Integrating Descriptive Models with an Analytical Model Culture – Lessons Learned at Ford

Kyle Post, George Walley and Judy Che

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Ford Motor Company
In this Presentation...

- Motivation
- Descriptive & Analytical models at Ford
- Understand role for and line between descriptive (sysml) and analytical or implementation models
- Modeling and eliciting requirements through response diagrams tied to system models
- Exploring Model Based Failure Mode Avoidance
- Experiences in integration SysML and PLM systems for requirements and feature/function breakdowns
- Leveraging SysML in an Integrated Vehicle Analysis process
Motivation

As presented by Ford colleagues in the past, an increase and influx of models and model-based approaches are being used to develop, integrate, test, and manage our increasing complex vehicle systems.

Using SysML for descriptive modeling as a useful addition to analytical models

Descriptive Models
• Enable the transition from a document-based system engineering approach to a model-based approach

• Provide an abstract view of the system that can be analyzed before building more time consuming analytical models and implementation

• Is not restricted to a closed form mathematical equation as analytical models are

• Convey multiple viewpoints (e.g. Structural view vs. Functional view vs. Physical)

• Used as a master to coordinate and connect engineering toolsets (e.g. analytical models, PLM systems, test benches, etc...)
Distinguishing the purpose and value of different types of models in an overall MBSE strategy helped alleviate concerns that SysML was yet another modeling language to compete with existing analytical modeling languages.
DESCRIPTIVE / ANALYTICAL PROCESS BREAKDOWN

Customer Experience, Stakeholder Requirements

Verify Customer Experience

Verify Architecture, Behavior

Verify Dynamic Behavior

Validate Actual Customer Experience

Intended Behavior, System Architecture, Requirements, Trade Study Options

High Level Dynamic Models
Static Analysis

Model Based Design

Detailed Design
Generate Code

Descriptive Model

Analytical Model

Built System

Reference: SysML role in Model Driven Requirements Engineering (MoDRE) & MBSE, Kyle Post and George Walley, 2013
Descriptive Modeling using SysML

System high level functional requirements are modeled in SysML which are then decomposed into lower level behavior models.

Behaviors are partitioned into a logical architecture and/or physical architecture.

The functional system requirements and derived requirements are linked to the SysML behaviors using a Requirements Diagram.

Requirements gaps were identified when modeling the behaviors which were not apparent from the textual requirements alone.
Compared to a more textual document approach the models generate more constructive feedback on the proposed features which are quickly iterated on during review meetings.

In one case a proposed project, which was originally not kicked off due to questions on the ability to meet timing, was approved on the spot after creating a SysML model and walking the decision makers through the diagrams. None of the decision makers involved had ever heard or seen SysML before the meeting.
Intended Behavior, System Architecture, Requirements, Trade Study Options

System Model used to define the behaviors that the features perform along with the logical architecture

There is more engagement and debate of the system behavior and architectures earlier in the development cycle as people are able to interpret the diagrams easier than with textual requirements alone.
Designers build the analytical model based on the SysML behaviors.

Implementation of the model based functional specification resulted in more consistent behaviors, even when given to multiple suppliers, compared with similar traditional document based experiences.
DESCRIPTIVE / ANALYTICAL MODEL BREAKDOWN

Customer Experience, Stakeholder Requirements

- Verify Customer Experience
- High Level Dynamic Models
  - Static Analysis
  - Model Based Design
- Detailed Design
  - Generate Code
- Verify Architecture, Behavior
- Verify Dynamic Behavior
- Validate Actual Customer Experience

Intended Behavior, System Architecture, Requirements, Trade Study Options

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Descriptive Model
Analytical Model
Built System
Integrated Vehicle Analysis

- Fully integrated vehicle system models are needed to simulate vehicle-level, cross-functional attributes (e.g. Fuel Economy, Performance, etc.)
- Vehicle models are built up of sub-system models from various domains created by subject-matter-experts
- Objective of Integrated Vehicle Analysis (IVA): Develop and optimize system design for critical vehicle level attributes

Cross-Domain

Cross-Attribute / Cross-Function

Model architectures, models, data
Challenges:
- Vehicle system models can be very complex
- Simulations of different attributes require different models (i.e. fidelity, operating range, etc) – requires planning and coordination
- Numerous domains & dozens model developers/integrators participate
- Communication across domain areas – vocabulary, processes, tools, interfaces
- Integration & testing of vehicle models is a tremendous task

Cross-Domain

Integrated Vehicle Function & Attribute Analysis (IVA) Capability

Cross-Attribute / Cross-Function

Model architectures, models, data
Vehicle System Analysis Process

Vehicle System Analysis Process

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Vehicle System Analysis Process

ANALYSIS PLANNING
- Program Information
- Test Events

MODEL DEVELOPMENT
- Vehicle Reference Architecture
- Analysis Architecture

DESIGN ANALYSIS
- Model Specifications & Requirements
- Model Interface Templates

SysML Model Representation
Simulink Model Transformation

- Georgia Tech student with Chris Paredis

Simulink Model Transformation

Vehicle System Analysis Process

ANALYSIS PLANNING

MODEL DEVELOPMENT

DESIGN ANALYSIS

Vehicle System Analysis Process Diagram:

- Program Information
- Test Events
- Analysis Architecture
- Vehicle Reference Architecture
- Analysis Architecture
- Model Specifications & Requirements
- Model Interface Templates
- Component Models
- Vehicle Models
- Results Analysis
- Test Execution

