A Systematic Approach for Organizations to Generate Set-Based Knowledge

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Premise

Typical product development systems prioritize identifying the "best" solution early. However, this approach is not ideal due to three reasons.

Substantial early cost commitment	Limited control on cost after early commitment	Limited product knowledge early on

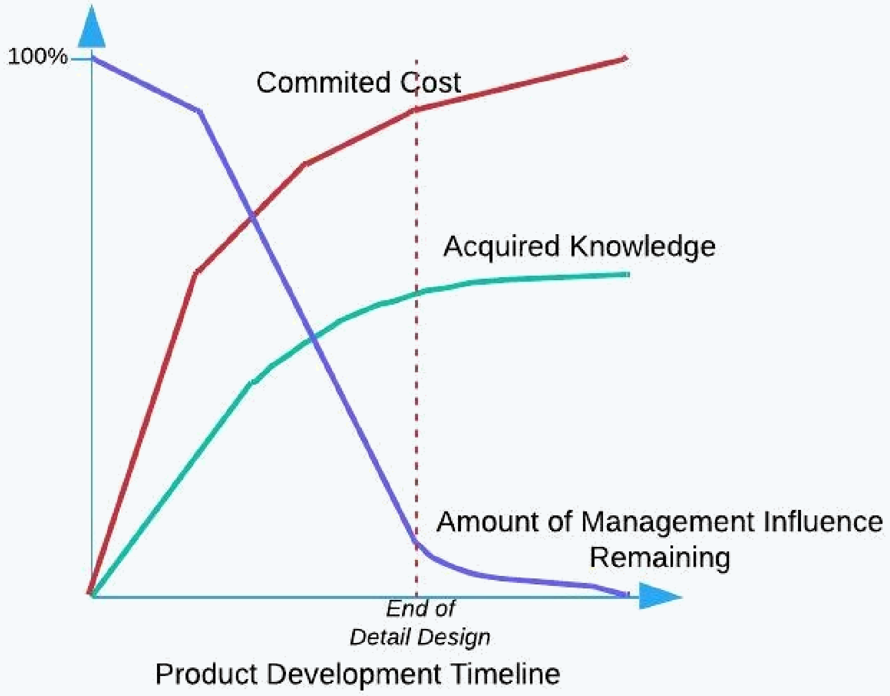
Furthermore, early identification of the "best" solution results in,

Wasteful rework	Increased development costs	Longer development timelines	Higher likelihood of selecting suboptimal solutions

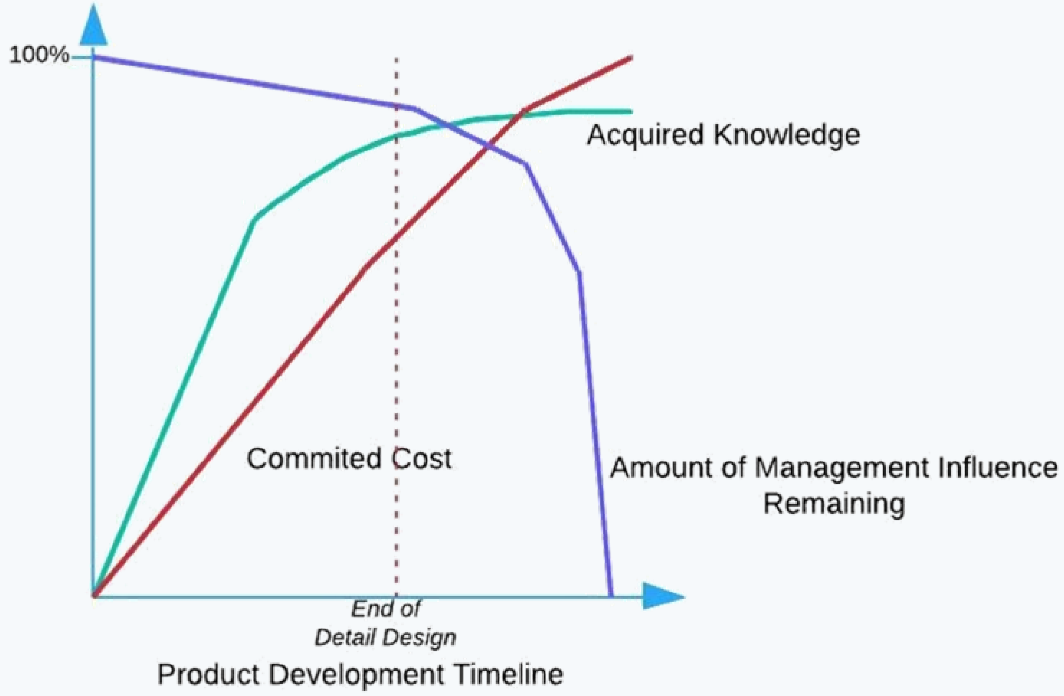
Set-based concurrent engineering focuses on generating knowledge and delaying decision-making to understand the complex and conflicting relationships among a product's design goals, constraints, and design parameters.

