JOUN TECHNOLOGIES

Model Based System Engineering

Overview and Applications

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Abstract

Model-Based Systems Engineering (MBSE) is a modern technology concept that uses digital design models to make systems faster and more efficient. Within digital technology, MBSE utilizes the concepts of the Digital Twin (digital presence of a real object) and Internet of Things (IoT). MBSE is an effective tool in organizing, future prediction, and preparation for mass System of Systems (SoS). This paper will look at an overview of MBSE, its transition from the aerospace industry to the automotive industry, and emerging application areas such as decision making, cybersecurity, smart manufacturing processes, smart cities and 5G networks.

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Introduction

With the uprise of the Digital Twin and the Internet of Things (IoT), it is important to discuss a third tool called Model Based Systems Engineering (MBSE). MBSE is part of the larger field of systems engineering, where systems are studied and documented based on their components, procedure and even personnel [3]. As its name suggests, MBSE is a model-based systems engineering approach that aims to study complex systems in terms of design, evaluation, and authorization. MBSE uses data to create analysis and interpretation of information to better optimize the system architecture, typically in the early concept phase. [5]. MBSE uses a discipline-specific approach to develop a system model that can help all parties understand how the process is framed and under which constraints. MBSE has been used extensively in the aerospace industry and subsequently been used in the automotive industry. It is poised to have even wider usage as system design become more complex.

MBSE Overview

Model Based Systems Engineering (MBSE) is a systems engineering tool used to analyze, simulate, and propose a solution to complex system engineering problems. This tool is described by Shevshenko to have three main components: the system that must be designed, the modeling organization, and the context of this designed system. It is important for the model to represent the real-life components in a structured manner. MBSE follows system engineering modelling domains with four main pillars: conditions, architecture, activities, and verification. These domains help simplify problems and prevent ambiguity. Furthermore, it helps stakeholders get easy access to all the generated information in an organized manner [3].

One common modelling language that is used is called SysML. SysML is formal language that has specific syntax that is based on the human language [3]. The analogy below shows how four parts of English speech relate to coding terms in SysML.

Noun	Conditions/Requirements
Verb	Activities/Behaviors
Adjective	Attributes/Characteristics
Adverb	Interfaces/Relationships

MBSE can be improved by integrating OpenCAE, which allows model Computer Aided Drawings to be added to the data and analyzed. This addition can be made through OpenMBEE, which is an open-source language which allows for unified storage of data, model viewing and web-based documents generation. This enables the integration of digital twins as an analysis tool and simulation of real-time operations [5].

Transition of MBSE from Aerospace and Defense to Automotive

MBSE was first introduced in the aerospace and defense industry, where it developed and evolved. Two notable applications of MBSE are NASA's Mars Rover Perseverance program and the Chinese Academy of Space Technology's development of manned aircrafts. During the Rover project, NASA modelled their information, automatically generated cross-document information and extended the lifecycles of the projects. On the other hand, the Chinese Academy of Space Technology wanted to unify the manufacturing processes of a manned aircraft. MBSE helped with that unification through simulating the functional aspects of the aircraft (structural, thermal and control). Using a model matching SysML code, MBSE was utilized to create a full product development cycle that included a requirement-focused implementation model of the digital aircraft.

The transition of MBSE from aerospace to the automotive industry made sense since both industries have a strong requirement to reduce life cycle costs and project risks. MBSE can visualize the product and utilize a development approach that is flexible based on various scenarios [7]. MBSE drives stakeholders, including customers, to be more confident in the process and more willing to contribute. This ultimately leads to a systems development process that is more interdisciplinary and interrelated [7]. Let’s look at a few applications of MBSE in the automotive industry:

a. **Safety and Reliability Analysis**

MBSE has been developed to now include an automotive package that can address safety and reliability constraints. Design problems and safety and reliability requirements go hand in hand. MBSE tool kits are used to assess both in critical systems.

