System models and model classification in tribological system development

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Abstract
Current requirements for the reduction of CO₂ emissions, as well as for the improvement of durability and reliability of sociotechnical systems such as passenger cars, lead to an increase in development effort in order to increase efficiency and system lifetime. Tribological systems play an essential role in the development of sociotechnical systems, but have proved to be particularly complex. The development of tribological systems, as part of the overall system under development, is an interdisciplinary effort. Involvement of solid mechanics, fluid mechanics, rheology, and many more scientific disciplines is essential to cope with the high number of nonlinear relationships, which often cause unpredictable system behavior. This paper contributes to the scientific field of tribology by introducing concepts of model-based systems engineering for the specific case of elastohydrodynamic lubrication states. The elastohydrodynamic lubrication state of tribological system has been chosen as example to show how system models can be used to better describe the behavior of a system by connecting several specific models. In order to gain an overview of the models used in tribological system development, a system cube was used to structure the models. The system cube enabled gaps and overlapping model zones to be identified. Finally, the role of system models in development and the benefit of using system models to solve problems that cannot be solved by a single technical discipline but only in an interdisciplinary effort are discussed. An approach to connect models and methods to describe a system in an elastohydrodynamic lubrication state is presented.

KEYWORDS
model-based development, model-based systems engineering, specific model, system cube, system model, tribological system, tribology

1 | INTRODUCTION

Systems are becoming increasingly complex and hence require adapted or novel approaches for their development. In particular, the development of a cyber physical system, which integrates cyber systems and physical elements to provide the desired system functionality, poses new challenges for engineering. Model-based approaches such as model-based systems engineering (MBSE) support the development of such systems with consistent and reusable models that provide information for guidance system control. The model MBSE focuses...
on not only new possibilities for the use of digital twins in the in-use phases of a system's lifecycle but also the development of such complex systems. The motivation of this paper is to introduce the term system model, which is a key artifact of model-based development approaches, in tribology, which is often used in the area of model-based development. System models represent multiple views on a system, which allows engineers to better understand the interdependabilities of various subsystems and parts. Furthermore, the concept of structuring system models and specific models as defined by Hick et al. is applied to tribological systems. In a question form: Is the defined term system model of practical use in a model-based approach to solving a specified technical problem and can an overview such models be obtained? A check has to be made whether system models can be used to meaningfully describe a system on a high level and whether they provide an added value in a model-based development process. Therefore, insight is provided into how system models enable a more comprehensive system description in combination with other models in the development process. As a starting point, a common understanding of system models, which are an essential artifact of MBSE, is established and interactions of models and methods in development are discussed.

Model-based development of complex sociotechnical systems aims to describe systems with models rather than with documents. As the term system model is an essential part of MBSE, the principles and concepts of MBSE are considered. The overall aim of implementing MBSE is to improve product quality while reducing risks. In general, the use of formal and semi-formal models provides advantages such as the consistency and traceability of information throughout a development project. As described by Hick et al., the term system model must be tailored to given boundary conditions such as the area of application, the organization it is used in, and more. The development of tribological systems is investigated as an example, in order to show the derivation from a general definition to a practical application.

Tribology is a combination of multiple disciplines and tribological behavior is the result of several effects from nano- to macro-scale level, leading to complex system behavior. This makes the field of tribology suitable to demonstrate the advantages of the use of multiple system models in a development process. Furthermore, tribology has a huge and often underestimated impact on global energy consumption, as about 23% of the world's total energy consumption is used to overcome friction and remanufacture worn parts, which not only causes additional costs but also increases emissions and is therefore an important field of research. To develop technical systems in an effective and sustainable way, a set of models are used. This set includes system models, which have a very broad scope, and specific models, which focus on one aspect in detail.

To classify different models used for tribological investigations, the general model classification scheme has to be adapted, particularly regarding its dimensions that build the multidimensional grid, which have to be tailored to the field of tribology. System models focus on merging different views of the system, for example, common system understanding and statements. Specific models focus on single views, but in technical detail. In order to classify different models, three dimensions (each coordinate of the grid is defined as a dimension) are defined by structuring the required information about tribological systems. Current modeling approaches in the development of tribological systems are considered and structured within the conceptual cube for tribological models to provide a common understanding of models used and their targets. An analysis of possible gaps and overlapping areas of different models is supported by this concept. The following sections validate the defined term system model as proposed by Hick et al.

