

IPIC 2024

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Simulation-based Assessment of the Impact of the Learning Curve and Robust Worker Scheduling on a PI Inspired Assembly Factory

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Physical
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Agenda

1. Context
2. Agile Assembly Center
3. Case Study
4. Learning Curves
5. Methodology
6. Experimental Results
 1. Learning curve parameters sensitivity analysis
 2. Learning Rates and Learning Impact
 3. Montecarlo Simulation
 4. Discussion
7. Conclusions
8. Future work

Context – Durable Goods

- Complex and large durable goods
- Customized goods
- Large plan floor space requirements
- Complex and expensive transportation



Source: <https://www.overweightpermits.com/what-is-an-escort-vehicle/>



Source: <https://theconstructor.org/construction/heavy-construction-equipment-types/26305/>

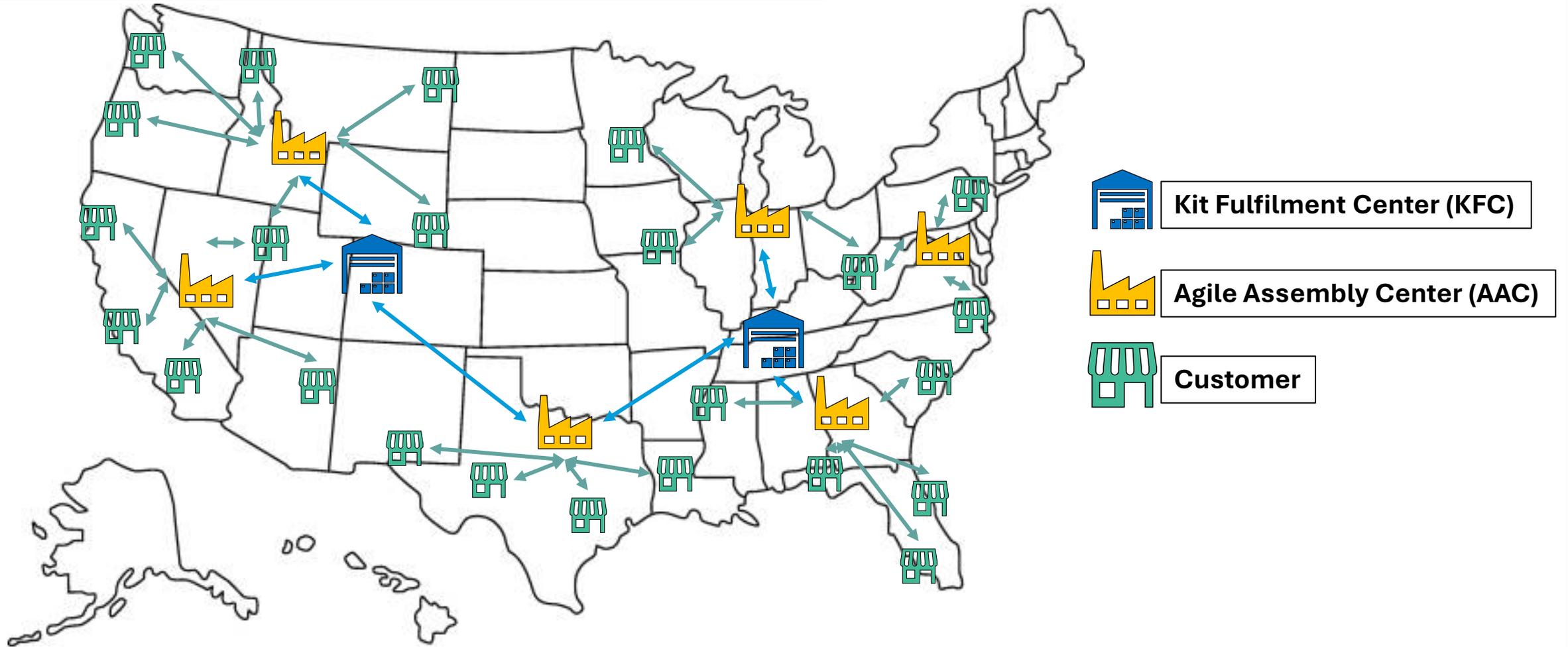


Source: <https://www.freepik.com/free-photo/>

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Context - Hyperconnected Logistics Network



