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Method for systematic creation of test scenarios for early customer involvement

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Abstract

Verification planning for engineering complex systems lacks a systematic procedure for creating test scenarios. Test scenarios can be generated by combining test cases, or by integrating test cases into pre-specified scenarios. Based on a systematic literature analysis a method is developed to simplify verification planning by creating new test scenarios and enriching existing ones. To assist the V&V engineer in planning test scenarios, a catalogue of combination premises is created to support the method. The method is evaluated in the development of a platform for emergency management. Evaluation proves that the method makes modelling of test scenarios more efficient.

Keywords: Systems Engineering, test scenario creation, verfication, customer involvement

1. Introduction

In the early phases of product engineering process, customer and system requirements of a system are defined [1]. To enable early proof of requirements fulfillment, the verification of system requirements and the validation of customer needs should already be considered when defining system requirements. This means an extension of available approaches integrating customers in early stages in the engineering of complex systems, like for individualized production approaches [2, 3]. Test cases and test scenarios are carried out in the verification and validation activities. An early involvement of the customer is essential to proof the fulfillment of customer requirements within the engineering process at an early stage and to be able to implement relevant changes. It is also essential to test dependencies between system components at an early stage, taking the customer into account. The test cases of interdependent system components are brought together in test scenarios, as dependencies and relationships within the system between subsystems or system elements based on requirements can be verified and validated in test scenarios. In addition, early testing with the customer through test scenarios allows to identify errors in early phases of the engineering process, thereby avoiding costs (cf. rule of ten for error costs [1, 4, 5]). In practice, often the problem arises that the definition of boundary conditions limits the generation of test scenarios. In addition to the theoretical approach of combining test cases into test scenarios, other methodologies are relevant in practice, like the integration of test cases into pre-specified scenarios. For example, in the automotive industry, test vehicles provide a scenario context for a variety of test cases to be booked into test runs in order to reduce costs and increase feasibility. The aforementioned points illustrate a need in generating test scenarios and the necessity for a systematic approach to support the verification and validation (V&V) engineer. The CREXDATA research project, funded by the European Commission, is investigating various Data Science (DS) and Artificial Intelligence (AI) technologies that will be developed and evaluated in the case of weather-inducted emergencies [6]. The CREXDATA consortium

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consists of 16 international partners from research and end users. The Cyber-Physical System (CPS) to be developed in CREXDATA is a generic platform for real-time critical situation management, flexible action planning and agile decision using extreme scale and complex data, integrating also rescue robotics systems [6]. The DS/AI technologies developed will be evaluated as test cases in various test scenarios of the weather-induced emergency use case using a scenario-based Systems Engineering approach [7]. Test cases such as displaying weather forecasts (TC1), complex event forecasting (CEF) in sewer network (TC2), flood visualization in Augmented Reality (AR) (TC3) and text mining in social media (TC4) are combined into a test scenario which can be carried out in exercises of a fire department. The research presented in this paper answers the following research questions (RQ):

- **RQ1:** What techniques exist for creating test scenarios?
- **RQ2:** How can surrounding scenarios be used to execute test cases and thus become test scenarios?
- **RQ3:** How can test cases be combined to a test scenario?
- **RQ4:** Which premises must be considered?

This paper presents the findings of a systematic literature analysis and practical relevance in engineering CPS. In light of the findings of the research and the practical relevance demonstrated in the CREXDATA project, a synthesis of diverse techniques for test scenario generation and integration is presented as a method. Furthermore, general and scenario-specific premises that must be considered when developing test scenarios are identified. Both the method and the premises are carried out in an application evaluation according to the Design Research Methodology of Blessing and Chakrabarti [8]. The method for systematic creation of test scenarios for early customer involvement is developed for engineering products as well as production processes.

