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Collaboration in Model-Based Systems Engineering based on Application Scenarios

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Abstract
The engineering of mechatronic systems is a challenge due to the various domains involved. MBSE is regarded as the future paradigm of product engineering to face this challenge – not restricted to any domain or industry. The core concept is a system model which allows a holistic perspective of the system in a domain-spanning way. MBSE gained momentum within the last years. Nevertheless, numerous barriers exist that inhibit the implementation of MBSE; especially there is little attention on the socio-technical aspects of product engineering as stakeholders, their roles and responsibilities and how to organize modeling processes in projects. Application scenarios are suggested as an approach to define and analyze situations in product engineering, when the system model provides benefit. It describes e.g. ways to create or to use the system model and to collaborate and interact on them. This will help to gain more acceptance of the MBSE approach.

Keywords: MBSE, stakeholder, roles, processes, application scenario

1 Introduction

The engineering of mechatronic systems is a challenge due to the various domains involved. According to INCOSE, Model-Based Systems Engineering (MBSE) is the future paradigm of product engineering to face this challenge [1]. The focus of MBSE is a system model which allows a holistic perspective of the system in a domain-spanning way by describing its requirements, structure, behaviour and first concepts of its shape, e.g. by sketches. According to [2], the MBSE concept comprises of the creation of the system model and the corresponding project activities with the help of models (Figure 1). Currently there is much focus on the technical aspects of MBSE to define the system model. From this point of view, the goal of an institutionalized MBSE across academia and industry as promoted by INCOSE in [1] seems to be realistic. Nevertheless, we fear that this vision is not realistically achievable, as research on the project issues is strongly neglected at the moment. Of course, there are many methods for the creation of the system model for SysML as described in 2008 by Estefan [3]. But only recently there had been efforts to create more accepted MBSE approaches and even languages, e.g. the LITHE concept that tries to consider the capabilities of the system modeler [4]. Up to now the approach suffers lacking acceptance in application [5] as it especially does not fit into existing processes [6]. Thus, numerous barriers exist that inhibit the implementation of MBSE. The technically-driven work in the research field has to be enriched by more socio-technical aspects. One is about the stakeholders of the system model, their roles in MBSE and their interaction in modelling and using the system model.

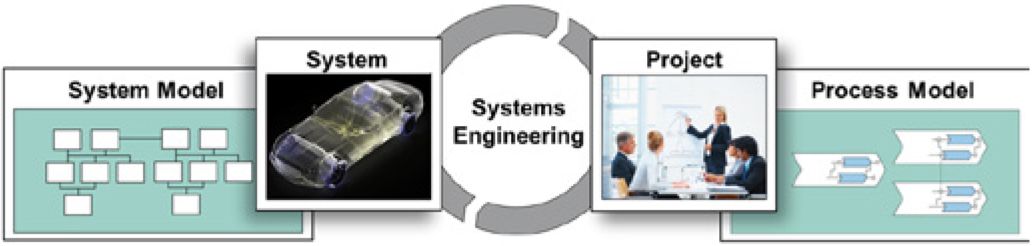

Figure 1 The MBSE concept according to [2]

Within this paper we identify stakeholders of the system model and analyse their roles, relations and responsibilities in developing and working with it. The methodical basis are application scenarios of the system model in product lifecycle. Application scenarios describe tasks or issues in product engineering not restricted to any industry or domain to be supported by a system model and define the interaction of the stakeholders and their responsibilities by using the system model. This supports a more structured way of modelling in accordance with existing processes and especially collaboration of stakeholders. The issues presented make no claim to be representative of all possible issues.

The paper is structured as follows: In section 2, relevant terms and concepts for this paper are introduced. Sections 3 to section 5 create input to define the application scenarios. In section 3 an analysis of current changes and challenges in product engineering is preceded, followed by a deeper analysis of the concepts and objectives of the MBSE approach in section 4 and a discussion of the stakeholder, roles and competencies in section 5. The application scenarios are based on an analysis of the tasks, roles, competencies and responsibilities of the stakeholders of a medium-sized high-tech company currently not participating in the MBSE approach but doing research in it. The paper concludes with a short summary and an outlook on future work.

