Development of a Potential Analysis for the Introduction of Sustainable Digitization Solutions

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Abstract. This paper presents a methodical approach that addresses the challenges of the development process to ensure sustainable product use. Consideration of user behavior in the use phase of products is imperative for efficient support by the technical system already in the development phase.

For these and other challenges, the developed approach combines methods of system engineering with the human-technology-organization approach. It helps to identify and develop optimization potential in the area of digitization solutions in the early phases of the product lifecycle. To do this, a technical system is analyzed in its current state and the requirements of the stakeholders. By defining socio-technical system elements and applying a structured approach, recommendations can be outlined holistically. As a result, the recommendations lead to an increasing level of digitization of the technical system and ensure a targeted development process.

Furthermore, the methodical approach includes modeling methods to deal with the complex system behavior. The modeling language SysML as well as task-related analysis methods are used to highlight faulty states and promising aspects. In addition to the human-technology-organization triad, the basis of the developed approach is the V-model, which is applied in phase-oriented design processes or iterative design steps. This makes the usage of the approach particularly advantageous for interdisciplinary development teams.

Keywords: systems engineering · socio-technical systems · digitalization · potential analysis

1 Introduction

The topic of sustainability has become increasingly important in recent years. The findings of science and research show that, especially in industry, considering sustainability aspects is indispensable. In order to take the important sustainability aspects into account in the early stages of product development, the entire product life cycle must be considered and examined for potential to obtain a sustainable product.

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A particular challenge is to assess the role and behavior of people as users of a product. On one side, the users' behavior is highly relevant for the sustainable utilization of products; on the other side, developers need to assure sustainable products and operability. Therefore, much research focuses on requirement management to guarantee targeted and holistic development work and decisions. Especially digitalization solutions or so-called cyber-physical systems have the potential for sustainable products and utilization if they are implemented deliberately and by deep system understanding. Challenging is a successful integration of cyber-physical systems in existing and complex organizational structures and processes.

This paper presents a methodical approach for examining existing physical processes for optimization potential with regard to digitization solutions. The aim is to identify optimization potential of the existing technical system for effective support of humans, to identify possible points of influence in processes, and to integrate digitization solutions into the so-called socio-technical system.

The methodical approach is based on system engineering (SE) methods in combination with the human-technology-organization (HTO) approach. SE refers to a problem-solving process. Therefore, problems need to be outlined and specified.

2 State of the Art

First, the HTO approach is briefly characterized by introducing socio-technical systems. In the following, SE is shortly outlined as well as the V model as the established model of development processes. Subsequently, SysML as a modeling language is introduced.

A socio-technical system is characterized by the coexistence of a technical and a social subsystem. The subsystems are connected by tasks. The human-technology-organization (HTO) approach according to Strohm and Ulich [1] is established in human factors science. The aim of the HTO approach is to improve processes in so-called socio-technical working systems holistically on several economic levels such as companies, organizational units, working groups, or individuals. Therefore human, technology, and organization are defined as system elements of the socio-technical system and influence each other as a consequence of the common task. The organization of the HTO approach is characterized by its structure, processes, and management structures. Humans have individual characteristics, such as health, competencies, or motivation. Technology can be characterized by its functionality, selection, or implementation. If one of the three elements is changed, this has an impact on the other elements. Defining tasks and functions of a planned system brings the network behavior into focus to hinder suboptimization. Plus, developers are encouraged to allocate functionality of the whole working system to humans or machines precisely. Mentioned analysis methods on behalf of the HTO approach are observations and written or oral interviews. [1].

SE mainly signifies an interdisciplinary approach to develop successful systems fulfilling the requirements of stakeholders. Therefore, the requirements are defined in the early stages of the development process to continue the process of system design and validation [2]. Furthermore, in the understanding of SE technical and economic aspects are mentioned, such as time, quality, testing, training, maintenance, operation, and disposal, to ensure a structured and reliable development process and result. In general, a "system" in the SE context consists of system modules pursuing a common goal. System modules can be software, hardware, persons, or any other unit [3].

