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APPROACH FOR CLASSIFYING THE AUTOMATABILITY OF VERIFICATION AND VALIDATION TECHNIQUES

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ABSTRACT

Simulation is a proven method in industry and research to constitute the basis for further decisions. Therefore, the credibility of its results is of major importance. Generally, simulation studies are guided by procedure models comprised of several phases with specific results. To assess the credibility, verification and validation (V&V) is used by applying V&V techniques to these phase results, which requires significant effort. Additionally, the amount of processed data increases and there is a growing desire for real-time-adjustable models, increasing the effort required for V&V while reducing the time available. One way to address these challenges is to automate V&V. For this purpose, the paper transfers the notions of automation and associated automation levels to the domain of V&V in order to assess and classify the automatability of individual V&V techniques. The effort for application of V&V techniques can be reduced while keeping or increasing the credibility of simulation.

1 INTRODUCTION

The available data stock in industry and research is growing due to the development of IT processes and the networking of companies (Schelter et al. 2018; Steiner 2017; Tanase et al. 2018). The sheer amount of different types of data increases the degree of complexity of the data. Other aspects are, for example, the heterogeneous data sources and the speed at which data are generated and have to be processed. In this context, both simulation and verification and validation (V&V) techniques, among others, have more and more complex data available in a shorter time (Schelter et al. 2018). In addition, there is a growing desire for real-time analyses and short-term insights from the available data. This creates the need to integrate these data into the simulation at short notice. New challenges for the V&V of models and simulation arise from it, as V&V must be carried out in shorter time and associated with potentially more or increasingly complex data. The available data can be used in the development of models, which in turn generate output data. In addition, data are needed for V&V within the mentioned models. For example, in case of a large amount of complex data, a manual assessment by means of a desk checking is often not expedient, as the available data cannot be sufficiently analysed. This makes the choice of the V&V techniques to be used particularly important, also considering the cost-benefit ratio of a simulation (Law 2008; Wang 2013). The work of Huber and Wenzel (2011) indicates that V&V effort is increasing, showing user awareness of the importance of V&V. On the other hand, van der Valk et al. (2022) show that V&V is not explicitly mentioned in a large part of current simulation studies, leading to the suspicion that it was not very intensely performed. This can be explained by the effort required for V&V.

One possible approach to meet these challenges is to automate the V&V process. Automating V&V with a complex data basis can save time, increase confidence in the results of a simulation and, thus, in the decisions based on them. In order to realise the automation of V&V, first the V&V techniques performed

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during V&V must be automated. However, not all V&V techniques can be automated to the same extent. Criteria are needed to evaluate the automation potential of V&V techniques. However, no such criteria can be found in the literature, so a first approach has to be developed.

2 THEORETICAL BACKGROUND

In this section, the topics simulation, V&V, and automation are explained shortly with the aim to introduce the necessary basic elements for a first approach to evaluate the automatability of V&V techniques.

2.1 Simulation

Simulation is a widely used method in industry as well as in research for analysis, forecasting, or decision support (Banks 1998; Fleischmann et al. 2015; Kleijnen 2005; Kuhn and Wenzel 2008; Law 2015; Terzi and Cavalieri 2004). Further use cases can be found in Kuhn and Rabe (1998) and Rabe and Hellingrath (2001). In this context, simulation examines systems that either already exist in the considered form or systems that are purely theoretical (Law 2015). According to Deutsches Institut für Normung e.V. (2014), a system is defined as a “set of interrelated elements considered in a defined context as a whole and separated from their environment”. Especially when considering complex systems, it is often useful to represent them in the form of a model, which is a simplified representation of the real world (Banks 1998). In order to find solutions with the help of models, simulation can be used in case analytical solutions are not possible or their evaluation would take too much time (van der Valk et al. 2022). In the literature, there are a variety of definitions for the term simulation (Banks 1998; Law 2015). According to Shannon (1998), simulation includes “the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies for the operation of the system”. In the following, the definition of the VDI-Gesellschaft Produktion und Logistik (2014) of simulation is used: “Representation of a system with its dynamic processes in an experimentable model to reach findings, which are transferable to reality; in particular, the processes are developed over time”.

