Resource Planning by way of AI-Based Scheduling

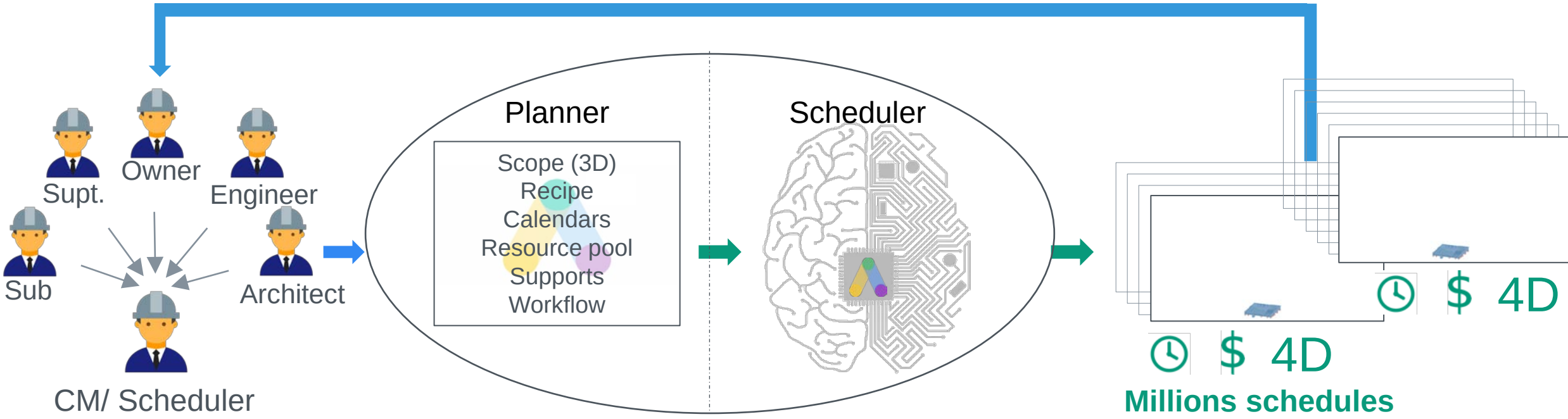
Henning Roedel, Ph.D.
Rene Morkos, Ph.D., Jeff Heuton, Ryan O’Rourke, Dimi Farmakis

2019 Construction CPM Conference
Jan 21, 2019

Outline

- Introduction to an AI-Scheduler
- Definition of Resources
- How many workers?
- How much formwork?
- How many cranes?
- Conclusions

Planner and Scheduler



Planning

Rule Set

Scheduling parameters

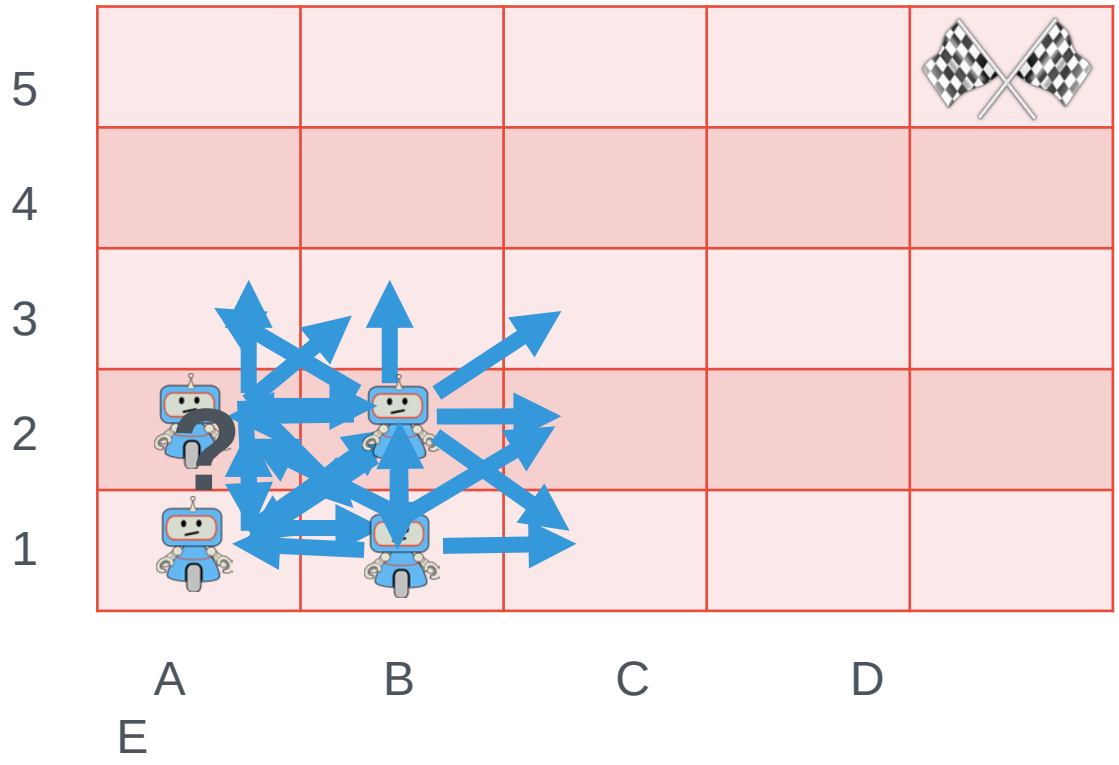
Scheduling

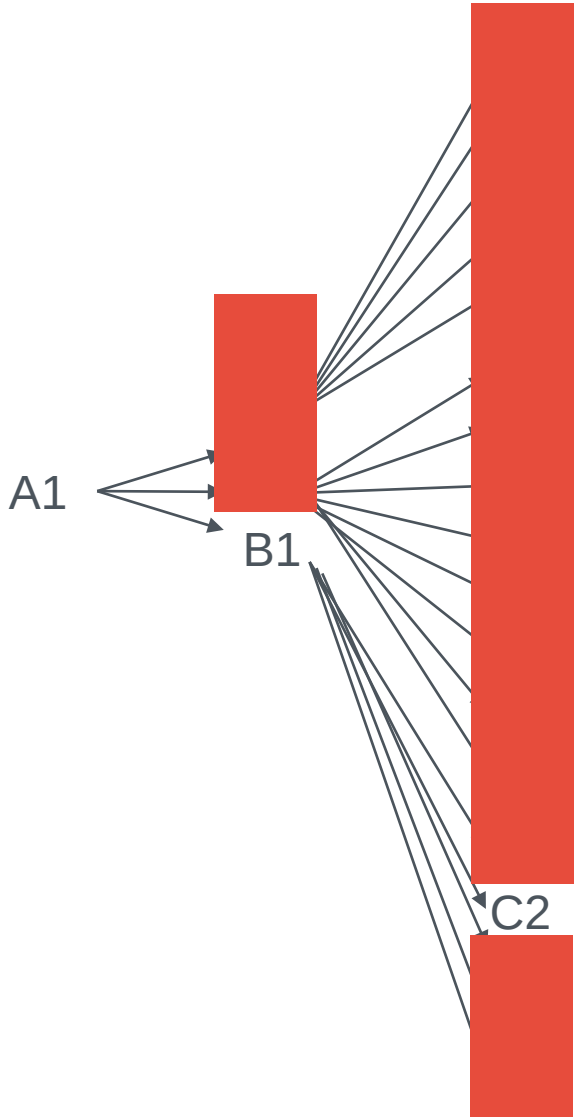
Resource allocation

Sequence Variation

How does Search AI work?

