SOCIAL SYSTEMS ENGINEERING – AN APPROACH FOR EFFICIENT SYSTEMS DEVELOPMENT

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ABSTRACT
Our objective is to establish an understanding of product development as a sociotechnical system and as a foundation for new methods to manage social and technical complexity. Existing approaches experience a gap in explaining today's phenomena and in managing rising complexity. One reason is a decoupled view on either technical or social systems. To bridge this gap, we describe product development as a dynamic sociotechnical system where interrelated functions link social and technical systems. The sociotechnical system is shown in a schematic meta-model. System functions are represented by interaction (human/machine) and communication (human/human). Based on this approach, complexity, with its major impact on the systems self-governance, can be identified and related to social and technical subsystems. This view helps to develop new approaches to measure and manage complexity. The meta-model is the foundation for development of engineering services and tools to improve effective system modelling and efficient system development. As an example, we'll show a derived UML meta-model currently applied to improve collaboration between different social systems in automotive development.

Keywords: social systems engineering, meta-model, complexity, network analysis, communication analysis, system modelling, system development, UML

1. INTRODUCTION - CURRENT SITUATION IN AUTOMOTIVE INDUSTRY
The development of a sociotechnical systems approach is a consequence of recent dynamics and changes in the automotive industry and a current lack of a comprehensive theoretical meta-model, which combines different areas of science, domains and aspects of efficient as well as effective product development. The automotive industry faces immanent challenges and hence changes (i.e. differentiation, integration of new technologies, process optimization) leading to a continuous learning and exploitation of knowledge. Recently the situation has significantly changed especially caused by CO_2 restrictions, market drifts and the economy crisis. As a consequence, completely new technical, economical, and organizational requirements have to be fulfilled: Due to the demand for fuel efficient green vehicles, product development has to leave existing paths of technology to new drive systems like hybrid and e-drive as well as light weight construction materials. Economically, budgets for individual projects are far more restricted to maintain flexibility in uncertain and still dynamic times. Therefore, intensifying cooperation, joint venture and network structure in manufacturing and product development seems to be the organizational solution to meet these requirements.
Summing up the empirical evidence, product development has to handle the drastically increased types of complexity and is simultaneously forced to operate more effective and efficient. Changes in organizational structures, processes, methods and tools like CAx- and PLM technologies to foster innovation are additional challenges. Furthermore, intensified, distributed collaboration in intercultural design teams exacerbates the governance and coordination of projects. Established management approaches and design methods are in place to solve these problems, but reach their limits because they are unable to explain, model and systemize today's phenomena. Literature provides different theories applicable for a subset of these phenomena. These theories often decouple technical and social aspects in product development to highlight science specific questions. To describe products/artefacts theories of technical systems are available. Design Theory and Methods take into account the process to develop technical systems. In Management Science and Organizational Theory different aspects of social behaviour and its governance play a role. As a consequence of decoupled theories, we have developed a meta-model based on Social and Technical Systems Theory combining different aspects of science and domains to handle increasing technical and social complexity and to

understand their relationship. Especially the occurrence of digital communication in engineering context is a key to understand how social systems cope with complexity and how self-organization works. The schematic meta-model of sociotechnical systems is a comprehensive approach, which allows the measurement of complexity in social and technical structures and functions. With the aid of statistical indicators, the system performance will be assessable and allows the derivation of improvements. Furthermore, the meta-model is the basis to collect, structure and provide information within a context in form of documents and data, so that IT services and tools can be developed and evaluated. Finally, the meta-model should help to improve coordination issues related to certain product configurations under consideration of social behaviour, design methodologies and IT services.

2. SCHEMATIC META-MODEL OF SOCIOTECHNICAL SYSTEMS

The schematic meta-model of sociotechnical systems should be able to describe the development and utilization of technical systems by a social system, to make complexity determinable, to reveal and intensify the ability for self-organization as well as to provide a basis for the development of IT-services. The formal structure of the meta-model regards the three system concepts from Ropohl: structural, functional and hierarchical concept [1]. The meta-model also respects the functional-genetic System Theory of social systems from Willke [2]. It regards the distinction of a system to its environment via evolutionary characteristics of internal complexity in structures and processes, the nesting of subsystems, the interaction with the system environment as well as the control of complex systems through symbolic methods, strategies and tools. Every complex system reproduces itself continuously by generating new structures and elements according to self-organization patterns. The used mechanisms are functional differentiation and symbolic-generalised governing mechanisms, which create a space of possible variations, where potential structures, processes and system status come to exist [2].

