Symptom: Too much inventory too soon on site

Mega-projects:

- 98% are facing **cost overruns** of more than 30%
- 77% are at least 40% **late**

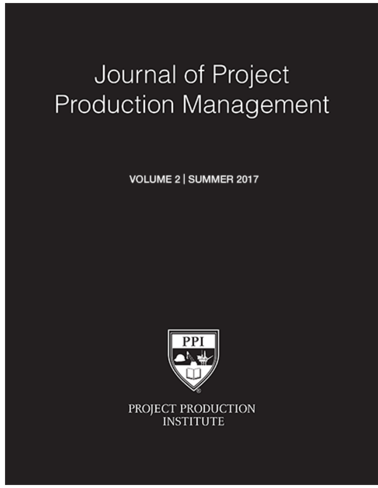
❖ McKinsey & Company

Mega-projects in oil and gas industry:

- 64% suffer **cost overruns**
- 73% are **late**

❖ E&Y

INTERVIEWS



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Question: Is it true that capital project supply chains operate on or near the so-called "Efficient Frontier"?

Not at all. We are working to change all that as a company.

Also, what we want to do is like the manufacturing world where deliver JIT.

There is probably a smarter way to do it.

I do think that the systems are fairly efficient.

I am not sure that there is a better way.

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Is it efficient that you ask for delivery significantly before material is required on site?

Although it's not efficient, if we delay a project, that has far more cost than equipment sitting around for 30 days.

There are complex models that are used to develop and sanction projects.

So, I don't think that it's inefficient.

How reliable are the tools and techniques? Can you describe projects where these tools and techniques have improved project reliability?

We meet 50% of our project schedules, however my own view is the schedules that are met are not world class and tend to be longer than the competition.

In my experience, the tools themselves are generally reliable. My confidence in their output increases with the skills and experience of the planners, estimators and project managers who develop and utilize the tools.

These tools and processes are less robust and so project teams focus on leveraging relationships and collaborative problem solving when faced with project delays.

Robustness is defined as lack of sensitivity to variability and unforeseen disruptions.

We set out to build **Stylized** models to explore the interplay between robustness and on-site inventory in projects.

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As a starting point, we model the problem as an RCPSP

The resource-constrained project scheduling problem (RCPSP) is a well-known standard problem in the context of project scheduling in the literature.

Basic Goal:

Find a plan that minimizes project duration.

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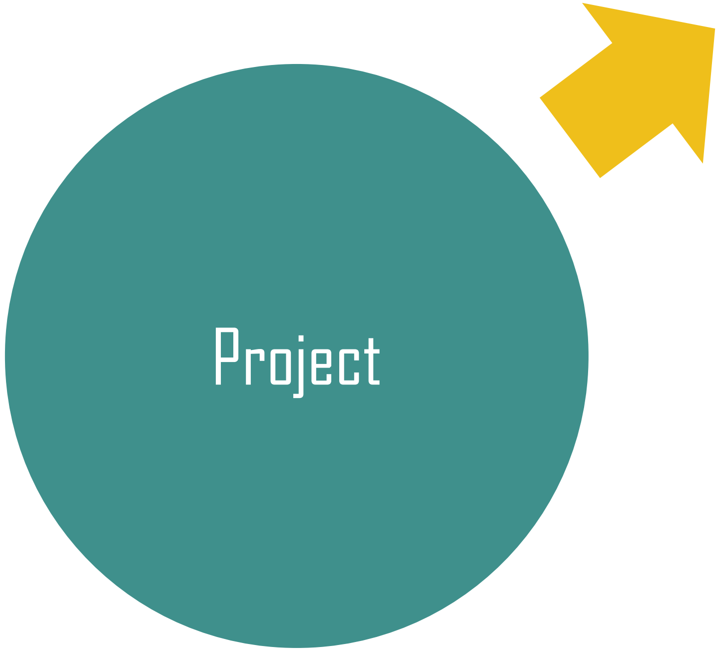

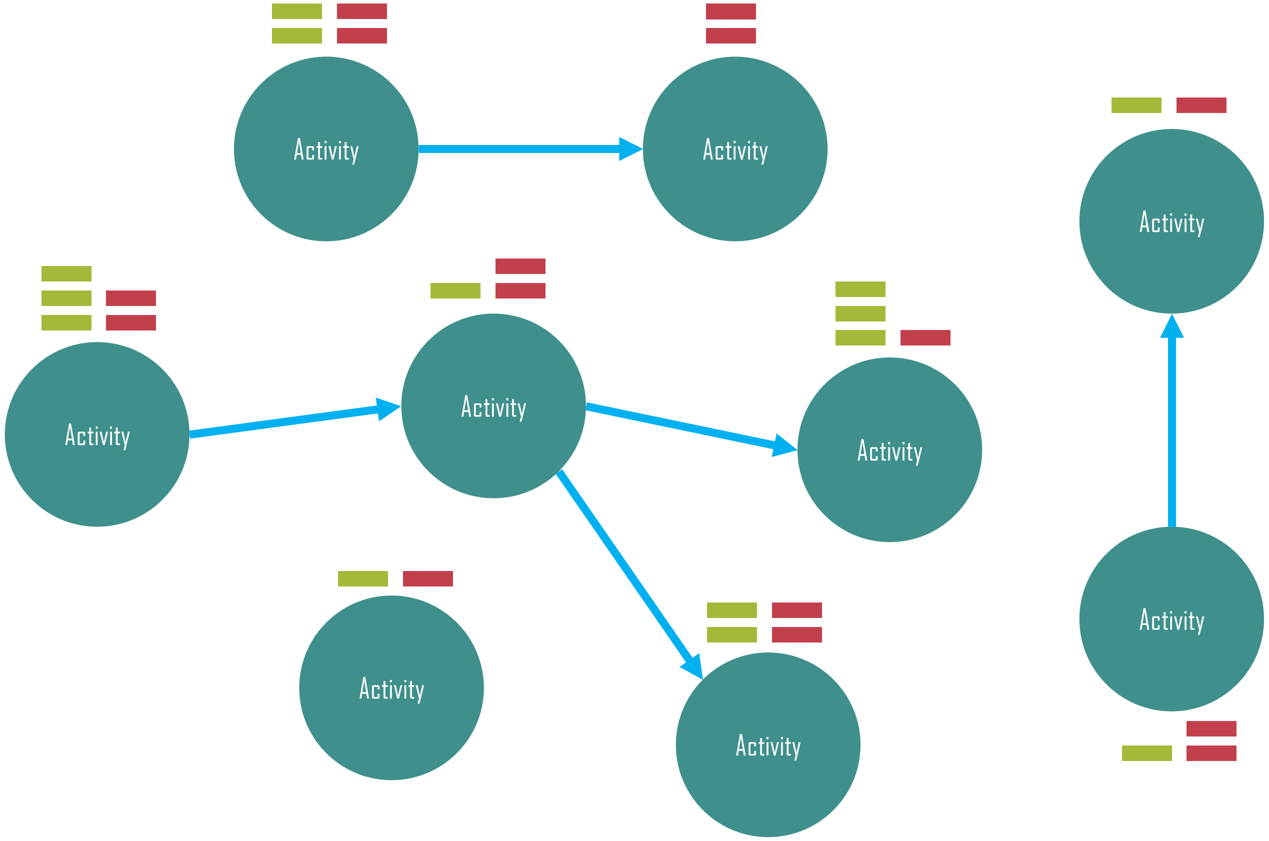

Activities

Precedence Constraints

Renewable Resources

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Renewable Resources vs. Material Inventory

Manpower, machines, tools, space.

Plan vs. Schedule

Plan is the flow of resources.

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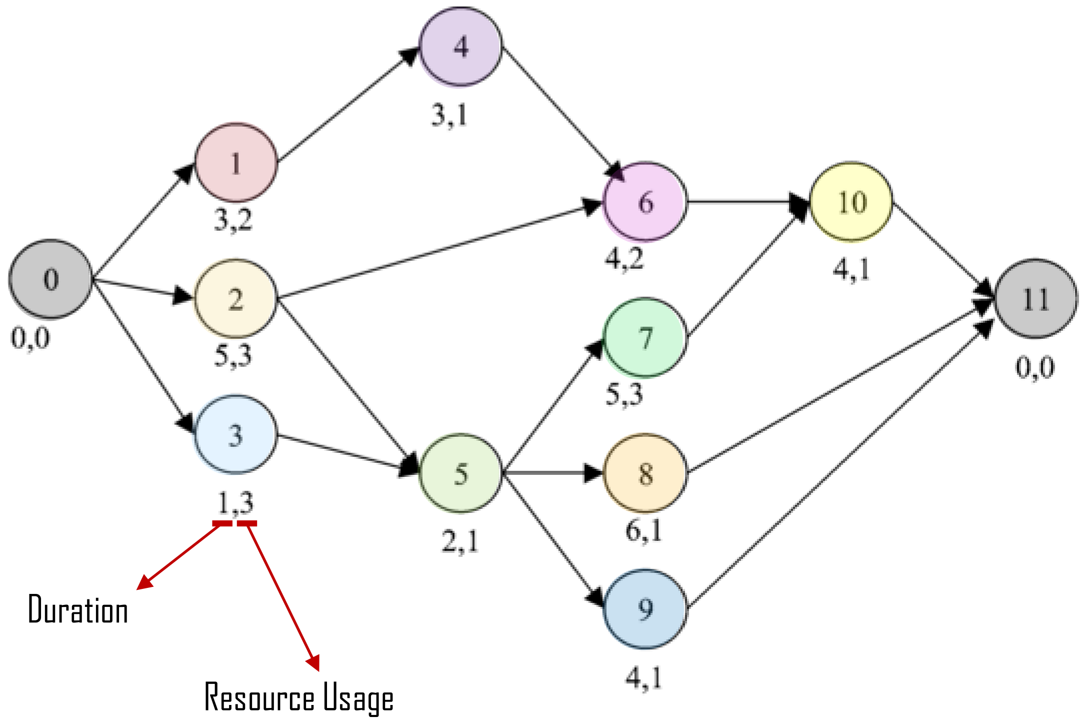
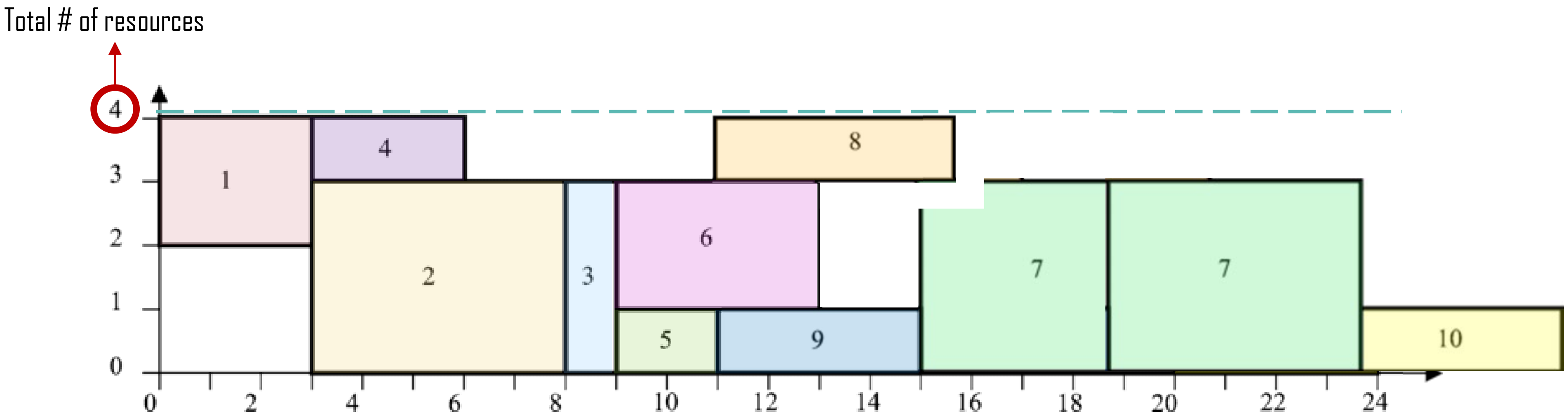
The Challenges of the **Stochastic** Resource-Constrained Project Scheduling Problem