1. Current state specifier
2. Future state generator
3. Current state == goal state check





- Tree
- Levels
- Leaves
- Exhaustive
- Improve Future State generator (no duplicates)
- Breadth first
- Depth First
- A* F(n) = g(n) + h(n)

Progressing Tasks to Lists

To-Do
All activities needed to complete project.

This is the plan

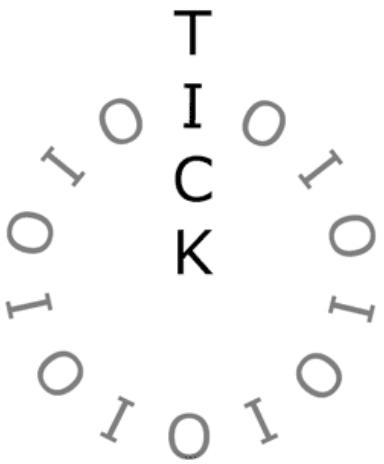
Can-Do
Activities that can be started at this current state.

Accounts for Precedence, Resources, and Space.

Doing
Activities that are in progress at this current state.

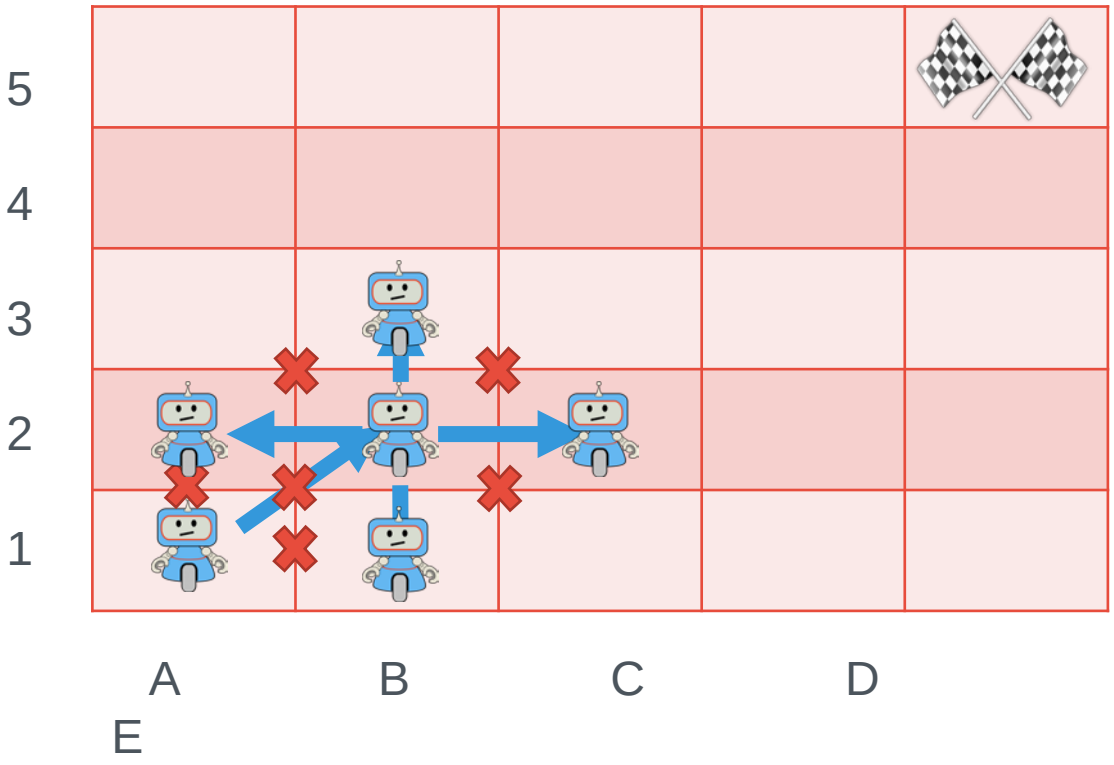
Done
Activities that are completed.

Schedule is finished when all activities in the To-Do list are in the Done list



How does AI Scheduling work?