In addition, it must be taken into account that simulation is used to investigate certain questions, e. g., in simulation studies. However, due to their complexity, the implementation of simulation studies requires a structured and targeted approach. Therefore, procedure models can be used. Established procedure models include the procedure model presented by Sargent (2013), the model proposed by Balci (1998), and the procedure model proposed by VDI-Gesellschaft Produktion und Logistik (2014). When using procedure models, the respective purpose and scope of application must be taken into account. For example, V&V is particularly emphasized in the procedure models for simulation studies by Brade (2000) and Rabe et al. (2008b) (for a short English version see Rabe et al. 2008a), which is widely used in German-speaking countries. Thereby, V&V is treated in a general way rather than on the level of detail of individual V&V techniques.

2.2 Verification and Validation

V&V play a crucial role both in modelling and simulation and, thus, also in conducting simulation studies, as it increases the credibility of the results produced (Balci 1998). Other quality attributes considered, especially for the software of simulation, include usability, security, efficiency, and compatibility (Kumar and Syed 2011). Verification asks whether a model has been formed correctly, i.e., whether the accuracy of the representation of the system by the model is maintained when the model is transferred from one form to another (Allen et al. 2005). Validation analyses whether the right model was formed (Rabe et al. 2008b). In this context, “right” indicates whether the system under investigation was sufficiently well approximated (Allen et al. 2005). The distinction between verification and validation makes clear that V&V is not a single action, but it must be carried out continuously throughout the entire simulation study (Brade 2000; Sargent and Balci 2017; Wenzel et al. 2008).

To apply V&V, phase results from procedure models are examined using V&V techniques (Rabe et al. 2008b). A comprehensive overview of V&V techniques can be found in Balci (1998), Rabe et al. (2008b) and Roungas et al. (2018). The authors also classify V&V techniques based on their characteristics. Balci (1998) distinguishes the four categories formal, informal, static, and dynamic, while Rabe et al. (2008b) evaluate V&V techniques in terms of their degree of objectivity. Additionally, both Balci and Rabe et al. highlight that not every V&V technique is applicable in every phase of a simulation study and state which V&V techniques are applicable in which phase. However, there are currently no approaches in which V&V techniques are evaluated or grouped with respect to their automatability. This new dimension for V&V is, therefore, added by the authors, so that practitioners can incorporate it into their decision making about how to implement V&V.

When looking at the procedure model proposed by Rabe et al. (2008a), which became part of the guidelines of VDI-Gesellschaft Produktion und Logistik (2014) (Figure 1), two strands can be identified. These can be described as strands of model development and data consideration. Furthermore, an explicit phase result is named for each phase. Thus, a direct integration of V&V into the procedure model is possible. In addition, the continuous character of the V&V becomes clear, because there are no separate phases for V&V. Instead, V&V is arranged along the whole simulation study shown in form of the right rectangle. In this context, no phase result is excluded from V&V. This applies, e.g., to raw data, to the concept model, as well as to the simulation results. Each phase result has to be validated and verified before continuing with the next phase. This leads to an iterative character of development, which can be very time-consuming.