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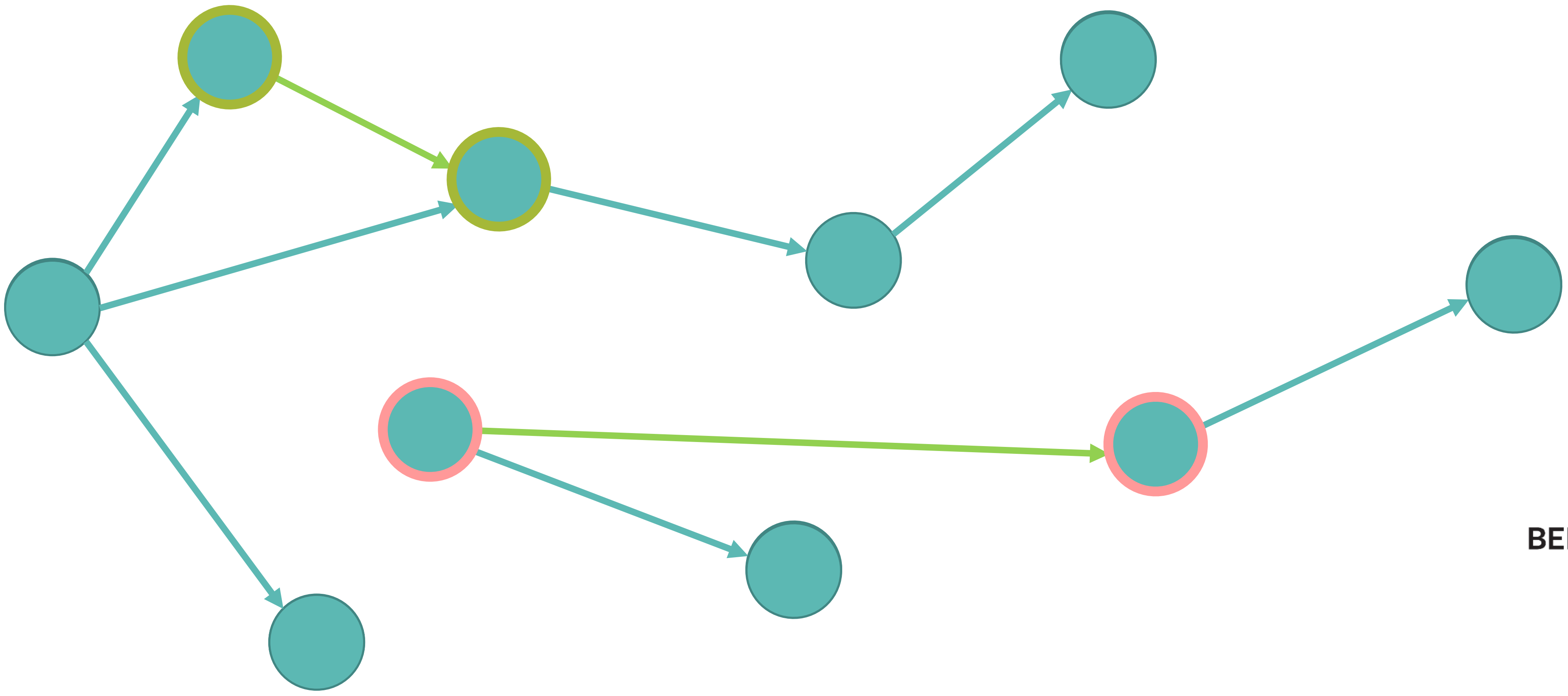
❖ A RCPSP example (Klein and Scholl, 1999)

Solving this challenging (NP-Hard) problem…

Flow-based Continuous-time Formulation (**FCT**)

Set of the additional arcs for the **Flow of Resources**: A



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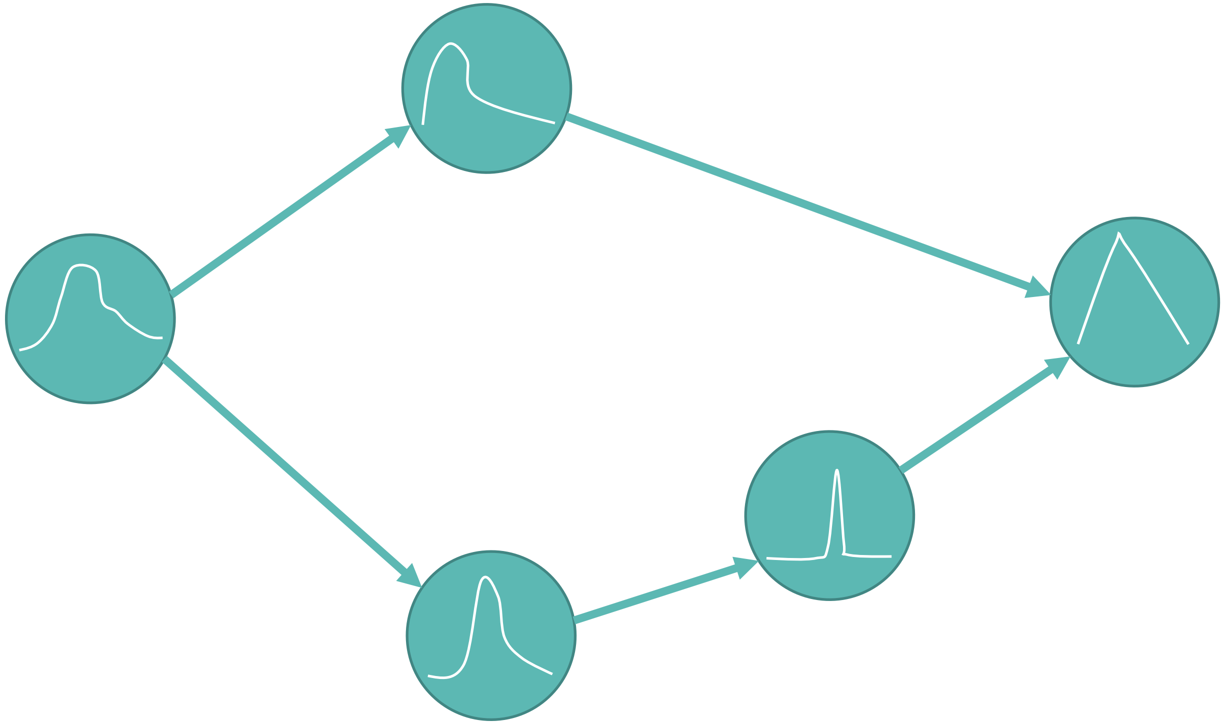
To account for the distribution of the duration of activities, it is effective to consider many **scenarios** in the mathematical model.



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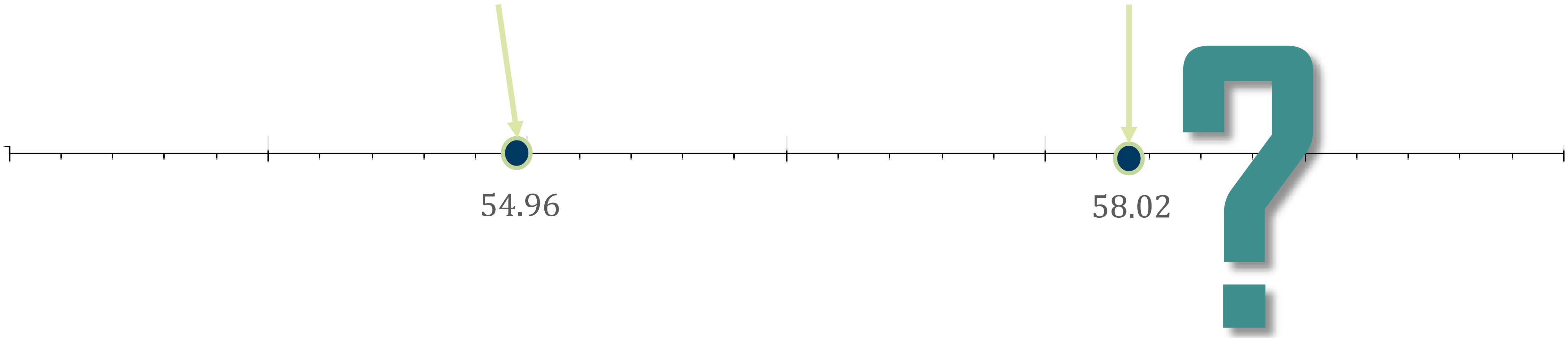
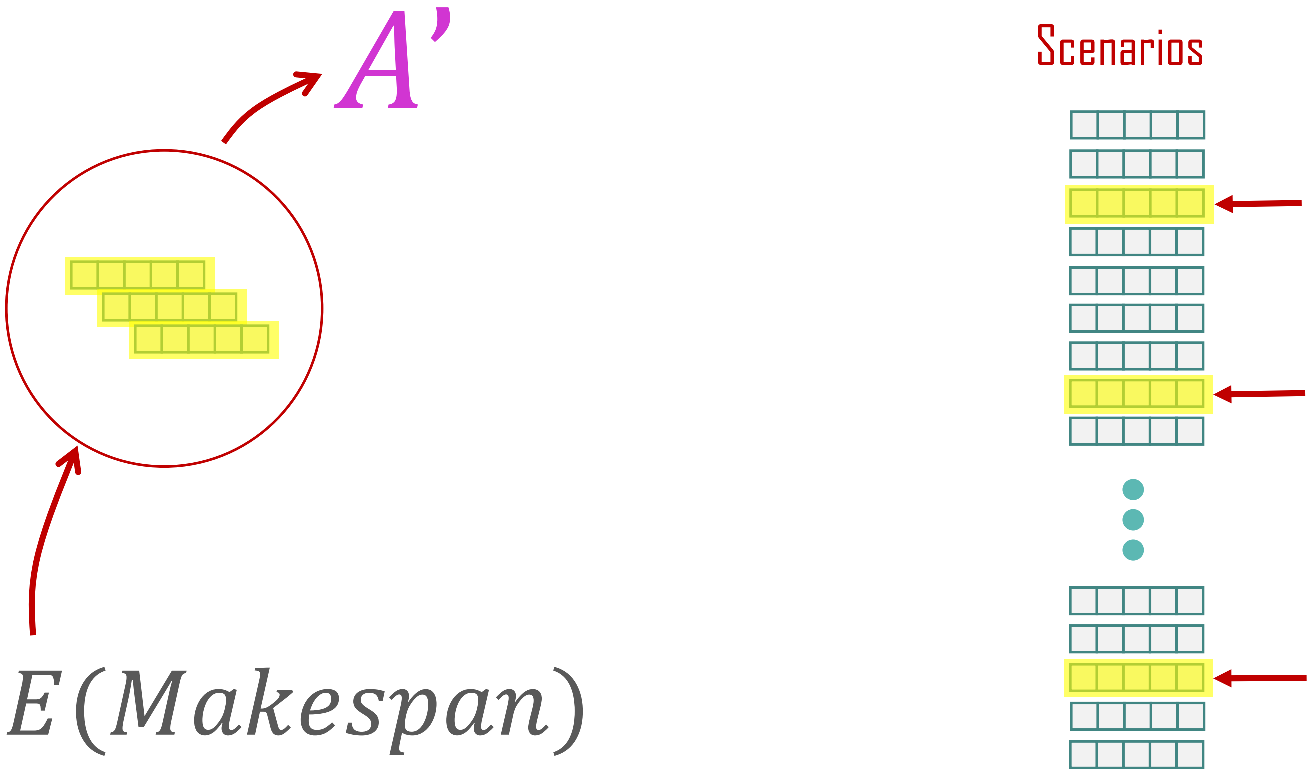
3000 scenarios

