Product Lifecycle – 4 Phases

Production

Creation

Disposal

Operations
Conceptual Ideal for PLM

Real Space ⟷ Virtual Space
Data
Information
Process

VS₁  VS₂  ...  VSₙ
Digital Twin Model

Physical Space

Virtual Space

20th Century
Substituting information for wasted physical resources

21st Century

Data

Information

Work Activity

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Information as Task Wasted Time, Energy, Material Substitute

\[ C(t,e,m,I) < C_W(t,e,m) \]

Task: Goal Seeking Activity with Minimum Physical Resources
Digital Twin Model
Scope & Scale - Tangible

Digital Thread

Physical Space

Virtual Space

Data

Information

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Digital Twin Types (DT)

- **Digital Twin Prototype (DTP)**
  - All Products that CAN BE made
  - [Images of aircraft prototypes]

- **Digital Twin Aggregate (DTA)**
  - All Products that HAVE BEEN made
  - [Images of aircraft aggregates]

- **Digital Twin Instance (DTI)**
  - Individual Products that ARE made
  - [Images of individual aircraft]
Digital Twin Model through the Lifecycle

Create  DTP

Build  DTP/DTI

Sustain  DTP/DTI/DTA
Categories of System Behavior

- System Behavior
  - Predicted Behavior
    - Predicted Desirable (PD)
    - Predicted Undesirable (UU)
  - Unpredicted Behavior
    - Unpredicted Desirable (UD)
    - Unpredicted Undesirable (UU)
System Engineering Models

Waterfall Model

1. Requirements
2. Design
3. Implementation
4. Verification
5. Maintenance

Spiral Model

VEE Model

- System
  - Subsystem
    - Assembly
      - Part
    - Subassembly
- System
  - Subsystem
    - Assembly
      - Part
    - Subassembly
Digital Twin Implementation Model

Figure 5
Systems Engineering vs. PLM/DT

- Systems Engineering is product realization focused while PLM is product lifecycle focused;
- Systems Engineering is functionally based versus Product Lifecycle Management which is lifecycle based;
- Systems Engineering concerns itself primarily with physical products where PLM concern itself with both physical and virtual products;
- Systems Engineering is document based, while PLM is digital based;
- Systems Engineering is a much deeper discipline versus PLM, which is much broader.
- Systems Engineering degenerates into system accounting
Digital Twin Evolution

- **Traditional**
- **Transitional**
- **Conceptual**
- **Replication**
- **DT Platform**
- **IDT Platform**

- **FRS (Front Running Simulation)**
- **Metaverse**

**Information Evolution**

**Physical to Virtual Maturity**
Digital Twin Metaverse

- There are multiple DT metaverses
- The DT metaverse supports both replication and prediction
- All laws of the physical universe are implemented and enforced in simulations for all inanimate objects
- DT interoperability is a requirement if multiple DTs.
- It is multiple participant immersive as avatars
- Meta capabilities are allowed for human participants as avatars
- Time can be synchronous or asynchronous with physical time depending on use case and DT type
- Cybersecurity is an embedded
Selected Publications

• Grieves, M., Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management. 2011, Cocoa Beach, FL: Space Coast Press.
• Grieves, M., Intelligent digital twins and the development and management of complex systems. Digital Twin, 2022, 2(8)

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