Premise *(Cont.)*

Traditional Product Development



Set-Based Concurrent Engineering (SBCE)



Premise *(Cont.)*

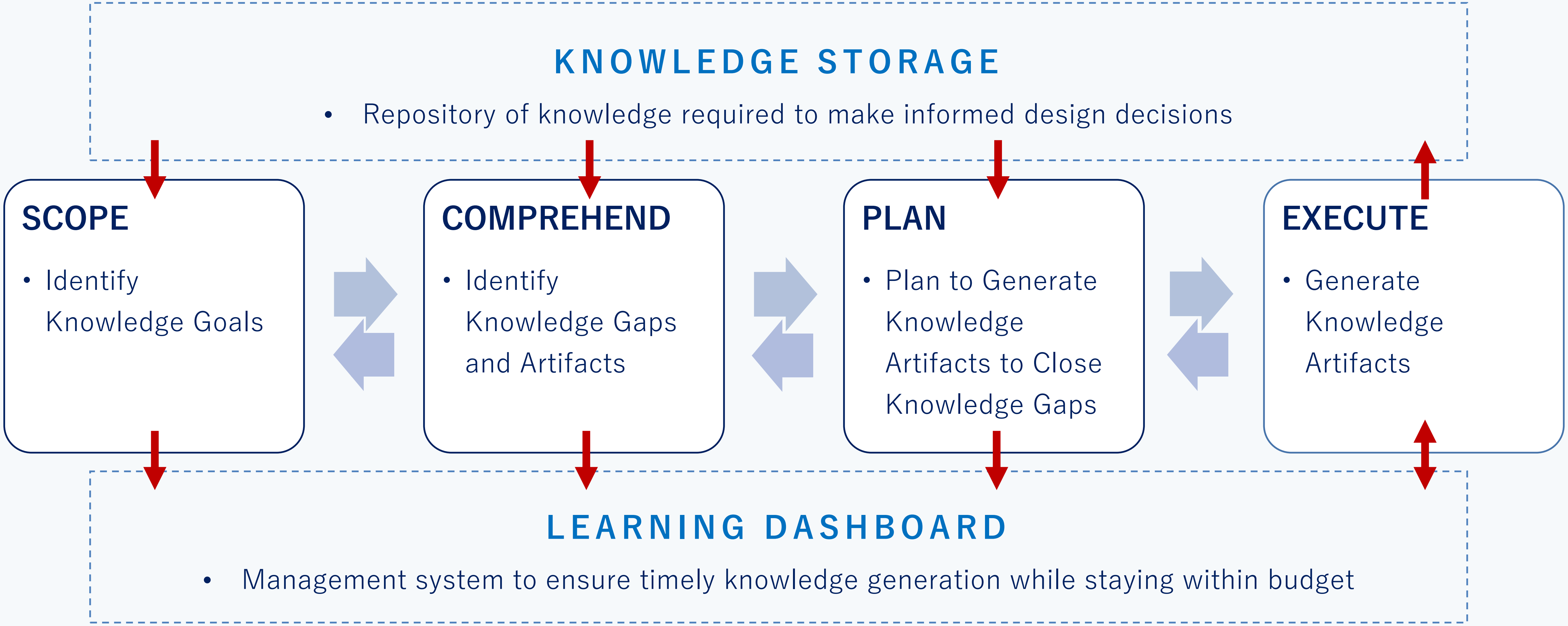
Design Knowledge Generation (DKG) Framework

Provides a set of tools for systematically generating knowledge.

