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Towards Transforming Legacy Products to their Model-Based Representations

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Outline

- Summary
- Research Question
- Diamond Process Model
- Reverse Engineering Process
- Case Study
- Major Challenges
- Conclusion and Future Work

Summary

Motivation

- Model-Based Systems Engineering (MBSE) gaining prominence in SE community
- With focus on Digital Engineering, the inability to transform legacy information to model-based representations remain a significant hurdle in the industrial adoption

Major Contributions

- Proposed a framework to obtain model-based representation of legacy products
- Framework employs a novel data-driven reverse engineering approach to determine the critical legacy requirements

Why MBSE artifacts for Legacy systems?

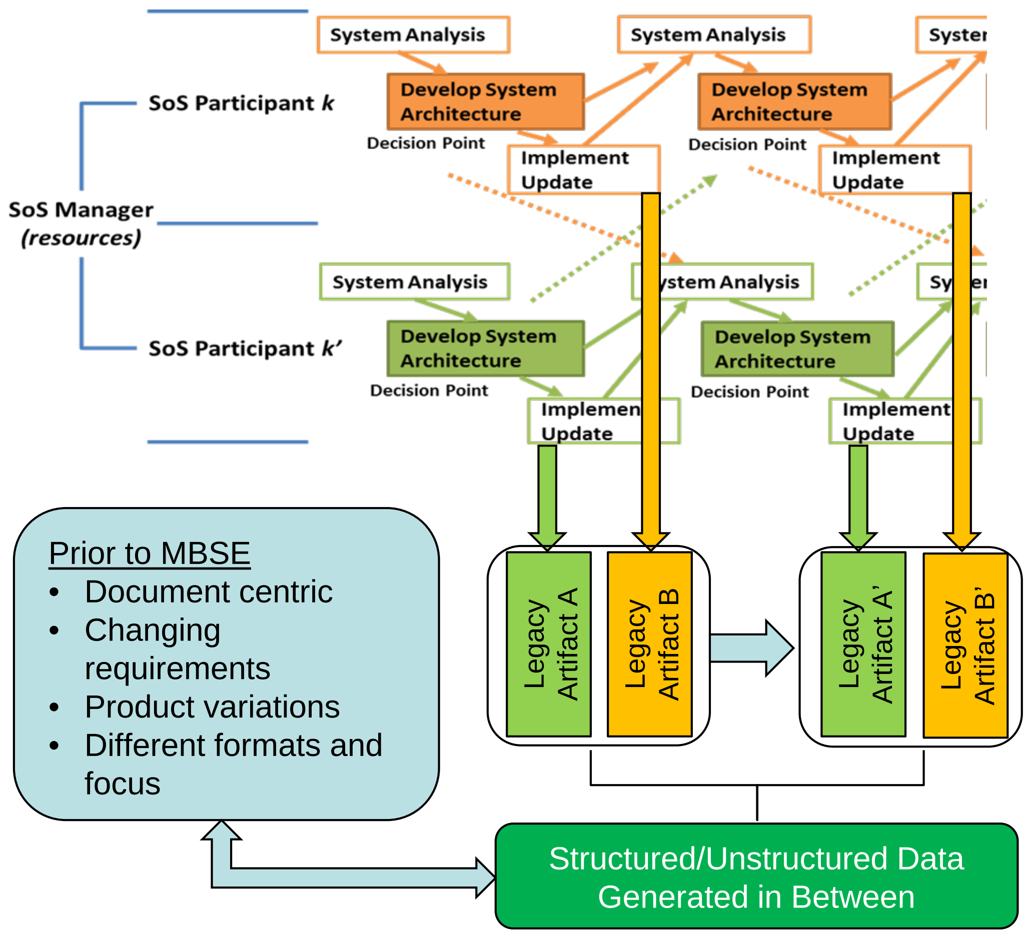
- Integration of legacy systems with new systems which have been designed and developed with MBSE