1. To-Do List
2. Can-Do List
3. Doing List
4. Done List

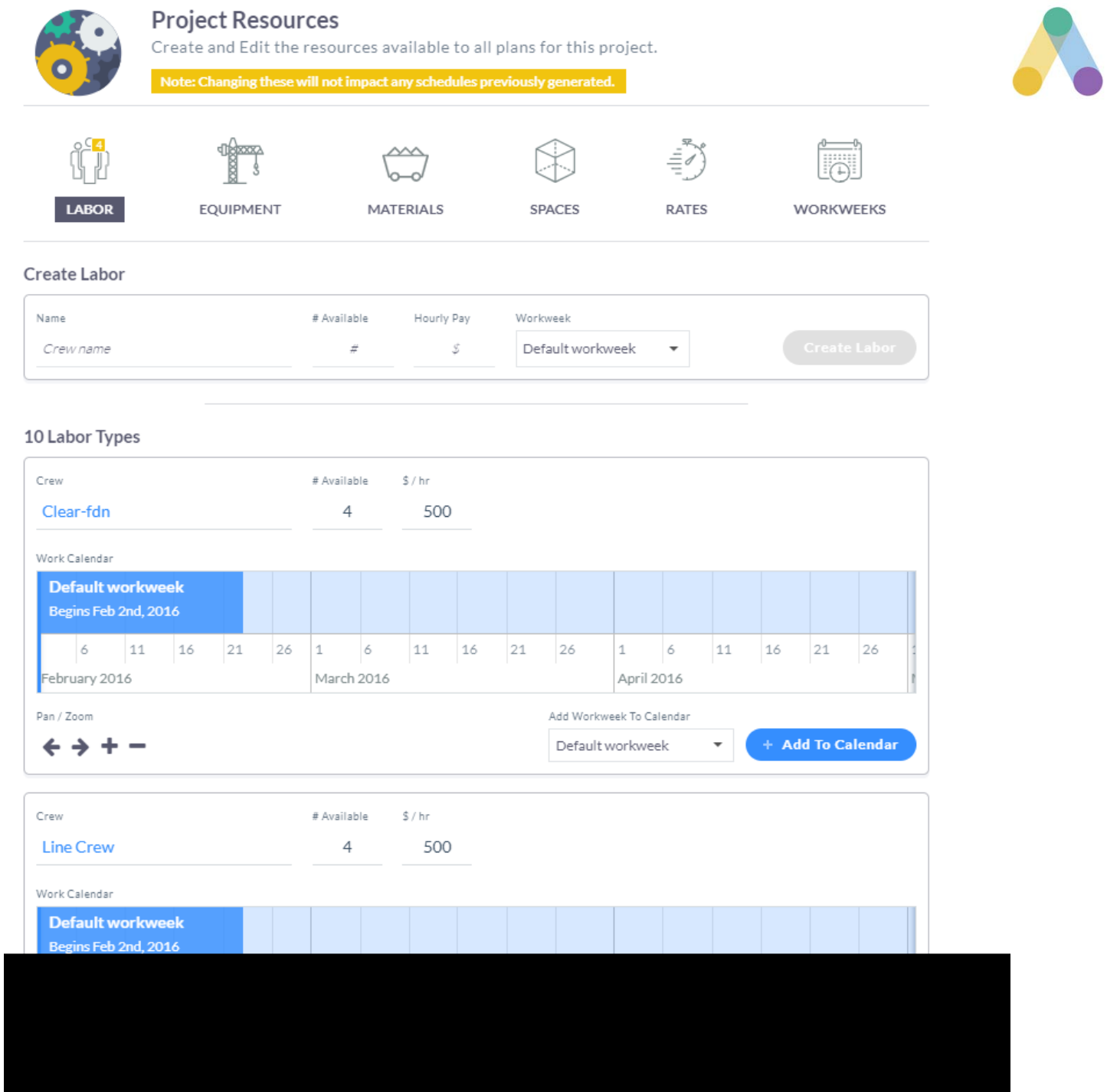


What are Resources?

- Resources are supplied and used to carry out the work of the construction project
- Onsite resources may be discrete or unary
- Labor, Materials, and Equipment are discrete and usually defined with positive integer values
- Space is a unary resource, meaning that it cannot be increased if overlapping with another space
- The addition of more resources may cause a combination of outcomes
  - Fast-tracking – more activities occurring in parallel
  - Crashing – shortening the duration of activities
  - No effect – the addition of more resources will not impact schedule

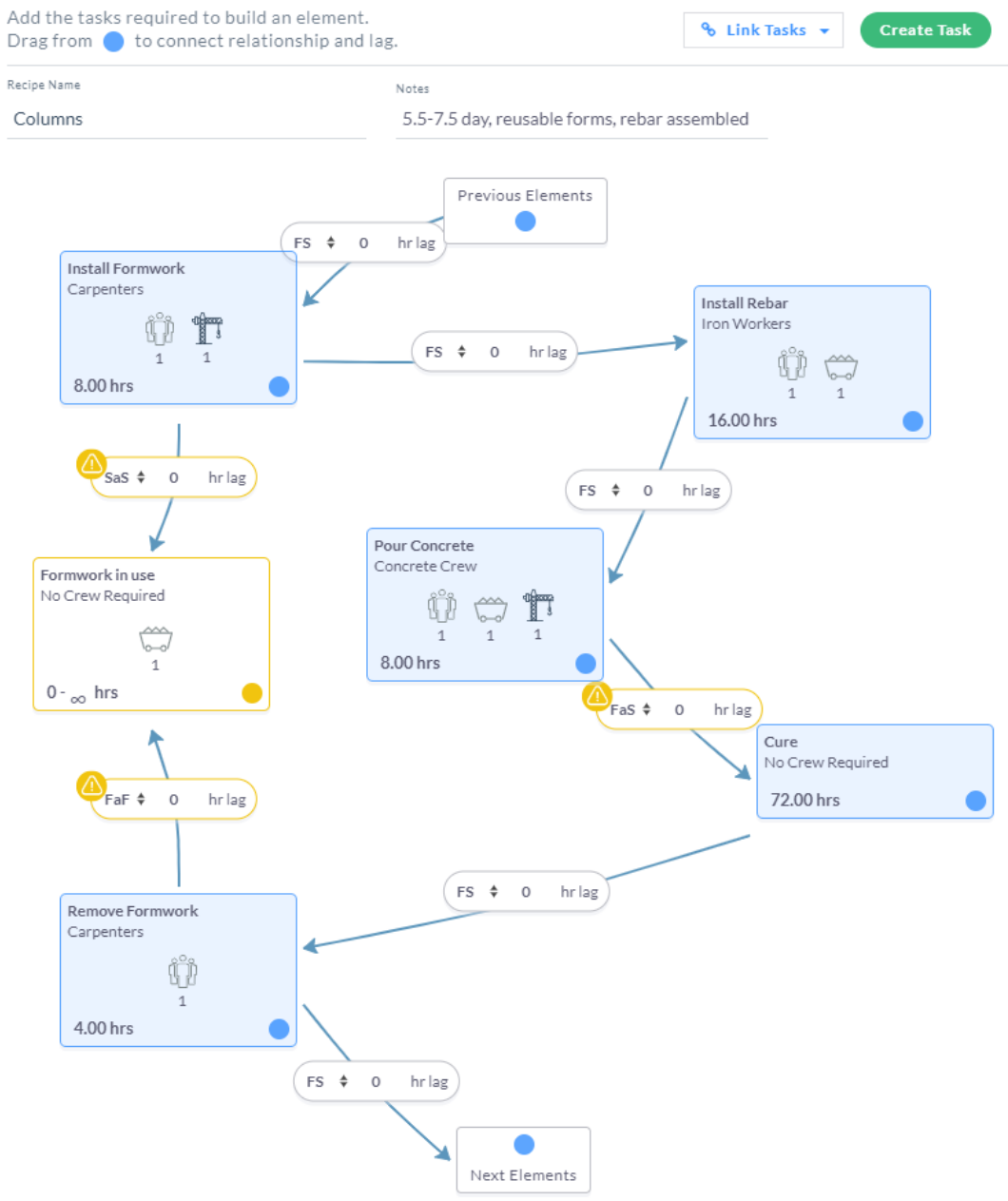
Resource Pool

- **Labor Crews** have calendars, # available and cost/work-hour
- **Equipment** have # available and cost/work-hour
- **Materials** have type, # available, and unit cost
- **Spaces** have type and capacity