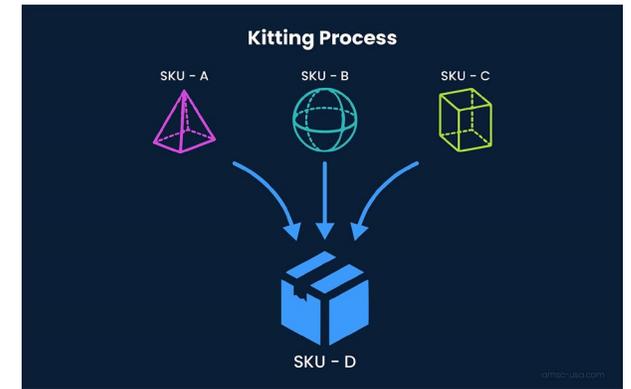
Context - PI Nodes

Kit Fulfilment Center (KFC):

- Facility in charge of preparing kits with components that will be used in the assembly process at the AAC
- KFCs produce kits that are easy and safe to transport between KFCs and AACs; and easy and safe to handle, distribute and use in AACs

Agile Assembly Center (AAC):

- Manufacturing facility that can be open to multiple stakeholders and concurrently serve the needs of several clients for small-series production of complex and large durable products
- Are meant to be temporary and easy to set up in locations close to the clients, reducing the logistics costs of transporting full assembled final products.



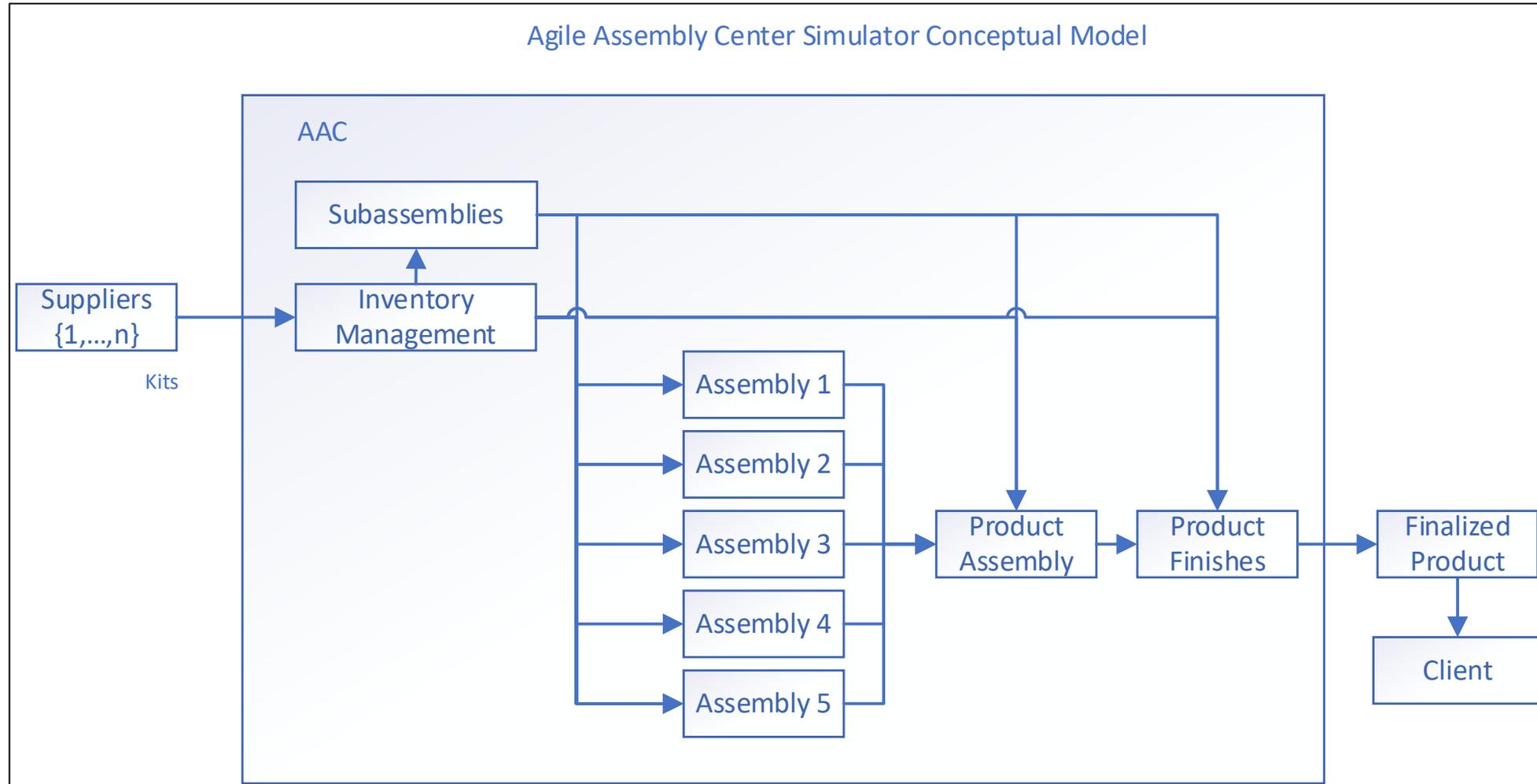
Source: <https://www.amsc-usa.com/blog/what-is-kitting-benefits-and-kitting-definition/>



