% shorter than LOB

TCM models labor resources







CIFE Stanford University

2014-15 CIFE Seed Research Project

Simulation-Based Approach to Accounting for Uncertainty and Variability in Look-Ahead Planning

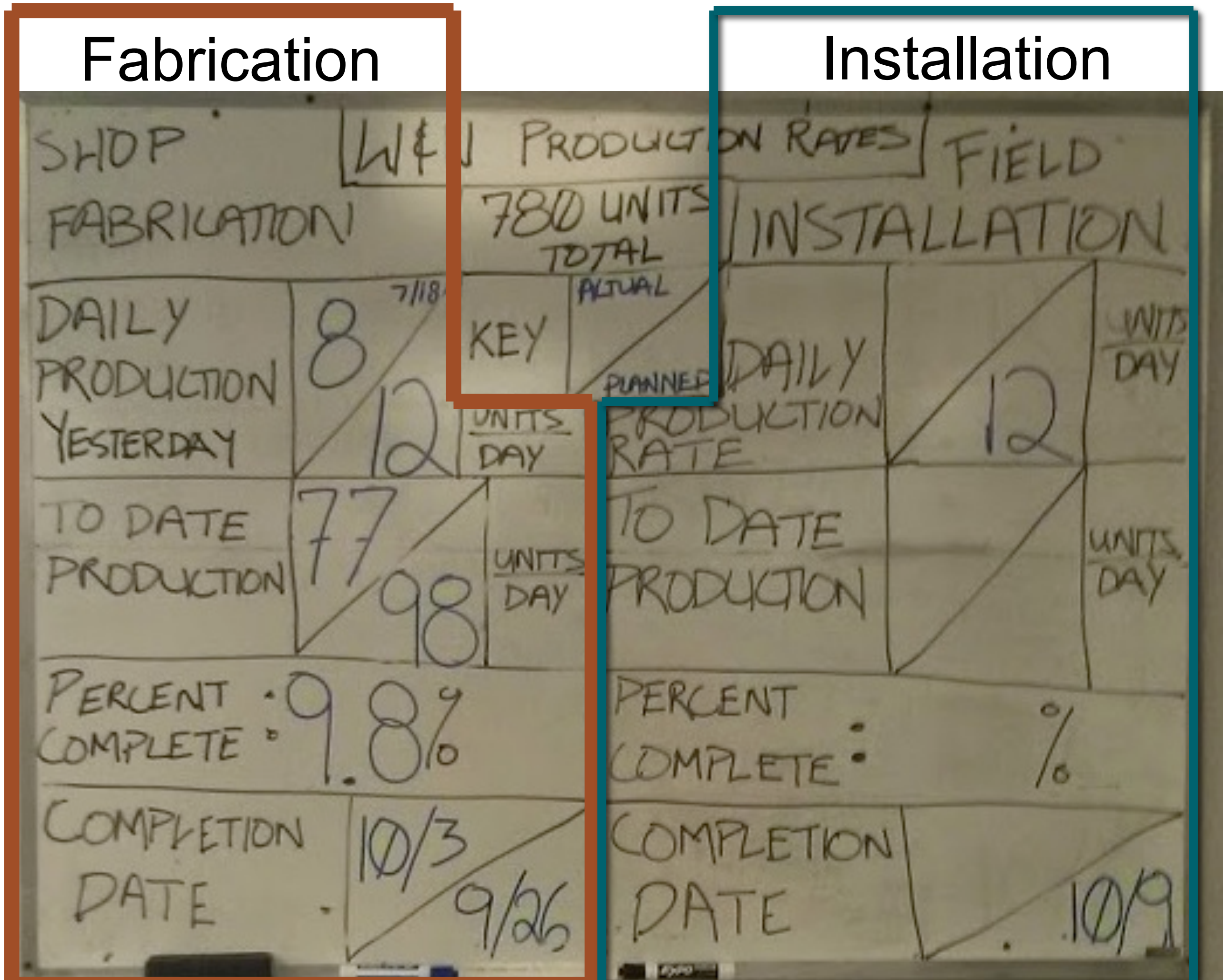
With Nelly Garcia-Lopez and James Choo

Motivating case: Curtain Wall Installation in 7-story office building in South San Francisco