The V model is a generic procedure model in the SE context such as described in VDI/VDE 2206. It describes the case-by-case required development and hedging activities. The left branch of the V model leads to the specified system design. The right branch leads through the verification and validation of the implemented solutions and system requirements. Challenging in an interdisciplinary development team is to arrange the requirements of a complex system traceably. The V model is one established procedure model to visualize targeted development work in the context of cyber-physical systems [4].

Applying SE methods in order to analyze systems and processes of a system modeling languages such as SysML are functional. They help to guarantee a sufficient specified target system in the product development process. Therefore, diagrams such as requirement, activity, or use case diagrams are included in the repertory of SysML.

For technical systems methods such as Fault Tree Analysis (FTA) are established to extract the causes and effects of faulty states quantitatively and qualitatively [5]. Therefore, main events, which are faulty states, are analyzed by subsequent key events, which lead in combination to the main event. This technique can also be applied by defining success as the main event instead of a fault state [5].

There are various examples of successful applications of the HTO approach to analyze human-machine interaction in working or safety contexts in various domains. The derived aims of applying the HTO approach are to increase productivity, quality, and safety. Especially, the physiological and mental effects on humans are examined and the outcomes of the analysis are reused to improve the following technical systems. [6].

This addresses the sustainability aspects because suboptimization of socio-technical systems can be prevented by holistic development processes. Well-considered system improvements provide the potential to deal with exhaustible resources. Also, reasonably integrated digitization solutions may increase efficiency.

Still challenging is to integrate the human-machine interactions into the whole development process. Especially in interdisciplinary development teams, the agreement on a common development procedure and tool is rarely unified. Developing complex technical systems, model-based SE methods and the V model are commonly used [7]. This is because this paper presents a concept to combine human factor science and SE methods.

3 Concept

With the help of the developed methodical approach, a system with a higher degree of digitization in the target state is developed from stakeholder requirements and a system in the actual state. The developed approach is based on methods and models of SE in connection with the HTO approach. Therefore, the system elements *human*, *technology,* and *organization* as well as an inner and outer system boundary are defined. The methodical approach can be applied by going through the development phases *initialization*, *analysis*, *verification*, *synthesis*, *implementation* and *validation* chronologically (c.f. Fig. 1). Analogous to the V-model, the methodical approach can also be applied time-invariantly (c.f. Fig. 3). The detailed process of gaining optimization potential of the actual system is explained by defining *tasks*. Optional, a deep analysis of the socio-technical system is done by applying SysML techniques and a so-called Success Tree Analysis (STA), captured from data collections.

3.1 Development Phases

At the beginning of the development work, stakeholder needs are discussed in the *initialization* phase (c.f. Fig. 1). The *analysis* phase includes the extensive investigation of the socio-technical system, including the modeling of use cases and processes. In the subsequent *verification* phase, the created system models are verified with the help of defined *tasks*. These first three phases deal with the system in the actual state which is to be improved (c.f. Fig. 1). By passing through the *analysis* and *verification* phase, faulty states and optimization potential are worked out, which are combined with digitization solutions in the subsequent *synthesis* phase. Until the *recommendation* phase, possible digital solutions are integrated as variants. From the *implementation* phase, the target system is focused. Therefore, one solution variant is selected and realized. Finally, compliance with the required stakeholder needs is determined in the *validation* phase. Figure 1 shows the development phases of the methodical approach. Like the V model proposes, there are phases of analysis and validation. In between, the methodical approach includes a verification phase of the modeled socio-technical system and its physical processes.

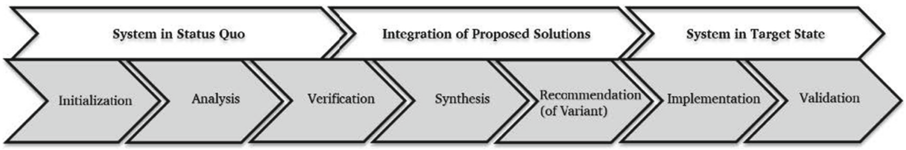

Fig. 1. Development phases of the methodical approach.