2. Fundamentals

The VDI/VDE 2206:2021 guideline defines verification as the process of evaluating whether the current engineering state aligns with specifications [9]. This process is of crucial importance in the integration of sub-elements into higher system levels. An early involvement of stakeholders is crucial to ensure proper validation and avoids unnecessary iterations within the engineering process. Similarly, VDI 2221:2019 addresses the continuous analysis of product engineering results in comparison to the specified requirements [10]. Verification ensures that the implementation meets the system requirements, whereas validation assesses whether the product fulfills its intended use and the needs of the stakeholders [9, 10]. In accordance with ISO 15288 [11] and the approach by Walden et al. [12], verification is defined as the provision of objective evidence that a system or element meets the specified requirements, typically through the utilization of inspections, simulations and tests. Validation is concerned with demonstrating that a system meets the customer needs [1]. In this context, the verification of system requirements constitutes an integral aspect of the verification process, which must encompass the formulation of test cases and test scenarios. The V-model, as outlined in VDI/VDE 2206:2021, classifies test planning under the planning of verification and validation. Test scenarios are one possible form of V&V scenarios and can be found alongside validation scenarios [7]. According to Graessler et al., test scenarios in the context of engineering CPS are defined as a combination of two or more test cases for ensuring execution of multiple test cases under the same environmental conditions [13]. In addition, a test case is defined as a procedure that serves to verify a property of a test item that has been specified as a requirement [13].

3. State of the art

In order to identify related work, a systematic analysis was first carried out to find possible literature reviews in which existing approaches for generating test scenarios are compared. For this initial review search, the following search string A was used in the Web of Science and Scopus databases established for literature searches: *("generat*" OR "creat*" OR "deriv*") AND ("test scenario*" OR "Testszenari*") AND ("engineering" OR "verification" OR "validation") AND ("review")*. A total of 13 documents was identified through the application of search string A, which were subsequently subjected to analysis. The analysis revealed presence of a single relevant review, which is considered in the following section. Baeumler et al. provides an overview of various methods for generating data-driven test scenarios for assessing automated driving systems [14]. The data-driven scenario generation process is extended and contains seven steps from scope definition towards scenario evaluation [14]. Baeumler et al. classify 64 different methods for generating scenarios in the overall scenario generation process and mapped the methods to six pre-defined categories [14]. One example is the methodology by Feng et al., which presents a general methodology for generating test scenario libraries for connected and automated vehicles (CAVs) that improves the accuracy and efficiency of evaluations [15]. The methodology is applied to practical case studies, including typical scenarios such as lane changes and highway-exits, and optimized for high-dimensional scenarios through reinforcement learning [16]. Zhu et al. present an overview of functional testing scenario library generation, where dynamic scenario generation is divided into four methods: combinatorial testing, knowledge and driving behavior-based generation, and data-driven scenario generation [17]. Baeumler et al. demonstrate that a multitude of techniques exist for the generation of test scenarios. Consequently, the objective of the systematic literature analysis is to identify the research gap concerning the integration of test cases within test scenarios, given the paucity of existing approaches. The specific search string B is used for the literature analysis: *("integrat*") AND ("test case" OR "Testfall") AND ("test scenario*" OR "Testszenari*") AND ("engineering")*. For the literature analysis several established data bases are considered. The literature analysis is based on the PRISMA approach [18] (cf. Table 1). The analysis reveals a limited number of relevant results for scenario integration and consideration of the real environment. Octaviano et al. present a strategy for automatically generating unit and integration test scenarios based on the use case model within an existing software development environment, comparing the results to a real-world system's test plan and highlighting both uncovered and newly generated test cases [19]. Tsai et al. propose a scenario-based functional regression testing approach using end-to-end integration test scenarios [20]. Yong et al. propose an expert system to automate the generation of test sequences for a train control system, aiming to reduce manual workload [21]. There are various methods for the generation of test scenarios as shown in the presented review.

Table 1: Results of the systematic literature analysis using search string B

data base	results
Scopus	16
Web of Science	3
IEEE Explore	34
Wiley Library	1
Google Scholar	52
total results	**102**
total results without duplicates	96
results after scanning title	16
results after scanning abstract	4
relevant results	**3**

Nevertheless, aspects of test scenario integration, e.g. through addition of test cases to existing scenarios, have been insufficiently considered. Moreover, the comparison between a surrounding scenario and the developed test scenario is not sufficiently considered. Given that changes in requirements can lead to changes in test cases, it is necessary to re-evaluate the test cases with regard to their integrability in different test scenarios. The following success criteria (SC) have been established for the purpose of evaluating the RQs:

