Model-Based Systems Engineering:
Past, Present and Future

No Magic
What is Systems Engineering?

- Interdisciplinary in nature
- Design and management of complex systems
- Focuses on the whole as opposed to the parts
- Identify goals, create alternative solutions, select best design, verify proper implementation and integration, assess how well requirements were met
- The engineering discipline that acts as the voice of the customer
Where is it used?

Systems Engineering is used to some degree on almost all products/systems of any significance today, whether as a formal practice or not.
Why is it important today?

- Systems are becoming increasingly complex
- Increase in subsystems, components, data, variables

This has been an underserved discipline!
State of Practice in Systems Engineering: Documents and Spreadsheets Rule!

• Document based approach works, but...
• How do we keep documents and designs properly synched?
• According to research, the majority of serious defects occur in early phases of the system lifecycle
SE Practices for Describing Systems

Past
- Specifications
- Interface requirements
- System design
- Analysis & Trade-off
- Test plans

Future

Moving from Document centric to Model centric

What is Model Based Systems Engineering?

MBSE is a disciplined, rigorous approach to systems engineering that uses visual modeling to support requirements, design, and analysis through conceptual, logical, and later phases of the system life cycle.
OMG Systems Modeling Language (SysML) is a graphical modeling language for specification, analysis, design, verification and validation of systems. It is dedicated for modeling complex systems that may include hardware, software, information, personnel, procedures, facilities, etc. SysML is built upon UML, with some extensions that are not required by UML. UML is reused by SysML (UML4SysML).
Why are visual models important?

- Simplify the representation of systems
- Eliminate or reduce ambiguity concerning concepts, relationships, intent, or structure
- Improves communication and understanding
- Provide a technical baseline
- Used for validation and verification at multiple stages in the development cycle, allowing for earlier detection of problems and defects.
System Model as an Integration Framework

- External Requirements
- System Documentation and Specifications

traceability rationale

viewpoint

System Model (SysML)

- Structure
- Behavior

requirements

- System Model (SysML)

- Analysis
  - closed form
  - discrete event
  - network

- Performance estimates

- System framework for design

- Mechanical Design Models
- Electrical Design Models
- Software Design Models
- Testing Methods and Models

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**Today:** Standalone models related through documents

**Future:** Shared system model with multiple views, and connected to discipline models
Paradigm Shift

Old design methodologies rely on build, test, fix

- Defects detected earlier in the process
- Less expensive to fix at these earlier stages
- Overall product quality improves
No longer a revolution

• It’s an EVOLUTION
  • SysML is changing to enhance usability, facilitate exchange of model data, and increase adoption
  • Integrating with PLM
  • Increased demand for interoperability with detailed design tools
  • Full system simulation
  • AI?
SysML v2 Objectives

- Improved precision and effectiveness
- Better consistency among language concepts
- Interoperability with other engineering tools
- Enhanced usability for both developers and consumers
PLM Integration

Integrating to PLM allows for automated data interchange between SE and other disciplines.
Deeper Use Case

Import BOM

Determine alternatives based on parts in PLM

Design decision based on simulation of all combinations

Publish back to PLM for domain specific design review
Detailed Design Exchange - DDS
### Wiring Design Model (SysML) - Generated, Fragment

#### Diagram

- ![Diagram Image](image)

#### Table

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<tr>
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Wiring Schematics (E3.series) - Imported, Fragment
What is our goal as Systems Engineers?

