A System Modeling Approach to Enhance Functional and Software Development

Saurabh Tiwari¹, Emina Smajlovic¹, Amina Krekic¹, and Jagadish Suryadevara²

¹ Mälardalen University, Sweden
² Volvo Construction Equipment AB, Sweden
saurabh.tiwari@mdh.se, {esc17001, akc17003}@student.mdh.se, jagadish.suryadevara@volvo.com

Abstract. This paper presents a SysML-based approach to enhance functional and software development process within an industrial context. The recent changes in technology such as electromobility and increased automation in heavy construction machinery lead to increased complexity for embedded software. Hence there emerges a need for new development methodologies to address flexible functional development, enhance communication among development teams, and maintain traceability from design concepts to software artifacts. The discussed approach has experimented in the context of developing a new transmission system (partially electrified) and its functionality. While the modeling approach is a work-in-progress, some initial success, as well as existing gaps pointing to future works are highlighted.

Keywords: Modeling · SysML · Systems Engineering

1 Introduction

In recent times, there has been a significant paradigm shift within construction equipment industry in terms of introducing new technologies such as electromobility and increased automation. For instance, electrification (i.e. battery-powered parts) is being introduced into products, hydraulic motors are being replaced with electric versions, new versions of drive-line system (DLS) where electrified hub motors (instead of torque power from the engine) are introduced into wheels.

The advanced technological changes in large complex products causes enormous challenges for existing software development teams. While the functionality remains largely unchanged in comparison with legacy systems and software, the new design concepts lead to major changes in hardware and software. Hence the traditional function development techniques largely based on small incremental changes to existing software is no longer valid and may lead to quality issues as well as maintainability and traceability problems. Model-based methodologies such as Model-based Systems Engineering (MBSE) and Model-based Design (MBD) are industry-wide considered as effective solutions in addressing, above described development challenges [1][2]. While traditionally MBD methodologies
are associated with only Simulink-based development techniques, currently these
techniques are being extended using SysML/UML-based modeling approaches.
In this paper, we present the SysML-based modeling approach considered within
the project for development of a new transmission system (partially electrified)
and its software.

In this paper, we describe a modeling approach developed within VCE (Volvo CE). The approach is presented using the ‘Brake’ functionality to capture the
transmission system behavior, in response to brake requests from the opera-
tor/machine. The modeling approach captures the functional behavior from both
problem (as seen externally) and solution domain (albeit implementation inde-
pendent) perspectives. Later, the SysML-based solution models can be further
refined into hardware and software views explicitly reflecting the overall design
concept(s), paving the way for traceable software architecture(s) which in turn
implemented using traditional Simulink-based techniques.

2 Background

Software Engineering Framework at VCE referred to as SE-Tool, is a customiza-
tion of the commercial tool Systemweaver. It is influenced by EAST-ADL framework, to support complete software development processes at VCE. It is primar-
ily used to develop the complete Electrical and Electronic (E2E) System in
software as well as hardware i.e., ECUs, Sensors, and Actuators.

MathWorks Simulink is a graphical development tool used to run simula-
tions, generate code, and test and verify embedded systems. All functionalities in
the Simulink represented by the blocks. The Simulink connects different blocks
and signals to simulation models that can be executed. Also, the block in a
Simulink work similarly to functions in a C/C++ program. Blocks are divided
into pre-defined MATLAB libraries based on their functionality. These libraries
include Logic and Bit Operations (e.g., blocks like Relational Operator and Log-
ical Operator) and Math Operations (e.g., blocks like Product, Divide, Add,
Subtract are included).

While both SE-Tool and Simulink-based frameworks satisfactorily cover the
development processes within Software domain, currently there are huge gaps
related to systems engineering domain like maintainability, traceability, incor-
porating new design concepts etc. Hence, there is a need for the “Model-based
System” approach compared to traditional function development approach.

3 Braking Functionality: An Example

The drive-line system consists of a clutch, a transmission, a drive shaft, and an
axle connecting the engine and the drive wheels. To describe the system modeling

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3 Volvo Construction Equipment AB, Sweden
4 We refer the reader to the standard for further details: [http://www.east-adl.info/](http://www.east-adl.info/)
5 [https://se.mathworks.com/products/simulink.html](https://se.mathworks.com/products/simulink.html)
6 [https://se.mathworks.com/help/simulink/block-libraries.html](https://se.mathworks.com/help/simulink/block-libraries.html)
approach, we model the ‘Brake’ functionality, based on the logical distribution of the system behavior in terms of the system components described above. Please note, to simplify the presentation of this paper both scope and all the figures and illustrations are limited to the behavior of the ‘Brake’ functionality.