3.2 Defining System Elements and System Boundaries

A central component of the methodical approach is the definition of system elements: *humans*, *technology* and *organization*. An outer, extensive system boundary separates the HTO system elements from their environment. Figure 2 represents the defined HTO system elements. An outer, extensive system boundary includes the whole socio-technical system and places it into a specific environment and context. For SE techniques it is functional to use an inner system boundary to focus on the technical systems. Therefore, the impact of the other system elements *human* and *organization* have to be considered, too.

Another central component of the methodical approach is the integration of defined *tasks* into the socio-technical system. The considered *tasks* enable the verification of the created system models. The *tasks* are responsible for the interactions of the HTO system elements.

Examples of the definitions, system boundaries, and tasks are given in Sect. 4.

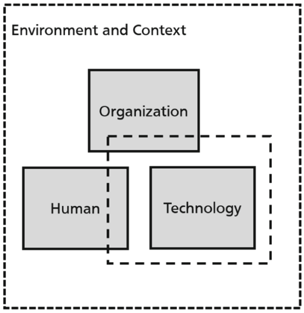

Fig. 2. System boundaries of the HTO system.

3.3 Detailed Methodical Approach to Gain Faulty States and Optimization Potential

Figure 3 exemplary shows details of the methodical approach; starting by considering specific *tasks* of the HTO system. Modeled use cases and processes support analyzing the *tasks*. With the help of data collections with former types or prototypes of the technical system, the HTO system behavior can be observed. Based on this, faulty states and optimization potential are derived. Drafting system requirements during the whole development process is supported as well as considering possible system solutions and, finally, a recommendation of a solution variant, which includes digitization solutions.

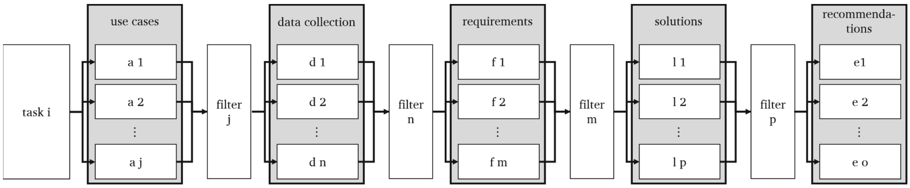

Fig. 3. Exemplary detailed concept.

For instance, *tasks* are usual or unusual user instructions and scenarios of the foreseen use phase of the product life cycle. Defining multiple *tasks* (c.f. index i, Fig. 3) will increase the reliability of the analysis results and are related to validation parameters (c.f. right side of the V-model [4]).

Modeling use cases, as well as system processes of the socio-technical system, is convenient for systematic and detailed analysis. In the *verification* phase (c.f. Fig. 1) the modeled system needs to be verified. Faults due to modeling need to be minimized because they affect the quality of the optimization potential and within this the development success. In Fig. 3 the variables a 1… a j symbolize verified use cases the socio-technical system has to deal with. In Fig. 3 the mentioned inaccuracies of modeling to be minimized are symbolized by filter j.

Furthermore, it is convenient to analyze the tasks of the socio-technical system within data collection methods such as field studies, interviews, observations and surveys. At first, the data collection methods will hand out objective statements about the socio-technical system. In Fig. 3 the objective statements are symbolized by the variables d 1… d n. Secondly, existing faulty states and ideas of optimization potential can be derived. To build the base for the optimization potential an STA out of a qualitative FTA [5] is a systematic and traceable technique. Modeling a success tree, defining the *task* or parts of the *tasks* as a main event is functional and helps to derive optimization potential traceably. Despite this, the combination of causes and effects of a socio-technical system stays sensitive to errors. In Fig. 3 this combination work is symbolized by filter n.

Referring to the V model [4] requirements of the target system are pointed out after the *analysis* and *verification* phase (c.f. Fig. 1). Depending on the requirement management, wording, or level of detail, there is room for interpretation, which is symbolized with filter m in Fig. 3.