(SC1) generate new test scenarios
(SC2) enriche existing test scenarios
(SC3) correlate surrounding scenarios
(SC4) consider changes of test cases
(SC5) combine test cases
(SC6) create combination premises
(SC7) model dependencies between test cases

4. Development of the method

As previously described in this paper, the method presented here adopts a comprehensive approach to the creation of test scenarios. In addition to conventional approaches to scenario generation, this paper will also examine the integration of test cases into test scenarios, their translation into surrounding scenarios, and the impact of test case changes or modifications. Based on the presented literature analysis and the practical relevance in the CREXADATA project, the method for test scenario generation and integration is developed. The method comprises four actions, which do not have to be successive, but can be used alternatively in the planning of V&V activities. The generic verification and validation process is shown in Fig. 1 below. At the beginning of the engineering process, customer needs are first identified. Based on customer needs, use cases, customer requirements and system requirements are derived. Test cases and test scenarios can support to validate fulfilment of customer needs or verify fulfilment of customer requirements and system requirements. The distinction here lies in test methods used in the respective test cases. While validation primarily utilizes test methods that engage stakeholders (e.g. System Usability Score [22]), verification employs test methods that can be used to verify the factual proof of requirements (e.g. Finite Element Method [23]). Test cases are derived from customer and system requirements. Test cases can be derived directly after the requirements were created. The earlier test cases are created, the earlier customers can be involved. The execution of individual test cases does not require the existence of test scenarios. The test cases created can then be combined to test scenarios. Test scenarios are required to test interdependencies between system elements, sub-systems or the overall system with each other or with the environment. For ease of use and to support the V&V engineer in the engineering process, the templates developed by Graessler et al. are suitable for creating and documenting test cases and test scenarios in the context of model-based planning to support the engineering of CPS [13]. Characteristics of the test case template are ID, name, test item(s), test procedure, system level, test case owner, detailed description (including environmental parameters, system state, users, input parameters, test case activities and expected results) and requirement reference(s) [13]. The test scenario template contains ID, name, test scenario owner, relevant test case IDs, test scenario activities and test scenario environmental parameters [13]. The next step after creation is to model test cases and test scenarios in the System Modelling Language according to the Model-Based Systems Engineering approach as described in [13] to ensure traceability between requirements, test cases and test scenarios. As described before combining test cases for generating test scenarios is only one technique to create test scenarios. The following Fig. 2 visualizes the developed method of test scenario creation for early customer involvement within this paper. The method consists of four alternative actions to create a test scenario for V&V which are described below:

The **first action** (“1” in Fig. 2) is combining test cases into a newly generated test scenario. Therefore, various techniques listed in the reviews in Chapter 3 can be used for this purpose. The previously presented definition and the test case template [13] can be used to combine test cases into pre-specified test scenarios. The aim when combining test cases is to combine test cases that are as homogeneous as possible in a sequence to form a test scenario. For this purpose, the attributes of the