Source: <https://stockarea.io/quick-guides/kitting>



Agile Assembly Center Conceptual Model



Case Study - Description

Product Characteristics

Complex and large durable product

Composed of 85 subproducts divided in 11 types according to their characteristics

Production Process

Each product requires 380 tasks to be manufactured

There is a learning process for the workers to achieve the target task processing time

Tasks are scheduled in blocks, and one block can't start until the previous one ends

Resources

60 workers from 7 different trades required in steady state

Different trades have different cost per hour

1 daily work shift of 8 hours

The worker pool doesn't change during the full production lot

Learning Curves

Plateau Learning Curve Model

$$y(n) = \max(K * n^l, K_0)$$

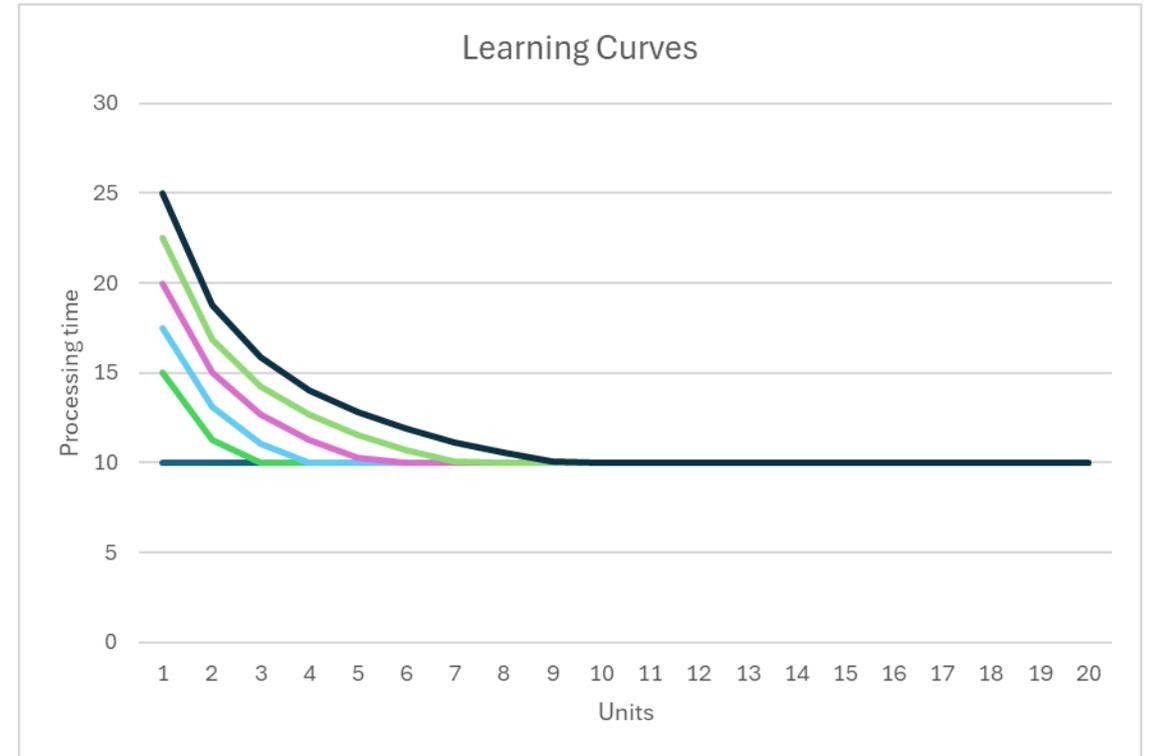
$y(n)$ = process time of the n th unit

K_0 = target processing time

K (learning impact) = processing time of the first unit

$$l = \frac{\log(\phi)}{\log(2)}$$

ϕ = learning rate



Methodology

Sensitivity analysis on learning impact and learning rates



Definition of **learning rates** per subproduct type



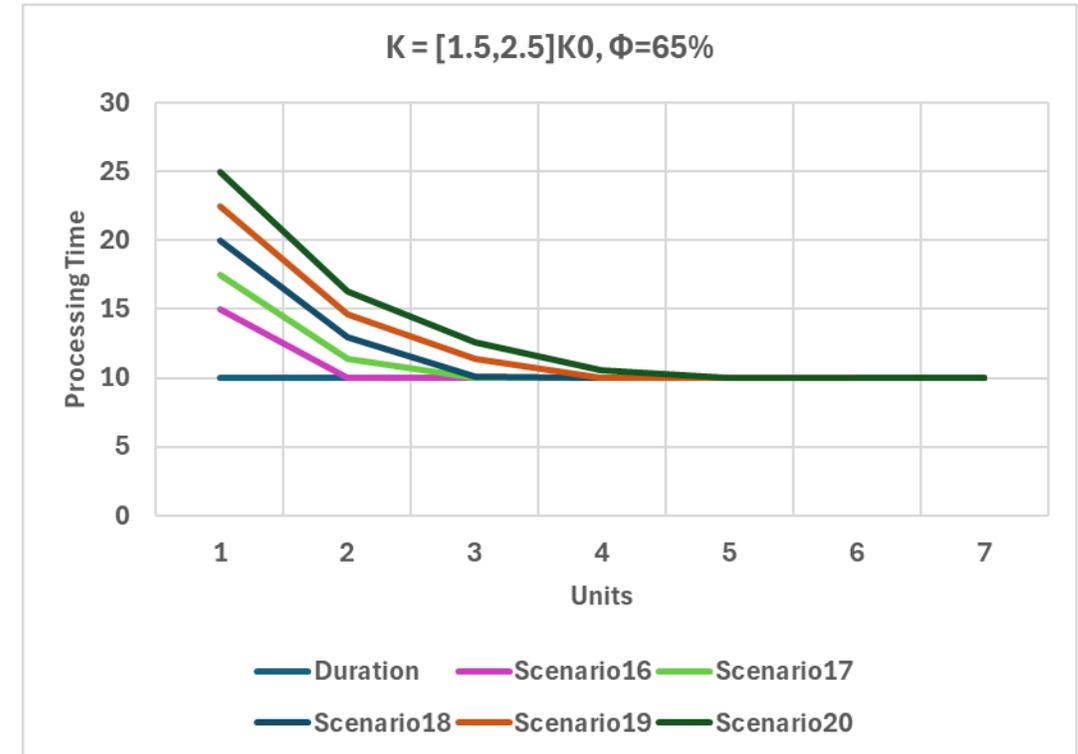
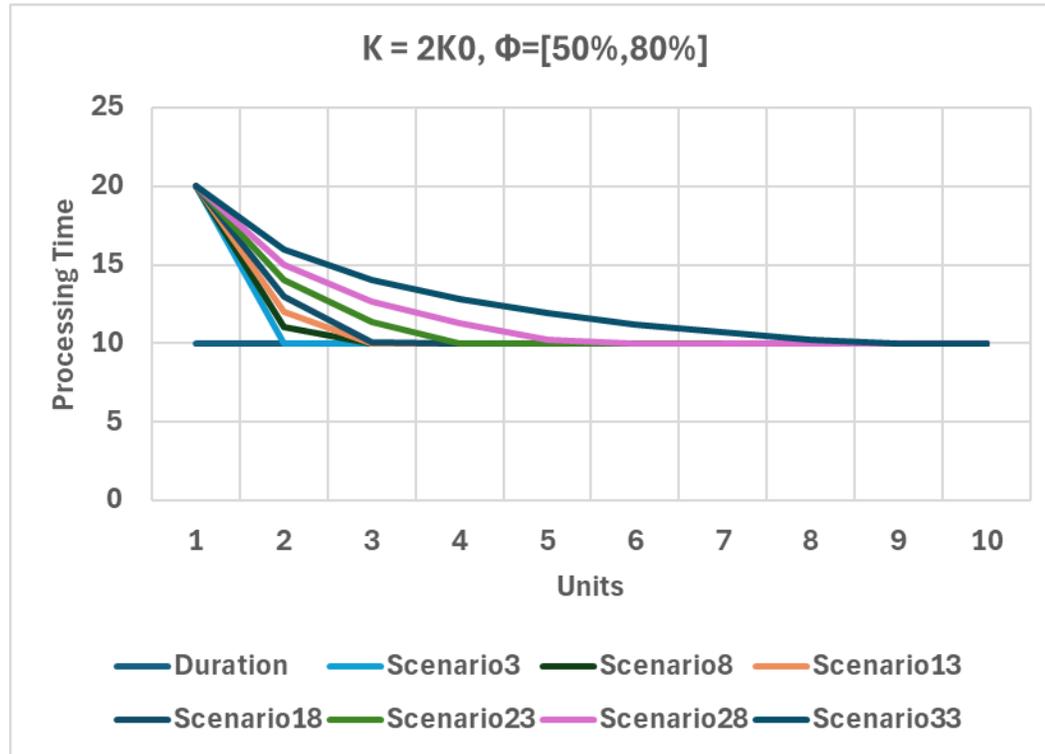
Characterization of initial **learning impact distribution** per subproduct type