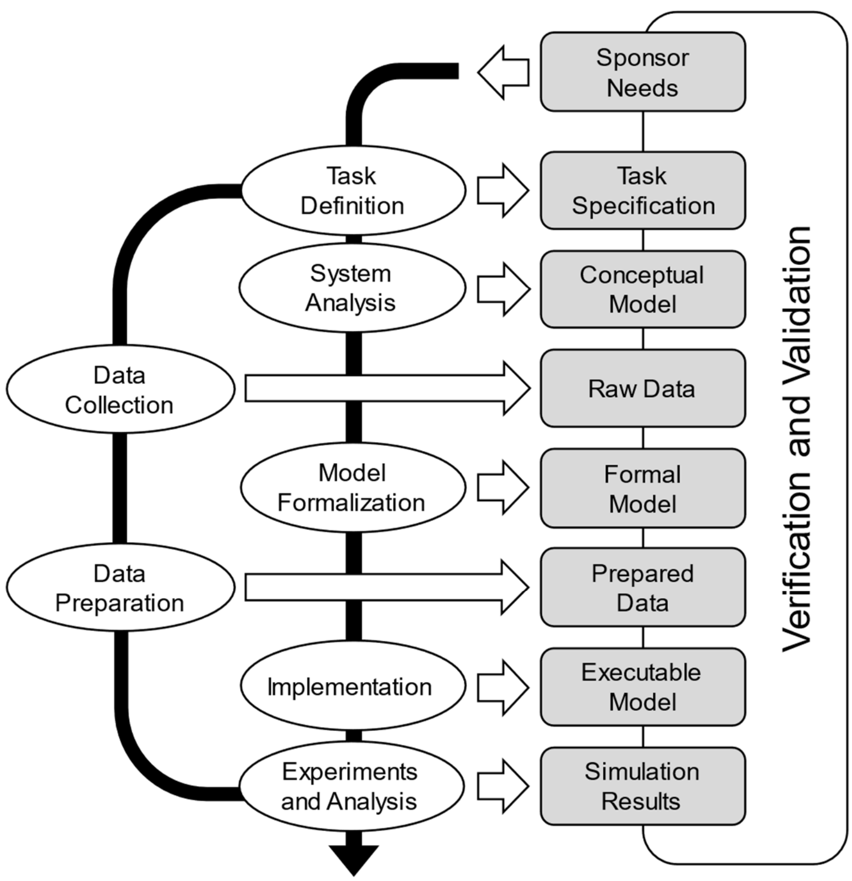

Figure 1: Procedure model for simulation studies with an emphasis on V&V (Rabe et al. 2008a).

2.3 Automation

To optimize time-consuming and labor-intensive processes, automation can be used. Automation can be found in a wide variety of application domains, e. g., process automation (Chakraborti et al. 2020), control of manufacturing processes (Frohm et al. 2008), or automated test cases in software development (Asfaw 2015). Automation can, therefore, take place in combination with physical systems, but also without them. The term automatic refers to "a process or equipment that, under specified conditions, functions without human intervention" (Deutsches Institut für Normung e.V. 2014). By including processes in the definition, it becomes clear that the definition is also applicable to the process of V&V and, therefore, the advantages of automation could be used.

The concept of automation is not to be seen as binary, but gradations are possible. Examples of such gradations can be found in Sheridan (1980) and Endsley and Kaber (1999). Both classifications have in common that they divide the distribution of tasks between humans and computers into levels of automation. Thus, a distinction is made between task areas that are either processed by humans only, by computers only, or by both together. Endsley and Kaber (1999) distinguish between the four areas of monitoring, generation, selection, and implementation, while Sheridan differentiates between the three areas of execution, analysis, and decision. Overlaps can be found in the individual areas. For the application of automation to V&V, however, the divisions according to Sheridan seem more appropriate, since V&V techniques must be carried out, the resulting input must be analyzed, and a decision must be made based on this.

Sheridan (1980) defines ten levels of automation in the domain of control and information processing shown in Table 1. Due to the descriptive representation of the individual levels and a related application domain, the automation levels according to Sheridan are suitable for transfer to the V&V domain.

Table 1: Levels of automation in the domain of control and information processing (Sheridan 1980).

Level of automation	Description
1	Human considers alternatives, makes and implements decision.
2	Computer offers a set of alternatives which human may ignore in making decision.
3	Computer offers a restricted set of alternatives, and human decides which to implement.
4	Computer offers a restricted set of alternatives and suggests one, but human still makes and implements final decision.
5	Computer offers a restricted set of alternatives and suggests one, which it will implement if human approve.
6	Computer makes decision but gives human option to veto prior to implementation.
7	Computer makes and implements decision but must inform human after the fact.
8	Computer makes and implements decision and informs human only if asked to.
9	Computer makes and implements decision and informs human only if it feels this is warranted.
10	Computer makes and implements decision if it feels it should and informs human only if it feels this is warranted.