$\min Makespan\ (using\ naive\ traditional\ approaches)$: A

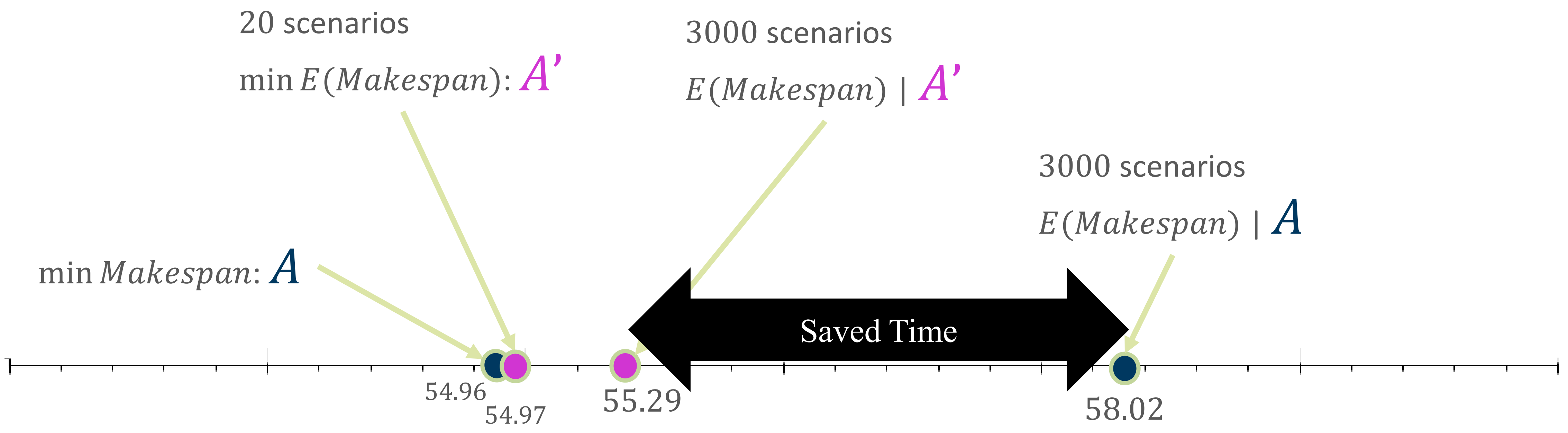
$E(Makespan)\ |\ A$



SAMPLE AVERAGE APPROXIMATION METHOD (SAA)



$$\min E(Makespan)$$



OBSERVATION:

SAA converges to the optimal solution as the **cardinality** of the scenario set increases.

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Test Problems

The Library PSBLIB

30 activities

$[1 \ldots 48] * 10 = 480$ problems

Parameter	Levels			
NC	1.50	1.80	2.10	
RF_R	0.25	0.50	0.75	1.00
RS_R	0.20	0.50	0.70	1.00

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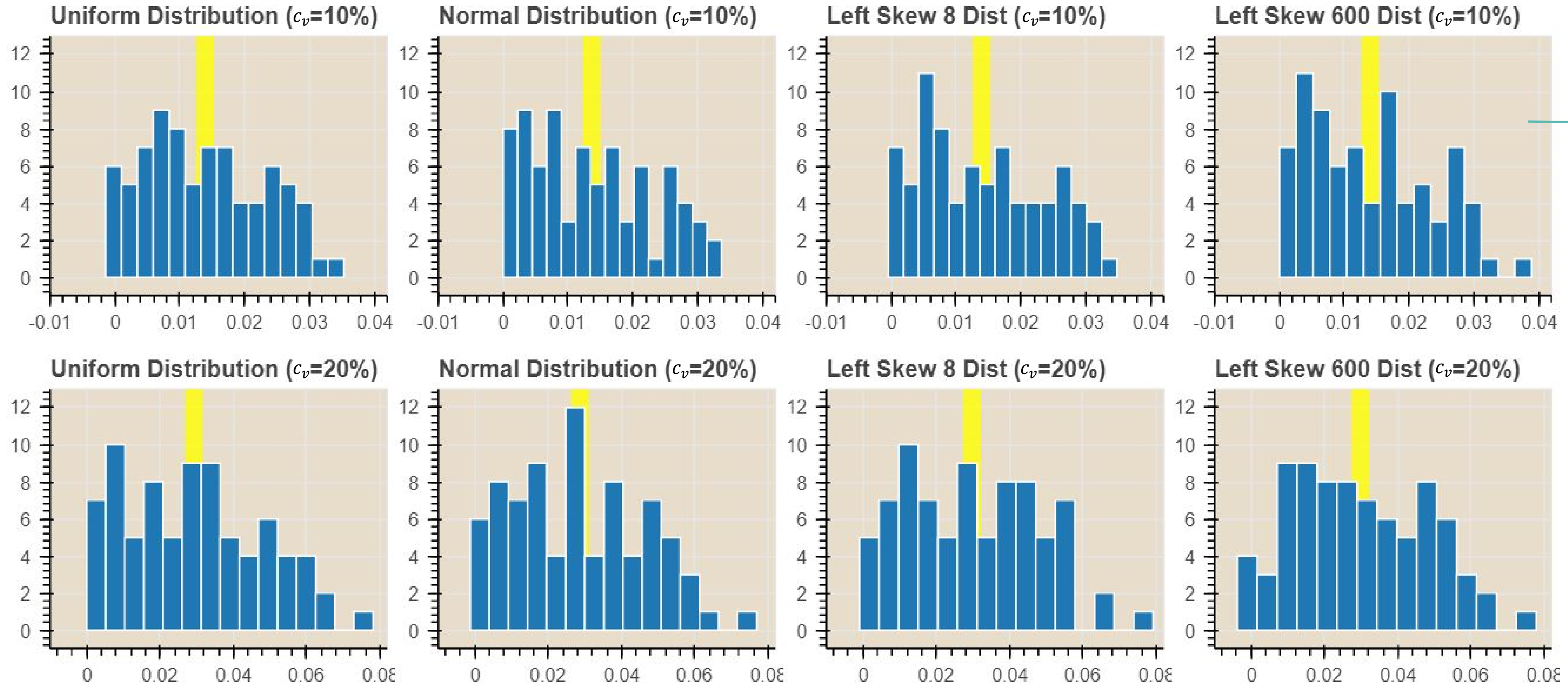
1.390%	1.370%	1.395%	1.399%



2.926%	2.868%	2.972%	2.980%

Mean of Saved Times (%)

Distribution of Saved Times

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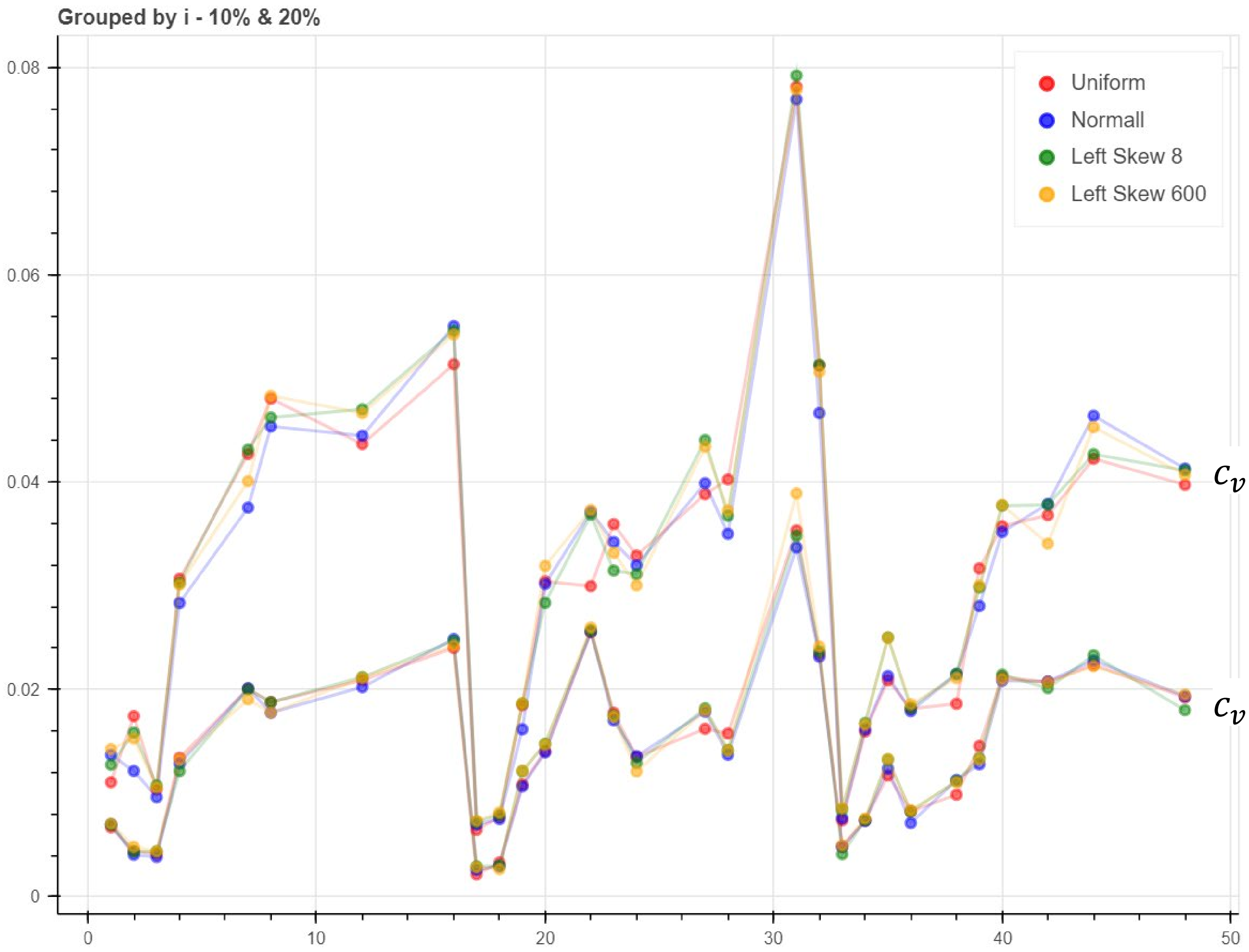

$c_v = 0.2$

$c_v = 0.1$

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OBSERVATION:

There is no strong **association** between $Saved\ Time$ and the distribution of each activity.

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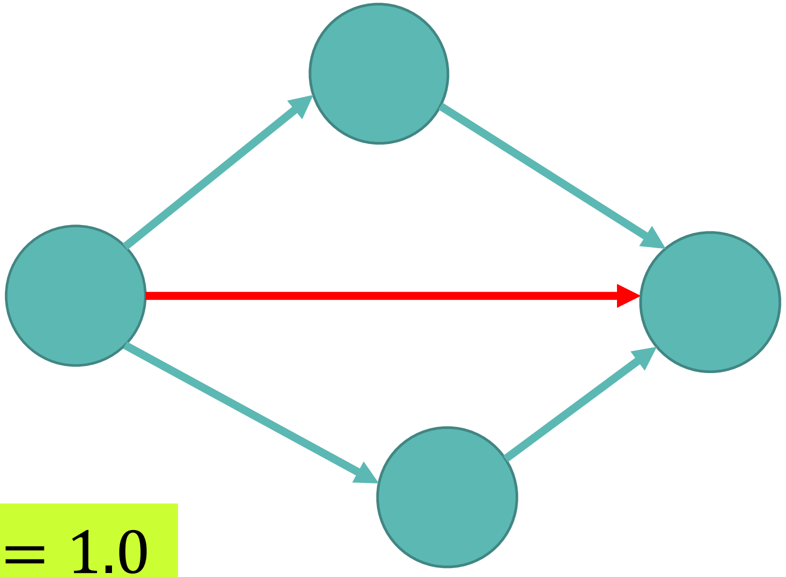
Network Complexity (NC)

The average number of **non-redundant** arcs per node (including source and sink).