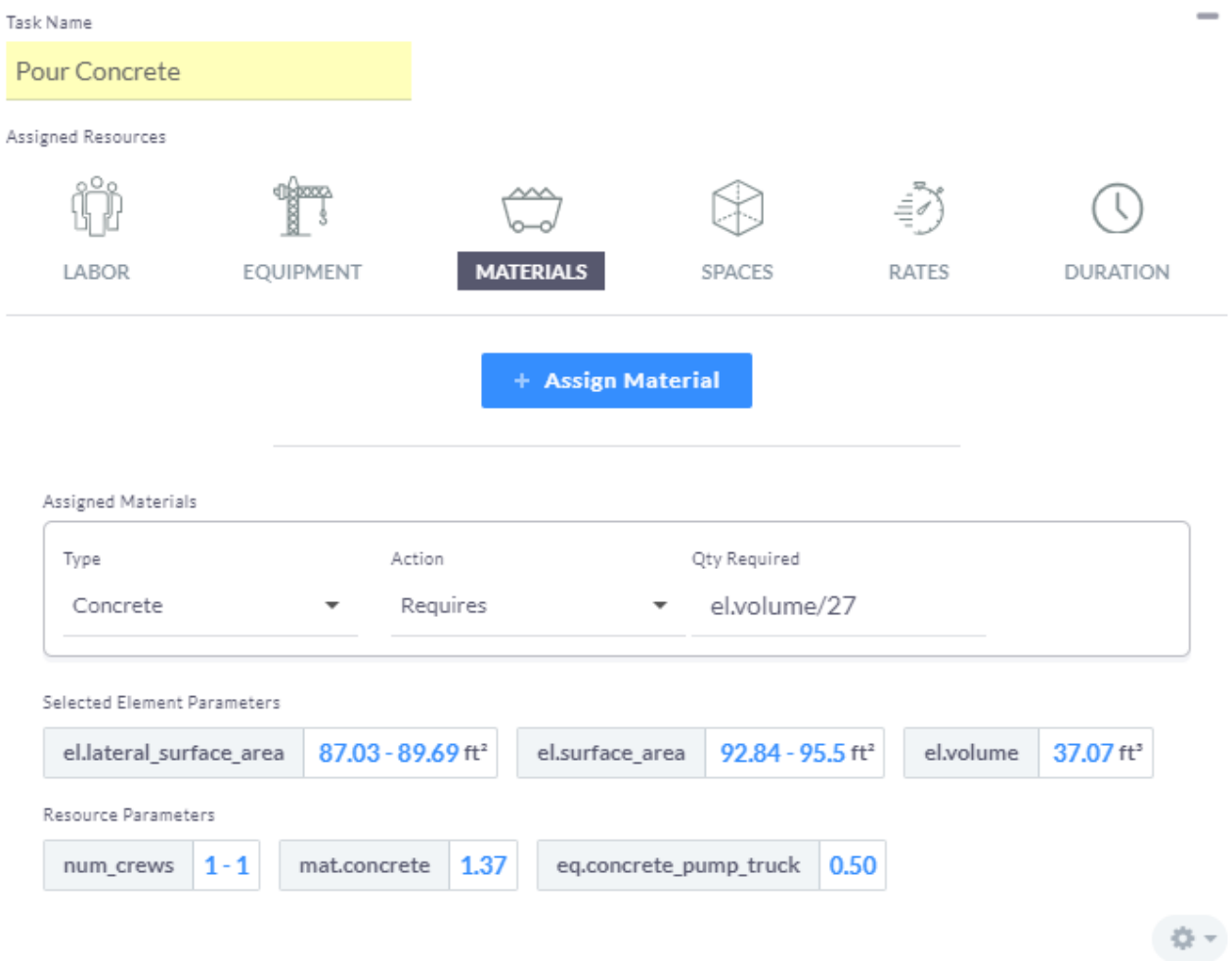
Creating Resource Use Requirements

- Recipes are the core of creating rules in ALICE
- Recipes are tied to 3D elements from a BIM – e.g. 1 recipe for all columns
- Support relationships between elements tie together recipes



Creating Resource Use Requirements

- Operations within recipes define resource requirements
- Calendars are crew specific
- Equations and geometric properties can be used to determine amounts of resources



Outline

- Introduction to an AI-Scheduler
- Definition of Resources
- How many workers?
- How much formwork?
- How many cranes?
- Conclusions

Case Study: How many workers?

Description of Task	Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sawcut AC	Subcontractor Work	X															
Remove AC	2 Workers	X															
Excavate Trench	2 Workers		X	X	X												
Compaction	1 Worker				X												
Drill & Epoxy Dowels	4 Workers			X	X	X											
Install Rebar	Subcontractor Work					X											
Set up Forms	4 Workers					X	X										
Install Trough	4 Workers					X	X										
Pour Concrete Lift 1	Self Perform							X									
Pour Concrete Lift 2 & 3	Self Perform								X								
Strip Forms (3 days after Lift 2)	Self Perform											X					
Install Drain Rock	4 Workers											X					
CLSM	2 Workers											X					
Base Course	3 Workers												X				
Pave	Subcontractor Work													X			
Pull Belt	2 Workers														X	X	X