Facilitates tracking the rate of knowledge generation.

Facilitates storing the generated knowledge.

Design Knowledge Generation Framework



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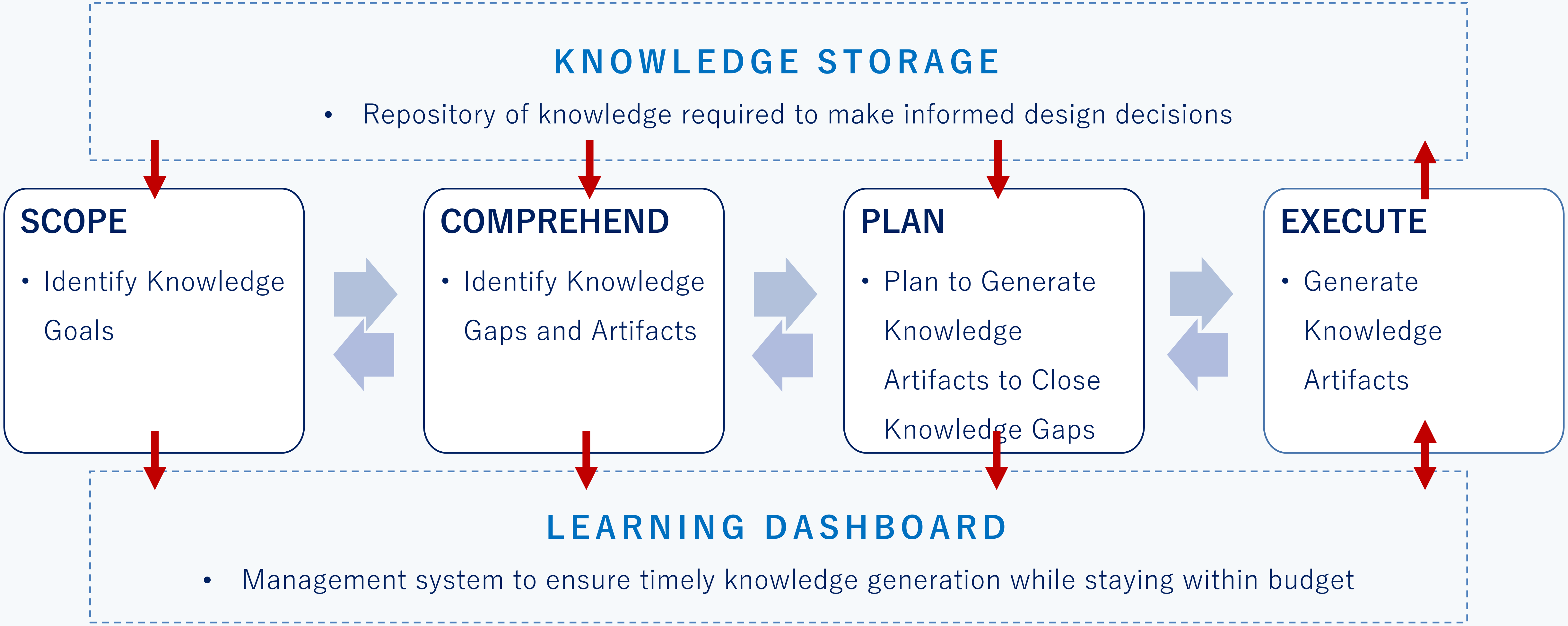
Design Knowledge Generation Framework



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Applying the DKG

What Type of Product?

- Better suited for complex products where understanding of design problems remains limited.

What Development Stage?

- Necessary to have developed product concepts, and gained a preliminary understanding of the design parameters, design goals, and various subsystems.

How to Initiate Knowledge Generation?

- Knowledge Generation can be triggered when a "Problem" is encountered.
- Problem Solving could focus on either,
  - Attaining established Design Goals.
  - Extending beyond current Design Goals.
- Design Problems should be broken down and solved at their lowest possible level.