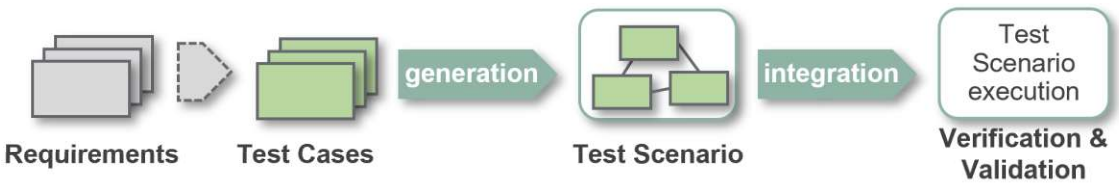

Fig. 1: Verification and Validation in engineering CPS

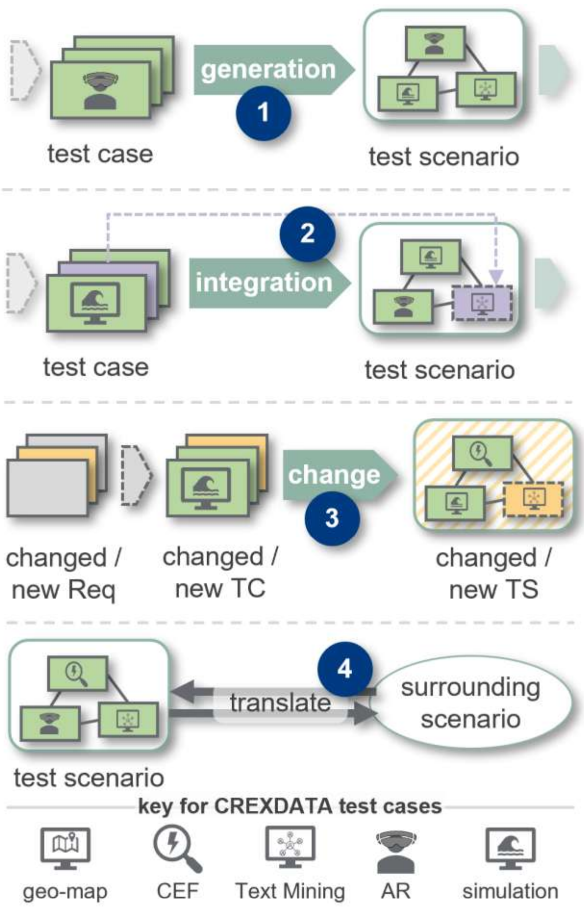

Fig. 2: Method for test scenario creation for early customer involvement

template can be used to identify similarities in the characteristics of different test cases. Not only are similarities to be considered, but also matching test cases can be combined into test scenarios: an output of one test case can be an input of another, and so this chaining of test cases in a series (parallel and/or sequential) can generate a test scenario.

The **second action** ("2" in Fig. 2) is integration of a test case into a pre-specified test scenario. The prerequisites for undertaking this action within the method are the existence of at least one test scenario and one test case that has not yet been assigned to a test scenario. Subsequently, the standalone test case is integrated into an existing test scenario. The test case is integrated into the test scenario in which the already integrated test cases exhibit the greatest similarity in terms of the attributes of characteristics with the test case to be integrated. During the process of integrating test cases into existing test scenarios, an evaluation is conducted to ascertain which test scenario sequence of existing test scenarios is the most suitable for the test case. In the event that the test case cannot be integrated into a pre-specified test scenario, it is necessary to determine whether test scenarios should be changed (as outlined in the following action three) or whether test scenarios should be divided into smaller test scenarios.

The **third action** ("3" in Fig. 2) is changing or even creating a new test scenario due to a test case change. In an iterative engineering process, changes often occur during the course of the project. Technical changes are unavoidable during the engineering process. Iterative engineering steps result in changes to the system requirements. A change to a system requirement therefore also requires a change to the associated test case, which has the objective of checking the underlaying requirement. Upon alteration of a test case that has already been incorporated into a test scenario, it is imperative to ascertain the extent to which the change to the test case affects the test scenario. In the case that changing the test case has no impact, no further action is required and the test scenario can be executed in the previously planned form. However, if the test case change has an impact on the test scenario, the test scenario must be adapted. There are two options for adapting the test scenario: (a) The changed test case remains consistent with the original test scenario, with only alterations to characteristics such as environmental parameters or the sequence of test cases. In this case, the test scenario is adapted to accommodate the changes. (b) Alternatively, the changed test case does not longer align with the original test scenario. In this instance, the existing test scenario is split, or a new one is generated with the changed test case (according to action 1).

The **fourth action** ("4" in Fig. 2) is the translation of a test scenario in a surrounding scenario. Surrounding scenario in this context describes a real scenario in practical application. Translation can take place in both directions. In the practical application of test scenarios, it is frequently the case that additional constraints must be taken into account when planning test cases and test scenarios. Economic factors frequently exert a decisive influence in this context. For instance, the reuse of test beds from previous engineering projects can help to avoid the costs associated with redesigning test beds and test environments. The most significant discrepancy between test scenario and surrounding scenario is often identified in environmental parameters. In consequence of the discrepancies in the attributes of the characteristics, it is necessary to translate test scenarios into surrounding scenarios and adapt environmental conditions of execution accordingly.