When looking at the methodological aspect within a development project, it is essential to also consider the interactions and interdependencies of models and methods, as well as the role of methods within the development process. A first distinction between the terms model and method was established by Estefan, who stated that methods define the how (to use and edit the modeled information), while models define the technical content and description of systems. In parallel, processes define the what and when. In the context of this paper, methods are considered from several points of view:

- Methods to achieve input from several sources (e.g., other models, text documents) that are necessary for the model to be generated;
- Methods to generate models and deposit the information (such as modeling guidelines);
- Methods to use the information a model contains for example, to connect it to information in other models;
- Methods to verify and validate the model (how it is embedded in the model-based ecosystem, does the content meet all requirements and stakeholder expectations, etc.) by, for example, comparing information described in a model with test bed measurements.

In a model-based development ecosystem, the use of the right model in the right place at the right time is one of the fundamental principles. Therefore, the framework of processes and methods within the development process have to be considered, adapted, and optimized in the sense of model-based development. Different kinds of information are exchanged within the framework, within its parts, or between them. The methods define in principle which information is exchanged between several models.

## 2 CURRENT APPROACHES TO DESCRIBE TRIBOLOGICAL SYSTEMS

To better understand the benefits of system models, a certain application of the basic concepts of systems models is required. In addition, the understanding of the term has to be specified for this application. To show the application of system models, the development of a tribological system, as part of an automotive passenger car powertrain, is considered. The term tribology is described as "... the science and technology of interacting surfaces in relative motion and of related subjects and practices," and the main tribological aspects in development are friction, wear, and lubrication. Tribology, as a separate field of science, was largely recognized after the initial Jost report, showing that the potential of improving tribological systems is huge, because of the impact of reducing wear and friction losses on worldwide energy
To reduce the ecological impact of systems, the whole product lifecycle has to be considered from concept and development on. While efficiency has huge impact on the in-use phase of the product lifecycle, production aspects, used materials, etc., affect the ecological footprint of the product too. It is therefore essential from an ecological perspective to not only reduce friction and wear but also to consider which lubricants and coating material are used.

The engineering challenges of tribological systems are rooted in the interdisciplinary and multiscale nature of tribology. In mechanical engineering, development targets focus on macroscopic system behavior (such as engine friction or wear volume) but tribological behavior is typically based on atomic forces in the contact surfaces at the nanoscale. For example, in order to improve the friction between two parts, it is necessary to understand certain micro- and nanoscale effects in order to define the macroscale behavior of the system. Additionally, the possible conclusions drawn from a model strongly depend on the model selected, the related model accuracy, and the level of modeling detail, etc. What makes the improvement of friction and wear in development even more complex is the fact that system properties have to be considered rather than the properties of individual components. The identification of cause and effect relationships is not exactly determinable, and better insight is only possible in retrospect, by studying the system's behavior. Research and development demand new approaches to describe tribological systems in detail and provide specific as well as system-relevant insights.

### 3 TRIBOLOGICAL SYSTEM DESCRIPTION

Tribological systems are complex systems. Highly sophisticated research and development activities are required to comprehend the structure and behavior of tribological systems. The structure and general impact factors of the behavior of tribological systems are shown in Figure 1A. As stated in the definition of the term tribology, two surfaces under relative motion are considered as a tribological system. These two surfaces can be separated by a lubricant as an intermediate medium. Furthermore, the environment, the loads acting on the system elements, and the kinematic situation have to be considered because they strongly affect the behavior of the system.
and the effects on different scales. In this case, the focus is on typical technical materials such as steel, although the principle effects are not limited to such materials. Furthermore, these interacting effects occur on different timescales (e.g., flash temperature in contact versus tribolayer formation through diffusion).

5 | CURRENT MODELING APPROACHES IN TRIBOLOGY

A well-known approach to model and describe a tribological system using simplified geometrical illustrations and easily understandable formulas was conceptualized by Coulomb. Coulomb’s concepts were the result of extensive investigations by him and former researchers such as Da Vinci and Euler to understand the phenomenon of friction. Coulomb’s model represents a model that tries to formulate the relationships between load and structural properties to describe system behavior on a macrolevel by reducing the complexity of the tribological system to a simple empirical relationship. It describes the occurring friction force as linearly dependent on the normal force with a proportionality factor called the coefficient of friction.  