3 SUITABILITY OF VERIFICATION AND VALIDATION TECHNIQUES FOR AUTOMATION

Levels of Automation for V&V techniques are elaborated in this section. As a first step, it is necessary to take a uniform view of V&V techniques and the inputs required to implement the V&V techniques to create a basis for a classification. This approach offers the possibility to assess V&V techniques in general, based on the required input regarding their automatability.

3.1 Uniform Description of V&V Techniques

In order to be able to assess the automation potential of V&V techniques, it is first necessary to take a uniform view of the multitude of different V&V techniques. A V&V technique can be regarded as a black box (Figure 2), regardless of its concrete implementation. This suggests that the processing of the input is the essential process within a V&V technique and, therefore, the automatability of the processing of the input determines the automatability of the entire V&V technique. In such a black box, four different inputs are processed according to the rules of the respective V&V technique and, hence, generate an output. The generated output is the result of the V&V technique, i. e., whether the validation or verification of the considered phase was successful with the chosen V&V technique. Thereby, phase results from the procedure model are checked by V&V techniques (Input 1). Thus, phase results are a necessary input for any V&V technique. In addition, technique-specific inputs are needed. When considering V&V techniques, a distinction must be made between the application of the V&V technique and its evaluation. In addition to the phase result (Input 1), depending on the V&V technique that is used, additional input is required (Input 2). This can be, for example, data for comparison with simulation results. Consequently, Input 1 and Input 2 must both be available to enable the application of the V&V technique.

The result of the application of the V&V technique is the specific output of the applied V&V technique. This output is required to perform the evaluation of the V&V technique and is, therefore, also to be considered as a specific input (Input 3). Again, additional input may be required (Input 4). A typical example for the evaluation of a V&V technique is an expert who evaluates the output of the application of the V&V technique. Like Input 1 and 2, Input 3 and 4 must also be available at the same time for an evaluation to take place. The gained output is the result of the V&V technique. Based on this result, the further course of the simulation study can be decided.

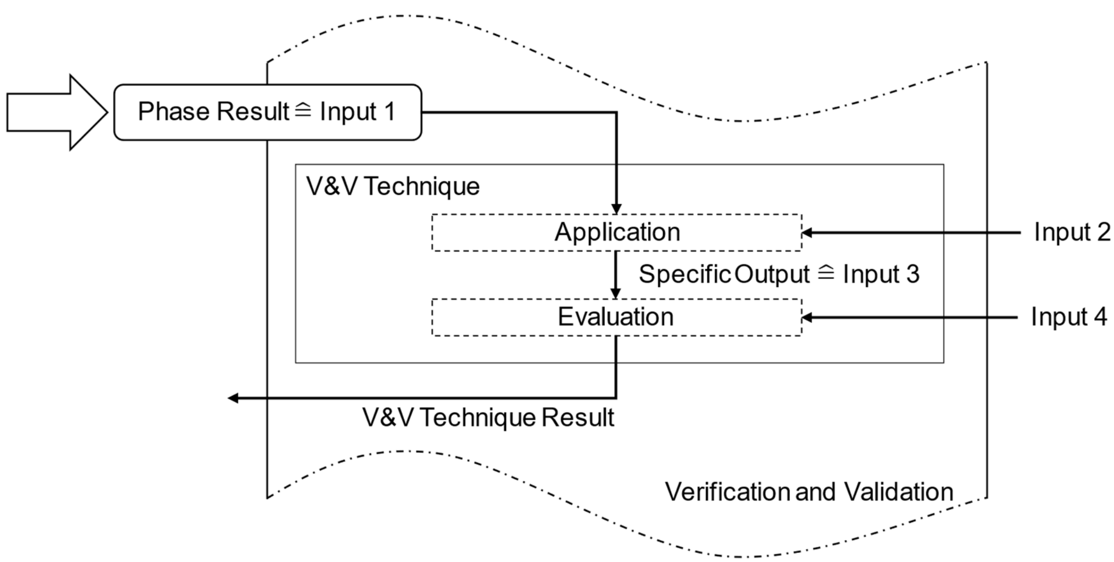

Figure 2: Consideration of a V&V technique as a black box taking into account its input.