2 Terms, Basic Concepts and Approach

ISO 15288 "Systems and Software Engineering" defines a stakeholder as "*individual or organization having a right, share, claim or interest in a system or in its possession of characteristics that meet their needs and expectations*" [7]. This claim or interest is represented by a *"concern"* – in accordance with ISO42010 *"any topic of interest in a system relevant to one or more of its stakeholders"* [8]. A concern is manifested in the course of the life cycle in many different forms of needs, objectives, expectations, responsibilities, dependencies, quality attributes and risks of one or more stakeholders. Examples for concerns are functionality, structure, cost or behavior of the system. So far the application scenarios for MBSE introduced here seem similar to the concept of concerns. As they describe tasks and issues in product engineering they also relate to the concept of use cases had known from software development [9]. Nevertheless there is an important difference: Concerns and use cases relate to the technical system under development, application scenarios relate to situations or issues in the engineering process where the MBSE is promising. Architecture Frameworks as DoDaF or the idea of CONOPS are different to this concept as they do not describe how to develop or use a system model. The application scenarios presented in this paper are identified and approved in a funded project together with an industry partner. On the one hand this partner is doing research in MBSE on the other hand there is an ongoing initiative in redesigning the value creation chain. With regard to these projects, typical roles in product engineering in mechatronic engineering in figure 2 are related to the current roles within this enterprise. The role of the Systems Engineer has been left free, as it will be defined in the projects in the context of MBSE and discussed within this paper.

Central Quality (CQ): Defines processes and methods for application in projects and supports projects in application, e.g. by FMEA moderators.

Design Center (DC): The different Design Centers (DC) are responsible for providing error-free components (developing and verifying components based on component specifications).

Quality Assurance (QA): The QA takes the responsibility for the tasks of quality assurance in the design center for qualification and acceptance of components.

Manufacturing (MF): MF takes all interests from manufacturing point of view and coordinates related tasks. This includes the creation of the manufacturing concept and the timely provision of manu-facturing resources. If manufacturing partner is involved, the MF represents the OEM interest and coordinates the related tasks.

Product Manager (PM): The PM is the repre-sentative of a Product Line in the product engineering process as well as member of the project team.

Strategic Purchasing (SP): The SP representative in the project team coordinates all tasks associated with the procurement of purchased parts as well as listing of new suppliers. The team "Strategic Purchasing" is responsible for establishing supplier base incl. supplier contracts.

Supplier (S): Suppliers are external partners providing services in development or manufacturing, e.g. As Co-Developer or Contract Manufacturer.

Systems Engineer (SE)

Technical Documentation (TD): TD is responsible for the editorial creation and design of product documentation (e.g. manuals) and CAD standards. The related technical information will be provided by the development areas.

Externals (E): All external partners not responsible for developing or manufacturing.

Figure 2 Exemplary roles in product engineering of mechatronic systems

3 Changes and Challenges in Product Engineering

3.1 From Mechanics to Intelligent Technical Systems

Mechanical engineering products are characterized by the close interaction of mechanics, electronics, control engineering and software engineering. This is aptly expressed by the term mechatronics. The conceivable development of information technology opens up fascinating perspectives which have the potential to go far beyond current standards: Keywords as “things that think”, “Cyber-Physical Systems” or “Industry 4.0” express this perspective on Intelligent Technical Systems (ITS) [10]. The creation of mechatronic systems or even ITS is challenging due to the various disciplines involved. Each discipline has its specific procedures, methods and mindsets. The main challenge includes not only the discipline specific work but also ensuring a uniform understanding of the system this represents the central challenge. The communication and cooperation across the boundaries of individual disciplines is imperative, current methods cannot handle this complexity [2].

3.2 From Simple Structure to Broker-Networks

The saturation of the mature markets, the emergence of new powerful competitors as well as greater pressure from customers or legal requirements initiate a sustained and increasingly tough competition for enterprises making them continuously search for approaches to improve processes and consumption of resources. For this, enterprises are increasingly working with external partners in the value chain (cf. Figure 3) [11]. Today not only standard parts or “off-the-shelf” components are sourced by the Original Equipment Manufacturer (OEM), but also large efforts are spend for the creation of R&D and supply chain networks – contract manufacturer and especially Co-Developers as e.g. Original Design Manufacturers

(ODM) are becoming strategic partners of the OEM [12]. This results in a shrinking manufacturing depth as well as a reduced R&D ratio – the enterprise just acts as an integrator, brand owner or as an extreme example as broker-network where there are only nonrecurring or temporary contracts for a distinct product idea, where even the broker does not know the sub-suppliers. These trends also will lead to manifold activities in the value chain coordination because of working in different time zones and with different cultural groups.