A far more sophisticated approach to describe tribological systems for lubricated contacts is the so-called elastohydrodynamics (EHD) models. Numerous different approaches for tribological models exist in many development projects for example, powertrain applications, and their associated journal bearings, piston–bore interface, gears, and roller bearings. Different lubrication states are often distinguished from dry friction, where no lubrication is involved, through mixed lubrication to hydrodynamics, where a dynamic lubricant film separates the solid parts completely. In EHD, several models have to be combined to gain system knowledge, for example, as the elastically deformable parts and hydrodynamic fluid behavior strongly affect each other. Figure 3 shows the models typically employed to describe an EHD contact.

These models can be classified as system models or specific models. System models incorporate multiple views of at least two technical domains or disciplines and therefore provide a broad view on a system.
In contrast, specific models provide more depth than system models by concentrating on the view of a single discipline and a single technical domain. For example, finite element (FE) models build on structural models which define the geometry of the system and on material properties that can be detailed to deeper levels (e.g., conclude macroscopic elasticity from molecular interactions). Thus, FE models are examples for specific models as they provide a detailed view for a mechanical engineer on one system aspect (structural behavior). Most wear models are system models because they incorporate several disciplines, for example, solid mechanics for contact pressure, materials science for abrasive effects, to describe wear on macroscale (as wear volume over time). Different models, which are used to describe the tribological system, are classified and allocated to the structure presented in the following section.

6 | TRIBOLOGICAL SYSTEM MODELS AND SPECIFIC MODELS ON DIFFERENT LEVELS OF THE SYSTEM STRUCTURE

To support the development of tribological systems, multiple system models and specific models are required. The system information, which is required to describe a tribological system, has to be analyzed and structured in order to classify models accordingly. To understand the position of the models within an established product development procedure model, the V-model according to VDI 2206:2004 is considered.

As the V-model globally and logically structures the development activities of systems on a certain level, multiple scales lead to multiple V-models (e.g., subsystem V-model as part of the system V-model). On each level, tribological models can be implemented and used for development. Figure 4 shows the principal contact situation on three different scales as well as development procedure on those scales in V-models. Depending on the development targets, investigations of the tribological systems on all three layers may be necessary. From our present point of view, no single model can represent a single source of truth. Therefore, it can be concluded that more than one explicit system model can exist or that a system model may be more than one single model. Several system models may exist on the same and on other levels (in this case from macro to nano) besides specific models on each level.

7 | STRUCTURED SYSTEM INFORMATION: TAILORING OF THE SYSTEM MODEL DEFINITION

As a tribological system consists of several elements, interfaces, and relationships, information used to describe a tribosystem has to be structured to establish a multidimensional structure for the classification of models that describe certain aspects of the system.

Referring to the elements of tribological systems, shown in Figure 1, there are two solid elements that are in relative motion to each other. To model the behavior of the tribosystem, information about their mechanical properties, which are the scope of materials science, as well as geometrical information about the surfaces and dimensions are required. Also, solid mechanics needs to be considered to describe motion and contact mechanics of the two solid surfaces, and fluid mechanics to describe the flow of the lubricant between the surfaces. In lubricated contacts, the properties of the lubricant are essential. The investigation of these fluid properties (especially dynamic viscosity and density) is covered by the scientific discipline called rheology.

By considering the properties and the required information to describe tribological systems, three dimensions are defined, which build the system cube:

- Discipline (breadth): Many disciplines of science and technology are involved to provide the required information. In this case, the focus
### TABLE 1  Models used in an elastohydrodynamics approach

| Model name                        | Description                                                                 | Level          | Discipline                  | Technical domain                  |
|-----------------------------------|-----------------------------------------------------------------------------|----------------|-----------------------------|-----------------------------------|
| Mixed lubrication friction model  | Description of friction between two surfaces (dry and hydrodynamic friction) | Macro          | Fluid dynamics, Solid mechanics | Tribological behavior             |
| Wear model                        | Wear volume of contact as function of operating point                        | Macro Micro    | Materials science, Fluid Dynamics, Solid mechanics | Tribological behavior             |
| Contact model                     | Contact pressure formation in contact zones on the surface                   | Micro Nano     | Solid Dynamics              | Structural behavior               |
| Hydrodynamics model               | Flow behavior and pressure distribution in the lubrication gap and surface topography influence on micro flow | Macro Micro    | Fluid dynamics              | Structural behavior               |
| Oil Model                         | Viscosity of the lubricant as function of temperature, shear stress, and pressure | Macro Micro    | Rheology                   | Structural behavior               |
| Deformation model                 | Mechanical and thermal deformations of solid parts                           | Macro          | Solid mechanics             | Structural behavior               |
| Materials model                   | Properties of materials (e.g., elasticity as function of temperature)         | Macro          | Materials science           | Structural behavior               |
| Multibody dynamics model          | Description of kinematic multibody systems regarding contact forces and motion | Macro          | Solid mechanics             | Structural behavior               |
| Geometry model                    | Geometrical description of system structure and surface topography           | Macromicro     | Solid mechanics             | Structure                         |
| Elastohydrodynamics model         | Tribological system consideration by combined views on system aspects         | Macro Micro Nano | Rheology, Materials science, Fluid dynamics, Solid mechanics | Structure Structural behavior Tribological behavior |