2.1 Structure

A sociotechnical system consists of one or more social or technical subsystems (see figure 1). The boundary of a sociotechnical system excludes the natural surroundings – that is: everything not included in the sociotechnical system. Every subsystem consists of elements or subsystems and is able to develop specific structures and properties. The specific system element of social systems is the human operation system, the human being. Under certain condition, at least two human operation systems are able to create a social system. All systems realize system functions by transforming input into output parameters throughout all events. In this situation, parameters can originate from the system environment and the structures and functions of sociotechnical systems themselves. Through the system functions, the particular states of subsystems and the whole system change. In the same way, system attributes and properties can be changed by system functions.
The essential system principle of sociotechnical systems is the coupling of social systems and technical systems via the system functions of technical genesis. Technical genesis contains all sub functions for the development and utilization of technical systems through one or more human operation systems. A technical system can also be a tool. For instance, an engineer can be considered as a sociotechnical system at her workplace while using a CAD-system (human operation system plus technical system used as a tool). Similarly, a car driver and the vehicle display a sociotechnical system as well. In simple words: we always form a sociotechnical system when in contact with a technical system.

2.2 Human operation system

Detailing the meta-model approach starts with the human operation system. Its rough structure can be separated into the psychological and organic system. The psychological system contains rationale mental and intellectual structures as well as functions. The organic system consists of all vegetative controlled structures and functions. According to Ropohl, the corresponding sub structure is expressed via the objective, information and active system [1]. Simply spoken, the active system carries out work by transforming material and energy whereas the information system gathers information via receptors from the active system and system environment and interacts with other external systems. Within the objective system, all objectives for activities are constituted and processed in relation to system, state and environment.
One fundamental function within the human operation system can be found in all target-oriented and reasoned activities. This scheme starts with defining objectives e.g. travelling somewhere with a fast and efficient vehicle or (if this vehicle does not exist) to develop it. The operation transforms the plan

and carries out a check for objectives' achievement. If not achieved, a repeated flow through the scheme of operation takes place. If achieved, the operation scheme or the function results in the designated output. All functions of social and sociotechnical system, especially functions of the technical genesis are considered target-oriented and composed of the scheme of operation. After all, couplings of the sociotechnical system result from interactions of the human operation system with technical systems. In addition to that, couplings between more than one individual, say a group with common objectives, are a social system.

