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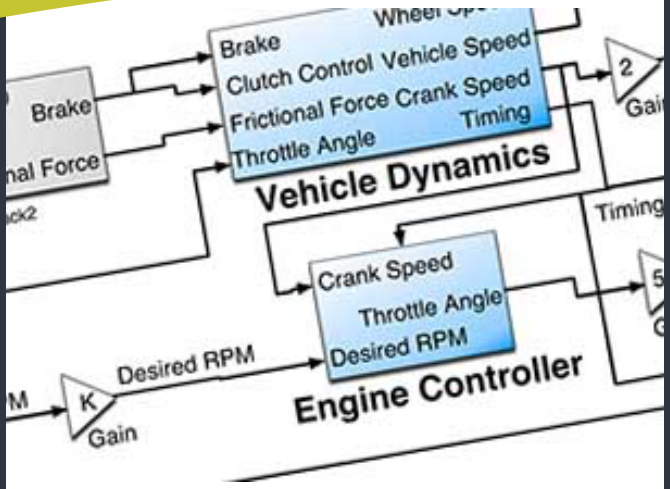

In this issue:

Solutions for a New Economy

MBSE emphasizes the rigorous application of systems modelling languages and architecture frameworks in the systems development lifecycle.

The Role of Model-Based Systems Engineering (MBSE) in the Digital Transformation

Model-based systems engineering (MBSE) has been an extremely popular topic within in the systems engineering (SE) community, with its capabilities promising value above and beyond of that of traditional SE techniques.

MBSE is a game changer as it takes the SE discipline and achieves it through a formalised set of modelling activities to support all stages of the SE lifecycle; requirements gathering and analysis, design synthesis, design analysis, system performance analysis, verification and validation. Approaches are applied in the early conceptual design phases of systems, continuing throughout to the later development stages of the lifecycle.

Though the shift in paradigm is highly evident in industry, given the huge benefits of implementation. There still remains some uncertainty in its implementation due to differences in terminology and nuances in implementation strategies and methods.

Loughborough University

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MBSE and its Origins?

Model-based systems engineering (MBSE) [1]–[3] is an evolution of the SE paradigm and is becoming standard practice in addressing the challenges presented by systems-of-systems (SoS) and the engineering of SoS [4]–[7]. A SoS is a collection of constituent systems which may not have any conscious knowledge of other systems which fall within a common scope of achieving a mission; i.e. they are managerially and operationally independent, they are geographically distributed, and they evolve independently. More can be found on SoS within its own technology guide [ref].

MBSE currently offers a set of approaches for system lifecycle management and given the types of systems, a means to mathematically model system behaviours and performance.

> "Model-based systems engineering (MBSE) is the **formalized application of modeling** to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."
>
> INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)

With system performance being a key driver for engineering approaches, MBSE provides a basis from which systems can be analysed statistically and provide the foundations required for evaluation and subsequent design iterations. SE itself developed as a discipline to manage the design of systems and complex systems, mainly in the 1940s with organisations such as the US DoD and NASA [8], [9].

MBSE, like SE, is a formalised set of modelling activities to support all stages of the SE lifecycle (Figure 1); requirements gathering and analysis, design synthesis, design analysis, system performance analysis, verification and validation. Approaches are applied in the early conceptual design phases of systems, continuing throughout to the later development stages of the lifecycle.