$NC = 1.0$

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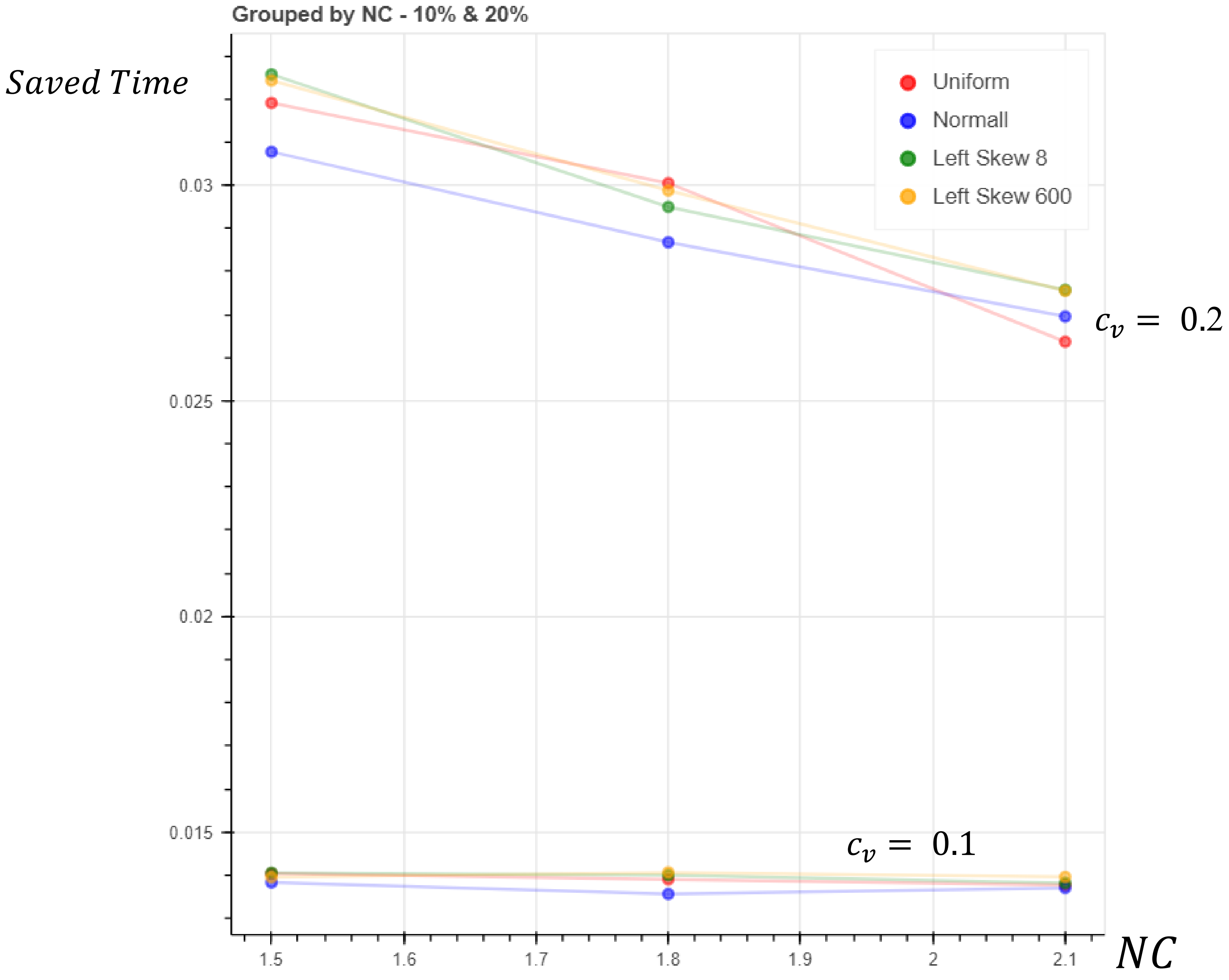

Grouped by NC - 10% & 20%
Saved Time
Uniform
Normall
Left Skew 8
Left Skew 600
0.03
0.025
0.02
0.015
1.5
1.6
1.7
1.8
1.9
2
2.1
NC
$c_v = 0.2$
$c_v = 0.1$

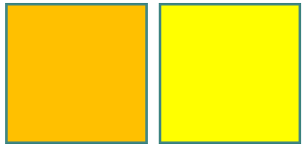
Resource Factor (RF_R)

- Reflects the density of the coefficient matrix (k_{jr})

$$RF_R = \frac{1}{J|R|}\sum_{j=1}^{J}\sum_{r\in R}\begin{cases}1, & if \;\; k_{jr} > 0\\ 0, & otherwise\end{cases}$$

J: Number of activities
$|R|$: Cardinality of types of resources (two in this example)
k_{jr}: Number of resource type r that activity j needs

Resources



$RF_R = 0.75$

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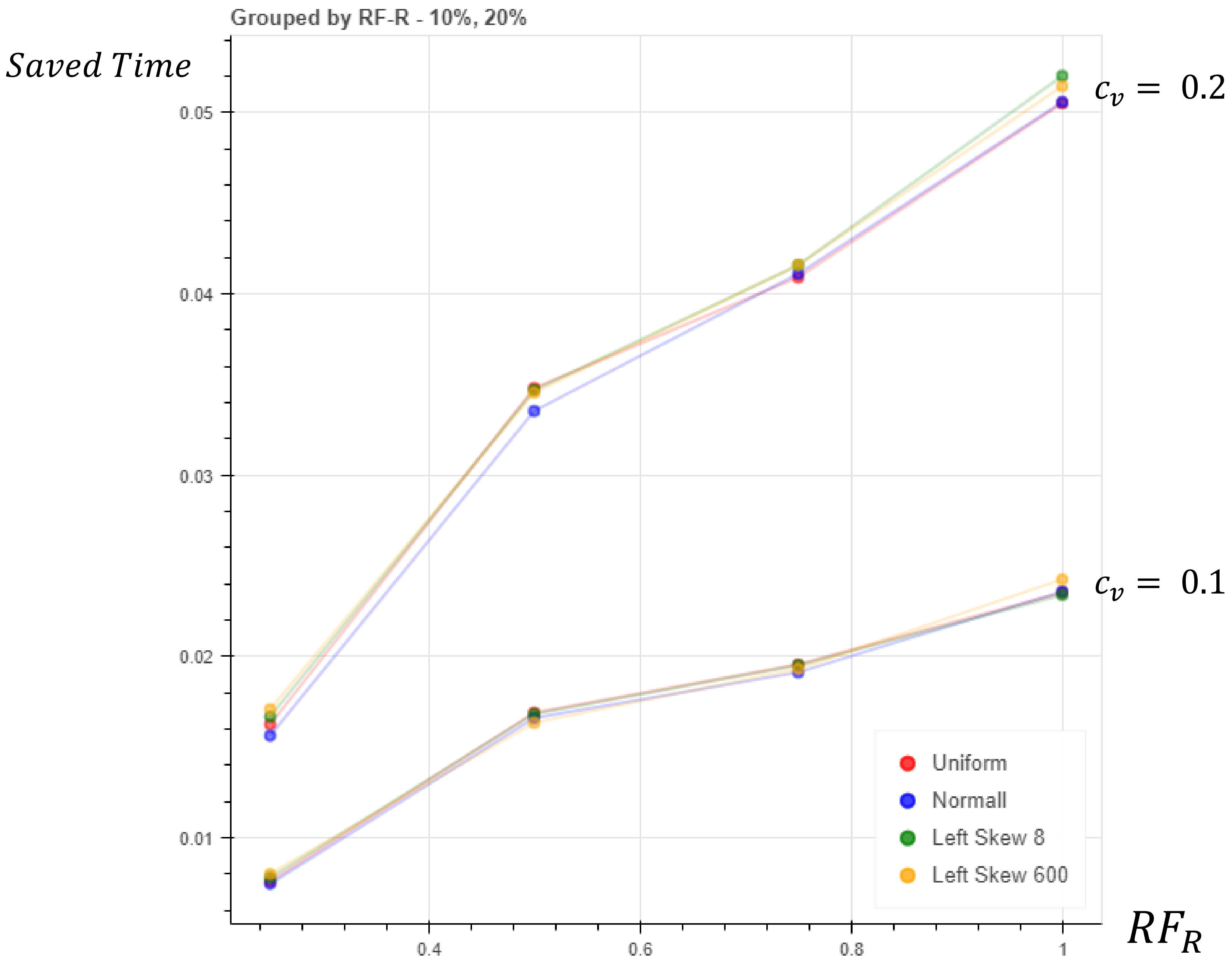

Grouped by RF-R - 10%, 20%
Saved Time
0.05
0.04
0.03
0.02
0.01
0.4
0.6
0.8
1
$c_v = 0.2$
$c_v = 0.1$
Uniform
Normall
Left Skew 8
Left Skew 600
RF_R

Resource Strength (RS_R)

- Measures the availability of resources

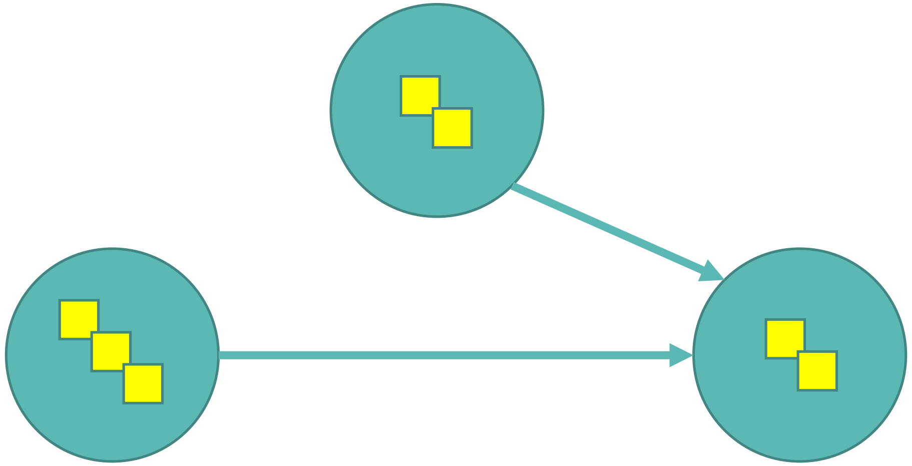
$$RS_r = \frac{K_r - K_r^{min}}{K_r^{max} - K_r^{min}}$$

K_r: Quantity of resource type r
K_r^{min}: The minimum required quantity of resource type r to have a feasible plan
K_r^{max}: The required quantity of resource type r to have the smallest makespan