Montecarlo simulation for 20 units and 100 units production lots

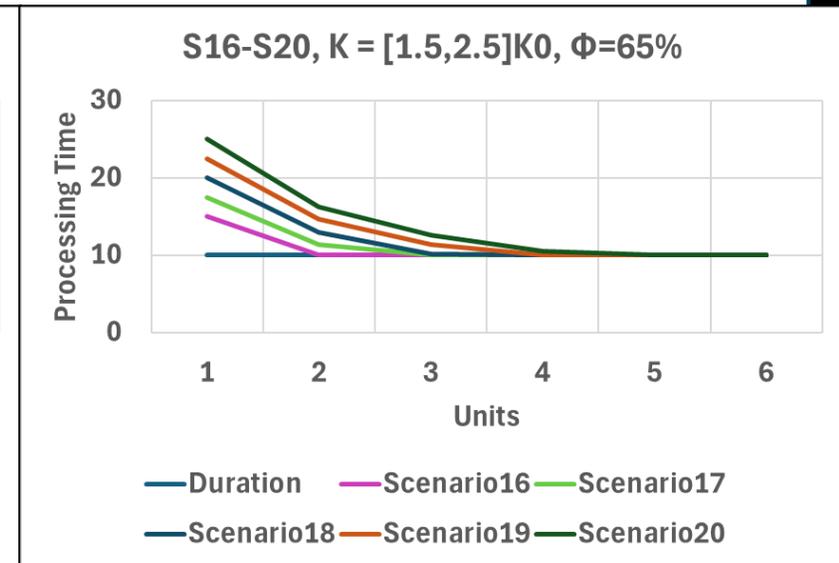
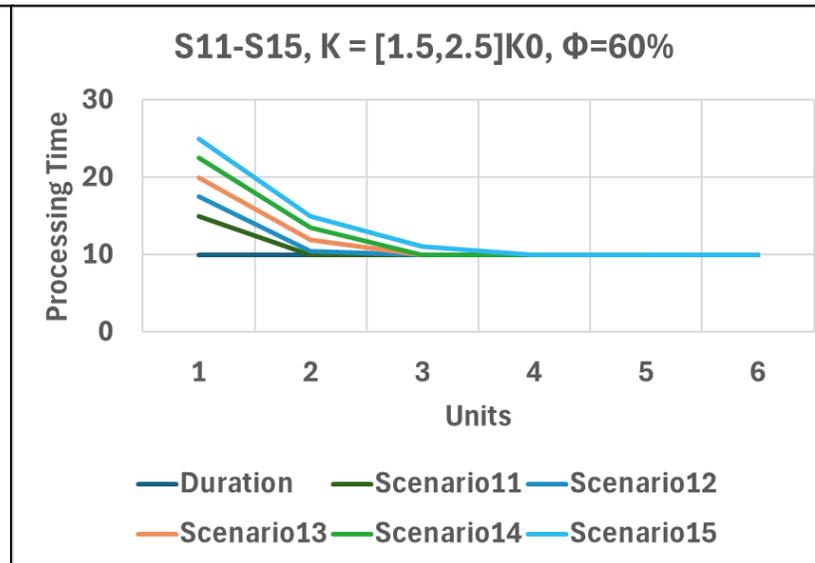
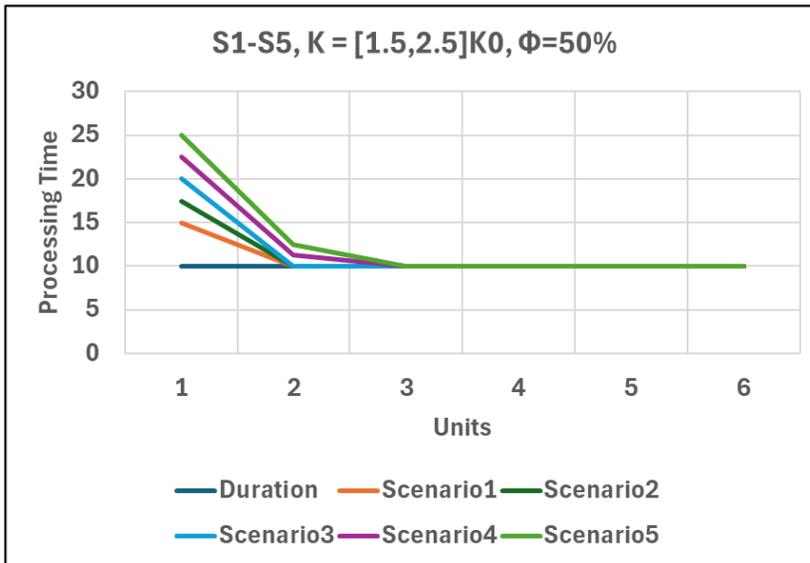
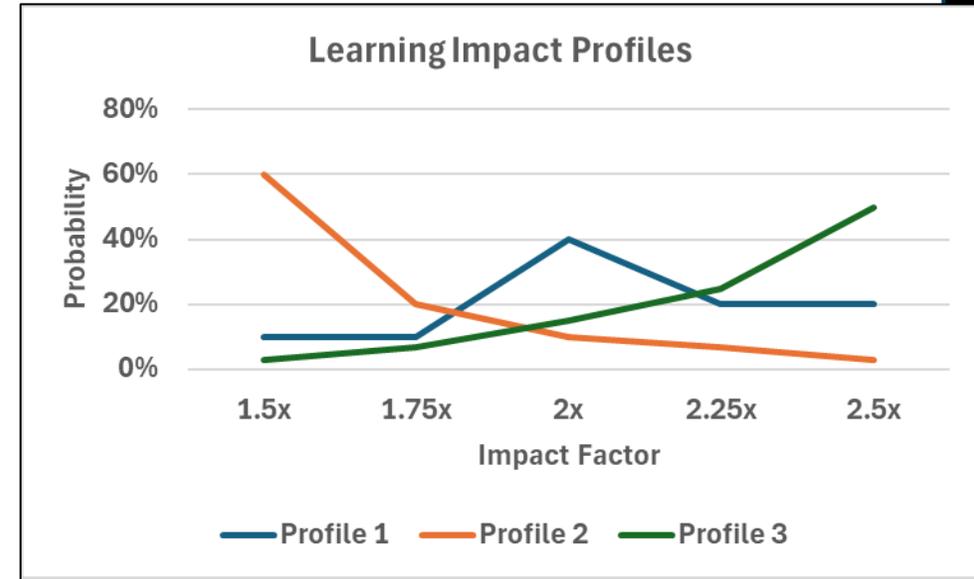
Experimental Results – Sensitivity Analysis

		Learning Rate						
		50%	55.00%	60.00%	65.00%	70.00%	75.00%	80.00%
Learning Impact	1.5	Scenario 1	Scenario 6	Scenario 11	Scenario 16	Scenario 21	Scenario 26	Scenario 31
	1.75	Scenario 2	Scenario 7	Scenario 12	Scenario 17	Scenario 22	Scenario 27	Scenario 32
	2	Scenario 3	Scenario 8	Scenario 13	Scenario 18	Scenario 23	Scenario 28	Scenario 33
	2.25	Scenario 4	Scenario 9	Scenario 14	Scenario 19	Scenario 24	Scenario 29	Scenario 34
	2.5	Scenario 5	Scenario 10	Scenario 15	Scenario 20	Scenario 25	Scenario 30	Scenario 35