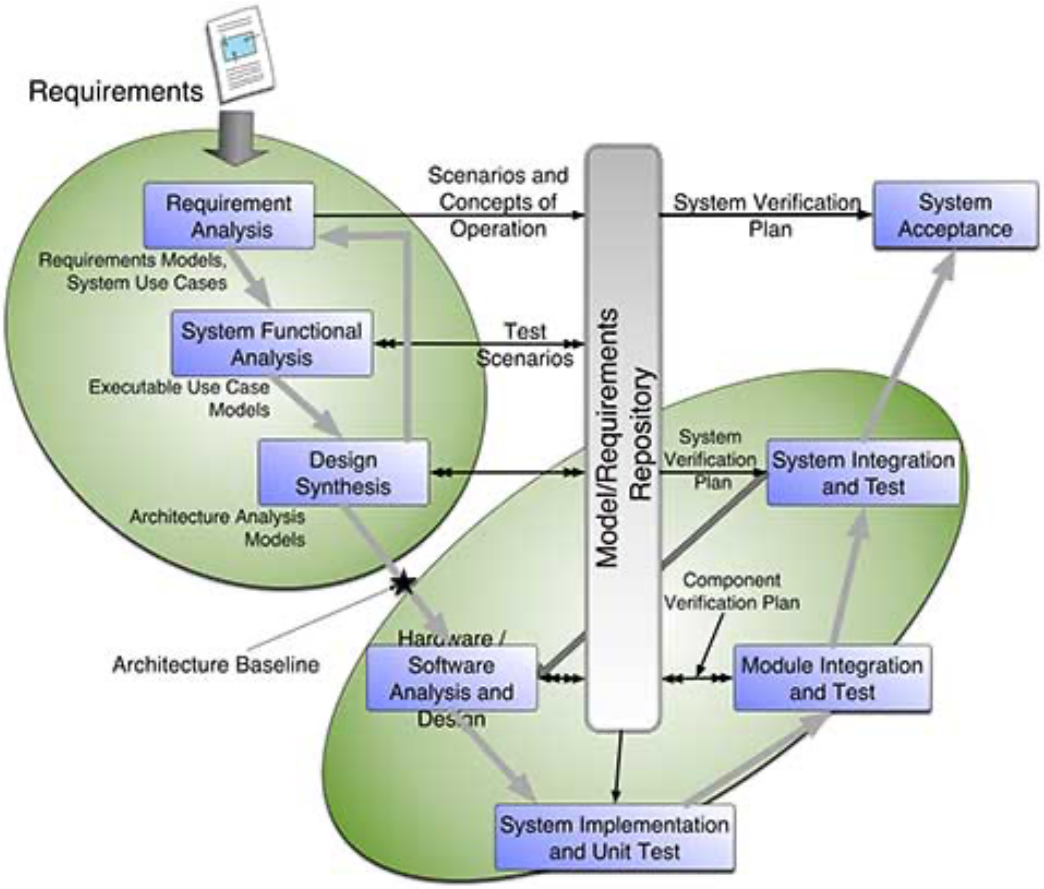

Figure 1: SE Lifecycle modelling

Strengths and Weaknesses of MBSE

Strengths

With the complexity of modern SoS rapidly growing, new paradigms and methodologies are required to integrate several engineering teams and stakeholders across the different types of SoS. A structured design and development process are vital from the conceptual phases, right through to development and operation. MBSE and in the case of this thesis, is seen to be the approach that can deliver on the most part, and more specifically, applying model-driven architecture (MDA) approaches to form the pillar of an understanding process and consequently design and development process for resilience.

The benefits of MBSE methodologies have been covered at length in [9], some of the key benefits can be rephrased as follows:

- A centralised set of interconnected models which are a reflective abstraction of reality depicting system requirements, system structure and system behaviour.
- The system model, or series of models, serves as a central repository for design decisions; these decisions can be traced back to elements within the model or relationships between elements.
- Increased ability to manage system complexity as the system can be modelled and viewed from multiple perspectives and allows traceability of requirements throughout model set.
- Effective in improving communication across all stakeholders.
- Automated processes for measuring system integrity and model completeness, which ensures higher accuracy in requirements verification.

MBSE enables the use of models to try exploring new architectures. Part of the SoS evolution process is to influence changes in the CSs and in their interactions. To obtain improved or new SoS capabilities, such as resilience improvements, the SoS architecture often must be changed; adding new CSs, modifying the capabilities of existing CSs, changing the structural configuration of CS interactions. The MBSE approach allows exploration of new architectures without the risk and cost of implementing them in the real SoS. A chance to explore resilient architectures in a design and development process specifically focussed around SoS capabilities.

Weaknesses

Measuring the effectiveness of applying MBSE methods is something which has not been consolidated, in terms of return on investment (ROI) within a SE development program. While research has been done in evaluating the ROI in SE [10], this too is insufficient to quantifiable assess SE as a process [11]. The desired end state for MBSE would be seamless data exchange within collaborative frameworks, enabled via common data standardisation, where traditionally SE (document-based) is synonymous with MBSE for activities across the entire engineering lifecycle. One of the biggest shortcomings of MBSE are the immaturity of tools and frameworks which often over-promote their real capabilities. Additionally, the limiting ability of tools to share models and data between each other is a huge limiting factor in the advancement of MBSE and one which needs urgent research and attention to further the MBSE cause.

How to benefit from MBSE

The communication and successful exchange of information between engineers and primary stakeholders is the key to any engineering project. Model-based systems engineering is a systems engineering methodology centered on exploiting models from specific domains to achieve a prescribed set of requirements [3], [6]. The shift from document-centric systems engineering methods to model-based methods has provided engineers with additional benefits as the paradigm continues to expand and introduce new tools and methods [12], [13]. These benefits can be summarised as follows;

- A centralised set of interconnected models which are a reflective abstraction of reality depicting system requirements, system structure and system behaviour.
- Increased ability to manage system complexity as the system can be modelled and viewed from multiple perspectives and allows traceability of requirements throughout model set.
- Effective in improving communication across all stakeholders.
- Automated processes for measuring system integrity and model completeness, which ensures higher accuracy in requirements verification.