SysML Model Representation

Ford Logos
Vehicle System Analysis Process

Overall Benefits:
- Improved communication across domains – model interfaces and requirements
- Common understanding of simulation goals
- Upfront planning of model/data needs
- SysML acts as master source of information – live/not static
- Process automation avoids errors
- SysML for model development and integration:
  - Reduces time better support upfront program decisions
  - Reduces effort support more programs

Observations:
- Version control and collaboration tools and methods essential
- Many of our users are not SysML experts; methods needed to support novice users
- Scalability SysML not an efficient way to store lots information
- Formal SysML semantics to manage variants would be useful
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Goals

1. **Improve efficiency in writing & managing requirements**
   Connect to and reuse requirements from corporate repositories in SysML model elements & synchronize updates.

2. **Associate parts & assemblies with the functions they deliver**
   Allocate functions and physical parts, which are managed in corporate repositories, in a visually oriented way.

3. **Realize new relationships and improve reporting & efficiency**
   Connect data sources that aren’t currently integrated via SysML models to reduce redundant or stale data, ease access to information for engineers, and improve reporting.

4. **Improve requirements and design work**
   Tie requirements to specific instances of real and simulation data points and data sets to a requirement’s context.
• As we began expanding our use of SysML models, we quickly found that SysML was not where we wanted to manage or even author details of requirements.

• The duplication in effort required to do initial requirements work in SysML and then transfer and manually synchronize them with corporate requirements repositories was non-value-add and cast a limiting view on the potential use for such models.

• In 2012 & 2013 we worked with InterCAX to begin exploring connections to some internal data systems, including PLM systems like Teamcenter\(^2\), where requirements, signal databases, and traditional CAD data/parts are managed.

\(^1\) OMG SysML is a trademark of The Object Management Group

\(^2\) Teamcenter is a trademark of Siemens Product Lifecycle Management Software Inc.
Bi-directional generation and synchronization of blocks<->parts/assemblies and functions<->actions/activities enables lightweight allocation in a very visual GUI.
Synchronizing requirements and activity structures between a PLM system and the SysML model has improved our awareness of how objects were being stored.
• Opportunities:
  – Reuse (and potentially storage) of shared requirements, parts, functions, etc...
  – Provide standards based, visually oriented environment for linking and displaying PLM-managed elements like requirements, functions, and parts

• Challenges:
  – Traditional physical CAD / parts & part assemblies data model doesn’t naturally mesh with how certain SysML elements are defined and stored
  – Determining where the SysML model provides a richer managing environment and vice-versa
  – Vendor tool and language support (model transformations, model management, APIs, import/export mechanisms)
Model-Based Failure Mode Avoidance (MBFMA)

Failure mode avoidance information (Inputs, Noise & Control Factors, Failure Modes, & Desired Output/Response) captured in a SysML model and used to dynamically generate P-Diagram in traditional form.

Example from an Adaptive Cruise Control System model

Requirements on a given function or interface can now be synchronized with multiple appropriate repositories (e.g. Teamcenter).
Response plots are great for collaboration and requirements discovery & elicitation, stacking system responses to be viewed in context to each other.

Labeled callouts can be made on either physical or digital (e.g. whiteboard vs. Visio) forms of the diagrams, against which requirements can be written, executable models created, and loose traceability established by manual reference to these call-outs (e.g. “Region A”).

SysML model preserves context of requirements and permits dynamic linking of requirements, regions, & models.

Principle challenges of current methods:
- Static Plots - changes to one don’t drive changes in others
- Static Regions - Call-outs have no underlying tie to data points, ranges, systems involved in given traces

Pilot Exploration of Response-Based Requirements

The team developed an initial prototype via extension scripts (DXL) in DOORS to import a bitmap of the response diagram from Visio into a top-level DOORS object, extract specific region call-out layer elements, and create/update separate database objects for each (e.g. 3.1 A, 3.2 B, & 3.3 C).

Visio Diagram

Diagram edited natively in Visio and stored by team on shared resource (share drive, SharePoint, etc)

Shared Storage

Updates pulled programatically upon request or scheduled periodically

Automating the synchronization of familiar-format diagrams with a requirements database, minimized tool changes while enhancing traceability

Utilizing the call-out notation to link requirements to static or dynamic plots of system responses improves contextual awareness when reading requirements.

Thank you!
Questions?
Authorization to use OMG SysML logo

Walley, George (G.E.)

From: Lana Olova <lovalana@omg.org>
Sent: Tuesday, January 14, 2014 1:02 PM
To: Walley, George (G.E.)
Subject: Re: Request to Use OMG Trademarks
Attachments: OMG-logo.jpg; OMG-SysML-logo.jpg

Hello,

You have OMG's permission to use the logos (attached). Let me know if you need further assistance.

Best regards,

Lana

At 01:02 PM 1/14/2014, you wrote:

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Name: George Edmund Walley III
Title: Technical Expert, Control Systems Engineering
Work Phone: 313-594-2912
Email: gwalley2@ford.com
CODE: OMG21
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Proposed Use:
We would like to use the OMG SysML logo in a presentation by Ford Motor Company at the 2014 INCOSE International Workshop regarding our growing use of SysML in conjunction with established analytical and implementation modeling efforts.