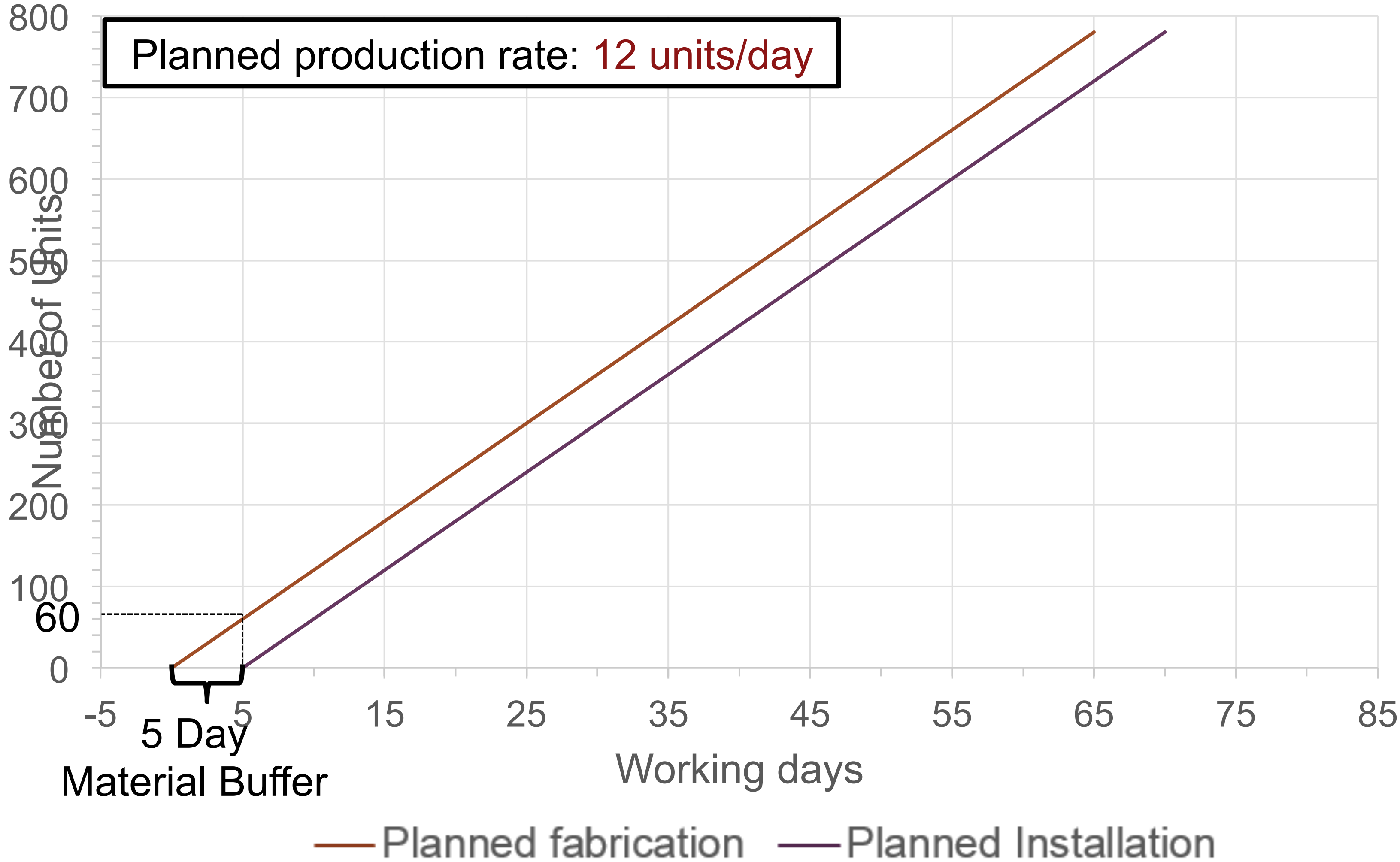
- Critical path activity
- Opens up work for other trades (e.g., finishes)
- Disrupts ongoing work (6ft staging area around the perimeter)
- Vulnerable to variability
- Field managers were concerned about the installation crew outpacing the fabrication crew