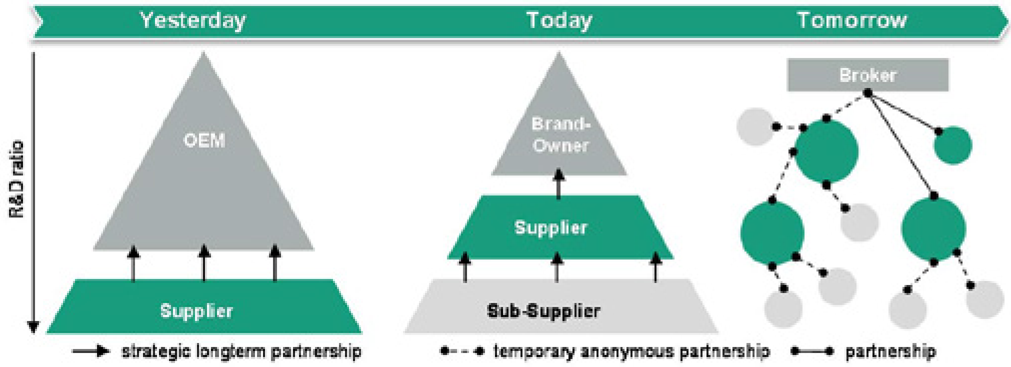

Figure 3 Trends in R&D collaboration according to [11]

It is for these reasons that enterprises start to methodically structure their engineering processes and pay more attention to the early project phase for better supplier integration and collaboration. One way is by defining process archetypes (as shown in figure 4 "A1: Off-the-Shelf – A2: OEM branded – A3: Best-in-Class – A4: Specialized Partner") The specification of the concept and thus the corresponding product or design IP is the core competence of the brand owner – but the component specification will be outsourced. The project is composed of single sub-archetypes, the "brand owner" will act as integrator of the final product.

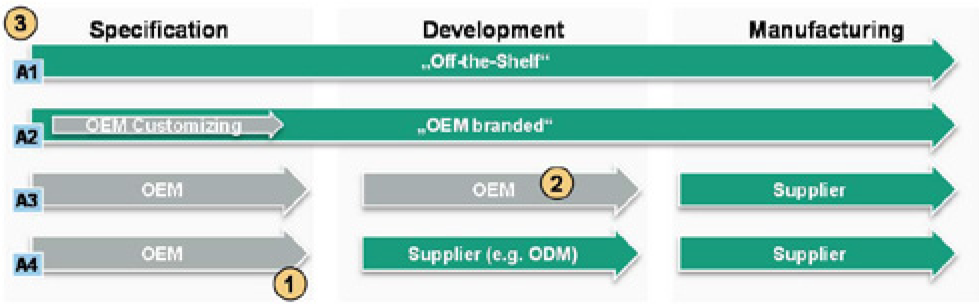

Figure 4 Archetypes of supplier integration (numbers relevant for section 6)

3.3 Complexity and the Lack of Transparency in Product Engineering

The changes outlined above span a complex field of action which is characterized by the technical aspects as well as the organizational aspects: The innovation leap from mechanics to mechatronics and finally to intelligent systems has led to a disproportional increase of complexity within the technical system; the creation of modular value networks caused interfaces within the technical system, its corresponding processes and the organizational complexity to be pushed to a higher level. Enterprises must be able to master cross-enterprise projects and processes and thereby control the resulting data and information to ensure transparency in the socio-technical system of product engineering. One approach to address this challenge is systems engineering, or more precisely, Model-Based Systems Engineering.

4 Model-Based Systems Engineering

Model-Based Systems Engineering (MBSE) describes the idea of a holistic description and analysis of the system based on models from earlier phases of the product development over the complete course of the life cycle of the product. It encompasses the graphical modeling for supporting the definition of requirements, design, analysis, verification and validation [13]. The reduction of the real systems to an initially abstract model supports the creation of a holistic understanding of the system [14]. The system model makes the numerous dependencies within a system visible; it allows transparency and heightens the chances of a development according to the principle "First Time Quality". At the same time, the model provides a platform for the coordination of the changes and the traceability from the requirements in the course of the complete life cycle and can easily be adopted world-wide through appropriate tools [15]. Figure 5 (left) summarizes some generic benefits of the system model discussed in literature.