Max 12 workers onsite Day 5, currently have 10 workers hired

Duration Calculations

Task Duration

8*3*2 / num_crews

Crew size

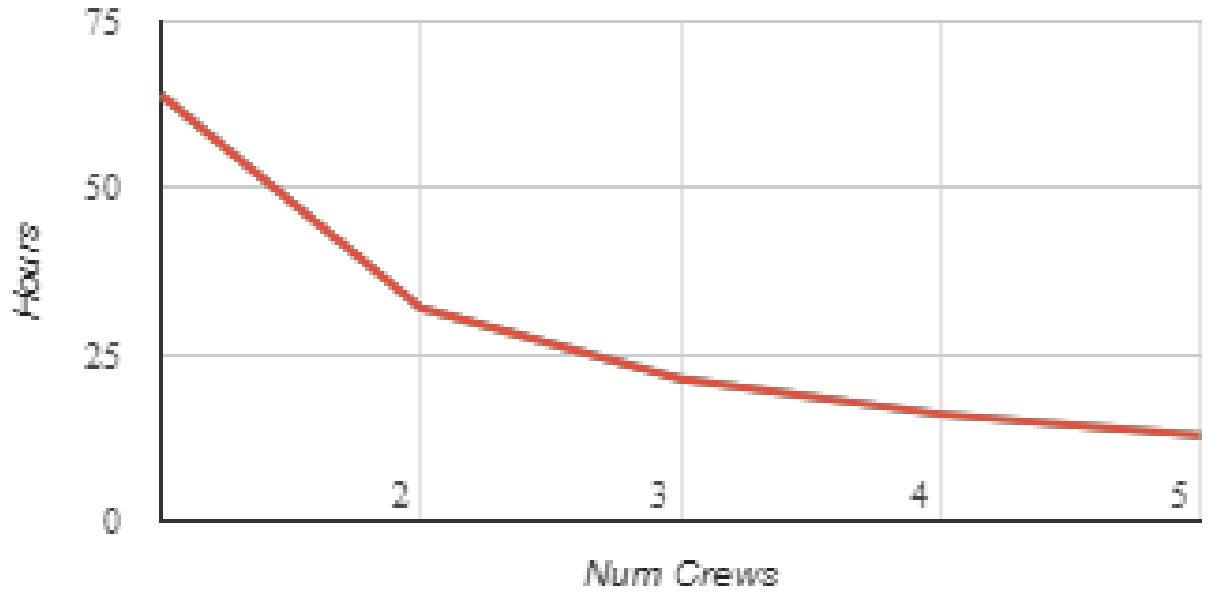
Number of Workers

Task Duration

Worker-hours / Num. of Workers = Hours

12.8 - 64

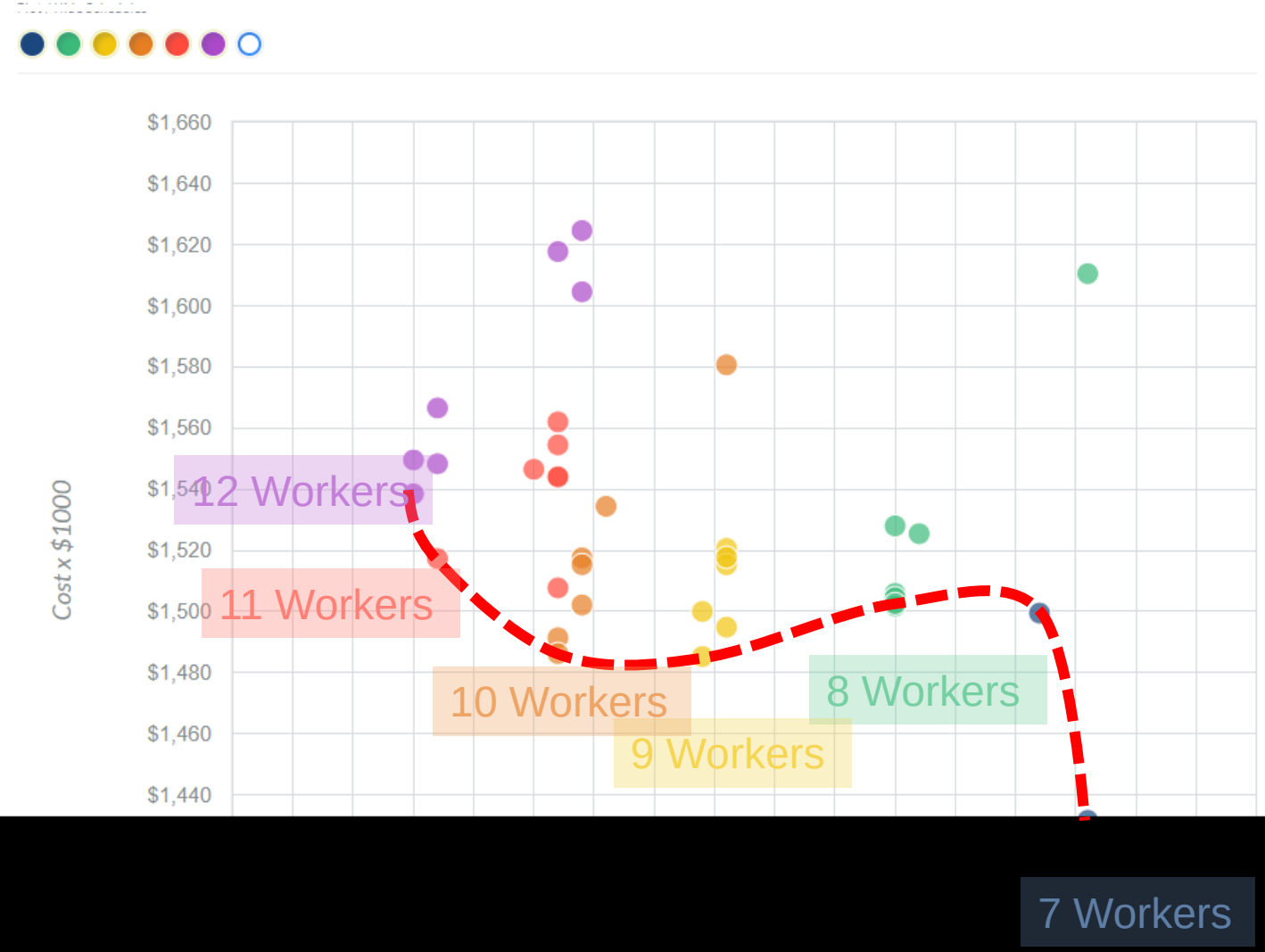
crew hours

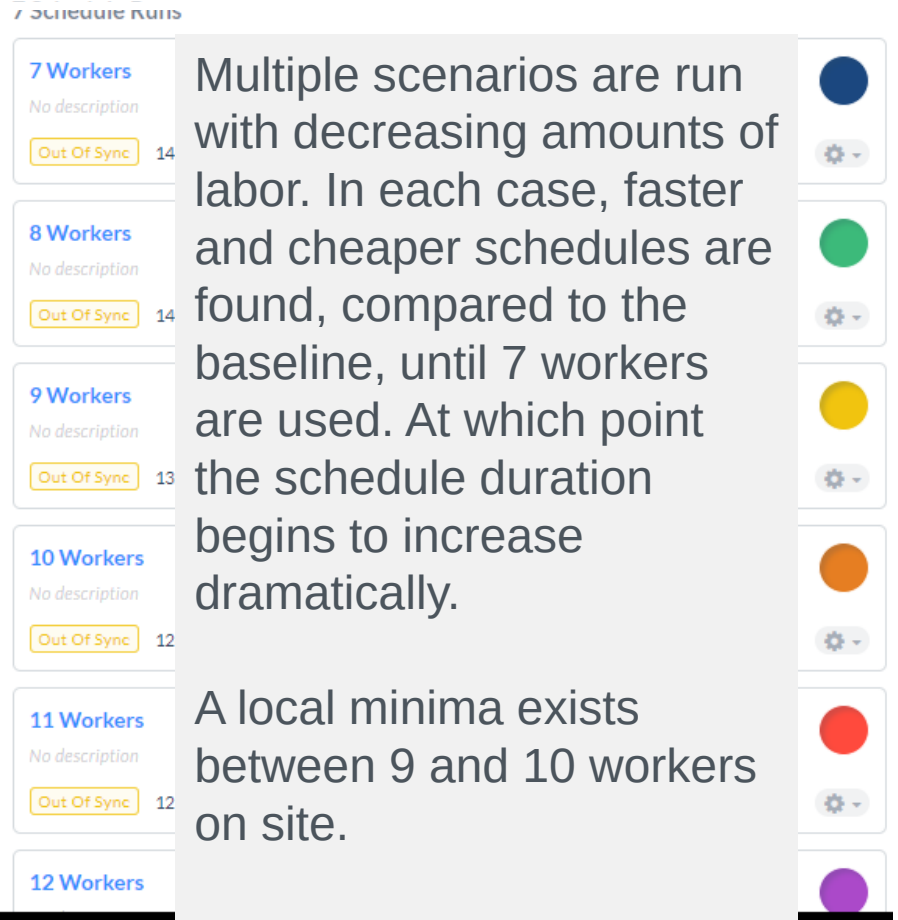


- Task durations were allowed to vary by the number of workers allowed on each task.
- Durations were calculated by converting original task durations into man-hours and then dividing by the number of available men

Note: ALICE currently only allows for up to 5 men to assigned to an operation

ALICE Schedule Results





Multiple scenarios are run with decreasing amounts of labor. In each case, faster and cheaper schedules are found, compared to the baseline, until 7 workers are used. At which point the schedule duration begins to increase dramatically.