Resources

4

$RS_R = 0.5$



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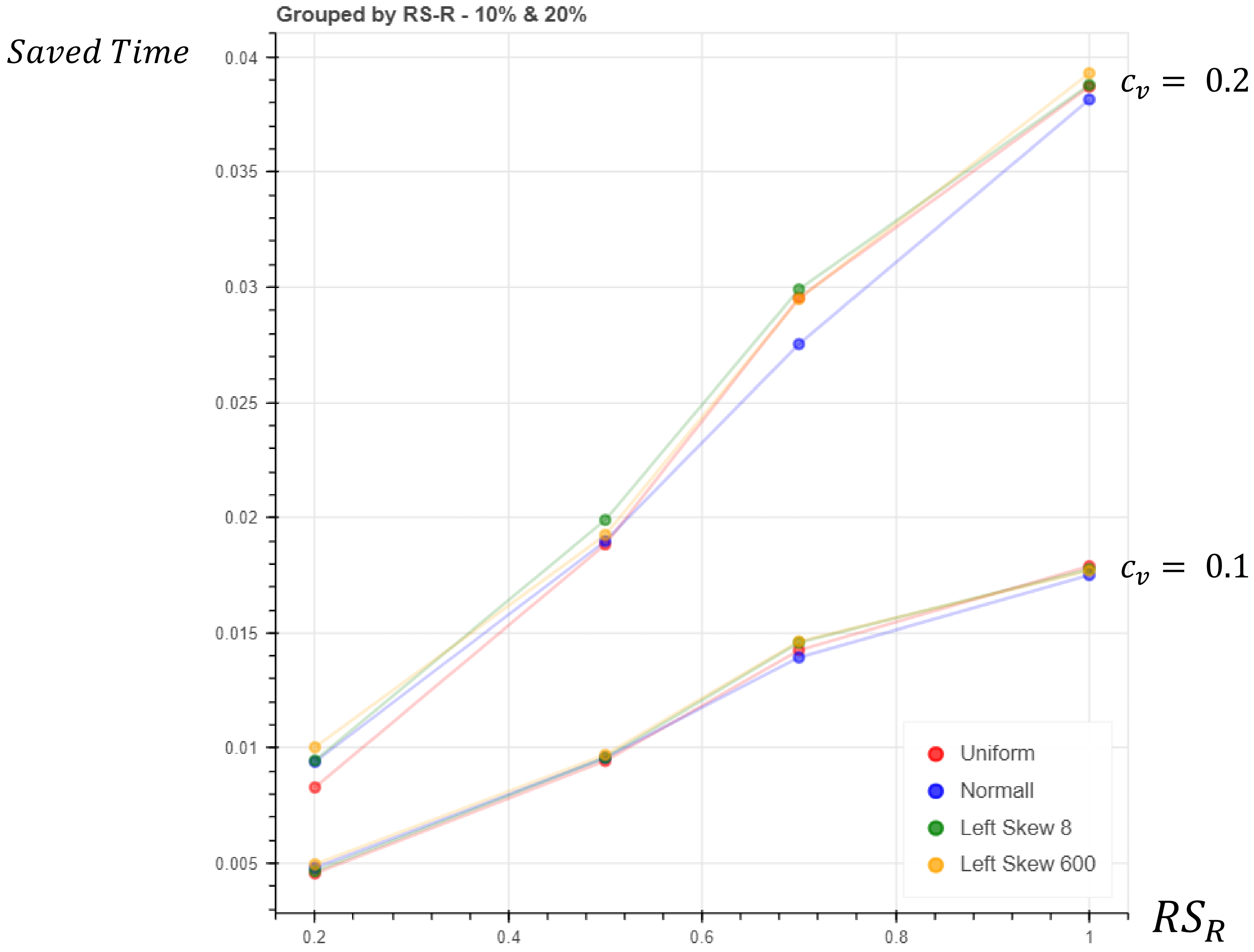

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OBSERVATIONS:

Consideration of robustness lowers projects' expected completion time.

Especially true if there is extra flexibility (fewer precedence constraints, extra resources)

Inventory
???

Question: How do you consider cost in your schedules?

"You have to build many cost models in **Excel** or something **outside of the scheduling software**. You would have to estimate the cost and everything outside of the scheduling software and make the decision. "

"The only thing that the scheduling software is really useful for is time, and sequencing and scheduling. **It's not a costing tool**. As far as I have ever been experienced, you kind of have to do some work outside of the scheduling software like Excel or a simulation modeling tool, and then use that data in the scheduling software."

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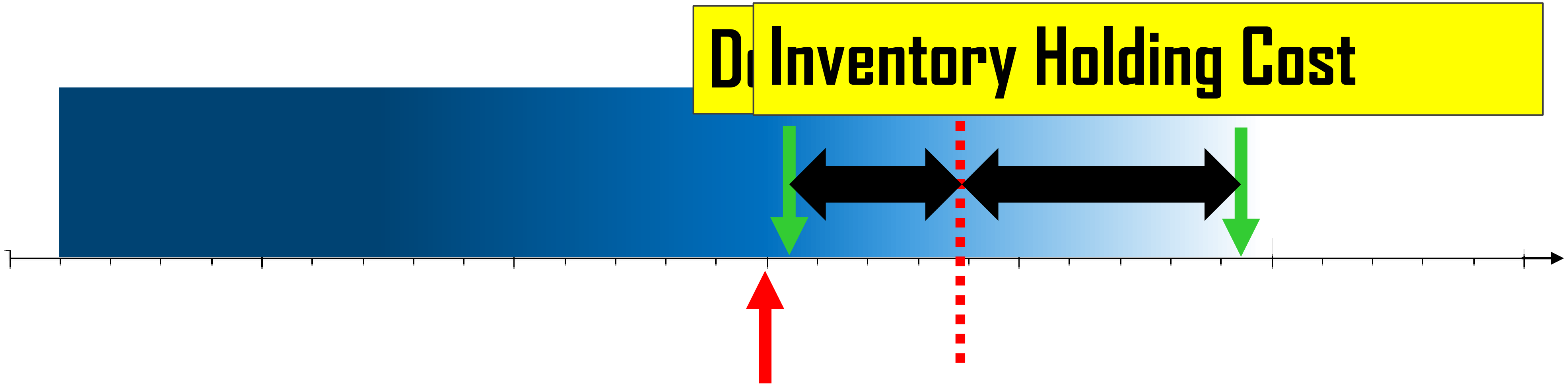
Uncertain Completion Time



When should materials be delivered?

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Now, we include inventory cost in the optimization….

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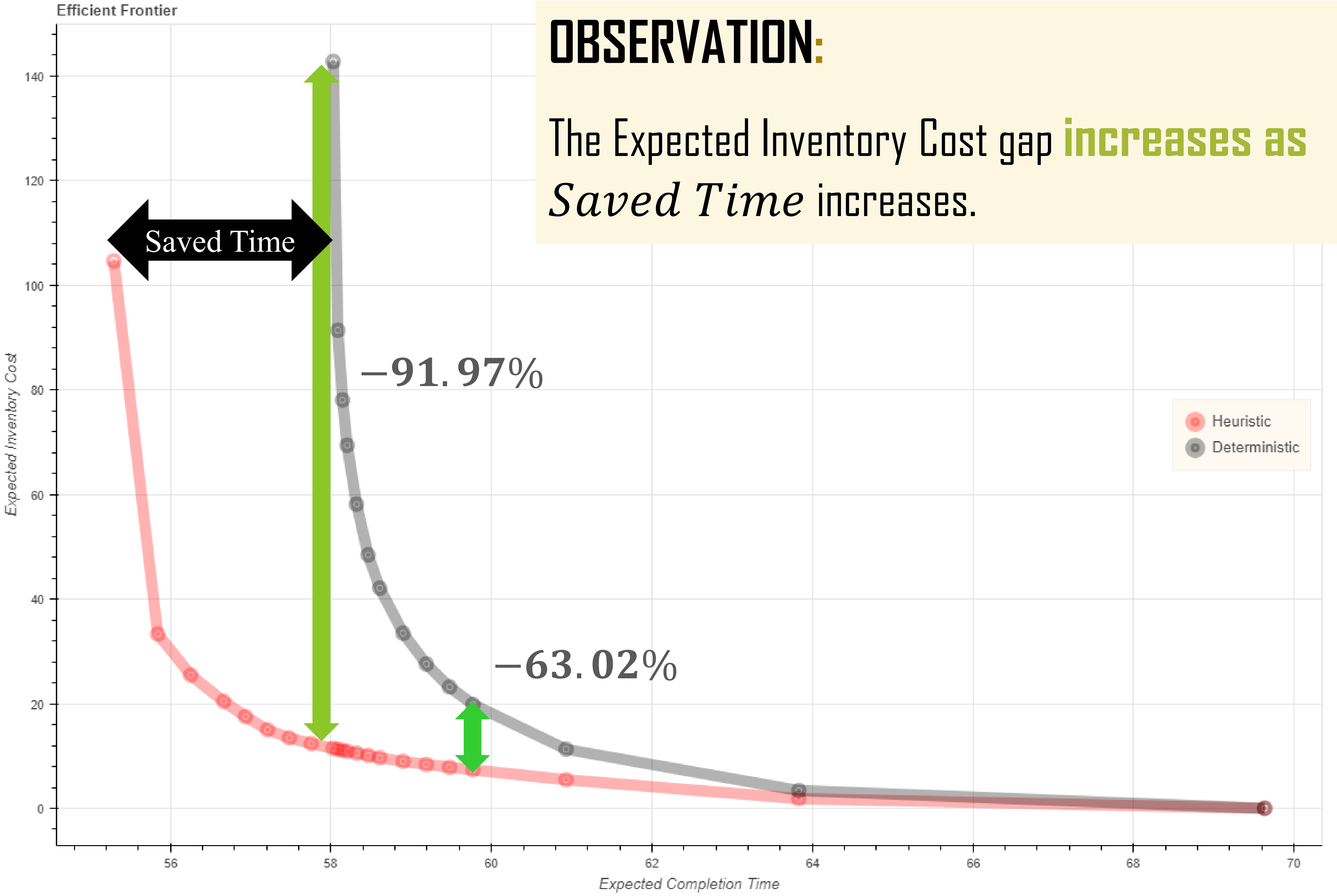

OBSERVATION:

The Expected Inventory Cost gap **increases as** *Saved Time* increases.

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Question: How does excessive inventory impact financial measures? Quality? Rework?

"The storage and handling are often haphazard. This can cause excessive movement and **increase the likelihood** of **damaged**, **defective** or **unsuitable** materials and equipment."

"**Rework** due to construction defects can be **extremely costly**, and the cost increases exponentially depending on where and when these defects are remedied."

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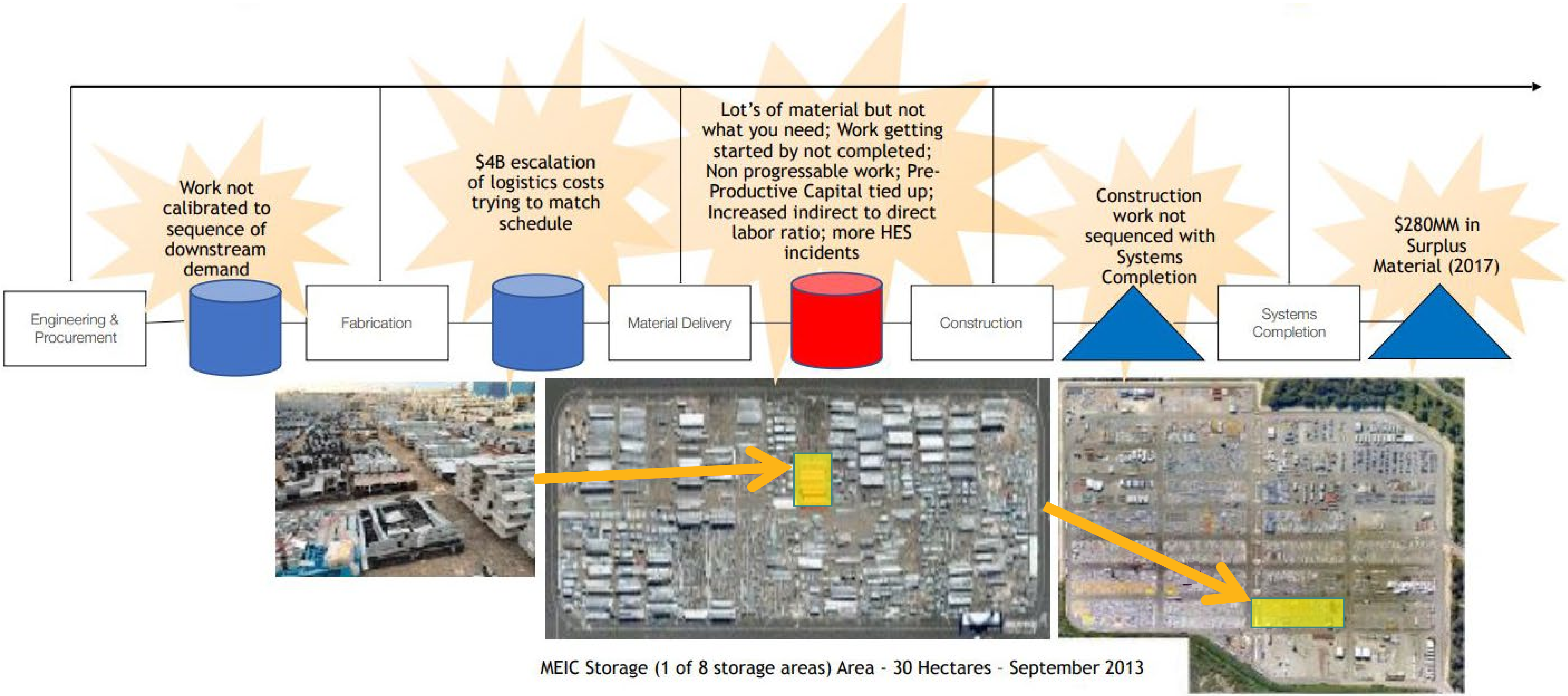

❖ Wayne Crabtree. Impact of Supply Chains on Major Capital Projects, PPI Symposium 2017.