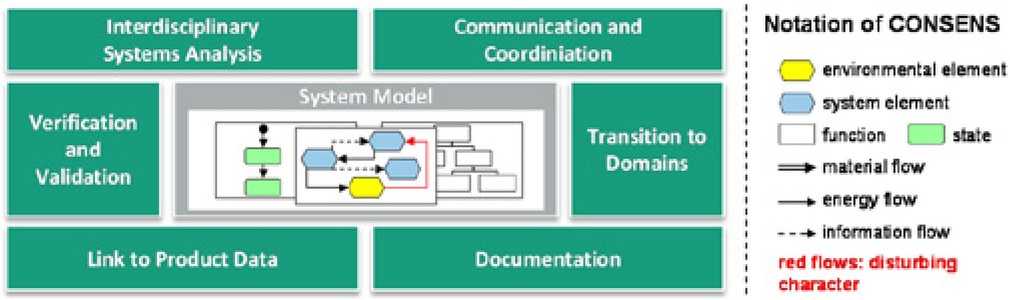

Figure 5 System Model and its Benefits (left) – Notation of CONSENS (right – excerpt)

The benefits mentioned require different approaches, an improved communication and coordination within the project asks for simple and less formalized notations whereas a linkage of the system model to product data to control versions requires a highly formalized approach. Communication and coordination might be improved by a white board approach, whereas the basis for data management is a dedicated software for MBSE. This of course depends on the strategy of the enterprise. However, all the models have to be sufficiently informative with regard to the situation and the problem. The content of the model differs from stakeholder to stakeholder depending on their concerns and viewpoints as well the level of information about the task at that point of a lifecycle. This allows a reduction of complexity during the analysis and the design of the system model; it brings different characteristics and properties into the foreground. The emerging single models are abstraction and simplification of reality and show certain aspects. The overlapping of the different perspectives and partial aspects allows for the description of the system as a coherent holistic system. For the creation of the system model, modeling languages are necessary, as well as sound methods for guiding the modeling activities and an appropriate tool [16]. Much work exists on the languages for MBSE (cf. introduction). All languages focus the main pillars of the MBSE approach: requirements, structure and behavior. The SysML adds parameter as a fourth pillar and CONSENS first concepts of the shape. Currently, there is a trend for new modeling languages that focus simple notations as CONSENS [16] or LML [17] for core activities of the systems engineer as many enterprises are not familiar with the MBSE approach and especially demands for simple approaches quickly generating benefits. Processes and methods for MBSE are also available, e.g. [18] or [19]. They all have in common, that they only describe in general the "what to" in the in the concept phase [4] – rarely the "how to" and in particular not the "by whom" in "what situation". An expert interview at the German INCOSE Symposium for Systems Engineering 2013 with 23 systems engineering-affine engineers from various industries has confirmed this: They assume benefits from the system model in product engineering for many disciplines are not only technology-oriented, but more and more for non-technicians (figure 6, left). Despite the fascinating opportunities of MBSE, it is questionable how the creation of the system model is organized. Existing methods do not point out, when and how stakeholders participate in modeling or working with the system model and how information is provided to whom in lifecycle. The creation of the system model of course is task of the systems engineer – but around 40% of the model content is expected to be delivered by others (figure 6, right) – e.g. in component specification. As product engineering is driven by large groups – even medium-sized projects involve around 100 experts [20] – the benefits of MBSE cannot be gained without clear descriptions for roles and responsibilities or at least guidelines to define them.

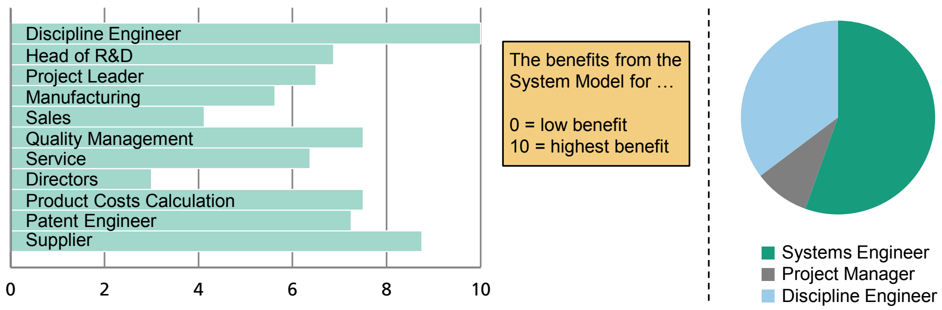

Figure 6 Benefits from the System Model for … (left) – responsibility for its creation (right)