A local minima exists between 9 and 10 workers on site.

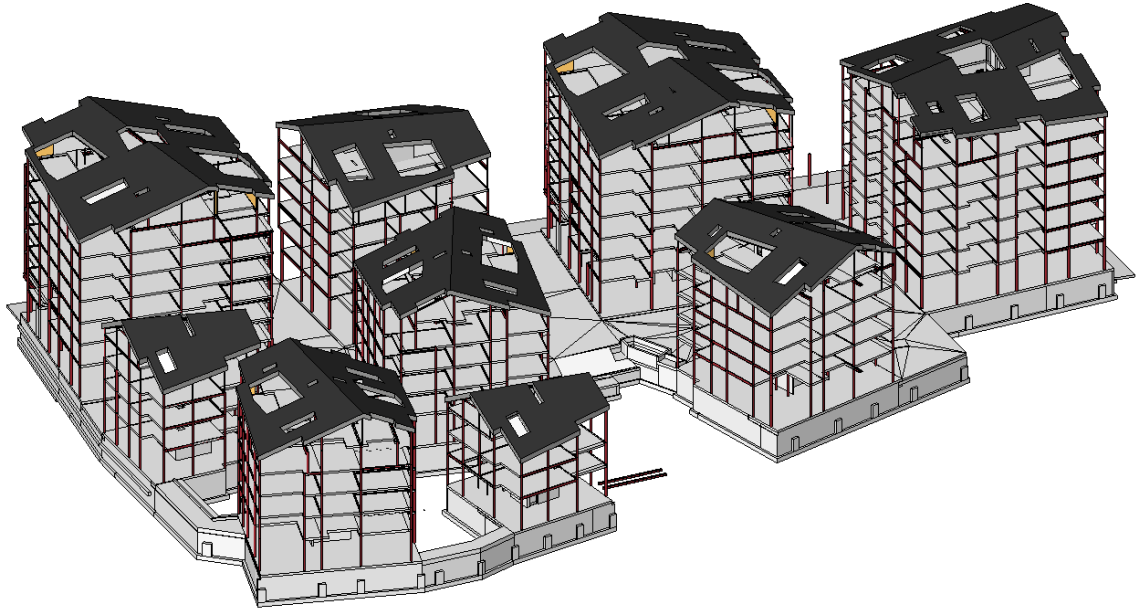
This analysis assumes that workers can be assigned to any task and that any task may have up to 5 workers working on it.

ALICE Fragnet with 7 Workers

		Day #															
Description of Task	Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sawcut AC	Subcontractor	X															
Remove AC	4 Workers	X															
Excavate Trench	5 Workers		X	/													
Compaction	1 Worker		X	/													
Drill & Epoxy Dowels	4 Workers			\	X	/											
Install Rebar	Subcontractor				X	X											
Set up Forms	3 Workers			\	X	X	X	X									
Install Trough	4 Workers					\	X	X									
Pour Concrete Lift 1	Self Perform							X									
Pour Concrete Lift 2 & 3	Self Perform								X								
Strip Forms (3 days after Lift 2)	Self Perform											X	X				
Install Drain Rock	5 Workers											/					
CLSM	5 Workers											\					
Base Course	5 Workers												X				
Pave	Subcontractor												X	X			
Pull Belt	5 Workers													X	X		

Note: '/' denotes starting first half of day and '\' denotes starting second half of day

Case Study: How much formwork?



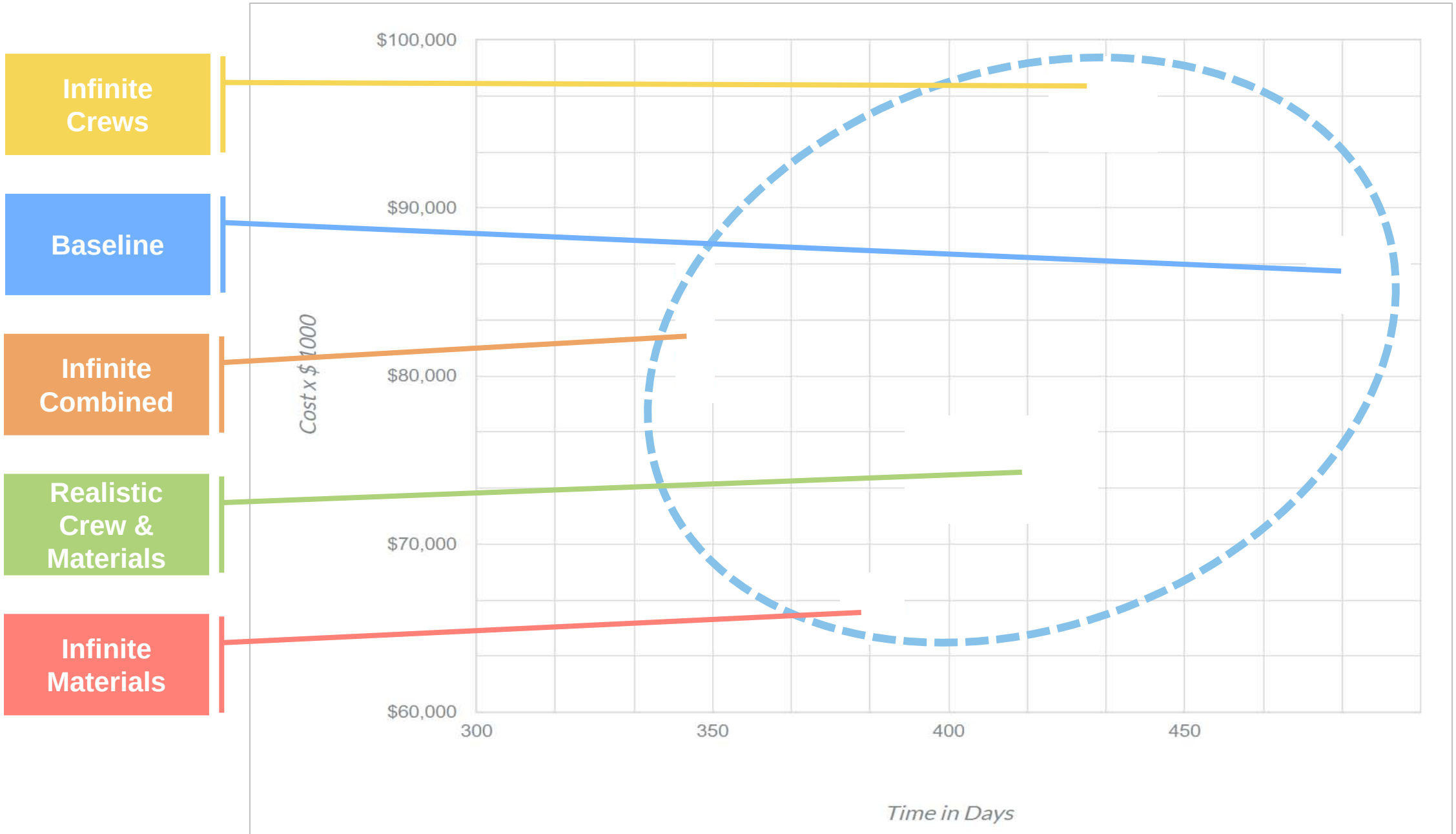
ALICE Scope

- Structural elements
  - Concrete slabs, columns, and walls
  - Steel columns and beams
  - Roofing elements