The visualization of these dimensions and allocated models results in a system cube that represents the model landscape at a certain state of development. This illustration represents a static view on the models used in development. Figure 5 displays the listed models within the grid, which is assembled using the defined dimensions. Specific models are marked yellow while system models are marked blue.

is on mechanics, divided into solid mechanics (contact mechanics, kinematics etc.) and fluid dynamics (flow and pressure distribution), materials science (elasticity, plasticity, microstructure, crack formation, dislocations, etc.), and rheology (fluid behavior).

- **Technical domain** (width): The structure of the system regarding the geometry of included parts as well as surface geometry is of interest. Also, the behavior of the tribological system, divided into structural behavior (deformation, load distribution etc.) and tribological behavior (wear, friction etc.), is considered.

- **Level** (depth): This dimension is structured top down from macro-, via micro- to nanoscale to consider the multiscale nature of tribological effects.

Depending on the application, additional dimensions could be introduced. If the tribological behavior of an internal combustion engine has to be described over the systems lifetime, a dimension for time will need to be introduced to describe the time dependability of effects and system properties (e.g., lubricant aging over time).

### 8  CLASSIFICATION OF CONSIDERED MODELS

Based on the concept of a system cube and with the definition of dimensions for tribology, a three-dimensional grid can be plotted. This so-called system cube is used to visualize different models that describe certain aspects of a tribological system. Based on this, conclusions about models used can be drawn, overlapping zones between models and gaps (aspects of the system not described by models) can be detected and interpreted. These conclusions can be used to develop interfaces between the models.

Models are representations of objects or systems in reality that combine several views and system aspects. To distinguish between
different types of models, their scope is analyzed. While system models focus on breadth and width—at least two technical domains or disciplines—specific models provide depth by detailing one technical domain from the viewpoint of one discipline.

To show the advantages of the presented model classification in the form of an adaptable system cube, an application is presented as a use case by way of example. In tribology, EHD models are often used to describe a lubrication state where hydrodynamic friction is predominant. These EHD models combine and coordinate different submodels to enable knowledge to be gained about system behavior on a macroscopic level. Information described by models has to be distributed, for instance, a hydrodynamic model defines the fluid pressure in the lubrication gap, which represents a mechanical load on a structural element, which is further used in a multibody dynamics model together with material properties (elasticity, thermal expansion coefficient, etc.) to calculate elastic deformations using the finite element method. These deformations themselves affect hydrodynamics by changing the gap geometry. Since information is used in different models at different stages of development, a methodical approach is required. System models, in this case EHD models, represent a set of multiple views to support the distribution of information between models. It should be mentioned that it is not always possible to clearly allocate a model to a definite view. This concept is intended to demonstrate a way in which numerous models can be structured to enable further analyses.

The boundaries of each model are not fixed, rather they depend on the scope of the specific application. For example, a geometry model generated by CAD (computer-aided design) is in most cases used to define the geometric design of parts, subsystems, and systems. In other cases, a CAD tool can be used to generate a generic three-dimensional model to visualize a product for the customer. If necessary, it can be rendered in more detailed with information about the surfaces, tolerances to provide additional aspects, even on a microscale level.