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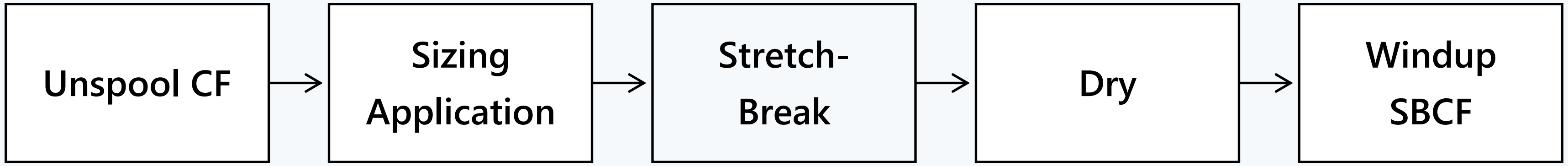
Let’s look at an Application!

Some Background...

The Stretch Broken Carbon Fiber (SBCF) Program at Montana State University is an R&D initiative aimed at addressing the challenges of manufacturing primary aircraft structures using SBCF.

Why SBCF?

- Carbon fiber is widely used in the aerospace industry for its excellent strength and stiffness.
- However, its inextensibility limits its use in forming complex geometries.
- SBCF involves breaking the fibers at their natural flaws by stretching them resulting in a higher formability.



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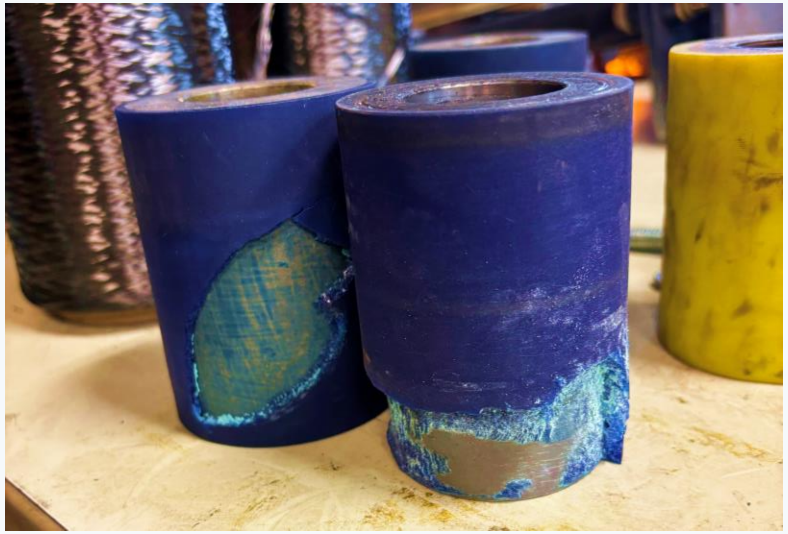
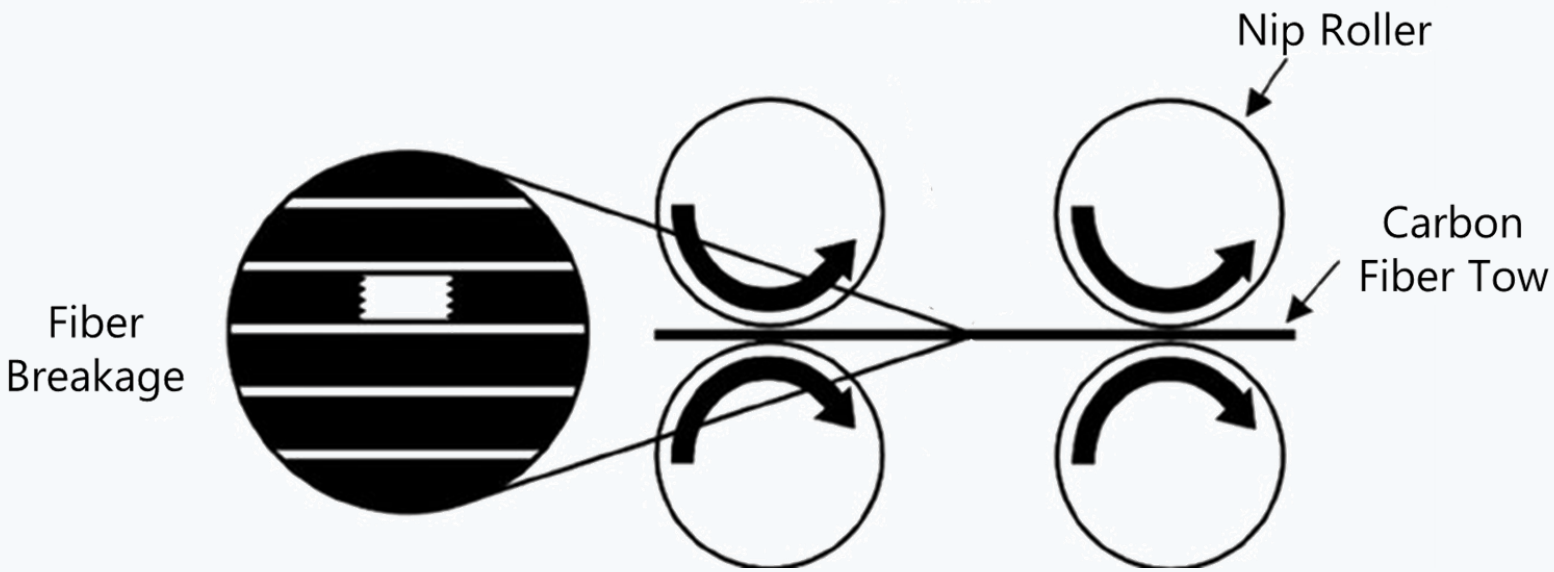
Scope Stage