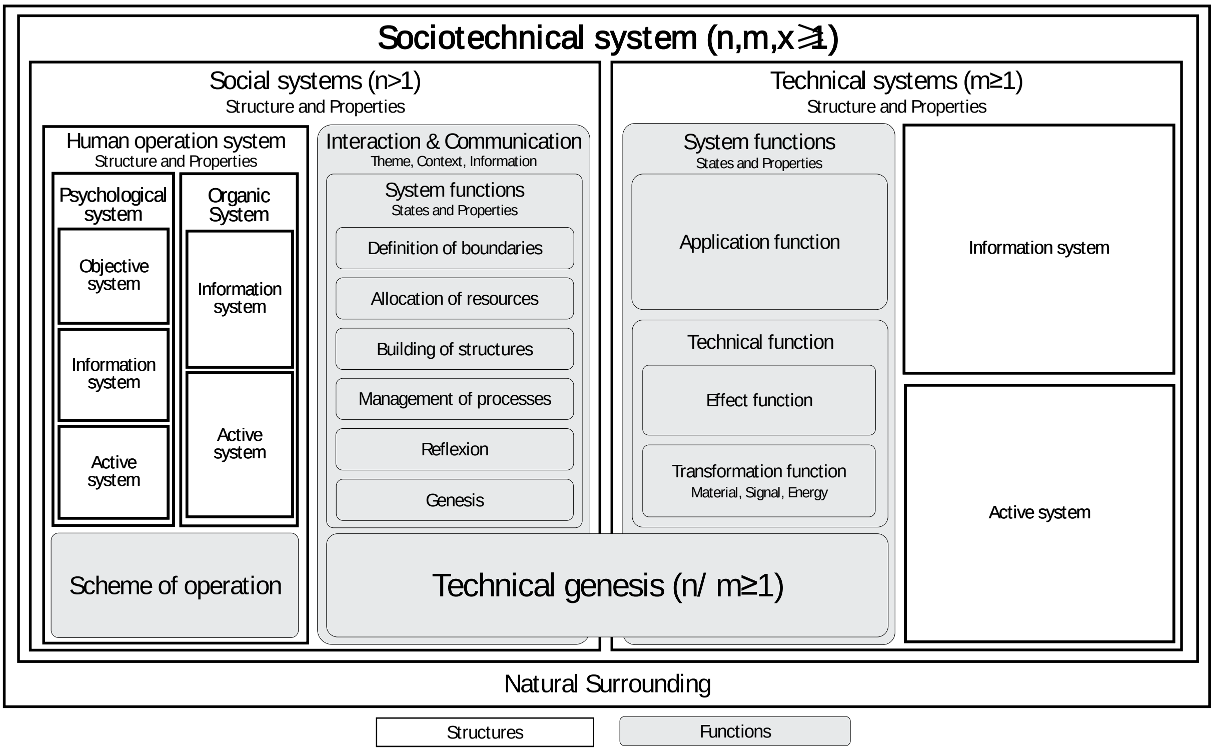

Figure 1: Schematic meta-model of sociotechnical systems

2.3. Social systems

Workgroups, teams, departments, business units, a corporate entity, society (customers) – these are typical social systems related to a formal, hierarchical line organization as known from product development. Depending on organizational structure, structures of project organization and forms of informal organization can be added to the list [3]. As an engineer, I belong to a team, a department, a business unit, a corporation. I work in one or more projects. I regularly meet colleagues from different domains and gather information about topics yet beyond the contexts mentioned above. All these things are couplings within a superordinate system – the respective corporation. Beyond this system, I am coupled with my family and friends, to an association and several institutions, to my household and my country. Each coupling usually has a meaning or a purpose. Via coupling, I become aligned to the system and if I decouple from the system, it still exists. So, how does coupling come about and how does a coupling of elements lead to a social and cooperative system?

2.4. Interaction and communication

As linguistic findings and new anthropological studies show, evolved gestics and language are fundamental abilities for social cooperation. Human gestic and language differ from animal's communication by a far more sophisticated ability for mutual exchange of cognition and intention. Therefore, it enables collective intention for conjoint action, which leads to cooperation [4]. Consequently, each social system can only exist because of communication. At the same time, cooperation determines and supports the development of communication and interaction. Interaction means interdependent acts between a sociotechnical system's human and technical systems. For our approach, we are interested in structurally evaluable communication. For example, observing spoken language shows that information is exchanged and processed via communication events regarding a specific topic. Topics may be predetermined by an agenda (i.e. a report about a test run) or may emerge spontaneously. They establish a semantic framework for information and a reference framework for communication events (information, inquiry, discussion, decision), which form the communication process. The central aspect is information, which is to be transferred (i.e. test run was successful). Additionally, each communication can be codetermined by a specific context (i.e. the test run was conducted within the scope of a specific project). Along with the exchange of information, communication has to fulfil functions to enable conjoint actions, respectively cooperation. Namely, these functions are availability of information, maturation of knowledge, objectives-instrument-identification, commitment and regulation of affect. To avoid dysfunctions in cooperation and to maintain connectivity, the following should be assured:

- All available information is accessible for everyone → availability of information.
- All exchanged information is consistent and comprehensible → low-loss knowledge integration.
- Objectives and instruments must fit → suitable objectives-instrument-identification.
- Tasks and follow up appointments between involved parties should be mandatorily arranged and should be documented → commitment for follow up activities and communication.
- Discussions should be moderated and reflected → sufficient regulation of affect.

As long as these basic functions are assured by interaction and communication, a social system can develop via the system functions proposed by Willke [2].

2.5. System functions of social systems

The individual formation of social system functions enables systems to process external and internal complexity. This is necessary for its self-preservation. Those functions include ‘definition of boundaries’, ‘allocation of resources’, ‘building of structures’, ‘management of processes’, ‘reflection’ and ‘genesis’. To give an example, the system functions could be processed as follows: the product development receives an order from the company to develop a more fuel efficient vehicle. A project for the development of a hybrid drive is initiated and a project manager is appointed. She receives objectives (boundaries), assembles a team (resources) and appoints roles, responsibilities and tasks (structures). She monitors task processing and target achievement and intervenes for corrective actions when necessary (process). The team meets on a regular basis and rechecks that all requirements have been considered (reflection). Finally, additional requirements cause continuous expansion of the team (genesis). In this example, a coupling is established between the newly assembled team and the new hybrid drive which has to be developed. Technical genesis is the binding function for realising the development of the hybrid drive and the coupling between social system and technical system. Prior to examining the technical genesis function, we will go into detail about structure and functions of technical systems.

2.6. Structure and functions of technical systems

In parallel to the social and the human operation system, technical systems can also be described by the structural system concept by Ropohl. That leads to a differentiation of information and execution system. Until today, no objective systems exist within technical systems. Structure and characteristics of information and execution systems can be exceedingly diverse. However, system functions of technical systems can be sub classified into two types of sub functions. The first type is the application function which could be travelling from A to B. Ropohl’s principle of sociotechnical differentiation of labour, which has to be applied to the human operation system and the technical system, states that technical systems take over human action i.e. performing physical work or processing information. The other type of sub function is the technical function which has no distinct contribution to the utilization of the technical system but enables the technical systems to perform its required behaviour. In order to do that, technical functions transform, transport and store energy, material and signals and realize a change or a maintaining of system states. Application and technical function of technical systems have to be specified within the technical genesis.