"Things can go wrong…

Weld failures:

- Remedied on the ground: 2 times longer
- Remedied after installation at quay-side: 4 times longer
- Remedied offshore: 10 times longer"

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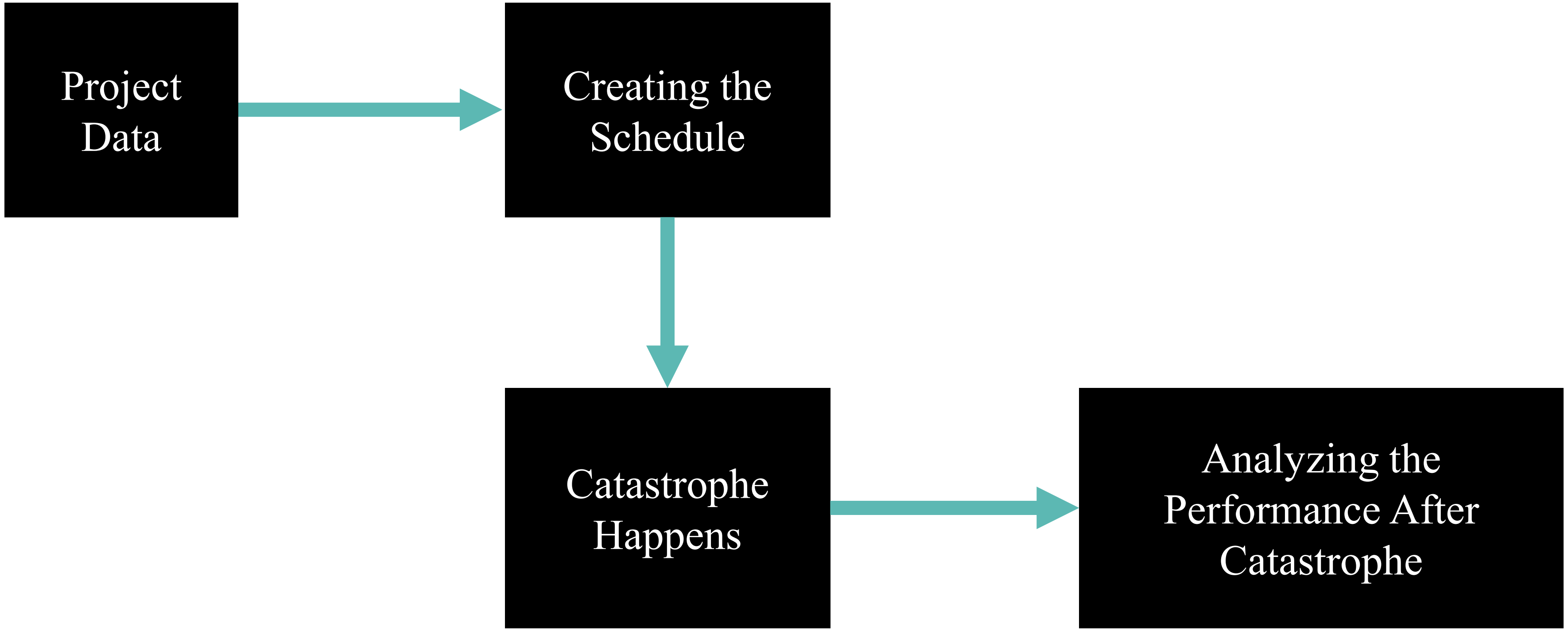
Catastrophe Simulations



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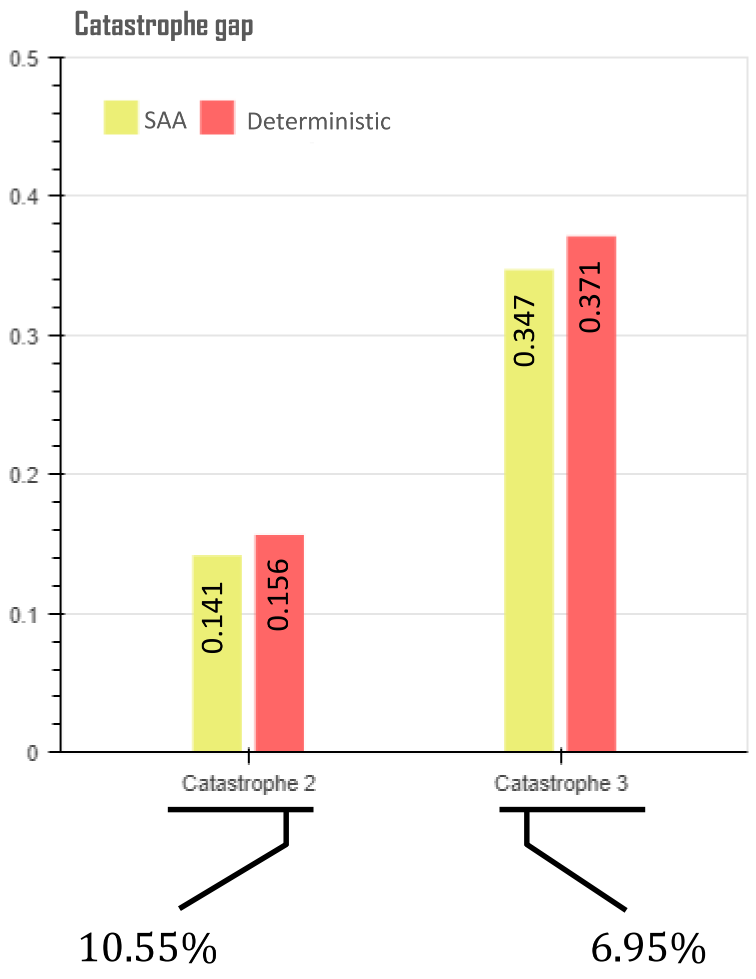

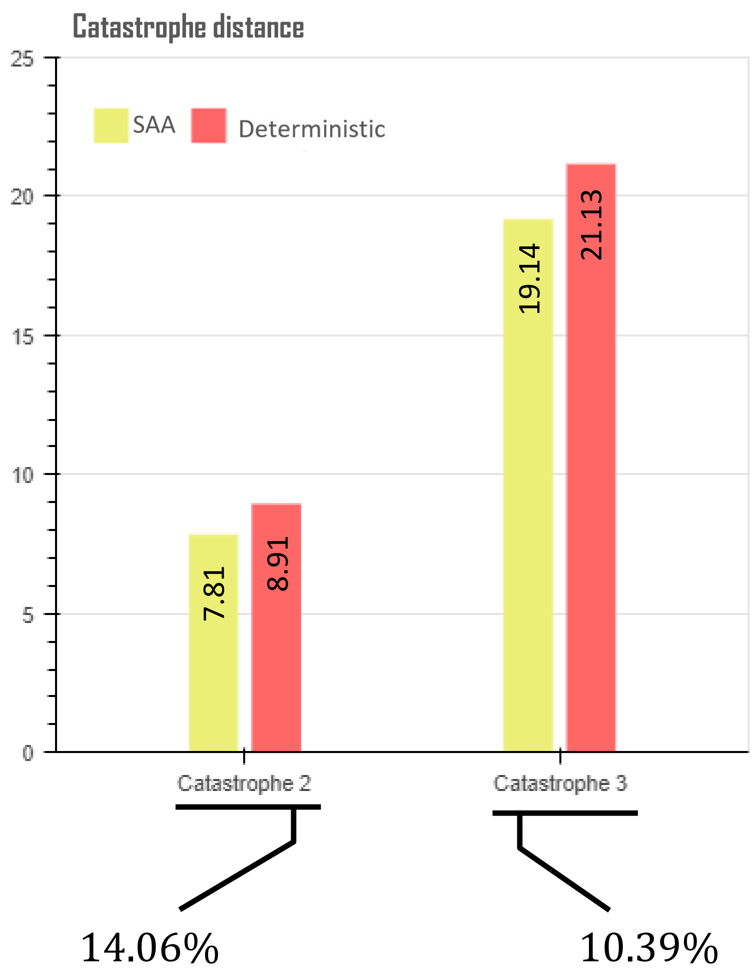

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Another Research Project:

Multiple Projects, Shared Resources

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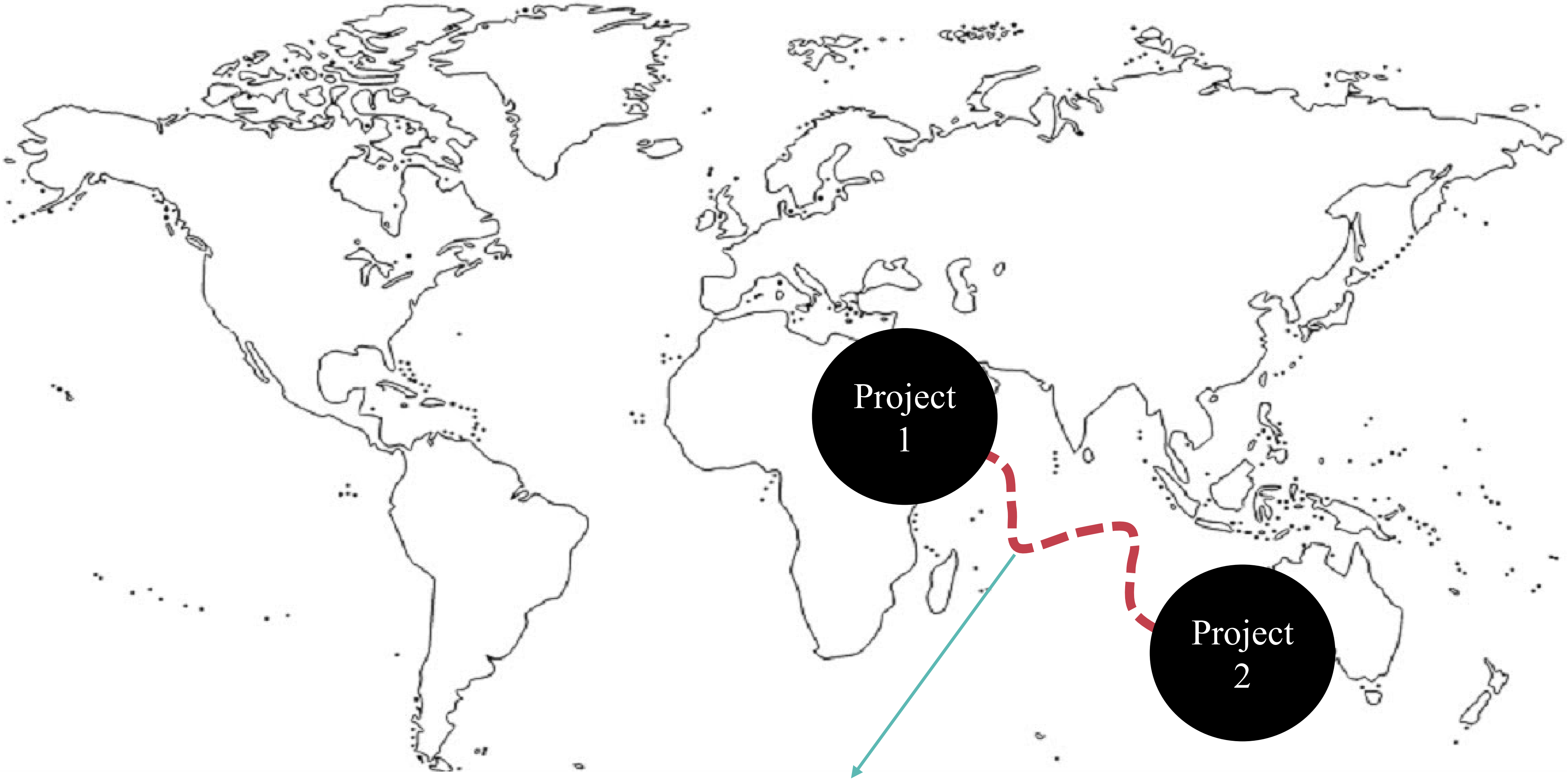