3.2 Input Types

Looking at V&V techniques as a black box shows that different inputs need to be considered. For this reason, combined with the fact that this input has to be processed, the input for V&V techniques needs to be looked at more closely. The considered phase results (Input 1) originate from the execution of procedure models. Thus, by considering the procedure model proposed by Rabe et al. (2008a), different inputs can be identified such as raw data, formal model, or simulation results (see Figure 1). Furthermore, there are more possible inputs for Input 2–4 like expert knowledge. To get a better overview and to be able to make a classification of inputs, as a step towards evaluating their automatic processing, input types were identified. The input types are document, model, data, human, and graphics. However, this classification is not yet sufficiently finegranular. This becomes clear when looking at the input type models. In the procedure model presented by Rabe et al. (2008b), for example, there are three different types of models: a conceptual model, a formalized model, and an executable model (see Figure 1). Automatic processing is possible to very different degrees for these types of models. Thus, a further subdivision is necessary within the different input types. This is achieved by specifications within a type. Taking the input type model as an example, the specifications are distinguished between non-formalized, formalized (not computerized), and formalized (computerized). In the following, the identified input types and the associated specifications are briefly explained and assessed in terms of their automatic processability.

Documents can have three different specifications. First, they can be unstructured. This may include, for example, initial collections of ideas for the model. Unstructured documents are readable and interpretable by humans, but difficult for computers to process, because there is no given internal structure. Furthermore, documents can be in a structured state. With the help of, e. g., the eXtensible Markup Language, such documents can be processed by the computer. The existing structure in the document enables automated processing. A mixture of structured and non-structured documents is also possible. In this case, some structures are predefined in the document, but can be supplemented by informal text. In such a case, automated processing is primarily limited to the structured parts. The attractiveness of such documents lies in the possibility of also being able to record individual comments and ideas that cannot be integrated into a fixed schema.

Models appear in different stages of development in a simulation study (see Figure 1). For automated processing, it is important whether the model is a formalized model. Formalized models follow defined rules in their representation. Thus, the relationships and processes represented in the models can be run through automatically. A restriction arises, however, for models that are not computerized. In such a case, transfer work is necessary first. Thus, the automation potential is to be classified as medium. Non-formalized models are not subject to any rules in their representation and creation. This provides capabilities, especially at the beginning of a simulation study, to implement ideas and structural approaches. However, such models can basically not be validated automatically.

The processing of *Data* has a high potential for automation. However, data quality must always be taken into account when dealing with data and, in this context, data preparation. Data can be used for different purposes in V&V. These include, for example, data that are used for comparison with generated simulation data or key performance indicators that provide the basis for the evaluation of V&V technique output. Such key performance indicators sometimes require expert knowledge, since in some cases they have to be adapted to the individual requirements of the system to be mapped or to the simulation model. If such adjustments must be made, the automation potential can be classified as medium.

Human beings, with their knowledge, represent an essential component of many V&V techniques. Experts from different fields can contribute their knowledge to the process of performing and evaluating V&V techniques. Since human knowledge mainly comes from their experience, such knowledge cannot be passed on to the computer automatically without further action. However, if the same knowledge is always needed, a partial automation of the knowledge transfer can be performed by filling in a pre-structured document. This document can in turn be processed automatically (see input type Document). However, if different knowledge is required that cannot be clearly defined in advance, a process step that requires that knowledge cannot be automated. The same applies if communication with or among experts is required in order to draw conclusions. If part of a V&V technology is dependent on the personal assessment or opinion of an expert, this cannot be automated.