Source: Genzyme Corp
http://www.sotawall.com/portfolio/United%20States/GenzymeCorporation-8568/

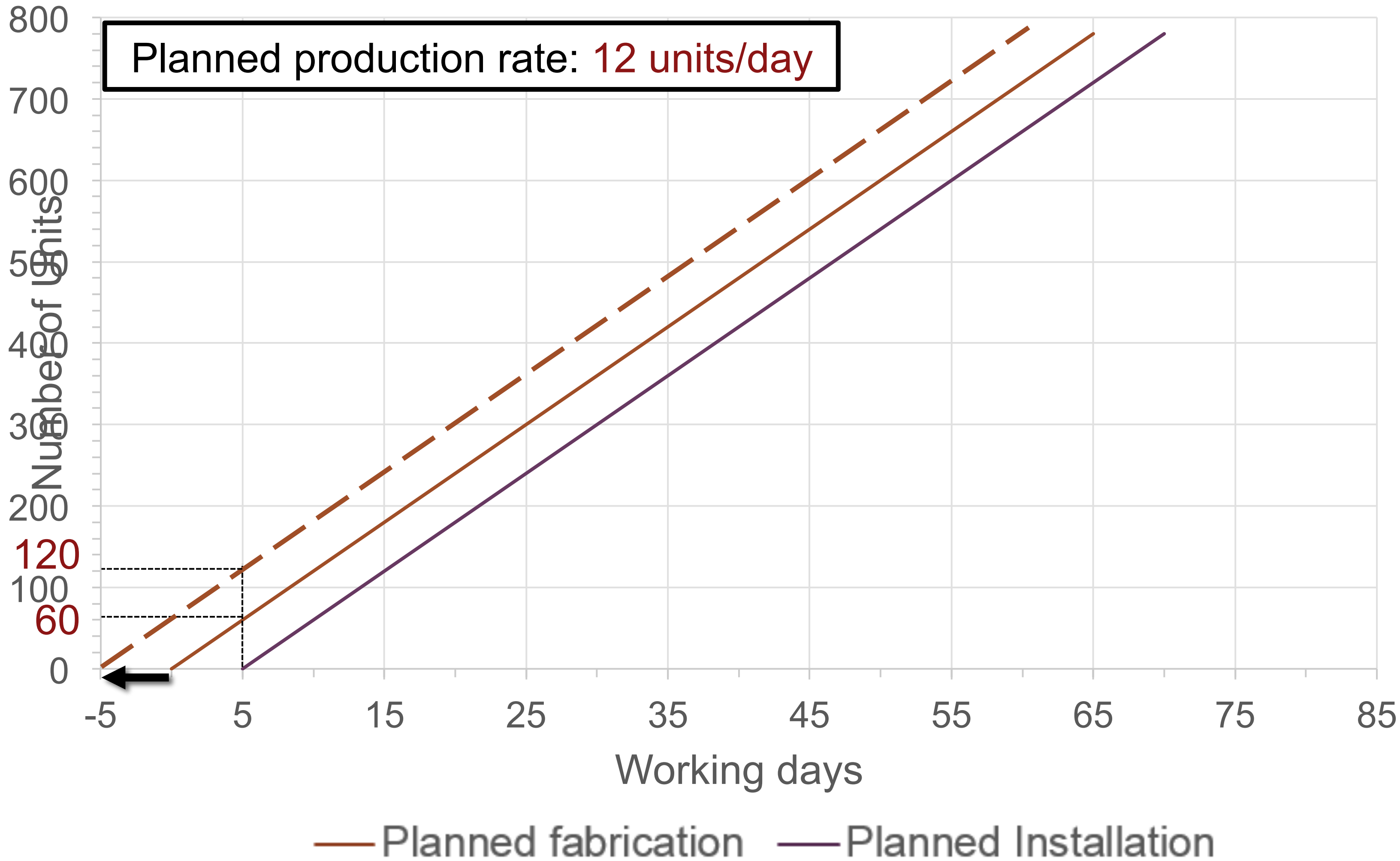
They tracked the fabrication and installation production and updated the chart daily