Problem:

- Stretch-breaking stops when the nip rollers reach around 115°F, and delamination occurs around 125°F.


Delaminated Nip Rollers



Stretch-Break Process

Scope Stage *(Cont.)*

Design Goal:

- Maintain nip roller temperature around 100°F during operation

Knowledge Goal:

- Quantify cause-and-effect relationships among factors influencing the temperature of the nip roller.

***Factors**. Design Parameters, Design Goals, Related Subsystems, etc.*

Initial Budget and Time allocation to solve the problem could happen at this stage

Comprehend Stage

Step 1: Map Architecture of the Design Problem

		Design Parameters								Outcome
		Material of NR	Line Speed	Sizing Conc.	Tension of CF	Temp of Sizing	Nip Force	Stretch Ratio	Thickness of NR	Temp of NR
Design Parameters	Material of NR									
	Line Speed									
	Sizing Conc.									
	Tension of CF									
	Temp of Sizing									
	Nip Force									
	Stretch Ratio									
	Thickness of NR									

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Comprehend Stage *(Cont.)*

Step 2: Assess Current Knowledge & Highlight Gaps

Assess the potential relationships in the problem architecture using the following rubric.

Level	State of Knowledge
0	We are confident that no relationship exists
1	We hypothesize the existence of a relationship.
2	We have observed a relationship, but we lack data-driven evidence.
3	We have observed a relationship, and we possess data to substantiate it.
4	We have quantified or visualized the relationship.

If a cell is empty: *No knowledge is available to confirm or deny a relationship.*

Comprehend Stage *(Cont.)*

Step 2: Assess Current Knowledge & Highlight Gaps

		Design Parameters								Outcome
		Material of NR	Line Speed	Sizing Conc.	Tension of CF	Temp of Sizing	Nip Force	Stretch Ratio	Thickness of NR	Temp of NR
Design Parameters	Material of NR		0	0	0	0	1	0	0	1
	Line Speed			0	1	0	0	0	0	1
	Sizing Conc.				0	0	0	0	0	
	Tension of CF					0	0	0	0	
	Temp of Sizing						0	0	0	
	Nip Force							2	0	1
	Stretch Ratio								2	1
	Thickness of NR									1

Level	State of Knowledge
0	We are confident that no relationship exists
1	We hypothesize the existence of a relationship.
2	We have observed a relationship, but we lack data-driven evidence.
3	We have observed a relationship, and we possess data to substantiate it.
4	We have quantified or visualized the relationship.