The Automotive Safety Package within MBSE has an interesting Hazard and Risk Assessment (HARA) section. HARA relates elements to a level of risk that they might present within their

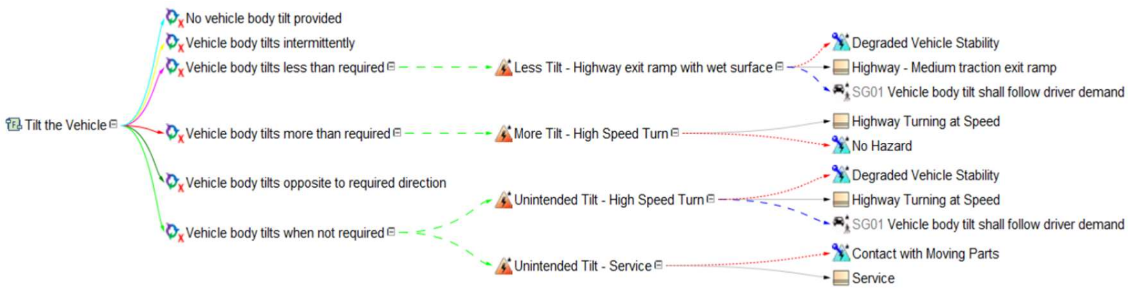

Figure 1: HARA Graphical Representation of Car Tilt Hazard Using MBSE [2]

behavioral functions. For example, in a vehicle tilt HARA assessment, as shown in figure 1, several hazard scenarios data are shown in graphical form [1].

b. Autonomous Electric Vehicles

According to Siemens, several countries are planning to move from Internal Combustion Engines (ICE) to electric compulsion systems [6]. By 2040, more than 50% of sold vehicles are going to be electric vehicles [6]. The complexity of electric vehicles makes techniques like MBSE imperative for design and development. Siemens is utilizing MBSE in 5 areas: Product Definition, Connected Engineering, Product Validation, and Integrated Program Planning [6]. Utilizing MBSE helps Siemens reduce variability, digitally raise their customer's concern, focus on engineering failure modes along with normal behaviors of a vehicle, and include everyone in the product development cycle [6].

c. VTOL

Looking deeper into the future, the aerospace and automotive industries come together through the concept of an air taxi. Using Vertical Take Off and Landing (VTOL), air taxis are being looked at in the context of a "smart city" approach to urban traffic issues. An MBSE technique called CUBE

(Compositional Unified System-Based Engineering) is used to identify the requirements, the system of systems (SoS), and the elements of the VTOL process [1]. CUBE will provide automotive engineers with an accelerated implementation of effective air taxis.

Other Applications

MBSE is currently used in different industries due to its capability to manage different components of the engineering and management processes within a system. Some of these applications include:

a. Cyber Security

Complex systems can be made more secure by using MBSE for "Threat Modelling" analysis. This can help cybersecurity stakeholders incorporate safety ahead of time and make systems more secure than the traditional approach of adding safety features post design. [3].

b. Decision Making

Decision makers can now utilize MBSE to build an integrated framework to solving a problem and to include their clients in the decision-making process. For example, some developers face the need to present large architectural views for their customers to elicit feedback. MBSE helps solve this problem by providing digital models of trace specifications, business activities, and standards for customers to mark-up. [8].

c. Smart Manufacturing

The digital thread concept was proposed by the US Air Force to join MBSE with precise design models. This framework was then developed to include product design, quality, performance, information exchange and equipment health that can be interchanged all throughout the product lifecycle. This digital thread can become a virtual test bed for simulating manufacturing processes and for checking their run-time quality in an optimized way [9].

d. Smart Cities

With the uprise of the Internet of Things (IoT), , the need for an efficient organizing tool has arisen. Smart cities are an example of a very complex system of systems (SoS). A smart city is an urban area that utilizes information and communication technologies to improve its citizens' quality of life and to respond to their growing demands in an engaging manner [10]. In a smart city, infrastructure, hardware, and software components need to interact quickly and intelligently to account for post-purchase design changes. The use of MBSE's SysML is imperative for smart city's frameworks and processes [10]. Below is an example of how MBSE can model such a city and how it simplifies its elements.