5 Stakeholders, Roles and Competencies in System Engineering

5.1 Stakeholders and Roles

A new procedure like MBSE requires a detailed description of stakeholders and roles, as well as the collaboration based on the system model requires new concepts for the related roles and their responsibilities. Of course, many of these tasks are not new in principle, but have to be (re-)defined in the context of MBSE. Current work does not focus on stakeholders and roles of MBSE, although role descriptions in systems engineering are discussed, as in [21]. There will be changes or extensions of the classical roles of the systems engineer and other stakeholders due to MBSE. The best known work on the systems engineer's role is by Sheard from 1996 [22]: She defined 12 roles for a systems engineer, whereas 11 can be considered as important (figure 7). The 12^{th} role is a compilation of different job advertisements that does not fit the business of a systems engineer. Besides these role descriptions, two superior views on the systems engineer exist: the "lifecycle view" versus the "program management view". Whereas in the former view, the systems engineer acts more "internally" in the product lifecycle and responsible for operations, the management view seems to be management and external customer oriented. MBSE is a life cycle activity; due to the idea of the system model management aspects gain more importance in future.

	Lifecycle View		Management View
1	Requirements Owner	6	Glue Among Subsystems
2	System Designer	7	Customer Interface
3	System Analyst	8	Technical Manager
4	Validation/ Verfication Engineer	9	Information Manager
5	Logistics/ Operations Engineer	10	Process Engineer
		11	Coordinator

Figure 7 Roles of the Systems Engineer according to Sheard

5.2 Competencies

Although the roles of a systems engineer can be allocated to different engineers in the organization – the necessary skill-set is quite challenging and often called “T-shaped”: broad knowledge about every aspect of the system and deep expertise on at least one discipline [23]. Without the detailed knowledge on one aspect (vertical part of the “T”), the systems engineer will not be accepted by discipline specialists. The horizontal part of the “T” is crucial to evaluate the impact of discipline-specific work on the system and project level. Due to these reasons, up to now Systems Engineers usually have a long-term experience in industry – this causes a dilemma for MBSE: On the one hand long-term experience is essential, on the other hand that new approach does not reach engineers that started their career about 30 years ago. To enhance the development of this skill-set, systems engineering curricula have been developed but focus mostly on the process aspects of SE and some additional soft-skill courses. MBSE requires new skills, as e.g. model theory and object orientation that is not addressed within these courses. Due to the characteristics of mechatronics, the systems engineer also has to understand many different domains (mechanics, hardware, software, cognitive science, neurobiology, etc.) and their specific aspects. The organizational challenges mentioned above require multi-project management capabilities and an increase of documentation effort [24]. All this goes along with higher requirements in soft skills to balance the needs of the discipline engineers. Enterprises see two types of future engineers: the specialists and the generalists [2] – The generalist is the systems engineer – a specialist in connecting specialists and is able to keep the bird’s eye view even in critical situations.

6 Stakeholders of the System Model

6.1 Application Scenarios for MBSE

Along with the implementation of MBSE and the resulting changes in collaboration and roles it is necessary to deal with the complexity. Based on the challenges in product engineering described above, here we define application scenarios for the application of MBSE based on the system model. As the application of user stories and use cases is very common in software engineering, we adopted this approach for MBSE implementation: application scenario. Each application scenario describes a typical task or issue in product engineering, the way of modelling the system model and the interaction of the most relevant stakeholders and their responsibilities within this process. There is a basic structure for each application scenario (e.g. cf. figure 8): Each scenario has a name, a lifecycle stage (also shown in figure 4) and an objective or motivation to show its relevance. Working with the system model is explained in three steps typically for the chosen scenario; each step has a meaningful title and an explanation: A short prose explanation gives general insights, but especially the graphical explanation shows relevant aspects of collaboration of stakeholders with the system model. To visualize the system model aspects the specification technique CONSENS was chosen (cf. figure 5, right side) and scenarios based on its system structure presented [16]. As well as SysML it supports in describing requirements, structure and behavior. Amongst other reasons here it is chosen due to its simple visual syntax and the given application in the mentioned reference project. The assignment of responsibilities is clustered according to the role description in figure 2 and the RACI matrix: R – responsible, the role has to ensure this task; A – Agree/Assign, the role has to check and confirm results; C – Contribute/Consult, the role has to support on behalf of R to complete the task; I – the role has to be informed. The application scenarios presented in figure 8 to 10 in this paper are only exemplary, but representative for issues in modern product engineering. A more detailed version e.g. contains product-specific technical and economical parameter to be specified in this scenario. Combining several of such scenarios empower the successful process-redesign for MBSE.