- No resource transfer
- Immediate resource transfer
- Transfer with delay

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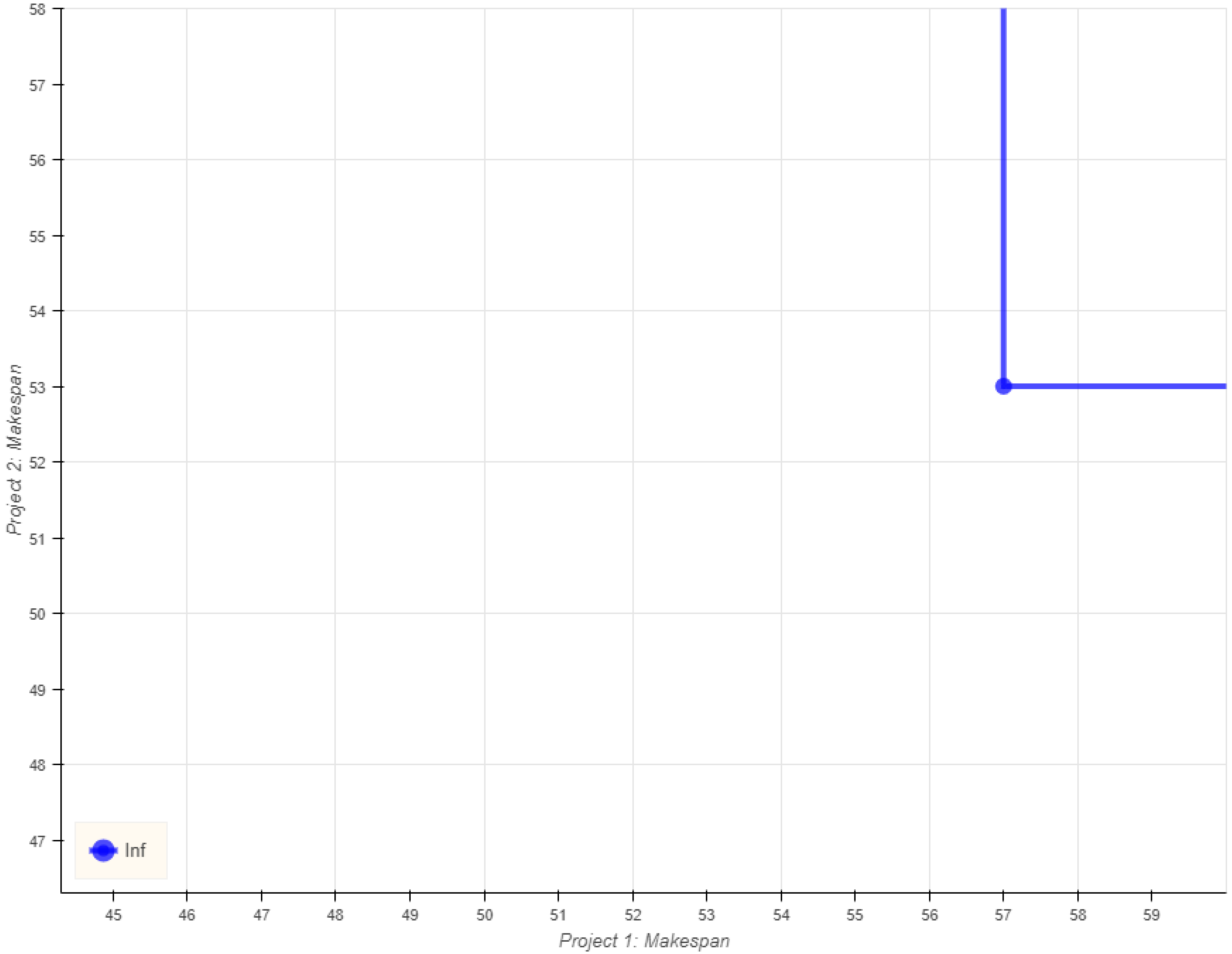

MULTIPLE PROJECTS

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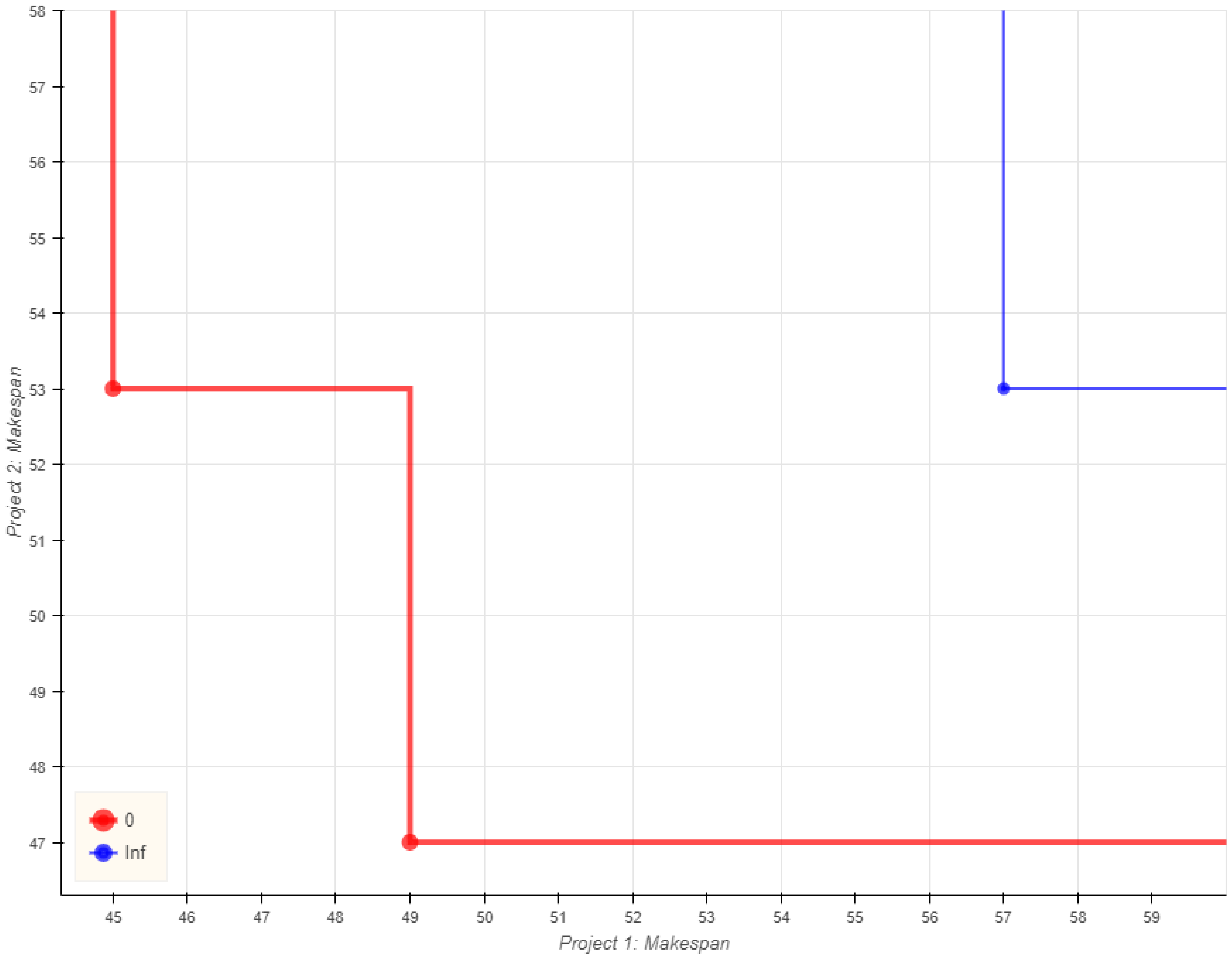

MULTI PROJECTS

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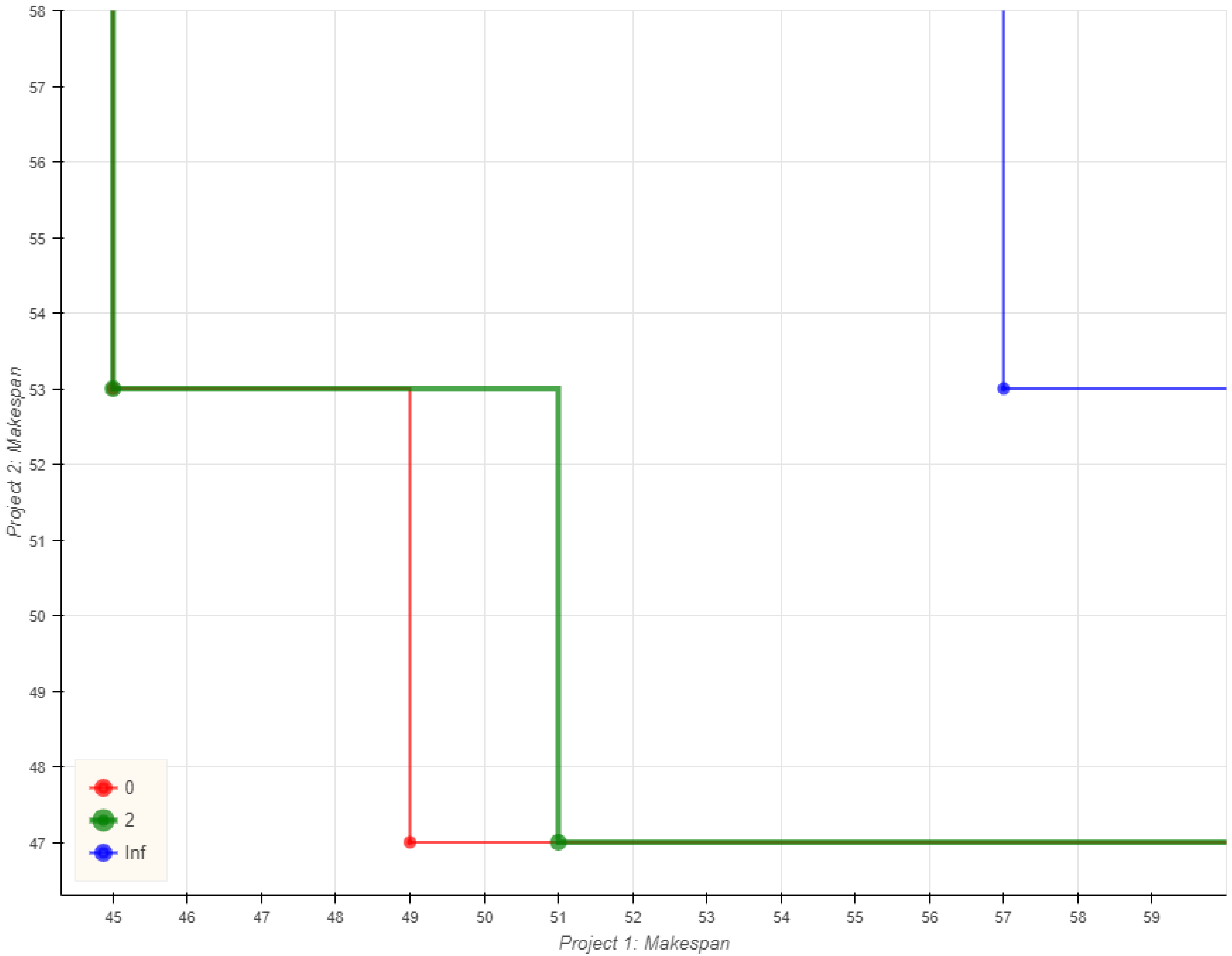