Experimental Results – Learning Rates and Impact

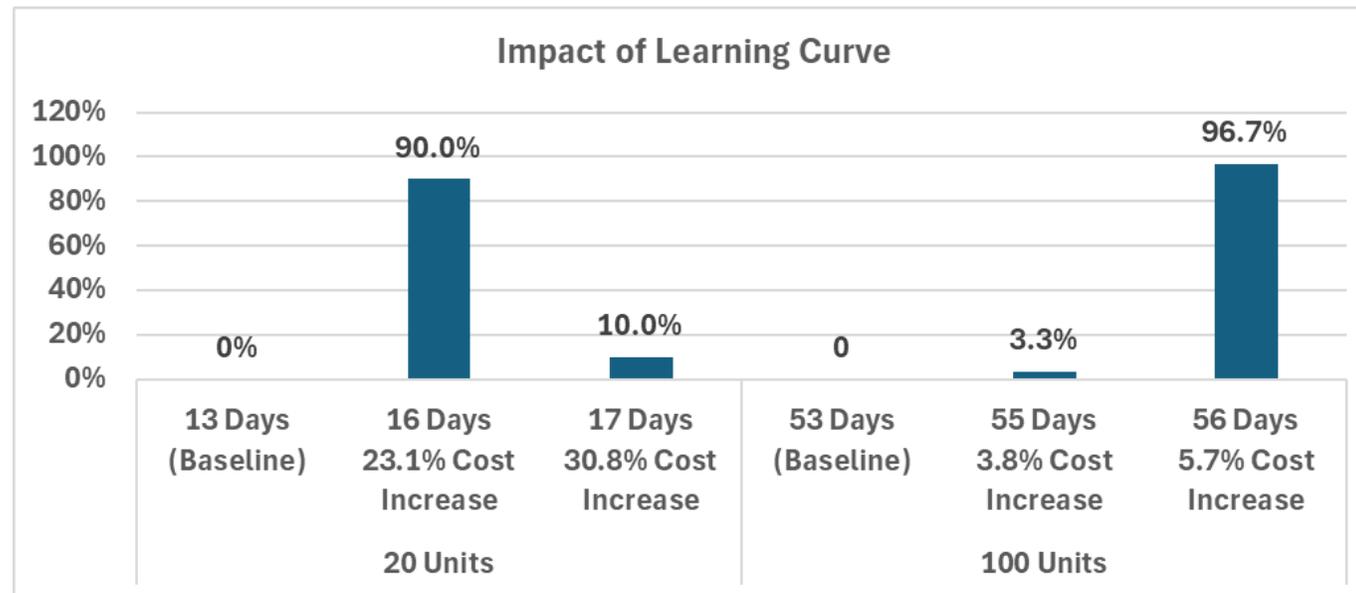
Subproduct Type	Learning Rate	Learning Impact Profile	Complexity	Time	Instances
1	50%	Profile 1	Low	Low	Multiple
2	50%	Profile 2	Low	High	Few
3	50%	Profile 1	Low	Low	Multiple
4	50%	Profile 2	Low	High	Few
5	60%	Profile 1	Medium	Medium	Multiple
6	65%	Profile 3	High	Medium	Few
7	50%	Profile 1	Medium	Medium	Multiple
8	65%	Profile 3	High	High	Few
9	65%	Profile 3	High	High	Single
10	65%	Profile 3	High	High	Single
11	60%	Profile 3	Medium	High	Single