The scope of an EHD model as displayed in Figure 5 is the coordination and integration of different models. It therefore provides system information on a macroscopic level to understand the structural behavior of the system (deformation, load distribution, etc.), tribological behavior (wear, friction, etc.), and the structure of the system (geometry, system elements, etc.). To gain knowledge about the interactions of different effects within the system (e.g., deformation influence on fluid flow and its effect on friction and wear) a system model such as an EHD model is needed in parallel to specific models, such as a hydrodynamics model (HD), which is used to model the flow of the fluid. Specific models provide depth rather than breadth and width. Other system models such as wear models (e.g., the well-established wear model according to Archard) also incorporate different disciplines, but focus on one technical domain (e.g., tribological behavior in form of wear). They are used as system models incorporated within the EHD system model to provide information about wear in macro- and microscale level. The integration in a greater context (through the EHD model) provides holistic system conclusions. This model landscape given by a system cube can also be used to analyze an existing model structure.

First, information must be analyzed regarding the system covered by or integrated within individual particular models. Based on that, a decision has to be made as to which areas of the cube (and therefore which system information) are necessary for specific and for system-relevant statements. In this example, the only model that may contain
information on a nanoscale is the contact model (e.g., modeling atomic forces measured by atomic force microscopy). To verify the friction of a technical system such as an internal combustion engine, information on a nanoscale is only required when deep understanding of the tribological effects is important. Furthermore, most models are allocated to solid mechanics, which may be the result of the application area (in this case mechanical engineering). If a tribological system is investigated regarding tribolayer formation by chemical reactions, the dimension and also the required models employed may be different.

In the next step, the overlapping areas are investigated. These overlapping zones represent system information about certain aspects of a system that are integrated in more than one model. They either result in conflicts or may indicate potential synergies. This requires management tasks that assure data consistency but can also lead to higher quality of the system description (if the system aspect is described by different models in different ways).

By analyzing specific models, it is evident in this case that the contact model and the multibody dynamics model overlap. The information about the contact has to be shared or compared between both models (as both models include information about the contact zone, like reaction forces, contact kinematics, and relative motion). In other cases, the information in one model can be used to validate the information in the other models to improve overall information quality. It has to be noted that the coverage of models in areas of the cube lead to the conclusion that many different system aspects are considered.

Conclusions about the quality or accuracy of that information cannot be drawn from the analysis of covered areas of the cube.

9 | SYSTEM MODEL FOR ELASTOHYDRODYNAMIC LUBRICATION STATE

In Figure 5, it was shown that several models (systems models as well as specific models) are required to describe a tribological contact in an EHD state. To provide further details on the concept of system models, an EHD system model is presented in Figure 6. As stated before, a system model is used to describe interdependencies between different specific models and system models by describing their logical relationships to gain conclusions about overall system behavior. With such an approach, it is possible to investigate the impact of a microscale parameter (e.g., surface topology) on macroscale system behavior (e.g., overall system friction). This enables better traceability, for example, of the impact of design changes throughout product development. Figure 6 also illustrates how tightly connected the methods and models for system development are. Input information as well as logical connections between relevant models and methods are used to gain information about the system in form of an EHD model. The approach to connect models and to enable cosimulation and parameter exchange is supported by system modeling approaches. Currently, the information flow between model and methods is neither described nor
modeled, which hinders the analysis of parameter changes that could be the result of design changes or a change of oil composition, for example.

While usually treated in the steady state, tribological phenomena are highly dynamic. This implies that a selected model may only be suitable for a certain proportion of a tribological system’s lifetime. The lubrication state of a system depends on the relative film thickness, which is affected by many factors such as the lubricant properties (as function of pressure, temperature, etc.), kinematic effects (current flow velocities in gap), and structural properties (surface roughness), which are all not static. As they change over time, a tribological system operates in different lubrication regimes (dry lubrication, mixed lubrication, or hydrodynamics), which also affects the models required to describe the system behavior. For the example of the piston–bore interface, the relative speed of the contact surfaces change periodically so that a contact model is required to describe mixed lubrication states as well as models to describe the system in a hydrodynamic state. A model-based approach provides the possibility to describe system properties such as the surface topology, which may change as result of wear, as time and state dependent. Understanding the scope of a model, its related boundary conditions, and its assumptions is key to selecting the right models and identifying interfaces between models.

10 | CONCLUSION

The described concepts for model-based development support engineers to better document the structure, behavior, and other aspects of complex systems. The cube also provides an overview of models used to describe different system aspects and therefore supports decision-making of whether a system is sufficiently described via models or not. This can be essential for decisions such as a product release, as the models are used as base for verification and validation tasks. However, the decisions about which models need to be generated to describe a system and which methods are applied during the development process have to be taken by experts. There is no rule-based approach to decide this as developers have different resources for simulation and testing and different experience with a certain system. These decisions also strongly depend on the development goals and customer requirements.