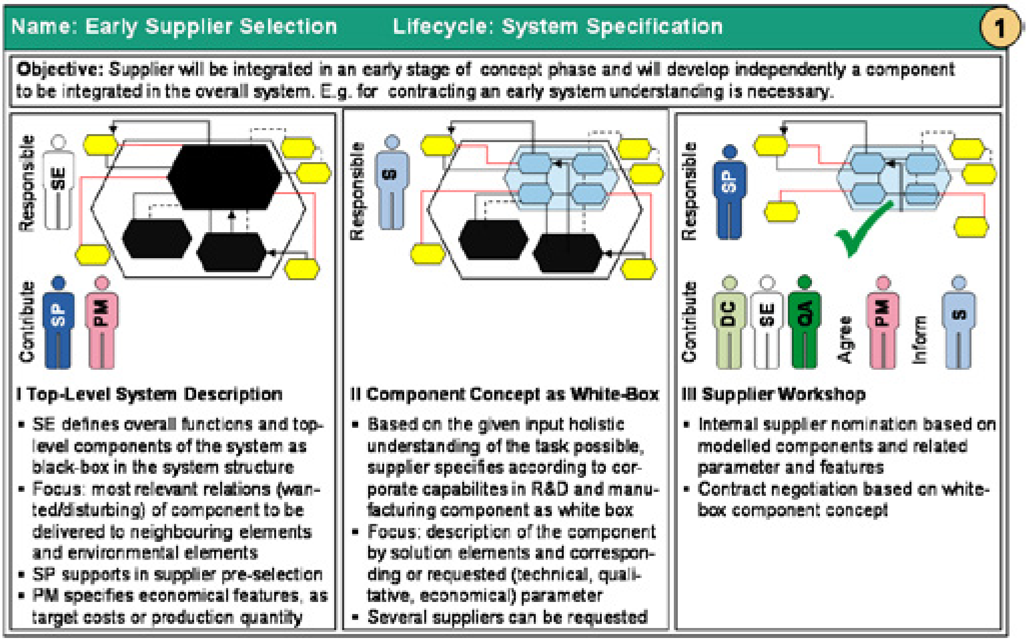

Figure 8 Early Supplier Selection supported by system model

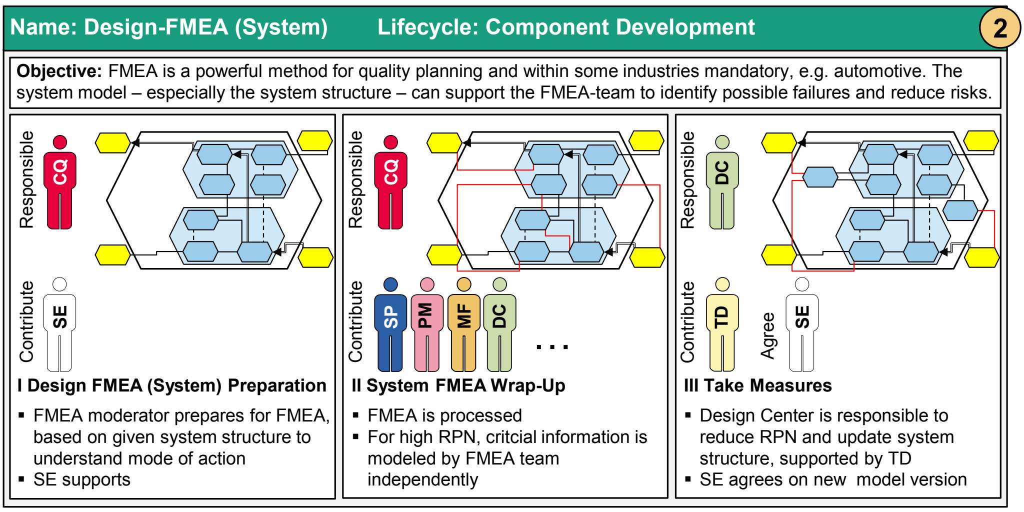

Figure 9 Failure Mode Effective Analysis (FMEA) supported by system model

6.2 The changing role of the Systems Engineer

The exemplary application scenarios give an initial impression of the systems engineer's role and responsibilities in MBSE-driven Product Engineering as well as the involvement of other roles. Based on the roles defined by Sheard, the exemplary scenarios assume an increase of management activities responsible by the systems engineer. This addresses the roles "glue", "technical manager", "process engineer" and "coordinator". Thus, the importance of the systems engineer in enterprises will increase in the medium term to ensure qualitative systems. This is a narrow ridge compared to the role of a product manager or project manager, responsible for the process activities in product engineering. The lifecycle view of the systems engineer of course still will be relevant – but more coordinating: Modeling as a core activity in MBSE has to be distributed across the members of a project team or even a competence center, e.g. by technical documentation. This has the side aspect, that the acceptance of the MBSE approach will be raised as all stakeholders realize the benefit of this approach in daily work. The systems engineer is responsible for the release of high qualitative models.

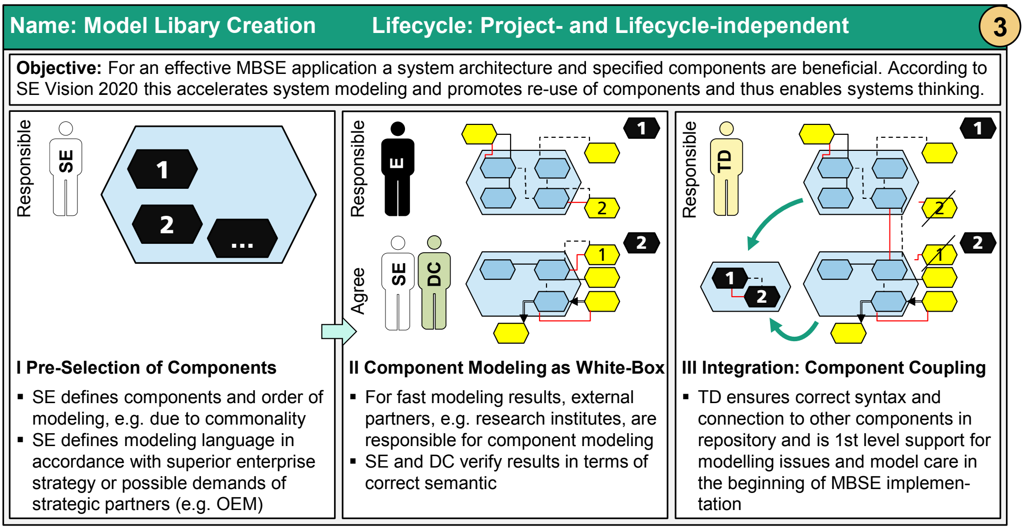

Figure 10 Model Library Creation in MBSE

7 Summary and Outlook

The application scenarios presented are part of an evolving toolbox for MBSE implementation and application in mechatronic enterprises. Distinct issues in product lifecycle are described by the scenarios and modelling and collaboration of stakeholders can be structured. The visualization of responsibilities and the harmonization of modelling and processes is a step towards more acceptance of MBSE. In this context we have shown that the role of the systems engineer might be more a management than a lifecycle role and modeling is more crucial for all stakeholders in product engineering than only for the systems engineer. Thus, the application scenarios serve as basis for redefining existing processes and implementing an integrated MBSE approach. As the stakeholders of MBSE are an inhomogeneous group, the information provided or requested by them regarding the system in system lifecycle will differ; how to organize and simplify the modelling process for them is part of our future research. Current research has to address more these socio-technical aspects of MBSE to achieve the target of the SE Vision 2020. Currently, only the technical aspects of MBSE are focused; the benefits for its users, fundamental processes and organizational issues are neglected. Research has to pay more attention to the needs of industry in MBSE and has to provide methods for collaborative model creation and usage in the entire product lifecycle.

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