Graphics comprise numerous visualization possibilities, especially of outputs. Their interpretation can be automated to varying degrees. Graphics with a known structure or known properties have a higher automation potential than freely designed graphics, since additional partly intuitive or experience-based knowledge is required. Thus, the interpretation of formalized diagrams such as Pareto diagrams that can,

e. g., be used as basis for discussions have a high automation potential, because the underlying data can be used, while individually created infographics tend to have a medium automation potential.

3.3 Levels of Automation

In order to classify V&V techniques with respect to their automatability using the identified input types and specifications, classification possibilities have to be worked out. For this purpose, the levels of automation proposed by Sheridan (1980) presented in Section 2.3 are applied to the domain of V&V. The three areas whose execution can be handled by humans, computers, or both together are adopted by Sheridan with slight adjustments. Characteristic elements of execution, analysis, and decision can also be found in V&V techniques. Furthermore, V&V techniques can be divided into application and evaluation as shown in Figure 2. Execution is the primary processing of the inputs and the application of the rules of the V&V technique in its application. Evaluation is the analysis of the technique's output. On the basis of the analysis, a decision is made whether the verification or validation was successful. Based on this subdivision, the ten existing levels of automation presented by Sheridan (1980) are transferred to four levels of automation for V&V techniques. The aggregation enables an initial and clear classification of V&V techniques with regard to their automation potential. These considerations lead to the following *Levels of Automation*:

Level 1: There is no form of automation of a V&V technique, in the area of input, implementation, or evaluation of the output. This corresponds to Automation Level 1 by Sheridan (1980), because only the human is involved.

Levels 2 to 4 according to Sheridan (1980) are not considered in detail, since in these levels the computer does not perform any executive and decisive tasks, which should be a focus in the automation of V&V techniques.

Level 2: Individual steps in the respective processing of input, application, and evaluation must be confirmed by a human. Steps that cannot be automated are carried out by a human. When evaluating the output of the V&V technique, suggestions for evaluation are presented by the computer as far as possible. The final decision is made by a human. For techniques to be classified in this level, the steps that can be automated must predominate. This corresponds to Automation Level 5 and 6 by Sheridan (1980), because the confirmation by the human being is emphasized, the focus of the execution is on the computer, and also (as large as possible) parts of the analysis are to be handed over to the computer.

Level 3: Processing of inputs is automatic after an (as formalized as possible) knowledge transfer. Intermediate results are presented to the human after the application of the V&V technique or after the evaluation of the output of the V&V technique. Additionally, adjustments can be made at these points. This replaces the confirmation of each step from Level 2. When evaluating the output of the V&V technique, prioritized suggestions are presented by the computer for evaluation. The final decision is made by a human. Thus, the execution and evaluation of V&V techniques at this level are predominantly automatic. This corresponds to Automation Level 7 and 8 by Sheridan (1980), because the human has a controlling main function to ensure the transparency of the implementation of the V&V technique, and the computer is responsible for the main parts of both application and evaluation including input processing and analysis.

Level 4: There is complete automation of a V&V technique. Both the processing of all inputs in the V&V technique and the evaluation of all outputs with subsequent assessment take place automatically. Finally, a result is presented to the human. The steps carried out are documented. This corresponds to Automation Level 9 and 10 by Sheridan (1980), because the computer takes care of all necessary actions. A difference between the developed automation levels and the levels according to Sheridan (1980) is that the computer must inform about the final result, because the further process of the procedure model is based on the result of the V&V technique.

By combining the classification of input types with their specifications and the derived Levels of Automation for V&V techniques, inputs can be assessed with respect to their applicability in the different Levels of Automation. These considerations are summarized in Table 2. For example, not formalized models can be inputs of V&V techniques that are assigned to Automation Level 1, whereas formalized (and computerized) models can occur in V&V techniques with any level of automation.