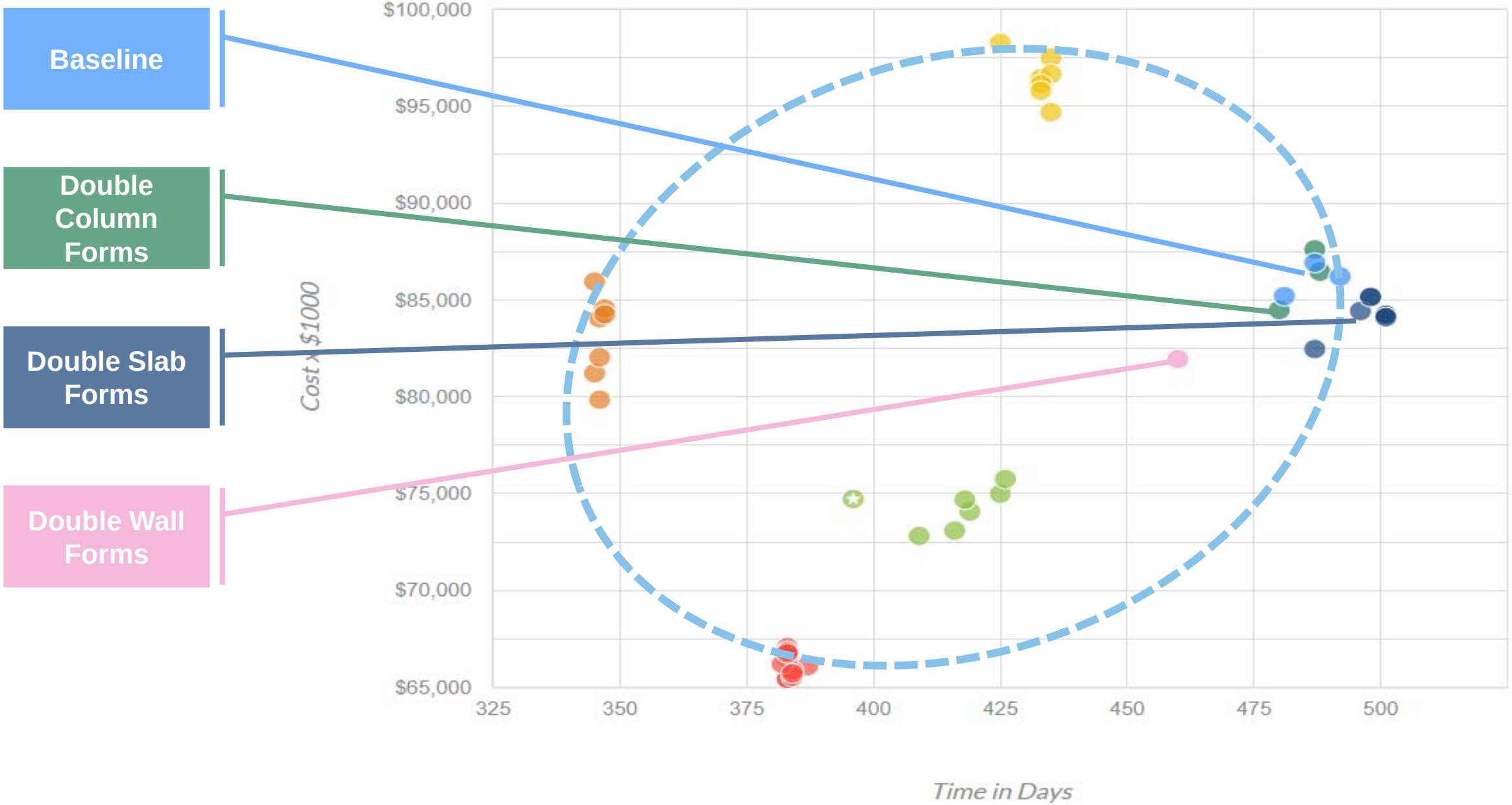
Resource Constraints

- Equipment
  - There are 5 stationary tower cranes that will be available on the project.
  - The crane installations are phased throughout the project
  - Crane 1 is available before Crane 2, etc.
- Materials
  - There are three different types of formwork:
    1. Columns
    2. Walls
    3. Slabs
- Labor
  - Not all crews are available at the start of the project

Case Study: How much formwork?



Case Study: How much formwork?



Case Study: How much formwork?

Scenario	Duration Calendar Days	# of Schedules Created	Duration Savings	Cost Savings	Wall Formwork	Column Formwork	Slab Formwork
Contractor Baseline	**500**	**1**	**Baseline**	**N/A**	**6**	**4**	**3**
ALICE Baseline	481	3	4%	N/A	6	4	3
Infinite Crew	425	7	15%	-12%	6	4	3
Infinite Materials	382	14	24%	24%	40	40	40
Infinite Combined	345	7	31%	6%	40	40	40
Realistic Crew & Materials	**396**	**7**	**18%**	**15%**	**10**	**4**	**5**

Case Study: How many cranes?