2.7. Technical genesis

The technical genesis represents the coupling between the social and the technical system, figure 2. It comprises both, the utilization and the development of technical artefacts.

The flow diagram of the technical genesis from Ropohl describes the utilization of a technical system by a human operation system with reference to the earlier mentioned scheme of operation. We would like to set the focus to the function of product development. The function comprises a number of sub functions, known from common design methods [6].

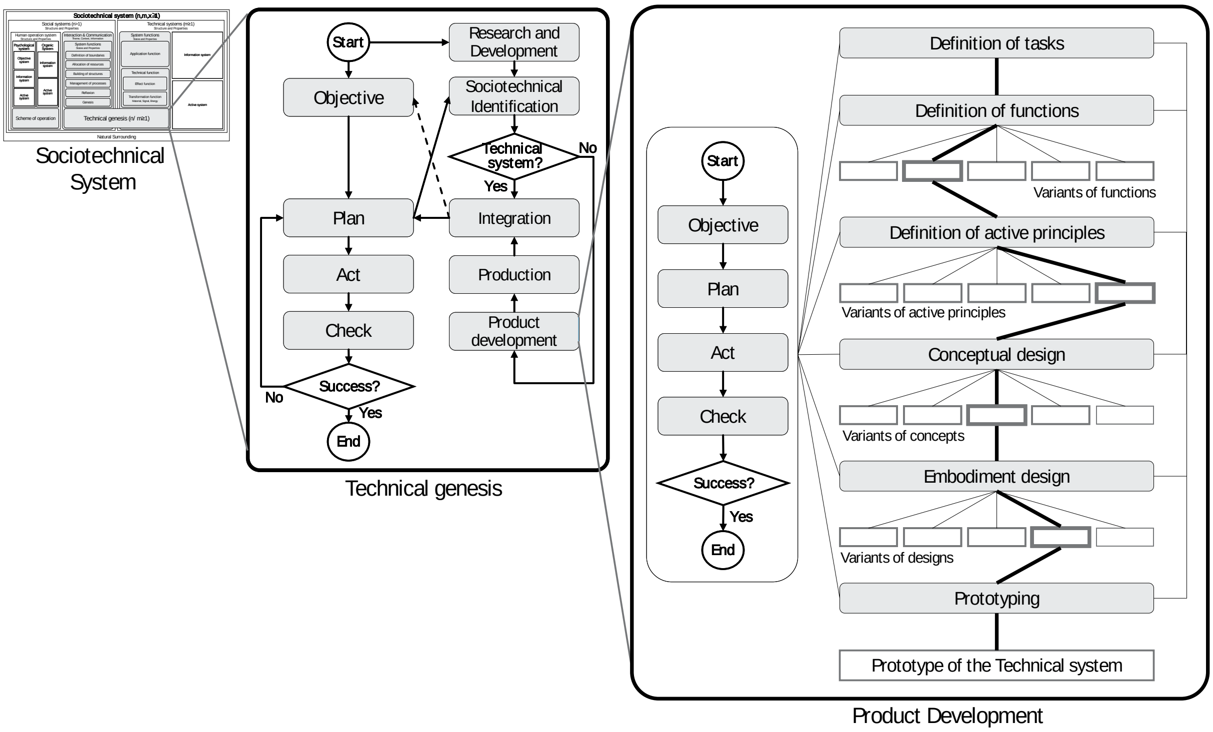

Figure 2: Technical genesis

The execution of the different sub functions leads to the generation of several partial models that represent the technical system. Variants of one model will be selected and provided to the next sub function. Finally, a complete product model has been generated that can be forwarded to production. All sub functions follow the scheme of operation which means they have an objective, are usually planned, and realized. They are completed when the final examination states the accomplishment of the objective. The sub functions are performed step by step iteratively until the synthesis of the product is completed. The social system of product development has to be capable of performing all those functions. The equivalence principle can be applied between the social systems' complexity and the complexity of the developed product. The social system has to adapt its own structures and functions in order to cope with those of the technical system. The principles to achieve are self-organization and self-governance. The more efficient a social system is in adapting to new conditions and requirements by applying the two principles, the more efficient it will be in developing technical systems.