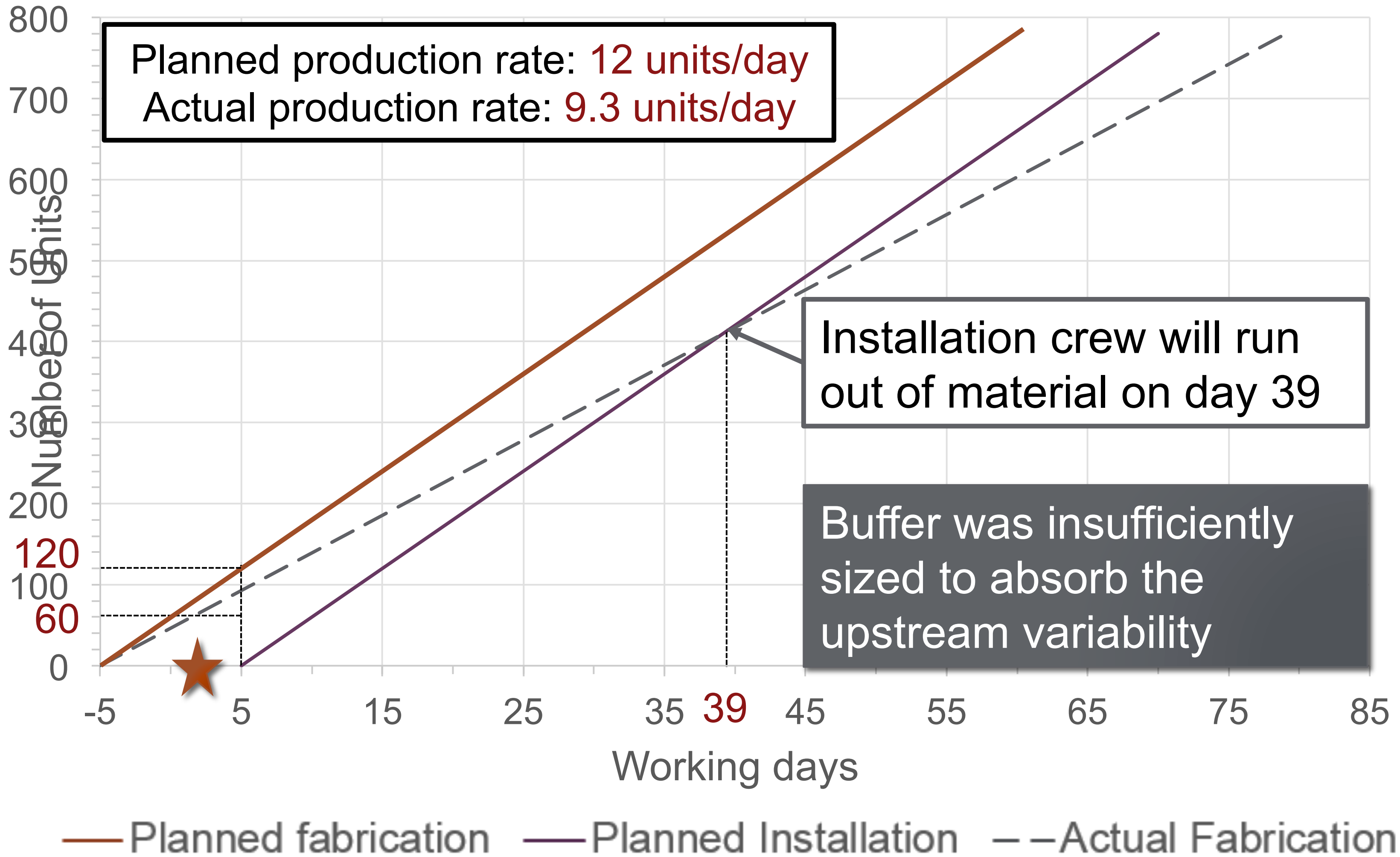
Line of Balance View of Curtain Wall Fabrication vs Installation