For each non-zero Relationship:

Target Knowledge Level	4 (Quantify or Visualize Relationship)
Knowledge Gap	Current Level – Level 4

Each cell could serve as an access point/interface for retrieving knowledge from the 'knowledge storage'

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Comprehend Stage *(Cont.)*

Step 3: Identify Knowledge Artifacts

		Design Parameters								Outcome
		Material of NR	Line Speed	Sizing Conc.	Tension of CF	Temp of Sizing	Nip Force	Stretch Ratio	Thickness of NR	Temp of NR
Design Parameters	Material of NR		0	0	0	0	1	0	0	1
	Line Speed			0	1	0	0	0	0	1
	Sizing Conc.				0	0	0	0	0	
	Tension of CF					0	0	0	0	
	Temp of Sizing						0	0	0	
	Nip Force							2	0	1
	Stretch Ratio								2	1
	Thickness of NR									1

A. Trade-Off Curve

B. Trade-Off Curve

C. Equation

D. Equation

Budget and Time allocation for each artifact could happen at this stage

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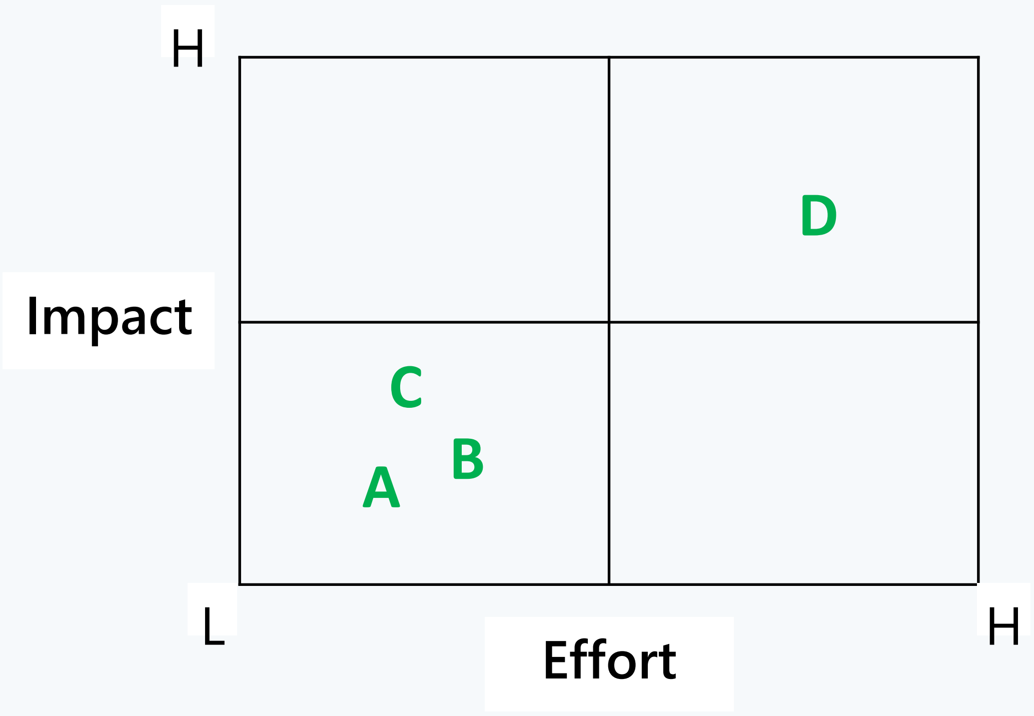
Plan Stage

Step 1: Determine Minimum Granularity & Method

Design Parameters	Granularity		Artifact			
	Range	Levels	A	B	C	D
Material of NR	70-95 (A)	5				
Line Speed	5-25 (m/s)	5				
Sizing Conc.	1-5 (wt%)	5				
Tension of CF	1.5-4 (lbf)	7				
Temp of Sizing	20-40 (°C)	3				
Nip Force	800-1400 (psi)	7				
Stretch Ratio	5-25 (%)	5				
Thickness of NR	0.2-0.6 (inch)	3				
Method			Experiments			

- For each artifact, different knowledge generation methods such as simulation, experimentation, etc. can be determined.

OPTIONAL Step: Prioritize Artifacts



For each artifact, ask the following questions,

- **Impact:** How much knowledge is generated by developing the artifact?
- **Effort:** How much time/resources need to be allocated for developing the artifact?