3. COMPLEXITY OF TECHNICAL SYSTEMS

This section addresses the question on which principles technical complexity becomes obtainable, measurable and objective assessable. The implementation of complexity indicators will be the basis for the development of further methodic- and governing-oriented approaches. A definition of complexity in respect to the most important characteristics in different areas of science is illustrated in figure 3. Taking into account the conclusion from literature research and the ideas from the sociotechnical meta-model, the implementation of a dualism by an objective and subjective perspective towards complexity is worthwhile [5]. The observer has to be taken into account when assessing the complexity of a situation, because the evaluation depends on subjective experiences and cognitive abilities. Another important characteristic of the dualism lies in the fact that the governance of objective complexity can only be done by the human active system. The governance of complex situation is not only based on objective descriptions, but also on human perspectives and their limitations.

3.1. Objective complexity

Objective complexity can be differentiated into structural and functional complexity. Structure represents the static shape of elements and relations including hierarchical perspective, whereas functions stand for a description of transformation processes. Using this description there is an increase of complexity caused by an increase of quantity and variety of relations and elements. Moreover complexity increases by the time dependent changes in structure and function, which is known as dynamic phenomena. Based on these characteristics, the complexity of technical systems as interacting elements will be discussed below. For the completeness of figure 3, common properties of complexity are mentioned. But they were not capable for the development of complexity indicators in our approach.

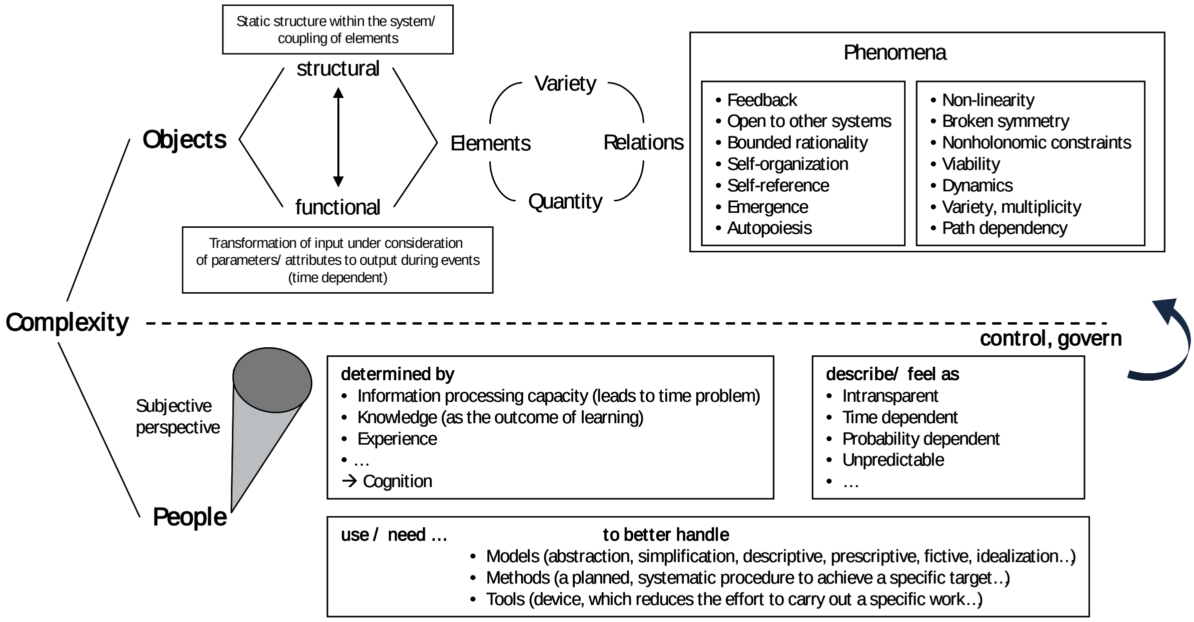

Figure 3: Understanding of complexity

3.2. Subjective complexity

Subjective complexity originates in situations where individuals try to capture and control objective complexity by means of existing instruments. Product development is already identified as a complex problem solving process [6]. Therefore a psychological insight of people dealing with complexity is useful. First of all, humans are physiologically limited in processing information, which leads to a specific duration to assess complexity. These time and processing boundaries of individuals can be extended by experience and knowledge about the issue in question and strategies to cope with those situations [1, 7]. Another aspect of subjective complexity lies in perception. How do people observe and describe complex situations? In this context properties like networked, dynamic, non transparent, probability-dependent etc. are mentioned, which lead to typical mistakes in coping with complex situations such as over steering or ignorance of side effects [8].
To increase efficiency and effectiveness in processing complexity, people develop and utilize models, methods and tools for obtaining and governing complex situations. The purpose of models is to abstract, simplify, describe or idealize real situations to an appropriate dimension. However methods specify procedures to use models and tools for objective achievement. Via the usage of tools, functions of the human active system are substituted or complemented by technical systems, which points to the relevance of the sociotechnical systems approach.