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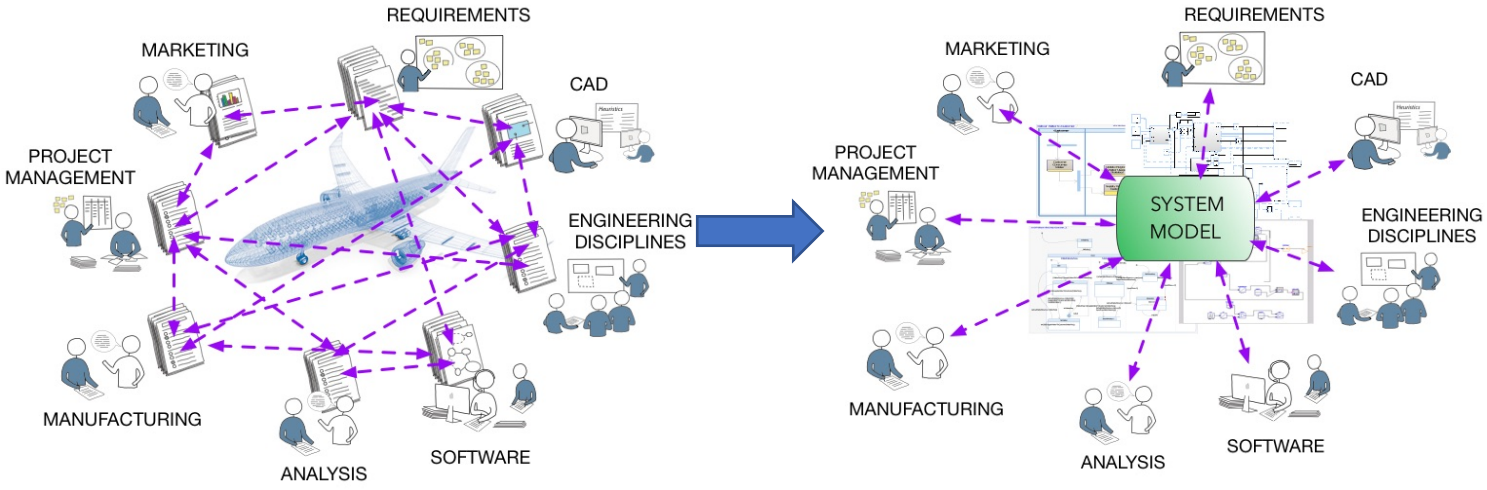
MBSE enables the use of models to try out new architectures [14]. Part of the SoS evolution process is to influence changes in the CSs and in their interactions. To obtain improved or new SoS capabilities, the SoS architecture often must be changed: Adding new CSs, modifying the capabilities of existing CSs, changing the structural configuration of CS interactions. The MBSE approach allows exploration of new architectures without the risk and cost of implementing them in the real SoS [15]–[17].

Implementation of MBSE

Implementation of MBSE approaches must be tailored to meet the requirements of a given development lifecycle plan of a system, service or product. It is essential that MBSE is requirements driven and all system design or analysis task are traceable back to systems functional and non-functional requirements. Traditionally, in the System V-model, this would be concerned with the activities on the left side of the model. Where a model can be defined in numerous ways; from a single line equation, to a complex set of architectural models, the model needs to be test-driven and often executable (simulation) to assess the performance and verify requirements are met.

Models can take many shapes and forms. Common MBSE approaches tend to be based within a system modelling language, such as UML or SysML [18]–[20], or within an architecture framework [21]–[23]such as DoDAF, MoDAF, NAF and so forth. Whichever the method of modelling a system, implementation is often done with system stakeholders in the loop of development. This ensures accuracy in the concept of operations (ConOps) and permits the elicitation of a full set of requirements. More on modelling languages and architecture frameworks can be found in related technology guides.



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Useful information sources

- **This Guide has been funded under the RAEng Regional Engagement Award.**

Videos:

No Magic – The Fundamentals of Model-Based Systems Engineering
https://www.youtube.com/watch?v=t4vRYhEWQOg&t=1239s

PTC - Who Needs Model-Based Systems Engineering (MBSE) in 6 minutes
https://www.youtube.com/watch?v=xHaWuK8mJ88

Websites:

https://www.nasa.gov/consortium/ModelBasedSystems

https://www.incose.org/docs/default-source/delaware-valley/mbse-overview-incose-30-july-2015.pdf

https://www.scaledagileframework.com/model-based-systems-engineering/

https://sysml.org/sysml-faq/what-is-mbse.html

Reports:

https://www.incose.org/docs/default-source/delaware-valley/mbse-overview-incose-30-july-2015.pdf

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