MULTI PROJECTS

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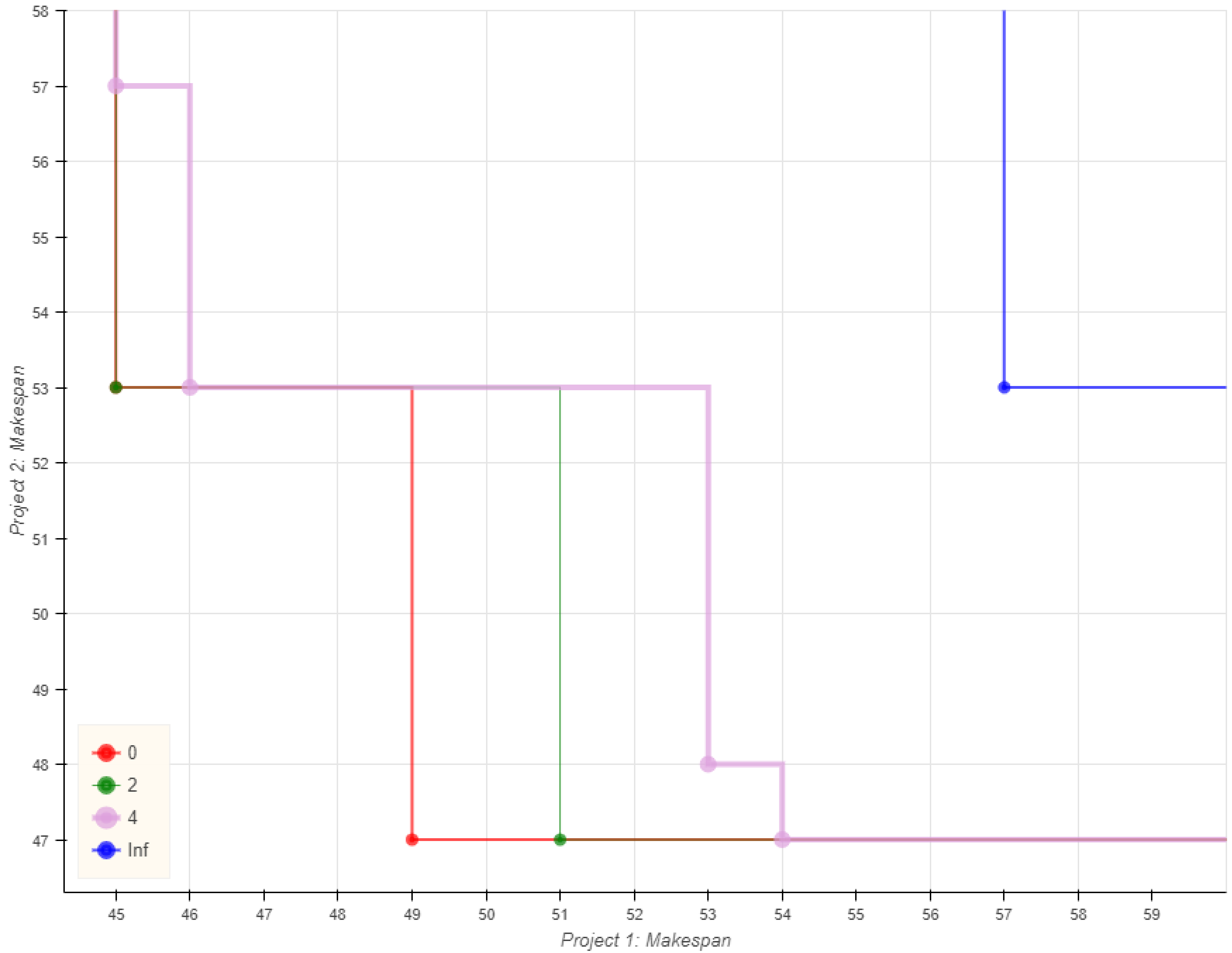

MULTI PROJECTS

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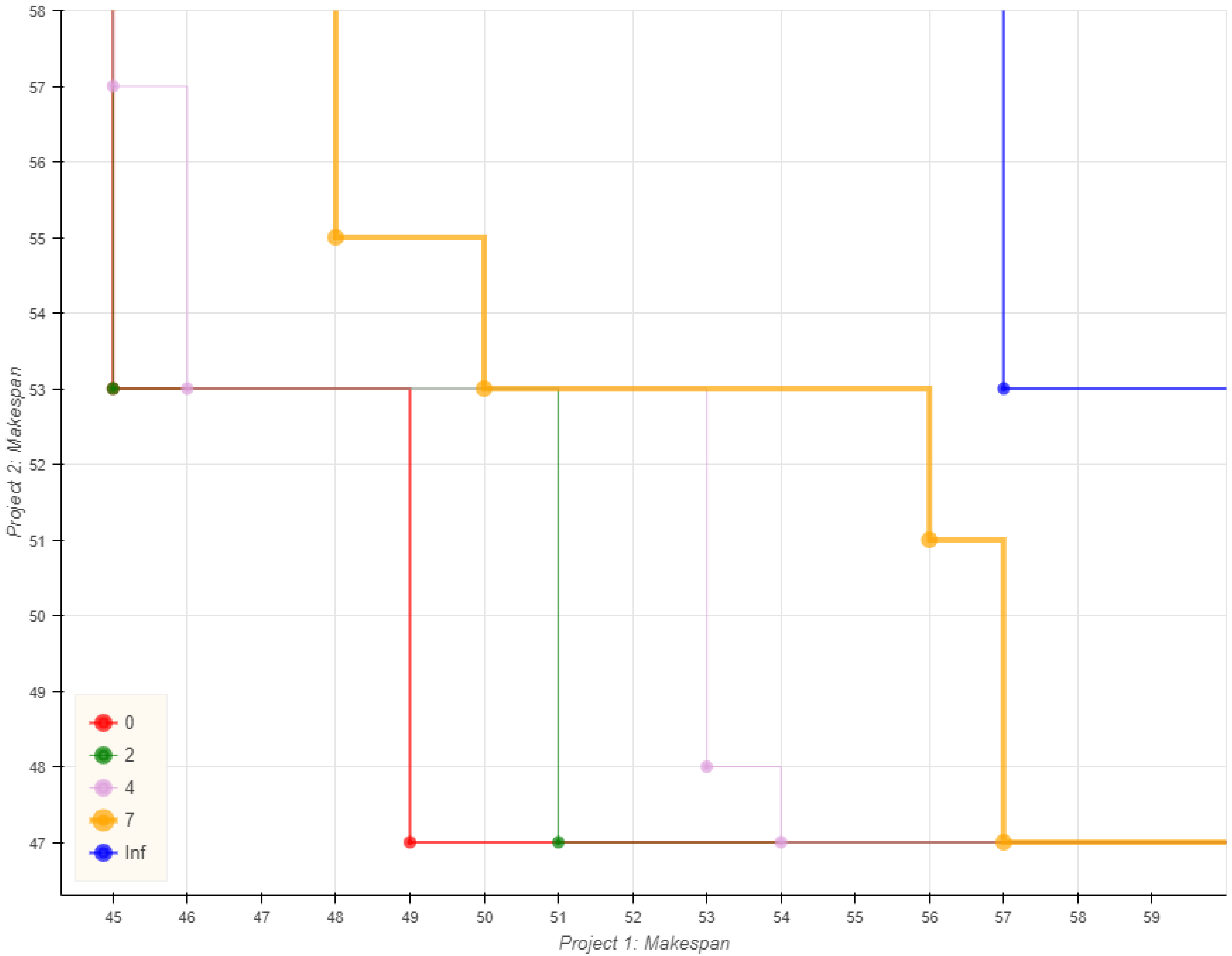

MULTI PROJECTS

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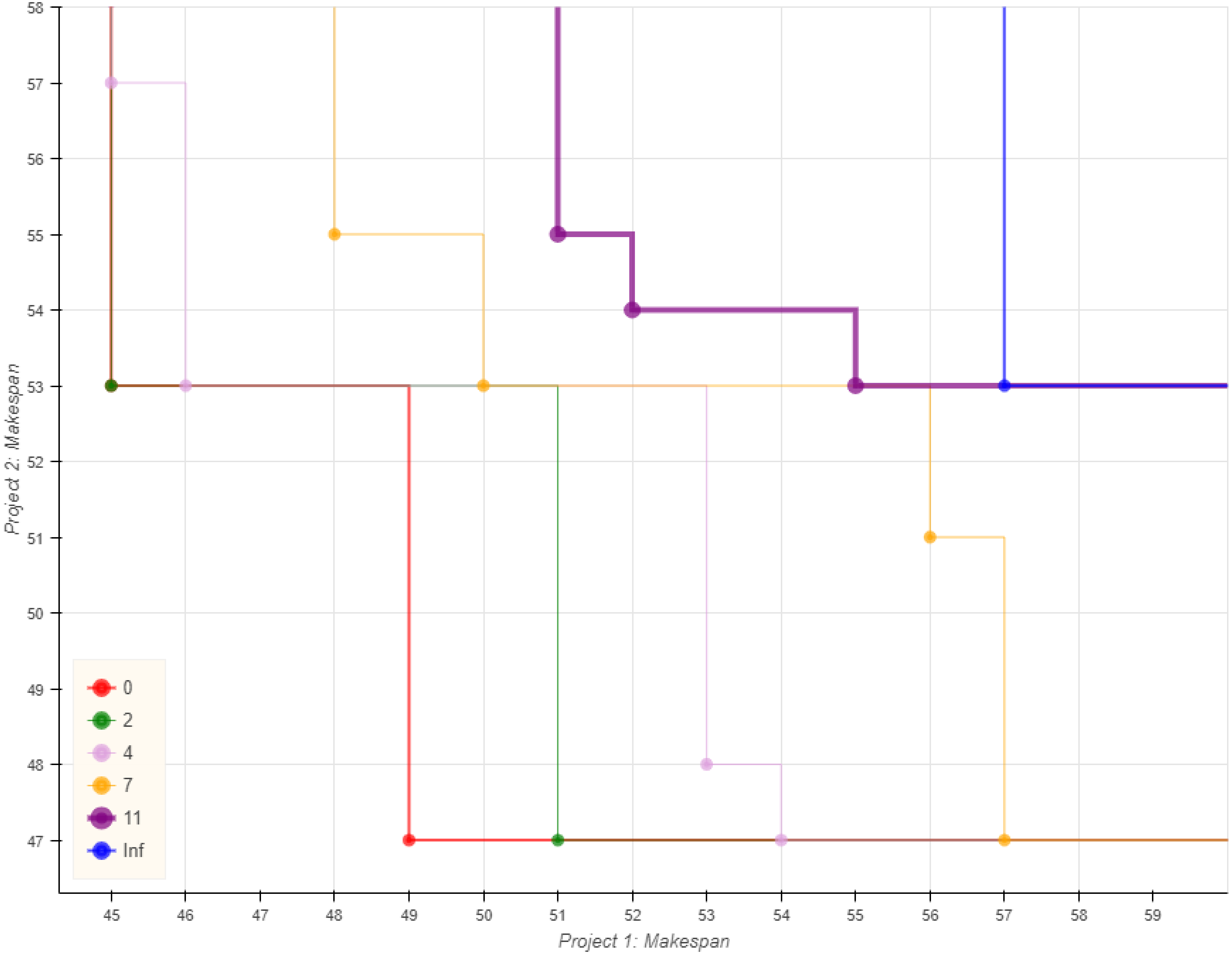
MULTI PROJECTS



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Future Plans

- Empirical exploration of inventory cost
- Incorporating more of the supply chain
- Improvement of tools and approaches
- Modeling other aspects of real-world inventory risk tradeoffs

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THANK YOU

Phil Kaminsky kaminsky@berkeley.edu

Arman Jabbari jabbari@berkeley.edu