The method presented in this paper is also mapped to the V-model of VDI/VDE 2206:2021 [9] in context of Systems Engineering in order to demonstrate its general applicability in engineering CPS (see Fig. 3). Decomposition takes place on the left thigh of the V-model, while integration takes place on the right thigh [1, 24]. The method for test scenario creation for early customer involvement is executed by V&V engineers in the *planning of verification and validation* (arrow from left thigh to right thigh in V-model). Requirements Engineering is located in the left thigh. Test cases are derived from the requirements, which are used to create test scenarios. The test scenarios are then executed using test items to be verified and validated. The execution of test scenarios and test cases is located in *verification* and *validation* arrows, which run from the right thigh to the left. However, the execution of the V&V activities relates to the test item(s) on the right thigh of the V-model. Once the requirement(s) of test item(s) are verified by execution and assessment of test scenarios, verified test items can be integrated into the next higher system level up to the overall system on the right thigh of the V-model. The third action of the aforementioned method is triggered by requirements changes in the yellow strand of the V-model, which encompasses processes of requirements elicitation and requirements management.

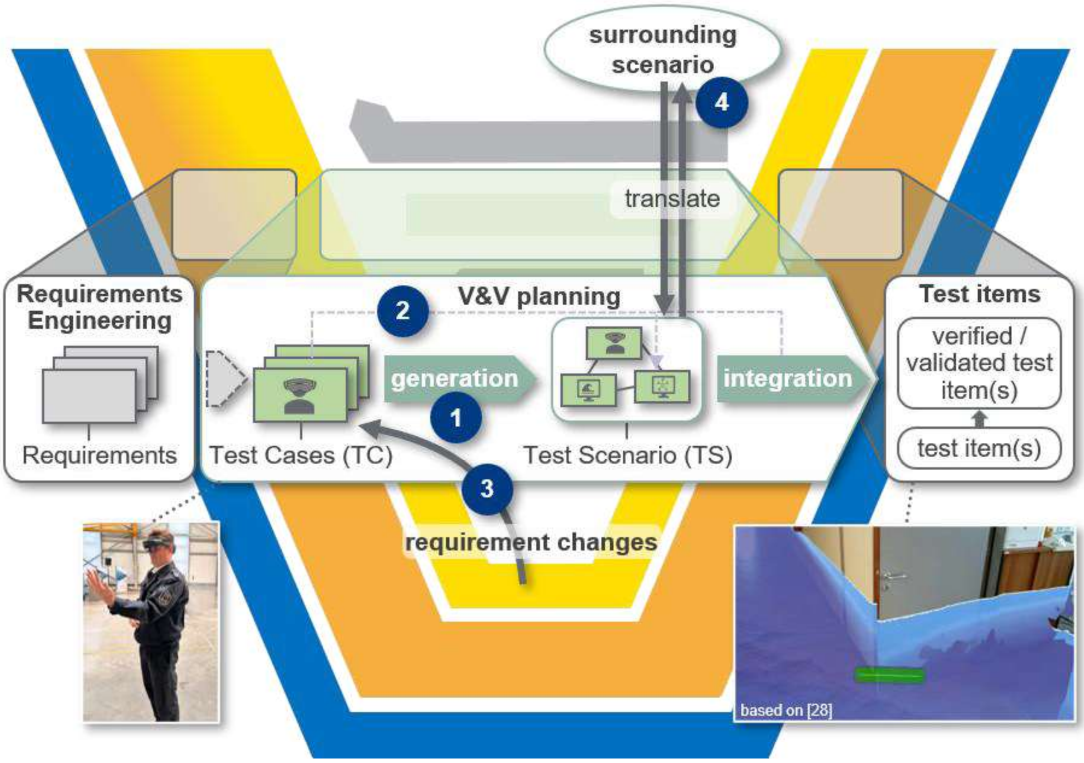

Fig. 3: Method mapped on V-model of VDI2206:2021

In order to assist the V&V engineer applying the method for test scenario creation for early customer involvement, a number of premises need to be considered when creating test scenarios. The catalogue of premises is divided into general premises and scenario specific premises. The general premises are:

- *free of contradiction:* Test cases contained in a test scenario must be free of contradictions.
- *feasibility:* Test scenarios must be feasible.
- *transferability:* Test scenarios must be able to transfer into surrounding scenarios.
- *consistency:* Test cases must be executed completely in test scenarios and cannot be split.
- *verifiability and measurability:* Test cases in test scenarios must be verifiable and measurable.

