Introduction to Model Based Semantic Machine System Design Process

Jussi Aaltonen
Tampere University of Technology
Department of Intelligent Hydraulics and Automation
Smart Simulators Research Group
Engineering Intelligence and Systems Engineering

- Development phasing controls the design process and provides baselines which coordinate design efforts.
- Systems engineering process provides a structure for solving design problems.
- Life cycle integration involves customers in the design process and ensures that the system developed is viable throughout its life.

Why Yet Another Design Process Model?

We need formal processes and methods
• To be able to handle ever increasing complexity of cyber-physical systems
• To be enable engineers to produce information instead of data
• To support data and information interoperability
• To strengthen collaboration and co-creation
• To enable corporate memory to capture even most minute details of creative process leading to finished product
• To improve design quality
• To product quality
• To be more agile and flexible
• etc
Increasing Complexity is Not a Problem if Addressed Appropriately

**F-4 (3rd gen)**

- Maiden flight: 1958
- Radar
  - Number of parts: 100
  - MTBF: 100
- Engines
  - Number of parts: 100
  - MTBF: 100
- Aircraft
  - MTBF: 100
  - Maintenance resources needed: 100
  - Software content: 5

**F-18 (4th gen)**

- Maiden flight: 1978
- Radar
  - Number of parts: 40
  - MTBF: 1000
- Engines
  - Number of parts: 74
  - MTBF: 400
- Aircraft
  - MTBF: 470
  - Maintenance resources needed: 60
  - Software content: 100
Design Processes for Machine Systems

- **VDI 2221**
  - Only for mechanical systems
- **VDI 2422**
  - For mechatronic systems controlled by a microcontroller
- **VDI 2206**
  - Micro-level: problem solving in general
  - Macro-level: V-Model
  - Pre-defined process-modules for recurring design steps
- **Combination of VDI 2422 and VDI 2206**
  - How to get from the requirements to the system design.
  - How to get from the concept to the embodiment design. Decision for the proper interdisciplinary exchange during the embodiment design phase

[VDI 2206 - Entwicklungsmethodik für mechatronische Systeme]
[VDI 2221 - Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte]
[VDI 2422 - Entwicklungsmethodik für Geräte mit Steuerung durch Mikroelektronik]
The Infamous V

- The V diagram of VDI 2206 is often seen as a depiction of the systems engineering process.
- However in reality the infamous V is just a rearranged waterfall.

V is meant to be used as a management tool which shows the relationship between design activities and test activities.

- It is not to be interpreted as a waterfall so that each phase must be completed before the next begins.
- Common mistake is also to forget that the V is only an overview of some of the aspects of the project cycle relating to development and test/evaluation at the various phases of the system life-cycle.

Simplistic straight forward use of the V view as a process model leads also to:
- Inability to prevent design defects
- Failure to consider changes to customer needs during development.

[System Engineering Guidebook for Intelligent Transportation Systems Version 2.0, California Department of Transportation, 2007]
The Infamous V
There is No Voodoo nor any Other Magic in System Engineering

Systems engineering is simply an iterative and recursive process for designing a solutions to meet specified needs.

1. Define needs
2. Divide them into manageable chunks
3. Design the solution
Semantic Machine System Design Process

- Systems engineering process for semantic product data management systems
  - *Systems conforming future Engineering Intelligence Ecosystem*
- Based on VDI 2221 and VDI 2206
- Simple waterfall
  - *Iterative*
  - *Recursive*
- Compatible with the infamous V – forms another branch of V
- Each process phase produces defined formal information
- Each process phase enriches the semantic model of the product
- Each process phase utilizes information provided by semantic model of the product
Spesification

- **Task**
  - Defined by parent process, customer requirements etc.

- **Task clarification and definition**
  - Interpretion customer requirements to exact technical specification
  - Parent process requirements to exact technical specification

- **Requirement specification**
  - Exact technical specification of the system

- **Allometric model**
  - Mathematical model of the requirement specification
  - Design parameters to requirements:
    - Power to weight ratio
    - Specific fuel consumption
    - Net weight / gross weight

---

**Example**

```
<table>
<thead>
<tr>
<th>Requirement specification</th>
<th>Allometric model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarify and define the task</td>
<td></td>
</tr>
<tr>
<td>Task</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
```

---

**Semantic Model and Information Management**

- Continuous improvement
- Validation against requirements / adaptation of requirements

---

**Task**

- Defined by parent process, customer requirements etc.

**Task clarification and definition**

- Interpretation customer requirements to exact technical specification
- Parent process requirements to exact technical specification

**Requirement specification**

- Exact technical specification of the system

**Allometric model**

- Mathematical model of the requirement specification
- Design parameters to requirements:
  - Power to weight ratio
  - Specific fuel consumption
  - Net weight / gross weight
Conceptual Design 1/3

- Function structure definition
  - Logical functions
  - Static relations
- Conceptual model
  - Simple black box describing static relation between input and output
  - Logic model
  - Statistical model
  - Simple disturbances included

Example
Conceptual Design 2/3

- Function structure definition
  - Material, energy and information functions
  - Dynamic relations
- Conceptual model
  - Simple black box describing dynamic relation between input and output
  - Disturbance and process models included
  - Typically dynamic lumped parameter model

Example
Conceptual Design 3/3

- **Solution principle**
  - Physical and chemical effects enabling desired functions
  - Operation principle
- **Distributed component/element model**
  - Typically system of dynamic lumped parameter models
  -Domains included into models
  - Separate component/element/subsystem/process models
Detail Design 1/2

- Preliminary design
  - Modular layout
    - Division to components or separate design elements
  - Initiation of child design processes
    - Tasks
    - Requirements

- Detailed model
  - Distributed parameter model
  - Parameter exchange with other design software
  - Child process model integration
Detail Design 2/2

- Final design proposal
  - Child process design integration
- Validated model
  - Final model validation against requirements
  - Complete model with all child process models

Example
Documentation

- Documentation
  - Production documentation
  - Assembly instructions
  - User documentation
  - Maintenance documentation
  - Etc

- Verified model
  - Model verification against prototype testing data
  - Finished model and complete to be used in life-cycle, integrity and other services
Conclusions

What do we want to achieve by this all?

• Formal easy to follow method for us mere mortals
  – Formal and interoperable outcomes
  – Clear steps and phases
  – Tool independent methodology

• Ability re-use and re-cycle designs
  – No need for reverse engineering to get inside original designer head
  – No need to manually re-validate for new or changing requirements

• To lure every engineer to peek out his own silo and comfort zone and see the big picture – customer requirements
  – Engineers are not so insular that they could not have interdisciplinary conversations – in fact most of them even enjoy it after a little practice

• Methodology and process models which allow each engineer to work on his/her comfort zone but share the vision of all others as well as the big picture without a need to turn into computer geek.
Thank you for Your attention!