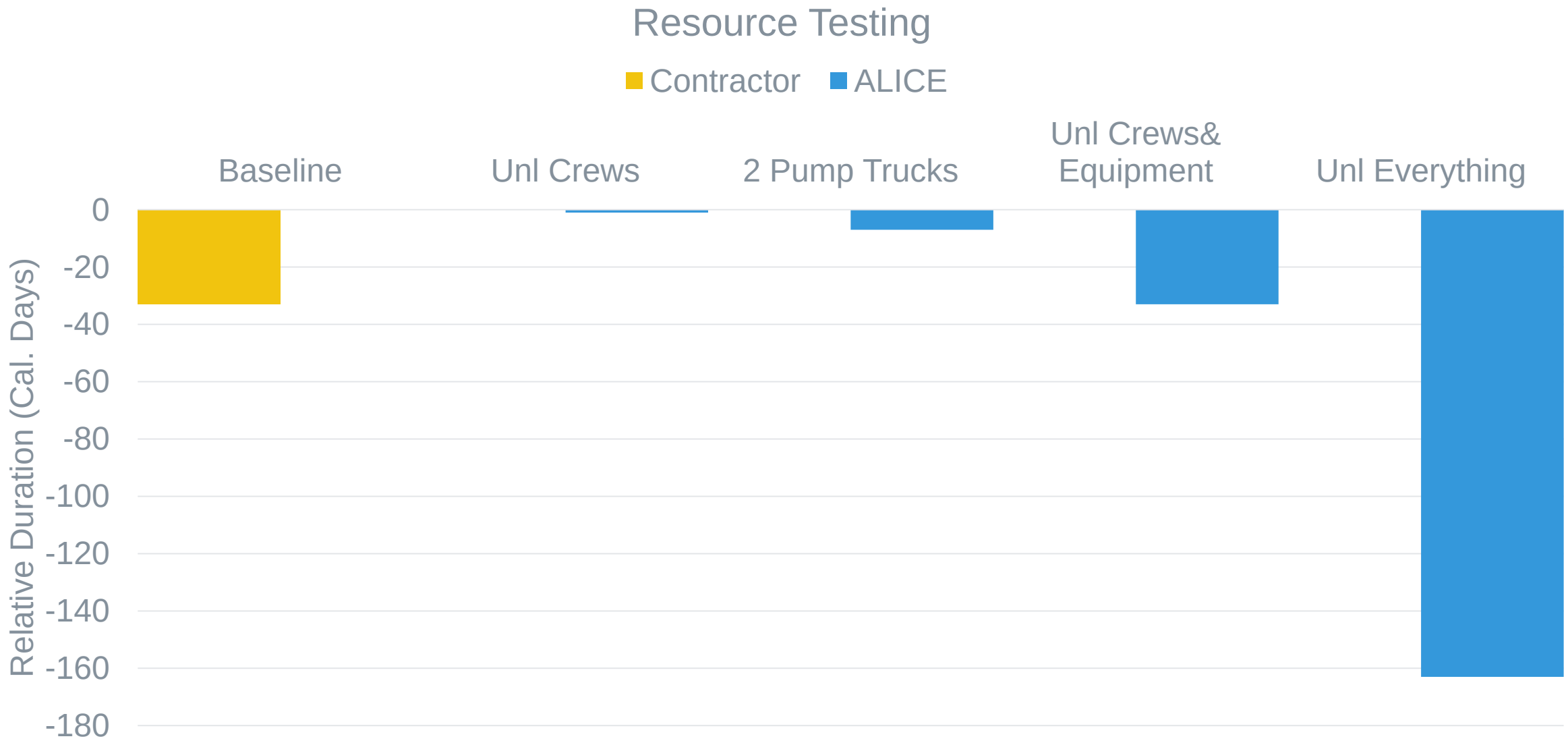
ALICE Scope

- High rise building
- Structural elements
  - Basement excavation
  - Concrete slabs, columns, and walls
  - Façade elements

Constraints/Scenarios

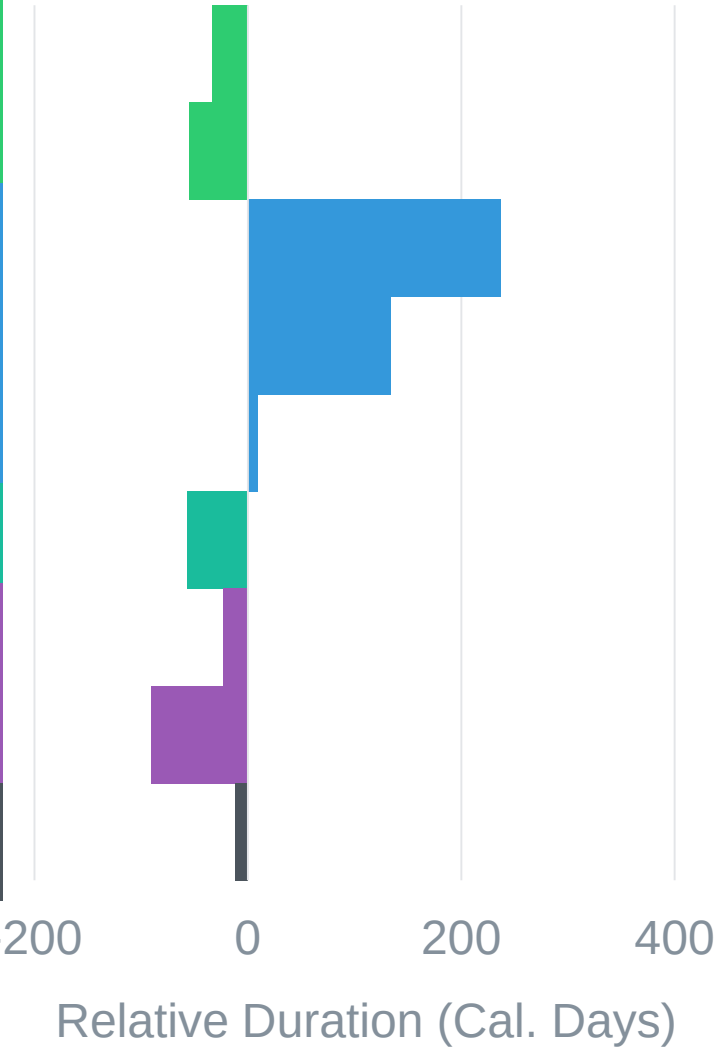
- Equipment
  - Current assumption is 1 crawler crane working lower floors and 1 tower crane working two shifts
  - Want to challenge assumption of nightwork permit
  - Pump truck required for large basement footprint
- Materials
  - 1 Set of formwork for core and deck system
  - Façade panels currently do not include windows
- Labor
  - Second shift for nightwork façade install

Case Study: How many cranes?



Case Study: How many cranes?

Cost	Duration	Scenario	
0%	0%	Nighttime Crane Use	1 Tower, 1 Mobile (Baseline)
-7%	-8%		2 Tower Cranes
19%	34%	Daytime Crane Use only	1 Tower (builds podium), 1 Mobile
3%	19%		1 Tower, 1 Mobile (builds podium)
-8%	1%		2 Tower Cranes
-7%	-8%	Nighttime Precast	2 Tower Cranes
-8%	-3%	Nighttime Glazing in Precast	1 Tower, 1 Mobile
-11%	-13%		2 Tower Cranes
-11%	-2%	Daytime Glazing in Precast	2 Tower Cranes



Conclusions

- New technology allows for quick development and iteration of logic- and resource-constrained schedules
- Schedules can both be resource-constrained or logic-constrained at different times within a schedule
- Resource constrained schedules require new techniques for analysis
- Unlimited resource schedule runs are a valuable technique for determining purely logic-constrained durations and the impact of different categories of resources
- Paired with what-if scenarios, valuable insights can be quickly gleaned prior to entering the field