Example problem: Smart city's traffic management

In a smart city, there are several contexts and elements for a traffic management system. This SoS can be looked at from a stakeholder perspective, capabilities, or an operational/functional perspective. We can even define several subsystems with the help of MBSE. In figure 2, we can see a smart city's traffic context system diagram, showing the interaction of the hardware, software (system entities) and the operators (external entities). These entities exchange data collectively to ensure the success of the SoS. Figure 3 shows the control system. This subsystem can help us specify where our data is going and coming from, to account for future software upgrades or purchases [10]. For instance, we can see that the traffic prediction receives sensor data which in turn goes into sensor processing and traffic flow calculations. This data is then used by the traffic generation report and so on. To make the city more efficient, this data can be used to perform a gap analysis and system redesign [10].

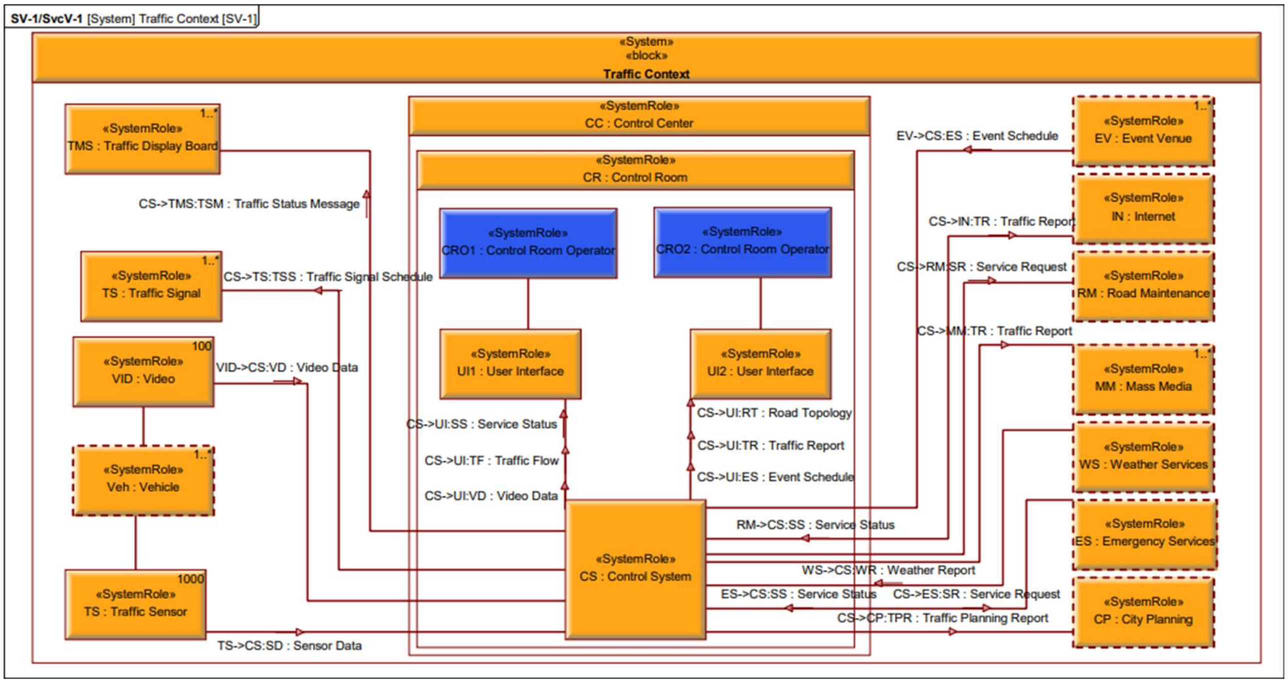

Figure 2: Traffic System Diagram [10]