- Introduction of block-upgrades and new capabilities to legacy systems

- Leverage legacy system design for future systems using MBSE

Challenges in Upgrading Legacy Complex Systems/System of Systems Architectures

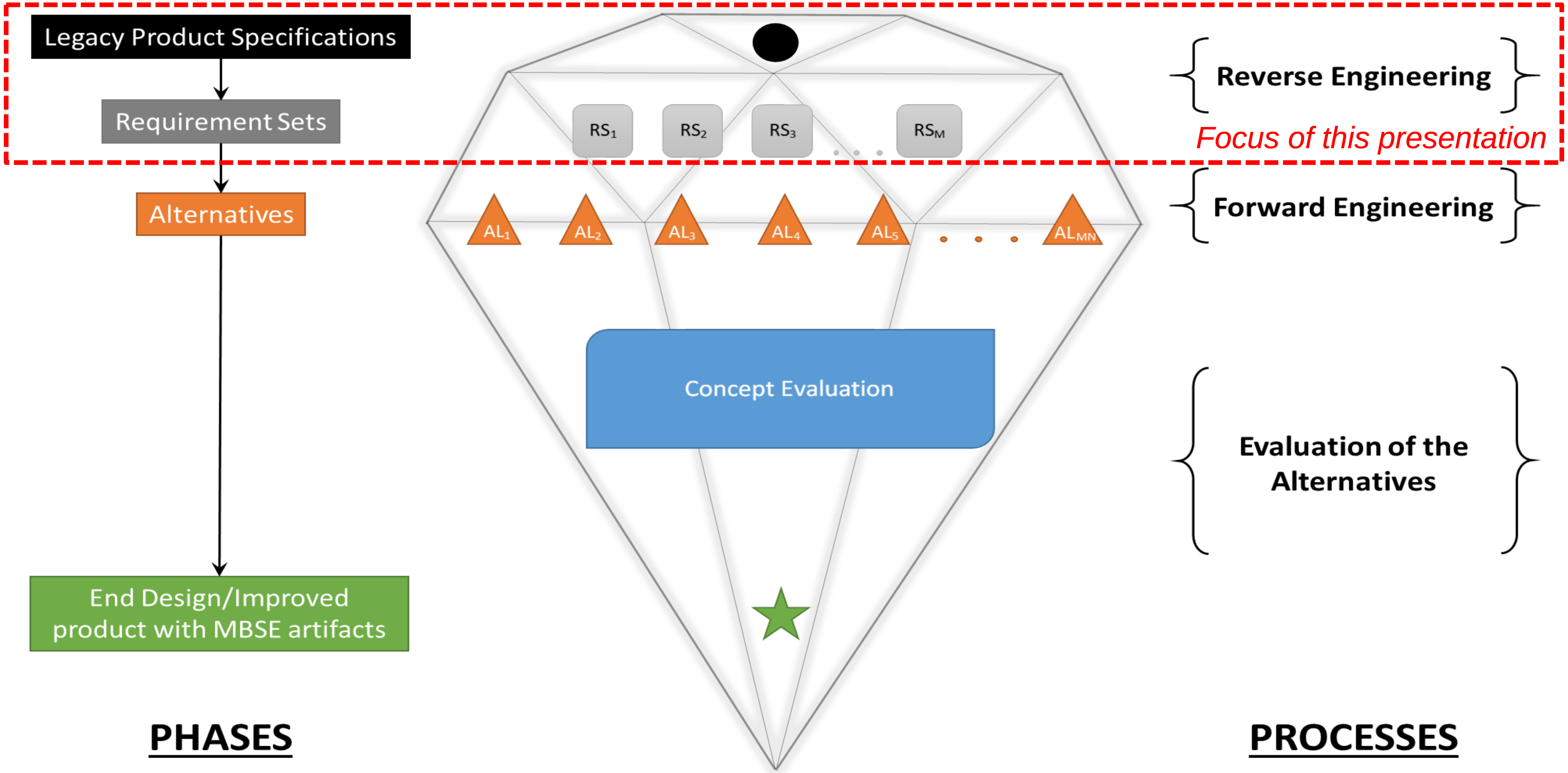
- Sequential SoS/Complex System updates by various stakeholders
- Updates transcend technical and programmatic constraints
- Legacy documentation and data issues – privacy, formats, loss of information etc.
- Can be hard to recover requirement set for purpose of new block upgrades



Research Question

"How to enable the transformation of legacy products to their model-based representations to ensure a smoother enhancement in future?"