3.3. Complexity in technical systems

In literature, several approaches to measure complexity of technical systems are discussed. The field of computational complexity focuses on the computability of algorithms with the inherent space and capacity problem [9]. In mechanical engineering, structural and functional complexity is mathematically described in a formal scheme, which is based on approaches from Computational Complexity, Information Theory [10] and Axiomatic Design [11]. In this section, we focus on describing technical system complexity on the basis of elements and relations along with their quantity and variety. We concentrate on relativizing a measurement, which reveals interdependencies in the meta-model and enables us to fully understand the sociotechnical system.

3.4. Structural complexity in technical systems

Structural complexity can be found in the information and active system of technical systems. The basis of the structure is constituted by elements and relations. Elements can be separated into peripheral and internal subsystems, depending if they are coupled to other systems in an input output relation or coupled internally to realize transformations. In addition, the hierarchical concept of Systems Theory distinguishes in classifying element clustering. Couplings can be separated from each other by their energetic, material, informational, time and space attributes. Another differentiation characteristic represents the coupling type, e.g. serial and parallel connections as well as feedback. Based on these characteristics, the structural complexity indicators can be defined as followed:

- Quantity and variety of relations of artefacts defined via attributes
- Quantity and variety of internal / external couplings
- Quantity and variety in coupling types
- Quantity and variety of elements / hierarchies
- Quantity and variety of peripheral and internal subsystems

3.5. Functional complexity of technical systems

Functional complexity can be separated into two categories: Application functions focus on how an artefact is used by a human system and technical functions express physical principles, which highlight the description and correlation between input and output attributes. The technical functions are partitioned into effect functions (if the output attributes change) and transformation functions (if there is a change in state). Attributes can be quantified or described via physical laws. According to this explanation, indicators for functional complexity are:

- Quantity and variety of technical functions defined via effect and transformation functions
- Velocity of function completion
- Quantity and variety of input and output attributes
- Quantity of system and environment states defined via attributes
- Variety of system and environment states

After sketching complexity in technical artefacts, it is notable that structure and function are different perspectives on an equivalent relational entity [1]. The difference appears in the relative stability of structure and in most cases the time dependency of functions. Finally application functions describe the utilization of a technical system in relation to the social system and its environment.

3.6. Existing methods to evaluate complexity in technical systems

Design structure matrices (DSM) facilitate the detection of dependencies between items. Primarily activities and their relations were considered by means of square matrices to optimize via sequencing [12]. Moreover this method is used to analyze and improve product architecture, information flow and organization structure [13, 14, 15]. Although this method identifies system internal dependencies, Danilovic developed the domain mapping matrices (DMM) to identify intra system dependencies [16]. On this basis, further research in analyzing dependencies between product architecture and the organization as well as product architecture and requirements were carried out [17]. Recently another approach to combine multiple domains (MDM) has been developed [18]. Matrices can be visualized by using networks in which items are represented via nodes and their relation via edges. Based on Graph Theory as the formal language and on findings from social network research, the network can be further analyzed through social network metrics (SNA) [19, 20]. Furthermore some findings in Network Theory about large networks are accessible and complement existing analyzing techniques. Research in applying these methods in design context increased during the last decade by focusing on connections between different domains like process, organization, product and communication [21, 22, 23].

Today these methods are only partially introduced into industrial practice, because of a high effort to obtain appropriate data, the variety of metrics which exist and the lack of standardized recommendation for action. Whereas the analysis of static networks is covered by methods and software applications, the analysis of dynamic networks has been explored less. Trier investigates an interesting approach in the context of knowledge management and developed initial methods to analyse the dynamic of networks [24].

4. COMPLEXITY OF SOCIAL SYSTEMS

The following section is about the social system in general, its inherent kinds of complexity and its position within the meta-model. As shown, the social system operates via communication. Social systems start relatively small. For the most part, a group of people may initialize a social system. With sufficient growth, the system no longer depends on any single individual. Corporate entities for example, may exist without their initial founders. It is the same for justice systems and states. At any time, specific individuals greatly influenced its history. But at any point, things had the potential to develop in completely different ways. Technically speaking, each operation influenced the systems further development. If you put a timeline on this, you could mark every single operation as an event. The sum of these events effectively developed the state the system is in today. The fact that each event could have played out in a vast variety of ways is also true for future events.