In order to fully evaluate a V&V technique with regard to its automation capability, all inputs must first be determined and classified with the help of Table 2. Subsequently, the V&V technique can be classified with respect to the Automation Levels:

- In Level 4, all inputs have an input type and a specification that are applicable in Automation Level 4.
- In Level 3, all inputs have an input type and a specification that are at least applicable at Automation Level 3, but not all are applicable at Level 4.
- In Level 2, some inputs have an input type and a specification that are only applicable in Automation Level 1, but the inputs that would also be applicable in Automation Levels 2–4 predominate.
- In Level 1, inputs predominantly have an input type and a specification that are only applicable in Automation Level 1.

Table 2: Proposed classification of input for V&V techniques.

Input Type	Specification	Applicability up to
Document	structured	Level 4
	unstructured	Level 1
	semi-structured	Level 3
Model	not formalized	Level 1
	formalized (not computerized)	Level 3
	formalized (computerized)	Level 4
Data	reference data	Level 4
	key value (in general)	Level 4
	key value (adapted)	Level 3
Human	formalized knowledge transfer	Level 3
	semi-formalized knowledge transfer	Level 3
	communication-based	Level 1
	estimation	Level 1
Graphics	diagram (formalized)	Level 4
	infographic	Level 3
	graph	Level 4

3.4 Exemplary Evaluation of a Verification and Validation Techique

To demonstrate the classification of a V&V technique, Face Validation is considered as an example in the following. Face Validation can be used during an entire simulation study, in this exemplary evaluation the validation of result data of a simulation will be considered. Table 3 lists the inputs required for Face Validation and their applicability according to Table 2.

Based on the criteria presented in Section 3.3, Face Validation can only be classified as Level 2 or Level 1 because inputs are involved which are neither applicable in Level 4 nor 3. The main difference between these two levels is the proportion of automated inputs. Since four out of eight inputs in Face Validation cannot be automated, the automation level does not predominate and the V&V technique must be assigned to Level 1. This is especially true considering the fact that the main aspect of Face Validation is communication between humans. Such communication cannot be automated.

Table 3: Evaluation of input for Face Validation.

Input	Input Type with Specification	Applicability up to
Simulated Data (as Phase Result)	Data – reference data	Level 4
Domain Expert	Human – communication-based, estimation	Level 1
Simulation Expert	Human – communication-based, estimation	Level 1
Historical Real Data	Data – reference data	Level 4
Project Documentation	Document – semi-structured	Level 3
Questionnaire	Document – semi-structured	Level 3
Notes for Explanation	Document – unstructured	Level 1
Notes for Documentation	Document – unstructured	Level 1

4 CONCLUSION AND OUTLOOK

This paper has presented a first approach to evaluate V&V techniques with respect to their automatability. Therefore, the concept of automation was transferred to the domain of V&V, and levels of automation for V&V techniques were developed. For this purpose, the basics of simulation and V&V as well as automation were briefly discussed. Furthermore, the input required for V&V techniques was divided into different types with specifications. This was necessary to be able to assign V&V techniques to automation levels based on their input. These automation levels were derived from existing automation levels to ensure that all relevant aspects of automation were considered.

By the developed classification possibilities of V&V techniques regarding their automatability in automation levels, the user is supported to accomplish a high-quality V&V with reasonable expenses. The conservative design of the choice of automation levels ensures that the automation capability of V&V techniques is not overestimated. The evaluation of already existing as well as newly developed V&V techniques with different characteristics is possible. In order to verify the evaluation and an automated application of V&V techniques, it is planned that these are tested with industrial partners under consideration of different use cases.

The future goal is also to develop an overview of the automatability of established V&V techniques. By applying V&V techniques in use cases, information will also be collected to derive a finer classification of automation levels. This should enable a better assessment of the automatability of the V&V techniques. The evaluability of V&V techniques with regard to their automatability is a first step towards a possible automation of the entire V&V process. The next step is to develop a tool that supports users in the selection and implementation of V&V techniques.

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