Diamond Process Model (DPM)



Reverse Engineering Process

- Initiates with the Legacy Product specification
- Objective is to identify the archetypal requirements which postulate legacy product design

<u>Key Points</u>

- Utilize the available information, such as project teams, PLM databases, and product characteristics to reverse engineer legacy product requirements
- Authors believe that identifying the team structure is the key to estimating the critical requirements (*Conway's Law*)

Forward Engineering Process

- Initiates with the requirement sets identified using the Reverse Engineering process
- Objective is to generate alternative product concepts for the identified requirement sets using MBSE
- Use MBSE methods such as IBM Telelogic-Harmony SE, INCOSE OOSEM – *prominent area of research in SE community*

Key Points

- Utilize MBSE methods to generate model-based artifacts
- Rethinking legacy product design in terms of MBSE provides opportunities for improving the legacy product design

Analysis of Alternatives

- The input to this step is the set of alternatives generated in the Forward Engineering step
- Objective is to identify the most promising concept for the legacy product
- Utilize methods such as complete life-cycle analysis (ISO 15288) to perform the analysis – *prominent area of research*

Key Points

- The design goals and objectives may evolve since the legacy product was designed (e.g. cost-effectiveness to robustness). The concepts can be evaluated against updated and revised goals and objectives.

Data-Driven Reverse Engineering Process

(Optional)

Legacy Product

Outpu

MB

Represe

What: For simi

obtain **mi**

- The process requires availability of a PLM database of products si

- The objective of **Classification** step is to ...he category (a ...elation matrix, T) ...ates team ...ns to legacy ...utput ...ristics (**Y**).

  ...chieved by ...nplementing a classification ...lgorithm upon the PLM ...atabase.

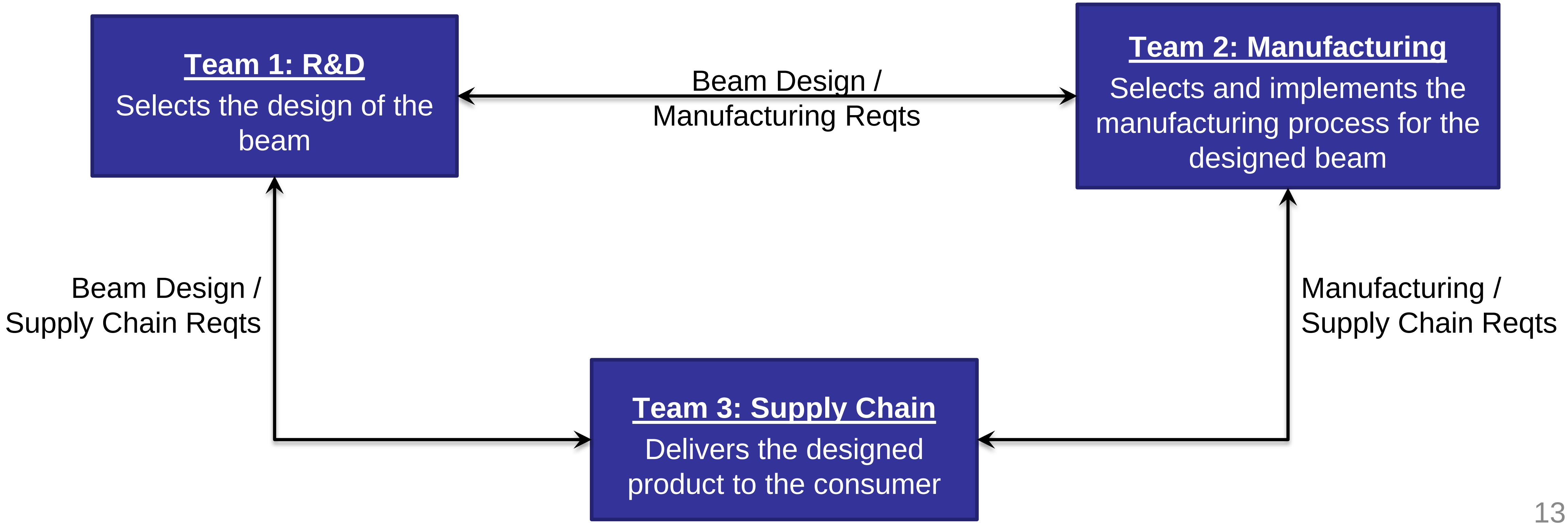
- Once the requirement sets are available for the legacy product an optional step can be applied to prioritize the requirement sets.