Ultimately it is about realizing successful systems!
Simulation - Cruise Control Example

[Diagram of cruise control system with states and variables]

Vehicle Speed

Engine Torque

Road Inclination

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Automated Component Selection

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<table>
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<th>bdd [Package] Structure [ Structure ]</th>
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<tr>
<td>sw : Sum Weight</td>
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<tr>
<td>shp : SumHP</td>
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<tr>
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</tr>
<tr>
<td>&lt;mode&gt; TotalCost : Real</td>
</tr>
<tr>
<td>&lt;mode&gt; TotalWeight : Real</td>
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<td>&lt;requirements&gt; Performance (HP)</td>
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<td>Id = &quot;SN1&quot; Text = &quot;The greatest performance in term of HP, closest to the target HP&quot;</td>
</tr>
<tr>
<td>&lt;requirements&gt; Cost</td>
</tr>
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<td>Id = &quot;SN2&quot; Text = &quot;The cheapest cost to build a car, much cheaper than the target cost&quot;</td>
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<tr>
<td>&lt;requirements&gt; Weight</td>
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<td>Id = &quot;SN3&quot; Text = &quot;The lightest car, much lighter than the target weight&quot;</td>
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```

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<th>block: HybridCar</th>
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<td>fuelType : fuel</td>
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<td>power hp : power(unit = hp)</td>
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<tr>
<td>power kilowatt : power(kilowatt)[u]</td>
</tr>
<tr>
<td>speed : speed[unit = rpm]</td>
</tr>
<tr>
<td>weight : mass[kilogram][unit = kilo]</td>
</tr>
<tr>
<td>price : price[unit = usd]</td>
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```

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<table>
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<tr>
<td>values</td>
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```

```
| requirements Target HP                                 |
| Id = "SR2" Text = "The target house power close to 140 hp." |
| <requirements Max Cost                                 |
| Id = "SR1" Text = "The maximum cost of a car is 30,000 USD." |

```

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No Magic

The Truth is in the Models™
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<th>Value</th>
<th>Weighted Ratio</th>
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<td>Target HP</td>
<td>140 hp</td>
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Maximum Cost

Maximum Weight

```plaintext
<<constraint>>
Fitness Constraint

constraints
{fitnessValue = fitnessHP + fitnessCost + fitnessWeight}

fitnessValue : Real
fitnessWeight : Real
fitnessHP : Real
fitnessCost : Real

<<constraint>>
Fitness HP

constraints
{fitnessHP = ratioHP * (1 - abs(targetHP - totalHP)/targetHP))}

targetHP : Real
ratioHP : Real
fitnessHP : Real
totalHP : Real

<<constraint>>
Fitness Formula

constraints
{fitness = ratio * (Math.abs(max - total)/max);
if(total > max) fitness = -fitness)

total : Real
fitness : Real
ratio : Real
max : Real

<<constraint>>
SumHP

constraints
{totalHP = hpEngine + hpElectricMotor}

totalHP : Real
hpEngine : Real
hpElectricMotor : Real

<<constraint>>
Sum Cost

constraints
{totalCost = enginePrice + electricMotorPrice + batteryPrice}

totalCost : Real
enginePrice : Real
electricMotorPrice : Real
batteryPrice : Real

<<constraint>>
Sum Weight

constraints
{totalWeight = engineWeight + electricMotorWeight + batteryWeight}

totalWeight : Real
engineWeight : Real
electricMotorWeight : Real
batteryWeight : Real
```
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Total evolution time: 50 ms

The best solution has a fitness value of 0.8024761904761905

Engine: Engine A
Electric Motor: Electric Motor D
Battery: Battery C
And the winner is...

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<th>battery : Battery</th>
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<th>totalWeight : Real</th>
<th>fitnessCar : Real</th>
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```
«block»
HybridCar_ADC : HybridCar

battery = Battery C
electricMotor = Electric Motor D
engine = Engine A
fitnessCar = 0.8024761904761905
totalCost = 15400.0
totalHP = 138.0
totalWeight = 594.0
```
Summary

• MBSE simplifies complexity
• Promotes consistent communication through use of a common notation and a single source of truth
• Provides rigor and discipline to system design and optimization
• Future is in assisted design
• It is not a silver bullet
  • Takes time to implement and fully realize the benefits
  • Requires commitment to developing a modeling practice
  • Benefits from development of corporate standards and reusable libraries
Thank You!

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