Subcontractor started fabrication earlier than planned



Actual fabrication rate was 22% slower than planned



Identifying variability factors and tracking them is not sufficient to size buffers appropriately

Look-ahead process (Hamzeh, Ballard & Tommelein 2011)

Break down processes into activities for look-ahead window → Identify constraints & make ready → Determine sequencing and design operations

Field managers correctly identified constraints

- PPC for curtain wall installation in previous project was 50%
- Main reason for non-completion was predecessor activity (fabrication)

But were unable to design the operation to avoid variability impact

- Variability was underestimated
- Material buffer was insufficient

Case summary: Construction managers want to manage variability but lack a formal method to do so

Aware of impact of variability

Constraint checking during look-ahead planning

Intuitive management of variability

Create inventory buffer to shield installation from variability in fabrication

No formal methods to analyze variability factors and predict impact

Will fabrication over/under-supply the site?
How is installation affected?

Activity execution is affected by activity variability factors and schedule variability factors

Activity variability factors:

- Labor
- Tools & Equipment
- Materials and components
- Information/plans
- Previous work
- Site conditions
- External

(Ballard & Howell 1998, Thomas et al. 2002, Tommelein et al. 1999)

Schedule variability factors:

- Work in process (Gonzalez et al. 2011)
- Site congestion (Morkos et al. 2014)

affect

Activity execution

leads to

Variability in execution:

- Start date
- Activity duration

Activity variability analysis needs to incorporate interdependencies between variability factors

Research method

Quantitative data analysis (Kuhn & Johnson 2012)

1. Exploratory data analysis → 2. Confirmatory data analysis → 3. Predictive modeling

1. Exploratory data analysis

- Identify variables driving activity variability

2. Confirmatory data analysis

- Statistically confirm hypothesis resulting from part 1

3. Predictive modeling

- Build model to predict variability impact on activity start and duration

Data acquired to date

Activity tracking data collected daily at a hospital building project by a CIFE partner over a period of 31 months (Nov 2011 – June 2014)

- 30,000 total activity entries
- We cleansed the data-set:
  - 25,170 activities entries with valid dates entered
  - Manually classified into 761 activity types and Uniformat categories

Data request

We need activity tracking data for building projects that have implemented Last Planner:

Data needed per activity:

- Activity Description
- Subcontractor/Team performing activity
- Planned start, planned finish, planned duration
- Actual start, actual finish, actual duration
- Reason for non-completion (category and root cause), reasons for changes in start dates and duration
- Predecessors, successors (or schedule network)

Please contact Professor Martin Fischer (fischer@stanford.edu) or Nelly Garcia-Lopez (ngarcial@stanford.edu) if you would like to be involved in this project.

Develop a unifying theory of project production management

Virtual vs. Physical Production
- Tradeoffs
- Automation
- Product-Organization-Process

Production Physics and Organizational Chemistry

How to estimate capacity

Multi-scale workflow examples

Rapid learning cycles
- Controllable Factors → Production Performance → Outcome Performance

Optimization
- What: EEE Performance
- How