- This step becomes essential when there are not enough resources available to perform forward engineering on all the requirement sets identified in the previous step.

- Onc... regression methods to estimate the unknown requirements ($\hat{X}$) based on legacy product characteristics and the team interactions.

Example: Beam Supplier Company

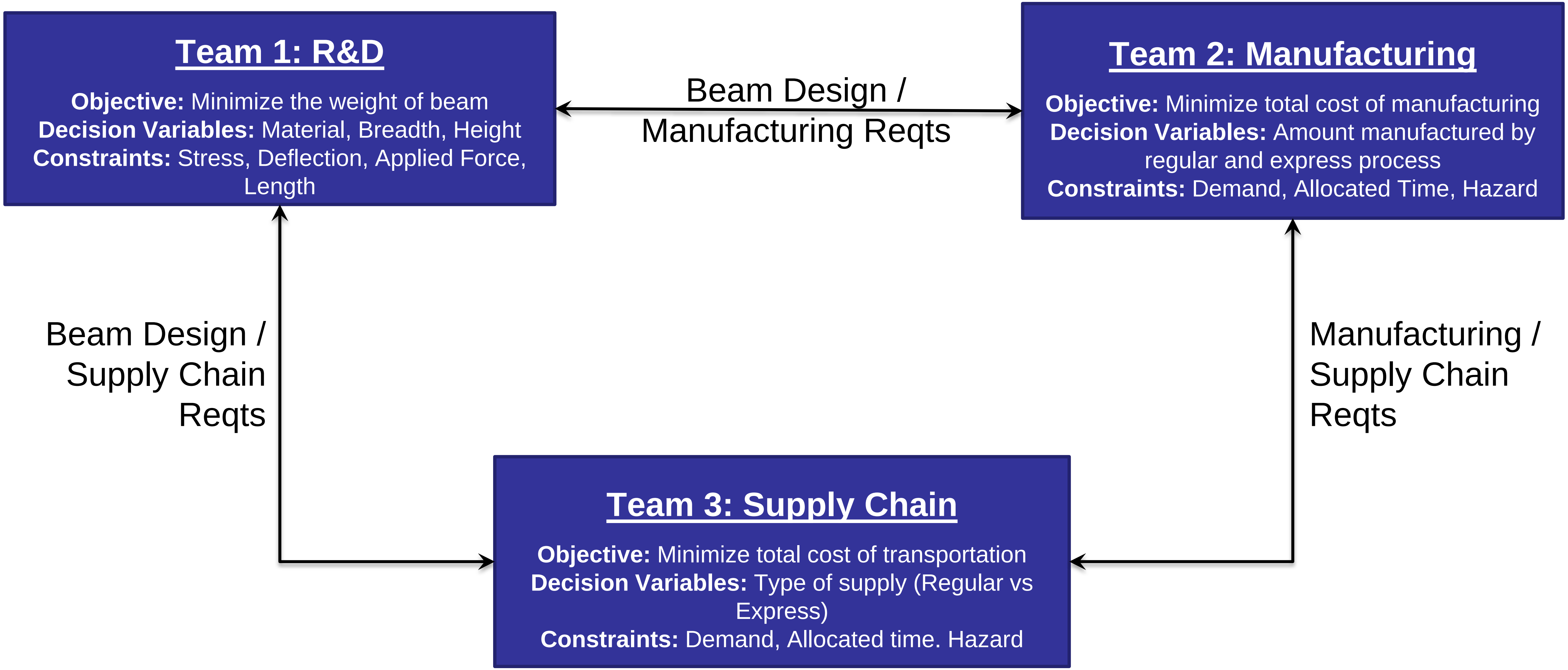
- Acquired a company with three depts: R&D, Manufacturing, Supply Chain.
- The objective is to *Reverse Engineer* design and supply process of different types of beams supplied by the company with the help of various supply orders.