In the *synthesis* phase (c.f. Fig. 1), the system requirements and digitalization solutions are merged and become variants of solutions of the target system. Until this point of development, the solution variants for the target system stay unvalued. Even the system analysis can be a solution open until this phase. After weighting depending on the development goals a solution variant can be recommended. The weighting is symbolized in Fig. 3 by filter p. Development goals can be aspects of time, costs, quality, especially sustainability.

4 Validation

The concept presented in this paper is validated by applying it in a development project on the technical system Vario-Load-Rescue (VLR), which is invented by the startup "inventied" and used in Technisches Hilfswerk (THW) contexts. "Inventied" produces and develops devices for civil protection. The VLR is one of those with the aim to support rescue operations by THW. The VLR is a carrier, loaded with rescue items, and has currently a low digitalization degree So, the socio-technical system was specified by THW as *organization*, THW workers and system developers as *humans*, and the VLR itself as *technology*. Also, the validation of the concept dealt with observing a THW operation simulation, where THW workers operated with the VLR in a realistic scenario and were charged with realistic *tasks*, such as building underpin constructions. The inner system boundary, to limit the SysML modeling effort, included the VLR, as well as its rescue items. The outer system boundary also included the THW workers and their working structure. For example, phone calls and shouts were noted and analyzed, to gain the relevant operation information. This enabled the developers to analyze the communication and operational strategy of the THW workers and to differentiate the potential of organizational or technological nature. The SysML modeling included use cases of the VLR and the activities observed in the THW operation simulation. Through should and actual comparison in the operation simulation, fault states and time-intensive activities were outlined. Based on this, the observations were noted and worded as requirements for system improvement. Existing digital solutions, such as digital inventory or the visualization of underpinning constructions, were integrated into the modeled processes and finally recommended.

The aim of the development work was to increase the digitalization degree of the VLR to maximize its potential to support rescue operations, especially in time-critical situations. Characteristic weighting aspects also focused on robustness and availability (c.f. Fig. 3, filter p). This validation case is exemplarily for treating socio-technical systems to increase the efficiency of processes through digitalization solutions.

5 Conclusions

In this paper, a methodical approach was presented to identify potentials for possible digitization solutions in an existing socio-technical system, and then to develop and integrate corresponding digitization solutions in a guided manner. The development of the approach is based on the combination of engineering and occupational science methods. Thus, the approach is also applicable in the context of established development models, such as VDI/VDE 2206. Furthermore, the approach uses the established human-technology-organization approach. By defining the system elements organization and human, the structures in which the product is used become more visible. This has the advantage that the user behavior of products becomes more transparent.

In the context of a cooperation project, the presented approach could already be tested successfully. It could be validated that it is suitable to analyze a socio-technical system where the user behavior has a great influence on the technical system and its support potential. The approach guided through the development phases and enabled interdisciplinary development work as well as the outlining of constructive requirements for a target system with a higher degree of digitization.

The concept provides a guideline for implementing digitization solutions consciously and on the basis of objective considerations. The naming of filters and points of influence in the development process ensures transparency and traceability. The use of defined HTO system elements and tasks clarifies the relevance of the individual parts of a system. The creation of system models and links that visualize system-promoting or system-inhibiting effects help to outline the optimization potential and to implement solutions in a targeted and holistic manner.

The division of tasks into primary and secondary tasks ensures aspects of functionality in the development, but also creates room for the consideration of aspects of sustainability, such as maintenance or disposal activities. On the one hand, this opens up broader thinking about possible applications for the product. On the other hand, relevant sustainability aspects are thus systematically included in the early development phases.

The digitization solutions that are developed and introduced with the help of the present approach are an efficient alternative to or support for existing solutions. In addition, the focus of the developed methodology can be placed purely on the area of sustainability, so that mainly or exclusively optimization potentials with regard to sustainability are identified and corresponding solutions are implemented.

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