Corresponding to required “Brake behavior”, the DLS system “implements” corresponding “Braking” behavior within its scope, e.g., to create a tractive force on the machine and gives the machine the capability to move. Additional sub-systems and components (besides described below) may be required to increase the quality of the movement, but they are skipped in this paper, to keep the presentation simple. In order to perform braking, mainly following subsystems and external entities are involved:

- **Operator** represents a person who operates a machine by sending a “braking request” through appropriate interface.
- **Powertrain** is a subsystem that includes following subsystems: Engine, Drivetrain and Wheels(#4)
- **Requester** represents the braking pedal of the physical machine.

### 4 SysML-based Modeling Approach

The overall modeling methodology, as shown in Fig. 1, is primarily based on a reverse-engineering approach, i.e., capturing functionality from legacy concepts and corresponding implementations in the hardware and software (e.g., simulink-based environment). The modeling has been done using IBM Rhapsody tool.\(^7\) However, in this paper, for illustration purpose, the models have been re-drawn using other tool.

![Fig. 1. Overview of the SysML-based modeling approach](image)

The overall system modeling approach is divided into three stages.

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7 https://www.ibm.com/se-en/marketplace/rational-rhapsody
4.1 Functional Modeling (Structure)

The first phase of the modeling activity (refer to Fig. 1), is based on the product breakdown structure. Thus the modeling focuses on “structural aspects” using SysML BDD (Block Definition Diagram) and IBD (Internal Block Definition) Diagrams (as illustrated in Fig. 2 and Fig. 3 respectively). Besides modeling the physical architecture of the system-of-interest, the function behavior in logical terms (i.e. implementation independent manner) is captured too. The “braking behavior” is described below.

The Operator sends the signals to Requester, the ‘braking request’ is created. Requester represents the braking pedal. It creates a “propulsion torque event”, with return value of braking torque. The ‘braking request’ is then forwarded to Powertrain which communicates with Wheels, Engine and Drivetrain. Powertrain forwards the ‘braking request’ to the Drivetrain, where braking happens in actual. It is consisted of three subsystems: Generator, Dclink and four Hub Units. The Drivetrain transform, transmit and modulate mechanical input torque to actualize requested mechanical torques at wheel interfaces. After receiving the ‘braking request’, engine requests how much power needs to be generated and sends that to Generator through the Drivetrain. Generator transfers mechanical energy to electrical and forwards it to DcLink, and then DcLink transmits that energy and forwards it to four hub units which modulate it and send to Wheels.

The operations and signals identified to realize (logically) the “braking behavior” is represented in a block diagram as shown in Fig. 3 (the color scheme to be explained later). It can be noted that the model elements (structure) illustrated are named with prefix “Brake” to indicate the modeling is focused only on “analyzing” and capturing the “Braking” behavior in isolation. The structure indicates the logical decomposition or “allocation” of the function w.r.t the overall product breakdown structure. This is an important phase for both
4.2 System Modeling (Behavior)

It is the next level of modeling activity using SysML Statemachine diagrams to capture the functional behavior of the structural “parts” (w.r.to the system-of-interest). While in this paper, we restrict the behavior specification to that of “Braking”, this specification is “incrementally” developed by considering each of the machine functions separately and eventually “combined” (manually). For instance, in Fig. 4, the behavior of the HubUnit part of BrakeDrivetrain is presented. It can be noted the granularity of the (behavior) modeling effort is not arbitrary, but carefully chosen to cover the “new” parts, in this case the HubUnit (electrically steering the wheels).

As a result of the modeling activity described in previous subsection, it can be noted, there will be multiple state machines for the HubUnit (in other words, multiple HubUnits each pre-fixed with the individual function names). These state machines are “combined” to create a single state machine, at suitable granularity, that serves as the System Specification (for the DLS). Thus, this modeling phase also contributes to the overall system design decisions. For example, as shown in Fig. 4, the color scheme indicates the design decision to implement the corresponding operation in Software or Hardware (further explained in subsection below).

4.3 Modeling System Design (S/W & H/W Views)

This is the final phase of the SysML-modeling activity and concerns the detailed design modeling. As described in the previous subsection, the “software”
and “hardware” parts are identified during behavior modeling phase, as part of the system specification. This phase further requires extensive domain expertise (both system and software level), for the technical trade-offs to be made regarding whether a certain SysML Operation is to be implemented in software or hardware (e.g. sensor). For instance, as shown in Fig. 4, the blue color represents the design decision that the corresponding operation has been allocated to the software modules and red color operations allocated to the hardware components for realization of the overall system. Based on these, allocation views are modeled in SysML (skipped in this paper due to lack of space).

5 Conclusions

The SysML-based modeling approach presented in this paper is primarily a reverse-engineering effort in capturing functionality from legacy implementations in the hardware and software. However, the approach is generic enough to be extended into a useful modeling approach complimentary to existing software development approaches.

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