Types of supply orders

1. **New Product**
   - Affects the requirements at the lowest level (e.g., component design)
   - T_{12} , T_{23} active
2. **Manufacturing Process Refinement**
   - Affects the requirements at a higher level (e.g., assembly of components)
   - Only T_{23} active
3. **Supply order of already manufactured product**
   - Affects the requirements at the highest level in this example (e.g., supply of assembled components)
   - Only T_{13} active

Example: Beam Supplier Company



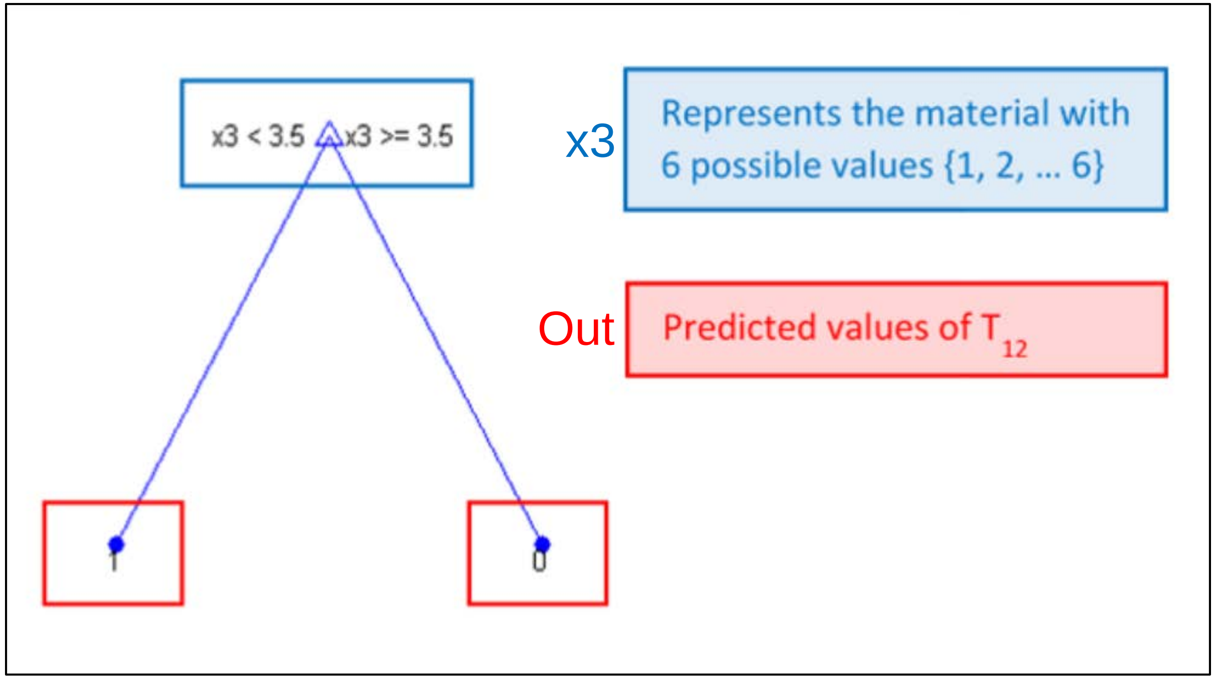
Data Generation

- Solve team-specific optimization problems using different cases described in the previous slide
- Generated dataset serves as a hypothetical “prior company data” transferred during the merger process

- Generated 40 data points with information on
  - Various costs (Supply chain transportation and manufacturing costs)
  - Time (Transportation and manufacturing time)
  - Beam Design Parameters (Beam dimensions and material)
  - Team interaction values, used to generate the data point, are also recorded