There may also be scenario-specific premises that need to be taken into account, e.g. time limits etc..

5. Validation

The method is applied as an application evaluation in the previously presented research project CREXDATA according to Design Research Methodology of Blessing and Chakrabarti [8]. The CREXDATA system is developed to link DS/AI technologies and process extreme data in emergency situations. Sample test cases were mentioned in the introduction and are combined into a test scenario according to the first action of the presented method. TC1 is dealing with the ARGOS system (developed in ANYWHERE project) as a geo-based multi-hazard early warning system for regional and national disasters [25]. TC2 is an algorithm for forecasting complex events and it is applied on data sets of a sewer network in order to identify complex events in various sensor data. TC3 deals with the AR visualization of flood management. Various components are taken into account: 3D water level, 3D/2D points of interest, 3D/2D routes and 2D areas [26]. TC4 analyzes social media posts and classifies postings according to relevance. Subsequently, relevant postings on media like images and videos are analyzed. CEF uses the outputs of the weather forecast visualization to predict where the sewer network will overflow first and how much rainfall will cause additional water to escape and accelerate the rise in water levels. This information can be used to calculate a route for emergency services by avoiding heavily affected areas. The outputs of TC2 are accordingly inputs (areas to avoid) for TC3, where a route to operation site for rescue forces is then visualized in AR. To get a better situational picture of the operation site, the TC4 is then used to identify postings in social media that show relevant media such as pictures or videos of the current situation using a text mining algorithm. Adding another test case in this existing scenario will follow the second action of the presented method. The test case to add is an urban flooding simulation (TC5). The urban flooding simulation is considering weather forecasts as input data in order to simulate the water distribution above the ground and providing input data for the AR application [27]. The third action of the method presented is triggered by requirement changes. Test cases will also need to be adapted based on changing requirements. The change to the requirement relates to TC3 for the application evaluation with the CREXDATA system. The original requirement is "*The water distribution should be visualized in augmented reality*". When the test case is carried out for the first time, it is noticeable that augmentation of water completely obscures the floor for emergency personnel wearing the AR device. The amended requirement is "*The water distribution should be visualized transparently in augmented reality*". Transparency enables users to see both augmented water level and to recognize possible dangers on the ground [28]. Changing the requirement implies a change to the test case. Nevertheless, the change to TC3 does not affect the test scenario, allowing the test scenario to be carried out in accordance with the original plan with a changed TC3. For the fourth action of the method presented, the existing test scenario is translated into a surrounding scenario. The surrounding scenario describes the real exercise scenario of a fire department into which the test scenario is integrated. In the fire department's large-scale exercise, an entire city district is considered. The urban flooding simulator in TC5 has an insufficiently large simulated area, necessitating an adjustment to this parameter for executing the test scenario in the surrounding scenario. The method demonstrates added value in systematic creation of test scenarios. The method presented was validated by an application evaluation in engineering CPS. It is transferable to other domains, such as production, to integrate the customer in the product or process design.

Through development of the method presented, success criteria set derived to answer research questions positively out in Chapter 3 are largely fulfilled. SC1-SC5 are completely fulfilled. SC6 is also fulfilled by considering general and scenario-specific premises. SC7 is only partially fulfilled in conjunction with the approach presented by Graessler et al. [13] which enables test cases and test scenarios to be modeled. Nevertheless, to be able to use the presented method completely model-based, surrounding scenarios would have to be modeled, which leads to extreme amount of additional work.

6. Conclusion

In this paper a method for test scenario creation addressing early customer involvement in engineering CPS is described. Based on a systematic literature analysis related work was identified and considered. For practical relevance, a method was developed that supports the V&V through four alternative actions in the creation of test scenarios. An application evaluation was successfully carried out as part of the European research project CREXDATA to assess the applicability of the developed approach. Results are considered initially as significant but statistical evaluation is not yet achieved. This will be addressed by extended settings in future work, targeting also the fundamental transferability of the approach to other domains, e.g. production processes. The automated creation of test scenarios according to the method presented in this paper is future work. To automate the presented method, a V&V information model is first required to use feedback information from executed test cases and test scenarios to assess customer and system requirements and customer needs.

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