Considering the development process of a passenger car, the accomplishment of vehicle targets such as performance or fuel consumption is critical. Not only do losses have to be reduced to meet legislative requirements regarding emissions, the reduction of losses also creates value for the customer of the vehicle as higher efficiency increases the range, reduces its ecological impact, and enables higher
powertrain performance. Friction reduction is one development route to improve efficiency. Therefore, the tribological behavior regarding wear and friction has to be modeled and verified by testing. The cube presented for tribological systems can be used, for example, to classify models that describe the piston–bore interface of an internal combustion engine. Extensive investigations of this subsystem are triggered in engine development to improve the friction caused by the piston–bore interface, as it contributes to a large portion of the engine’s overall internal friction. This tribological system, as part of the internal combustion engine, is itself a part of a superordinate system: the vehicle. The engine friction losses also depend on the operating point described on the vehicle level. Therefore, a friction map (defining the friction as function of engine speed and torque) is handed over to vehicle level, where it contributes to fuel consumption calculation. Subsequently, standardized test cycles are simulated to ensure a common baseline to gain information about the vehicle system’s behavior (e.g., fuel consumption). Figure 7 shows the position of the presented cube used to structure models that describe the friction of the piston–bore interface in a holistic vehicle development context.

In order to generate the models that describe the system under consideration, certain pieces of information are required. Therefore, hardware tests and other methods are required, for example, to characterize the surface topography (light microscopic or profile methods). Also, tribological behavior such as wear has to be verified by defined tests. For example, the friction single cylinder engine in combination with applied radio isotope concentration method provides an established way of measuring the friction and wear of an engine and to continuously log it online. The consideration of the greater context of the piston–bore interface shows potential for optimization (e.g., thermal management, operating strategy) as well as illustrating the strong dependencies between subsystems and components.

In conclusion, the potential of connected models in the development process and the interactions of models and methods needs to be further investigated. The example of a tribological system shows that only for one approach—the EHD model—a variety of models have to be orchestrated. One can imagine how many models are required in the model-based development of a complex technical system with numerous subsystems and components. The structuring and classification of models enables further analysis to improve development efficiency. For example, at the beginning of a novel system development, a handful of models might be available from literature and previous development. The cube can be used to identify which aspects of the system can be described and whether further models are required. The visualization in the cube presented here supports initiatives to use synergies and provides an overview of models used in the development process and how this structure of models evolves according to project progress. Tribological system development shows the need for a structure to identify the scope of different models in order to maintain an overview of system aspects and integrated views.

To connect models, the modeling of system functions is of interest as functions provide a solution-neutral description that indicates how a system behaves. Functional modeling as part of system design provides the possibility to connect models through causal relations as shown in Figure 6. Linked models used to enable information/parameters exchange (e.g., loads and boundary conditions for several methods) in particular provide possibilities for a more efficient development process. Furthermore, management of overlapping zones between models (same system aspects described by different models with different kinds of information) is required to use the best available information. A further challenge of complex development processes is to choose the right set of development methods. Sets of different methods are required to obtain information from several sources, process/deposit the information in the model and to provide information for further methods (e.g., material properties, loads). Due to the number of existing models and methods, it is essential to provide an overview over existing models and their relation to methods. In order to support approaches such as parallel simulation system models and a classification of models used in development may turn out to be beneficial. It also enables further steps to be taken toward model-based development approaches that rely on models rather than on documents, such as MBSE. The use of system models may also support the realization of a digital twin—a virtual and digital equivalent of a real system—which follows the path of virtual product development.

Nevertheless, the generation and validation of models will require further investigation. In product development, not only virtual methods (calculations, simulations, etc.) are available but also numerous testing procedures of physically existing models (e.g., prototypes). Providing an overview, structure, and classification of the models used to describe tribological systems enables the possibility of obtaining consistency and traceability within the development process of complex systems. Additionally, knowledge about the tribological system, how the system behaves, and reacts to parameter changes, can be preserved by models. System models can be used to describe interdependencies and interconnected system behavior, while specific models contain knowledge about certain detailed aspects of a system. In summary, many views on the systems structure and behavior are contained in such a set of models and described in a way to ensure reusability of the included information. Future system development approaches require structuring principles to integrate expert knowledge into an ever-expanding system description, in form of documents and models, to exploit unused potential.

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**CONFLICT OF INTEREST**

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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