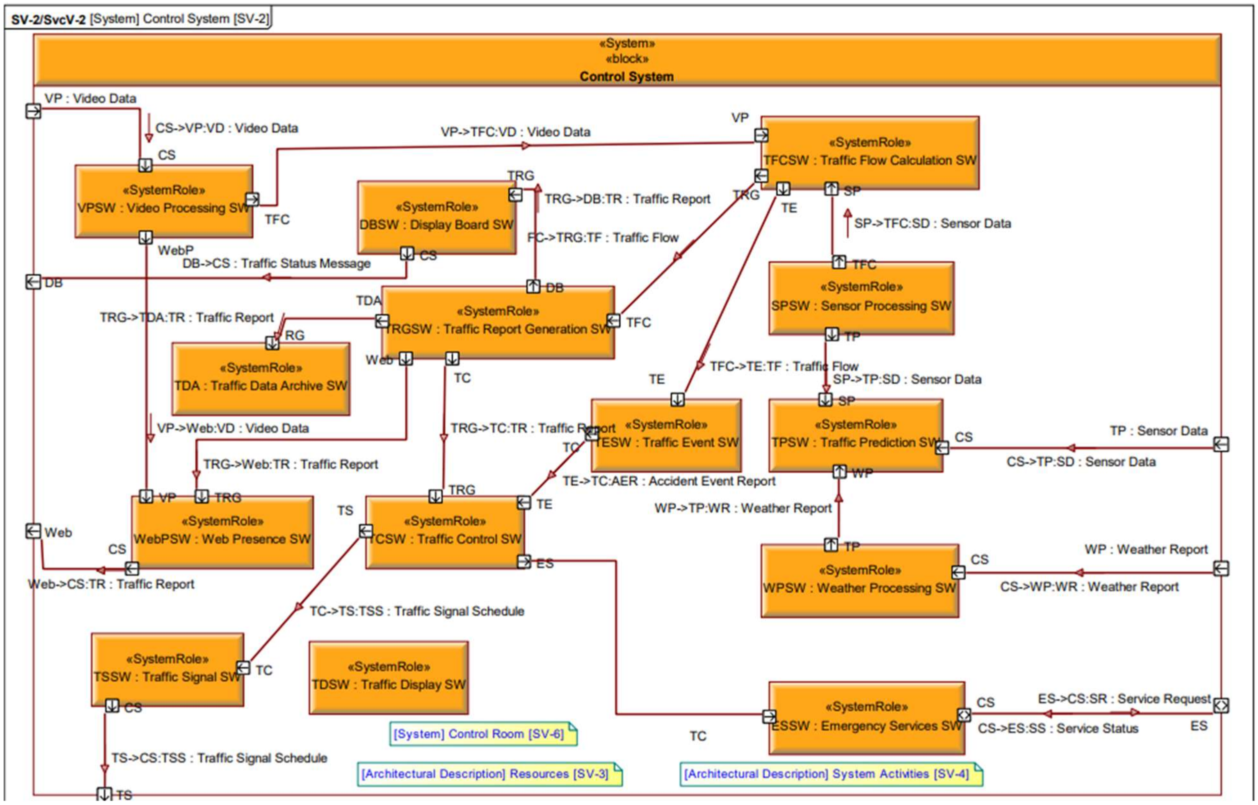

Figure 3: Control System of the Traffic System [10]

e. 5G Networks

Internet of Things (IoT) creates a huge challenge for 5g network implementation. Due to the large number and diversity of devices present in the world, communication companies will need to cooperate to optimize the IoT device information and network exchange. With 2G or 3G, a local base station is usually mounted in locations where there is high demand for these networks, and where there is a good number of low-band radio frequencies [11]. However, for 5G, where devices communicate with each other, there is a need to optimize the use of these stations for simultaneous low frequency use from different stations. For example, to use 5G on your cell phone on an airplane, there is a need to connect to several low frequency band stations in different locations. But there are several cell phones and devices utilizing 5G on this plane and the plane itself would be using 5G for communication purposes. The Dynamic Spectrum Alliance (DSA) has been created to resolve the 5G challenge among the biggest industries' partners [11]. MBSE has capabilities to resolve interconnectivity vulnerabilities between wireless connections within different fields (Each field has a different policy for using telecommunication standards). In 5G, the different standards for different systems (energy, communications etc.) will have to intersect and the latter can only happen through the utilization of a multidisciplinary tool like MBSE.

Final Thoughts

MBSE is a decision making and prediction asset. It has proven to be a useful tool when looking at complex engineering problems and design issues within the aerospace and automotive industries. The power of MBSE is just starting to be looked at more broadly, including in electronics, semiconductors, and a variety of industrial and consumer industries. Alongside other digital technologies, MBSE will help products become more innovative [1] and at the same time more sustainable [7].

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About the Author

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