For each event, a contingency space of possible operations exists. The number of possible operations, as well as the finally chosen operation, depends on the respective state of the system at the time of the event. This marks a degree of complexity as well as the systems mode of operation for dealing with this complexity. However, the contingency space is not bound to a single individual. As pointed out, individuals are temporarily bound to the system rather than being part of the system. Otherwise, one could not be bound to several different systems at a time (working environment, family etc.). The contingency space is not even limited to the inner environment of the system, for it may be irritated from the outside, which might lead to completely different outcomes. Therefore, the contingency space – and the probability of a single operation to be chosen – seems quite volatile. The contingency space is usually assumed as infinite and the probability for the occurrence of an event is usually treated as identical for each event and asymptotically zero. As my former argumentation points out, I do not agree with this static view of a contingency space. Even though, the result is the same: An evaluation of a social systems contingency space – and therefore an event based view of a social system's complexity – is, at this point, not possible. Therefore, a different approach on complexity is necessary.

Willke proposed different kinds of complexity connected to different functions of a social system. To utilize this concept, each event is retrospectively linked to one of the systems functions and therefore with the respective kind of complexity [2].The social System needs to handle each kind of complexity and each solution leads to a new kind of complexity. In other words, the system evolves with each step of processing complexity. According to Willke [2], a constituted system, performing the function of setting system limits, competes with other systems for resources and is therefore faced with resource complexity. Assimilating resources causes a new situation, where the coupled persons need to be kept involved in close interactive relations [2]. In this situation, social complexity arises, making it necessary to clarify accountabilities via role structures, causing functional structures to develop. Additionally, with this higher degree of connections between internal operations [2], process rules are necessary to handle the resulting temporal complexity. At this level, the systems operations have a higher capacity for independence from the environment. Up to this point, the system basically reacted to its environment. Now, the operations become contingent, marking the need for reflexion of the systems operations. This finally causes cognitive complexity - various opportunities for own operations, limited by the internal and external environment. Now, objective complexity is the sum of these kinds of complexity and is represented as a function of the complete communication process of the social system.

As a practical matter, the complete communication process can be recorded and conceived in a non-experimental environment, but extensive reduction of data content "on-the-fly" is necessary. For example, Bales developed the interaction process analysis (IPA) in 1950 and, in 1982, "SYMLOG" as a multiple level observation method for group behaviour. A comprehensive coverage of a communication process requires a degree of observation only possible in experimental environments. Even a complete record of each event still needs a high degree of post-processing. Current attempts to automatically analyse communication include the development of Social Badges [25], which record interpersonal communication and analyse it based on behavioural patterns. However, in these examples, the actual context of each operation is not taken into consideration. Relating actual events to their respective kinds of complexity can be seen as a compromise between close regard of content and rather descriptive approaches. In this context, an experimental study was conducted with focus on system functions. It has shown that a better fulfilment of each system function (each represented by specific hypotheses, i.e. a higher degree of integration of the person with the lowest share of communication represents a better fulfilment of the function "internal integration") correlated with better team results (measured via level of progress in the respective assignment), indicating the importance of the described system functions. Each event was categorized manually in a time consuming manner. However, a real-life project will create massive amounts of data, which indicates the necessity of automatic ways for post processing the incoming data. A study of a real-life project confirmed this necessity. Additionally, all mentioned approaches interfere to some degree with normal work life. Therefore, it is required to find a balance between observation of communication and interference with the observed system. We propose to predominantly use sources for communication data that are already used by the observed system. This includes protocols and email data. However, local laws and further restrictions must be taken into consideration. Our current approach includes pseudonymization of Email address data as well as black lists to anonymize the actual content of Mails. While evaluation of the social systems internal structure can be realized via social network analysis and steps toward Email analysis are already taken (i.e. [26]), the evaluation of interdependencies of single events (or sequences), their content and the outcome of the process, is a more difficult matter. It has been proposed, that "creating a robust coding scheme" and the "need for a more complete capture of data [...] where analyses can be done in real time" [27], are important implications for future group research in development processes. We assume this is also mandatory for the evaluation of said interdependencies. It is proposed, that the presented aspects of the sociotechnical system need to be taken into consideration when coding schemes for real time analysis of cooperation and development processes are designed.

