Semantically Integration Method for MBSE and MDAO

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1 Introduction

With the development of the automotive market, the complexity of product portfolios is increasing, while the frequency of market requirement changes is also rising. In this context, automotive OEMs face significant challenges in exploring feasible solutions for the next generation of vehicle development. Model-Based Systems Engineering (MBSE) effectively addresses these challenges by managing product complexity [1], establishing connections between requirements and solutions [2]. This enables design solutions to respond more effectively to rapid market changes while ensuring the consistency and continuity of requirements throughout the system's all lifecycle stages [3]. However, an alternative solution often necessitates early validation and trade-off analysis across multiple disciplines. MBSE is an effective approach for demonstrating multidisciplinary coupling relationships needed to meet specific requirements. Multidisciplinary Design Analysis and Optimization (MDAO) has already been applied in solving such multidisciplinary challenges [4]. By integrating MBSE with MDAO [5], it is possible to trace MDAO results back to the corresponding requirements, revealing implicit relationships between different requirements that arise from solutions domain [6]. In addition, MDAO also provides an early verification and validation method for MBSE [7]. This paper discusses a method of semantically linking MBSE and MDAO by establishing a domain specific metamodel for MDAO. This approach positions MDAO as a viewpoint for vehicle development. MBSE serves as the overarching framework throughout different lifecycle stages, ensuring the consistency of MDAO specification as more detailed or higher fidelity models are incorporated.

2 Methods

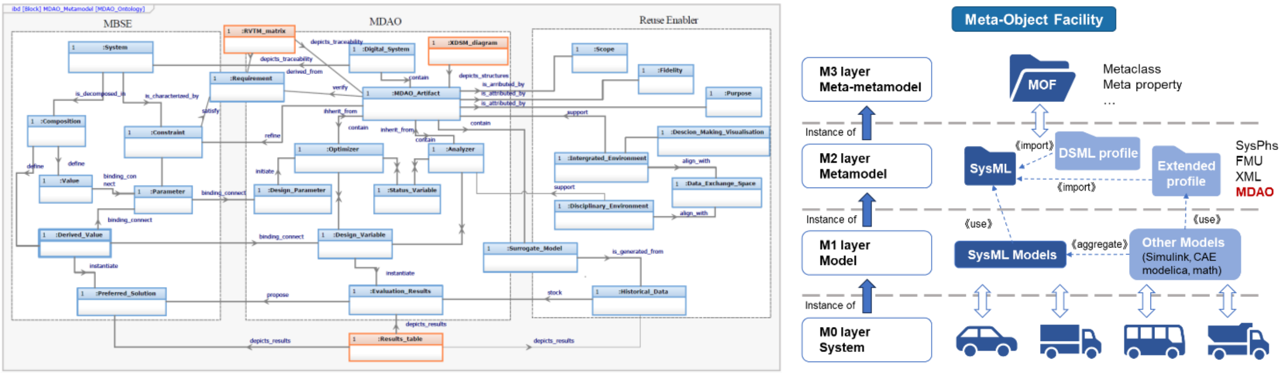
MBSE modelling language, such as SysML [8] can provide an extension mechanism. For example, it's possible to use SysPhs [9] profile to convert SysML model to a Modelica or Simscape model files. A profile of MDAO domain specific metamodel can be established [10,11], it will provide a new integrated approach to both disciplines. Additionally, by using two commonly applied analysis processes in MBSE—Requirements, Functional, Logical, and Physical (RFLP) [12] and Object-Oriented Systems Engineering Method (OOSEM) [13]—the feasibility of the integration can be ensured. On the one hand, on the perspective of Physical pillar within the RFLP approach, we can use SysML parametric diagram to describe the physical aspects of the system, ensuring consistency between MBSE and MDAO for system design parameters and other common attributes [14]. This helps establish traceability between requirements and MDAO results. Conversely, by defining coupling relationships across multidiscipline, the implicit connections between seemingly independent requirements can be revealed. On the other hand, based on the OOSEM approach, a description of the MDAO system itself can be created using a metamodel, enabling the expansion of integrated environments, model management, and data applications across different lifecycle stages. The methodology for integrating MBSE and MDAO includes different aspects: a set of common MBSE elements, a set of MDAO domain metamodel, and a set of metamodel that supports reuse processes, which includes aspects such as lifecycle management, tools environments, and data connection:

- MBSE aspect: A set of common elements that be shared between MBSE and MDAO, ensuring the consistency of design parameters, design variables, and other attributes.
- MDAO aspect: A profile of MDAO domain specific metamodel, which includes discipline models, analysers, optimizers, and other components.

- ➢ Reuse enabler: Provides feasibility for integrating MBSE and MDAO, enabling model management across the lifecycle:
  - Lifecycle management: Describes attributes such as the scope, fidelity, and purpose of models.
  - Tools environment: Defines the MDAO integration environment, discipline model running environments, data exchange protocols, and decision-making visualization.
  - Data connection: Manages data across simulation, test, and operational phases, supporting the surrogate model generation and integration of digital twin applications.

3 Results

The metamodel has been defined for integrating MBSE and MDAO by including the aspects above. The design variables and design parameters in the MDAO metamodel are linked with elements in the MBSE language, such as value properties and constraint blocks. These elements are imported into the SysML language as an extended profile. Through the Meta-Object Facility (MOF) metamodeling mechanism, instantiating the metamodel of the M2 layer results in the corresponding MBSE system model. In this research, the extended MDAO profile shares the same Meta-metamodel with SysML, allowing the development of the MDAO system within the MBSE environment. This includes work items like generating Extended Design Structure Matrix (XDSM) view. The generated XDSM can be directly transformed into the MDAO simulation environment as a specification, ensuring consistency between both disciplines. The simulation results from MDAO activities, such as Design Space Exploration (DSE) and Multidisciplinary Design Optimisation (MDO) will be fed back into the MBSE environment, tracing back to the relevant requirements, thereby enabling early verification and validation of conception.



a. MDAO domain specific metamodel definition in M2 layer   b. Instantiation mechanism by MOF

Figure 1: MDAO profile definition and implementation

4 Discussion

By establishing an MDAO metamodel, it's possible to model MDAO system's architecture within MBSE environment. Through the relationships between the metamodels, existing MBSE models can be reused as input specification for MDAO. This also facilitates the support for reusing and replacing multidisciplinary models across different lifecycle stages within the MBSE framework. The definition of an integration environment to improve the placement and execution of multidisciplinary models is currently an ongoing research focus. Further research is needed to determine how to define the data exchange interface metamodel between multidisciplinary models.

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