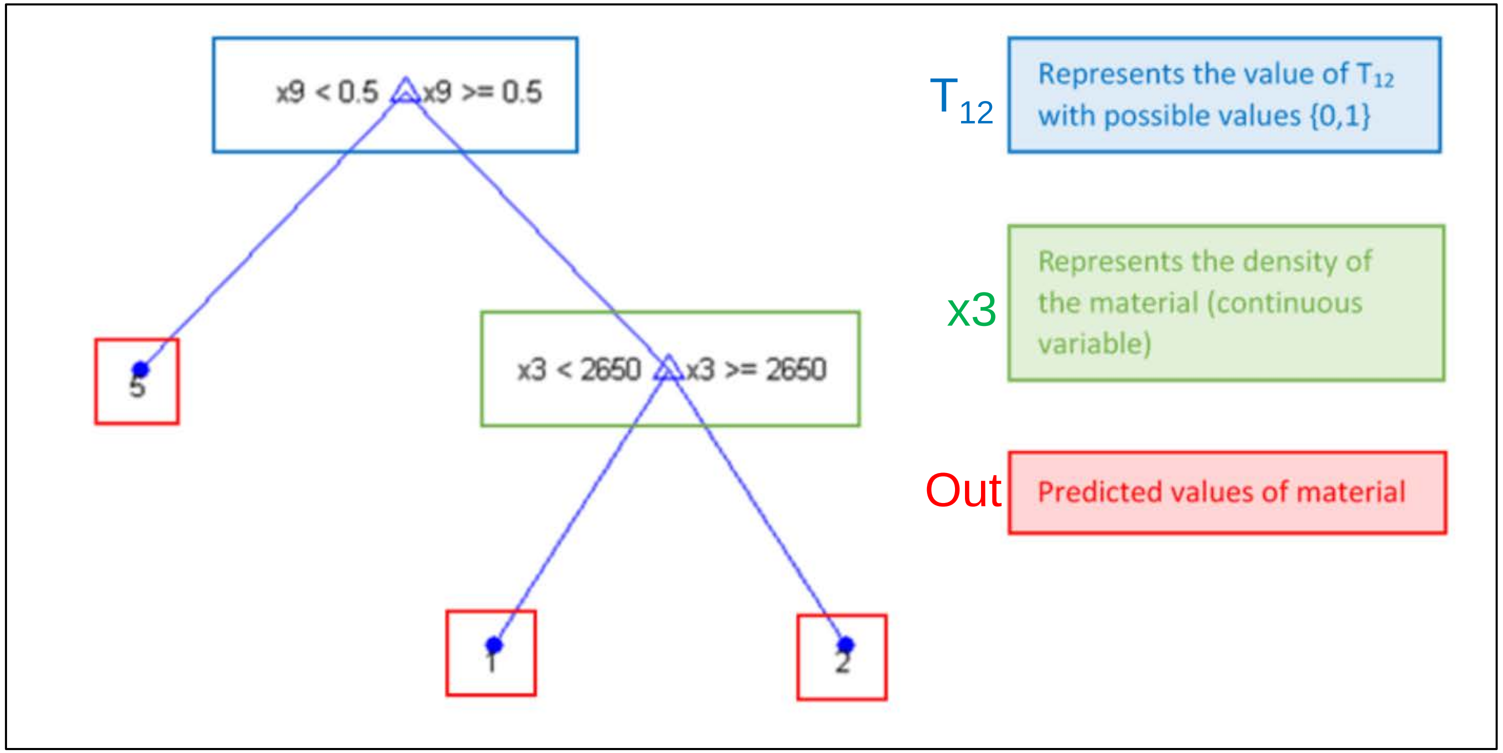
Example: Classification

- The objective is to classify given legacy product specification to a specific category of supply order using the supply order database
- For example, Classification and Regression Trees (CART), a popular classification algorithm, is implemented to predict T_{12} (interaction between Team 1 & 2)



