

A NEW PROCEDURE MODEL FOR VERIFICATION AND VALIDATION IN PRODUCTION AND LOGISTICS SIMULATION

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ABSTRACT

Verification & Validation of simulation models and results has been strongly investigated in the context of defence applications. Significantly less substantial work can be found for applications for production and logistics, which is surprising when taking into account the massive impact that wrong or inadequate simulation results can have on strategic and investment-related decisions for large production and logistics systems. The authors have, therefore, founded an expert group for this specific topic in the year 2003, which has analysed the existing material and then developed proposals for definitions, overviews on existing V&V techniques, practical hints for the documentation of the procedural steps within a simulation study, and a specific procedure model for V&V in the context of simulation for production and logistics. The results of this working group are available as a textbook, in German. This paper summarises major results.

1 INTRODUCTION

Simulation is an established analysis method for production and logistic purposes. It is frequently used when decisions with high risks have to be taken, and the consequences of such decisions are not directly visible, or no suitable analytical solutions are available. This, however, implicates that correctness and suitability of the simulation results are of utmost importance. Wrong simulation results, translated into wrong decision proposals which are then implemented, can imply cost that are by orders of magnitude higher than the total cost of the simulation study. This illustrates the relevance of verification and validation (V&V) within simulation studies in this application domain.

According to the differentiation of the terms verification and validation in the literature, the authors associate verification with the question "Are we creating the X right?" and validation with the question "Are we creating the right X?" (cp. Balci 2003). Verification does not prove the correctness of the model, but the *correctness*

of the transformation from one modelling phase into another one. Validation in contrast aims to analyse the suitability of the model related to the given task and the sufficiently accurate modelling of the system under consideration. For both – correctness and suitability – it is characteristic that they cannot be completely proven. Therefore, the goal of V&V is not the complete and formal proof of the model validity, but the estimation of its credibility. According to Carson (1989) a model is credible, if the sponsor accepts it as appropriate for his or her decisions based on this model.

As credibility is a question of acceptance, it depends on the specific persons involved. This underlines the subjective character of V&V. The aim should be to provide a systematic for this decision of acceptance, and to document it in a readable and transparent way.

Only by a systematic approach and by structuring into single, directly usable sub-tasks with specific V&V techniques, V&V can be managed. Just taking the final results of a simulation study into account is a very tight limitation for V&V. Therefore, a procedure model is required that defines V&V-related activities for each single modelling step and its results.

2 RELATED WORK

There have been numerous research efforts related to procedure models, V&V, and simulation. This chapter gives an overview on some literature in the field. However, it starts with some remarks on the differences between simulation procedure models and V&V procedure models.

2.1 Classes of Related Procedure Models

For an analysis of the related work, different classes of procedure models have been investigated: Most frequently *procedure models for simulation studies* are to be found, which to a different degree contain elements for V&V. The focus of these procedure models is to provide guidelines for the professional performance of simulation studies. This kind of procedure models assigns quite different

levels of relevance to V&V, measured in the weight given to V&V in the description of the model.

Procedure models for V&V, in contrast, are meant to guide a professional performance of V&V activities within a simulation study, i.e. they describe the activities to be conducted for V&V as well as the relationship of the activities to the procedure model for the simulation study. Obviously, both procedure models are important, have interdependencies and should be related. This research field has been influenced significantly by Sargent (1982), with many other researchers to follow. The importance of Sargent's work has been acknowledged by awarding the status of a "landmark paper" at the Winter Simulation Conference 2007.

The general context of V&V is, however, much broader than the application domain of simulation in production and logistics, that is the focus of this paper. Procedure models for V&V are of high importance in the domain of simulation for defence (cp. Brade 2003). Furthermore, other scientific disciplines have developed procedure models that relate to V&V activities, e.g. management science and, especially, computer science. Some of these approaches, e.g. the V-model XT originating from software engineering research, have a significant relevance for the development of simulation models.

Obviously, it is neither possible nor the purpose of this paper to fully review all the procedure models that have one of the relationships given above to the topic of this paper. Therefore, some selected literature is shortly discussed, trying to cover at least the major approaches with the most dense relationship to this paper. A more detailed presentation of the different models is provided by Rabe et al. (2008).

2.2 Procedure Models for Simulation

A significant number of procedure models for simulation have been published and can today be found in textbooks (cp. Banks et al. 2005; Law 2007; Hoover und Perry 1990) as well as in guidelines (cp. USGAO 1979; VDI 2008). The scope and the level of complexity of these models is quite heterogeneous. However, at least the following five elements can be found (sometimes using different terms) in nearly all of the models (Banks et al. 1988):

- Initialisation Phase, defining the problem and its feasibility
- Plan for attacking the problem
- Detailed Design, consisting of the actual computer code
- Testing
- Operation and Maintenance

These models show major differences in addressing V&V activities within the proposed procedure. However, independently of the different complexity and content they

typically just name V&V as an essential part of the procedure. Thus, they underline the *relevance* of V&V, but they do not guide the *execution* of V&V activities.