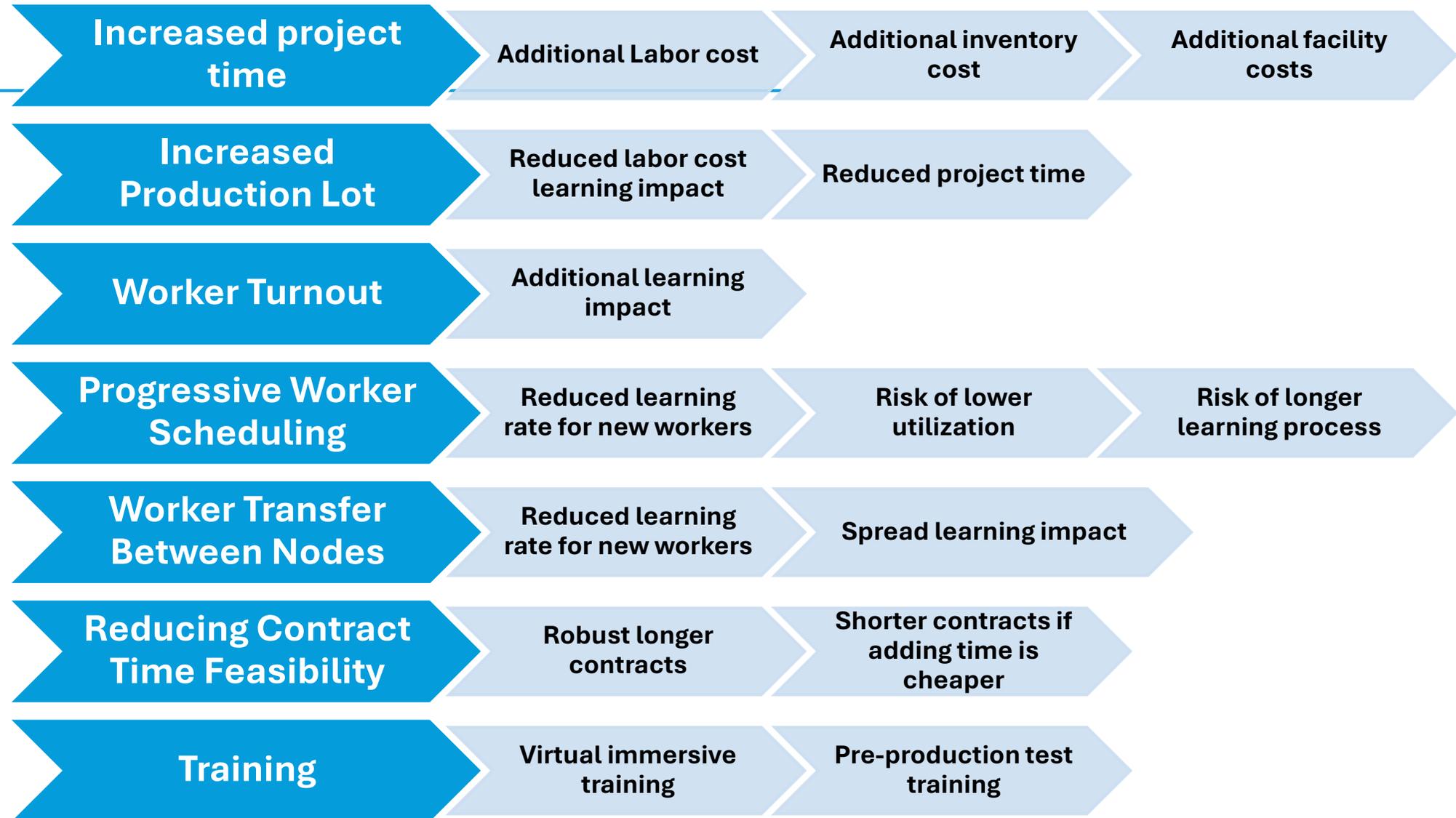
Experimental Results – Monte Carlo Simulation

*Montecarlo experiments with 30 replications

Production	KPI	Baseline	Learning Curve	% Change	Confidence Interval (95%)
20 units	Total Time (Hours)	102.3	126.4	23.5%	[125.8;126.9]
	Total Time (Days)	13.0	16.1	23.8%	[16;16.2]
	% Variation Time	0.0%	23.5%	23.5%	[23%;24.1%]
	% Variation Cost	0.0%	23.8%	23.8%	[23%;24.7%]
100 units	Total Time (Hours)	418.7	444.2	6.1%	[443.5;444.9]
	Total Time (Days)	53.0	56.0	5.6%	[55.9;56]
	% Variation Time	0.0%	6.1%	6.1%	[5.9%;6.3%]
	% Variation Cost	0.0%	5.6%	5.6%	[5.5%;5.7%]



Experimental Results – Discussion



Conclusions



Analyzing the impact of the learning process enables efficient worker scheduling and better planning



The additional costs associated with the learning factor need to be factored in when defining a project size to ensure financial feasibility and avoid unexpected cost



As data becomes available, learning rates and learning impacts must be updated. Finer granularity will yield more precise results. (Impact profiles at the task level and even on each individual worker will increase accuracy)



Preproduction training and virtual immersive training can be very useful to reduce learning impacts at low cost

Future Work

Add granularity to the learning impact profiles

Explore robust task scheduling algorithms to reduce learning impact at low cost

Add general disruptions on top of the learning curve

Explore strategies for dynamic production and labor rescheduling when disruptions occur

Thank you

- **Questions & Comments:**
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