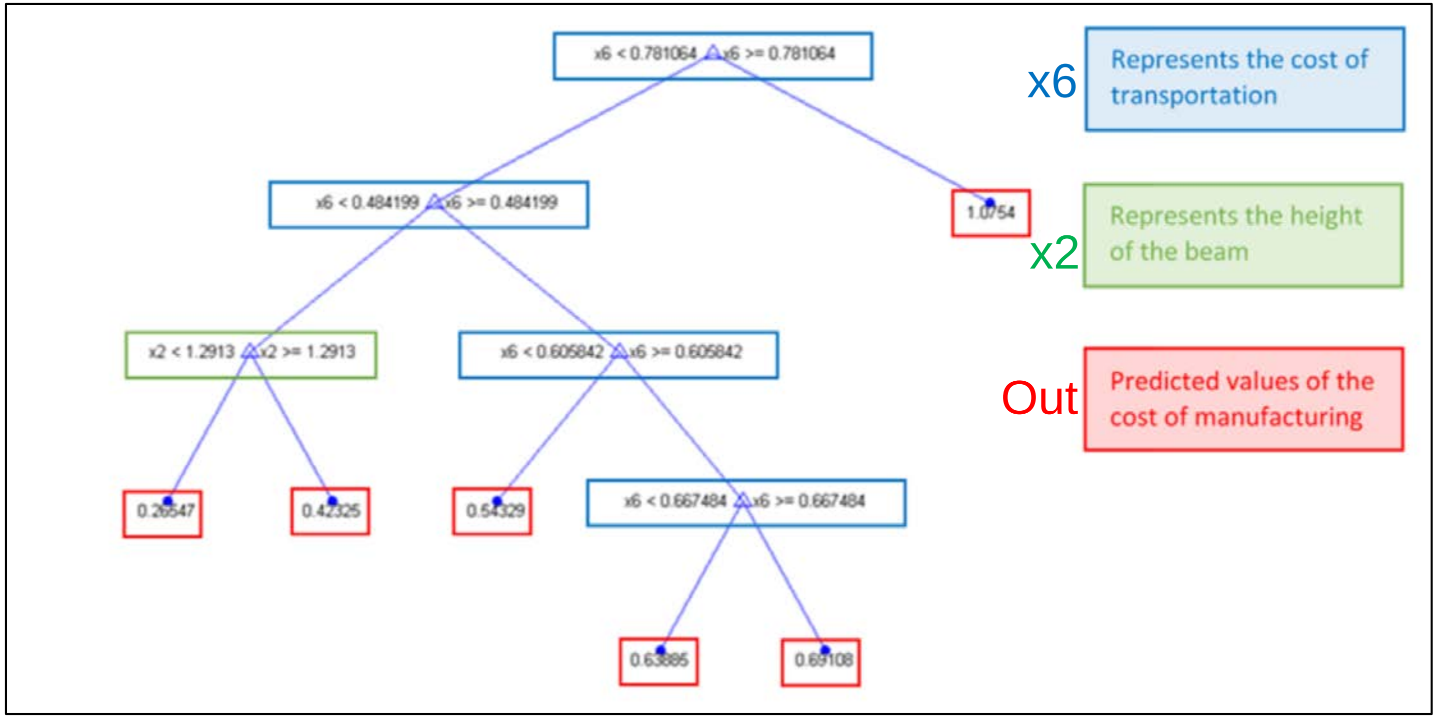
Example: Input Estimation

- Once the category is identified, we estimate requirements for the given legacy product specifications using regression on the database
- For example, implemented CART to estimate material values



Example: Estimating missing information

- Additional advantage is the ability to estimate missing values. This can prove crucial when distributed set of diverse players are involved in the design process; each team can get an estimate without violating IP issues.
- For example, implemented CART to predict the Cost of Manufacturing as a function of the cost of transportation and the beam height.



Major Challenges

- Identifying appropriate machine learning algorithms based upon the type of available data and the expected output

- Identifying and capturing the ‘relevant’ minimum information in the PLM Database

- Machine learning approaches usually require a large number of data points; issue for reverse engineering complex legacy products

Conclusion

- Proposed the Diamond Process Model (DPM) to transform legacy product information to model-based representations
- Focused on the *Reverse Engineering Process* to identify the critical requirements that led to the legacy product design
- Employs a novel data-driven approach utilizing the digital information stored for similar products
- Demonstrated its applicability to discover requirements and organization structure using a simple example

Future Work

- Explore the potential application to design new products that stem from a legacy baseline

- Mature the Diamond Process Model by investigating the applicability of additional machine learning models

- Demonstrate the Diamond Process Model for applications in real-world problems to support Digital Engineering; working with collaborators from Rockwell Collins to work with real-world data

Questions?

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