5. EFFECTIVE MODELLING AND EFFICIENT DEVELOPMENT OF SYSTEMS

The following section briefly introduces a systems engineering approach that respects aspects of the sociotechnical meta-model. It establishes a framework to support effective modelling, efficient development as well as complexity determination of technical systems. A fundamental basis of contemporary engineering is the generation and use of specialized, partial models to facilitate the different tasks that occur during the development process of modern products. Those tasks and their corresponding models range from the specification of a product (specification models), its functional and detailed design (functional and geometrical models) to the validation of its components (simulation models). The rising complexity within technical systems and within the technical genesis forms the need to establish new methods that help to display and design systemic dependencies between technical and social system entities. In order to reach effective modelling of technical systems the approach is to develop a comprehensive, detailed UML meta-model considering the sociotechnical meta-model. It comprises all partial models, including their relations, and embeds those models into the process of their technical genesis. This UML meta-model will serve as a scheme for PDM systems, enables engineering services for the social system and hereby supports an efficient development of technical systems.

5.1. Detailed UML meta-model

The developed UML scheme describes the coherence between the most important types of entities within the technical genesis of automotive systems. A detailed description of the model would go beyond the scope of this paper. However, this paragraph briefly introduces an extract from the scheme. The model of a technical system represents an aggregation of different partial models that can correspond to function, structure and hierarchy of its original when put into relation.

The UML meta-model distinguishes macro systems (*product models* e.g. the Mercedes-Benz E-Class), meso systems (*technical subsystems* e.g. the powertrain, the lighting system etc.) and micro systems (*elements* e.g. screws, gears, wires etc.). A micro system represents the smallest technical system. Its internal structure and hierarchy are not considered by the OEM. An analysis has led to the definition of eight major dependencies that are used to compose the meta-model (see Figure 4). 'Inheritance' indicates a child / parent relation and can be read as "A is a type of B". Children inherit relations from their parents (e.g. *requirements* inherit the ability to have *parameters* from *partial model*). 'Derived from relation' indicate an existence due to the existence of another entity. 'Specifies relation' can be read as A specifies B or B fulfils A. 'Defines relation' express that existence and attributes of B are defined by A. 'Coupling' refers to the link between in- and outputs e.g. between *technical functions*. 'Composition' and 'aggregation' follow the UML specification.

Figure 4: Extract from the UML meta-model

The figure also shows some of the classes that are necessary to integrate the technical system into its sociotechnical development process. Three different types of *activities* within the sociotechnical system are distinguished. The *technical function* which is at the same time *partial model* and *activity*, describes the relation between in- and output attributes (see technical function in the sociotechnical meta-model). *Social functions* represent the functions of the human operation system and the social system. These functions are not considered in detail as the focus of the scheme lies on the development process (see social functions in the sociotechnical meta-model). The *design function* represents an activity within the technical genesis. Although there are a great number of different design functions, only few are worthwhile considering in the scheme. Five of them are exemplarily displayed in the extract. *Activities* and *events* represent a *process* whereas an *event* is defined by a preceding *activity*. *Events* finally define *statuses* that belong to *partial models* or to the relations between them. The UML meta-model is currently being implemented for two examples in the automotive industry. The mechatronical rear view system focuses on the challenges of systems engineering at the interface between mechanical and electrical development. The development of a vehicle's side panel is looked at in respect to the collaboration between engineering design and styling.

5.2. Engineering services to improve Social Systems Engineering

The developed UML meta-model was translated into a class diagram and is currently implemented in a software prototype. The software represents a framework that supports different graphical representations like SysML diagrams, realizes interfaces to specialized modelling tools like CAD or requirements management software and provides access to the data-backbone that is implemented as a SQL database. The framework embeds engineering services which support efficient development, e. g.:

- The visualization of context related views enables the providence of relevant information to specific engineering tasks and supports a domain comprehensive understanding of the system. Back and forward tracking between the different entities allows engineers to browse, understand and analyze the system. Impacts of modifications can be determined and rationales be retraced which helps engineers to cope with the technical complexity.
- Synchronization of engineering data supports the process of coordination between different social systems. That can e.g. be applied to validation processes where the provision of consistent, up-to-date input data, post processing of results and propagation of status between different departments are supported.
- The system models enable a fast creation and evaluation of systemic alternatives and support the decision-making process. The models can be used as documentation of the technical genesis including the performed changes, chosen and rejected concepts and their corresponding responsibilities.
- The provision of system indicators like technical and social complexity enable an analysis of product development's efficiency and enable derivation of actions for system governance.

6. CONCLUSION

The presented approach enables a combined description of social and technical systems at the same time. This facilitates the determination of system parameters, impacting systems self governance, and represents the basis for the definition of system models that support the sociotechnical process of technical genesis. Both aspects present the basis for the analysis of organizational efficiency for an entire self-organization of social systems as well as the efficient development of technical systems = Social System Engineering (SSE). However, there is still a need to improve methods for real-time interaction and communication analysis, improve dynamic network analysis as well as to enable an effortless generation of technical system models in order to enable a real-time capture and evaluation of the system parameters and to support efficient system development.

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