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Plan Stage *(Cont.)*

Step 2: Develop Action Plan

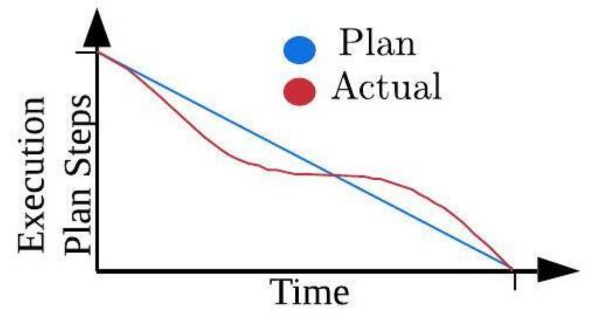
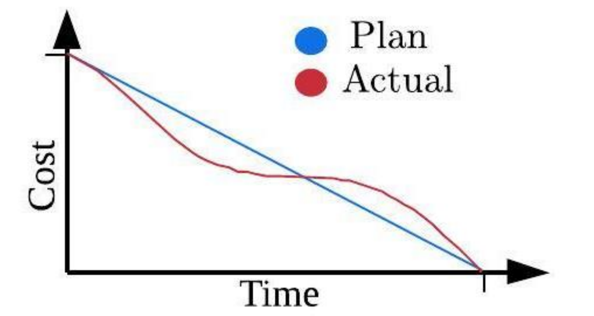
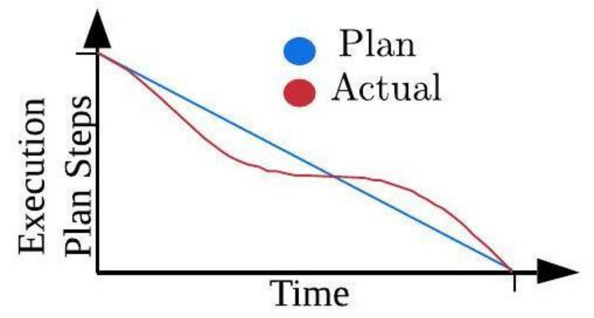
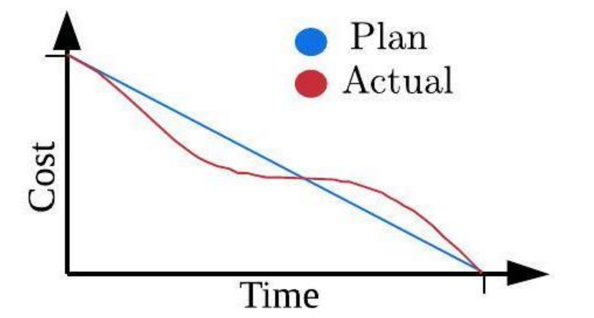
- Preparation varies based on the method chosen for artifact development.
- Following is an example action plan we developed for Artifact D.

Activity	Plan Time		Who	Actual Time	
	Time Required	Date(s)		Time Required	Date(s)
Outline Experiment Procedure					
Identify equipment, materials and personnel required.					
Budget Cost					
Acquire material/component for experimental and testing setups					
Setup the experiment configuration					
Finalize the Data capture and analysis plan					
Setup the testing configuration					
Conduct experiments and capture data					
Analyze Data					

Execute Stage

- Implement planned activities

Learning Dashboards

<table>
<tr><th colspan="3">Knowledge Artifact Tracking</th></tr>
<tr><th>Knowledge Artifact</th><th>Progress Burndown</th><th>Cost Burndown</th></tr>
<tr><td>Trade-off curve showing the relationship between nip roller material and nip force</td><td>
</td><td>
</td></tr>
<tr><th colspan="3">Knowledge Goal Tracking</th></tr>
<tr><th>Knowledge Goal</th><th>Progress Burndown</th><th>Cost Burndown</th></tr>
<tr><td>Generate knowledge to identify cause-and-effect relationships among factors influencing the temperature of the nip roller.</td><td>
</td><td>
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Conclusion

The DKG

- Provides a set of tools for systematically generating knowledge.
- Facilitates tracking the rate of knowledge generation.
- Facilitates storing the generated knowledge.

Application

- Better suited for complex products where understanding of design problems remains limited.
- Necessary to have developed product concepts, and gained a preliminary understanding of the design parameters, design goals, and various subsystems.
- Trigger Knowledge Generation when a "Problem" is encountered.

Next Steps

- Continue applying the framework with the SBCF research group and partner with at least one company to implement the framework.

Thank You

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