2.3 Procedure Models for V&V in the Simulation Domain

The focus of procedure models for V&V is on providing guidance for a professional V&V process. For this purpose, a consistent procedure that is related to the procedure model for simulation is of utmost relevance.

Several procedure models for V&V can be found in the literature. Furthermore, there are several papers giving an overview on V&V techniques. As these techniques are not in the focus of this paper, the interested reader is encouraged to study the paper from Balci (1998), which gives a very broad overview on techniques. For an overview on the use of such techniques for different phases of the simulation study, hints can be found in Balci (1998a) and Rabe et al. (2008).

As one of the first systematic approaches, Naylor und Finger (1967) propose in a first step to formulate the assumptions on the real system under consideration, in a second step to test these assumptions intrinsically (e.g. for consistency), and in a third step – which then requires the existence of an executable model – to analyse the model's behaviour with respect to the assumptions. In contrast to this general and qualitative approach, Gass (1977) proposes to rate the steps of the modelling process quantitatively on a given scale (without proposing a specific set of such steps). From these ratings, a confidence level can be calculated for the overall model. The disadvantage of this approach is that it pretends objectivity, whereas the base of the calculation are subjective estimations which do not follow any systematic scheme (cp. Sargent 1996).

An approach that names criteria for V&V was provided by the General Accounting Office (USGAO 1979). These criteria include documentation, theoretical validity (concerning the validity of the conceptual model), data validity, operational validity (concerning the validity of the executable model), model verification, ease of maintenance, and usability. A quite similar approach with slightly different terms was proposed by Sargent (1982).

In the 1980s and 1990s, especially the Department of Defense (DoD) with its Defense Modeling and Simulation Office (DMSO) has driven major activities in the V&V domain (cp. Balci et al. 2002; Brade 2003; Davis 1992). In this context, the V&V process is part of a general problem solving approach, which comprises the procedure model for simulation as well as a process for accreditation (DMSO 2007). For each process element recommended practises are given as a guideline (DMSO 2007a). Similar research towards a generic V&V process in the defence domain can be found in Europe. In the year 2004, first

efforts have been started to harmonize these approaches, internationally (cp. Brade et al. 2005).

A procedure model that has significantly influenced the work of the authors resulting in the V&V procedure model described in chapter 4 of this paper, was presented by Brade (2003), defining a stepwise procedure for the V&V of models and simulation results. It is based on a simulation procedure with explicit intermediate results, which are the input for the next phase. The main idea behind Brade's approach is that the result of each phase has to be considered, intrinsically, with respect to the directly preceding phase, but also with respect to *all* preceding phases. Thus, the number of such relations grows with each phase of the modelling process, leading to some kind of triangle (fig. 1). Because of its strong relationship to the intermediate results, this model requires a very careful documentation of each result. Consequently, a clear definition of the type and level of detail of the documentation within each of the proposed phases is needed.

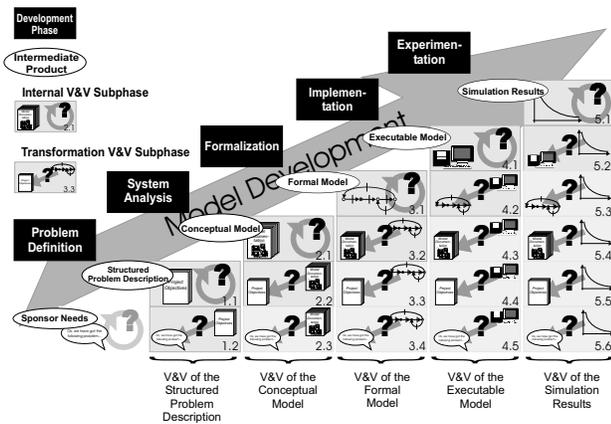


Figure 1: Procedure Model for V&V (Brade 2003)

Comparing the approaches mentioned above, it becomes obvious that the point of view and the level of detail are very different. Approaches like the one by DMSO are meta models that propose a general procedure for the V&V process. The other models suggest specific procedures, which then differ in their scope and content. All models have not been designed for applications in production and logistics, at least not specifically.

2.4 Models Related to V&V from other Domains

Simulation for production and logistics is an interdisciplinary research field, covering aspects of operations research, mathematics, statistics, computer science, and engineering. Most of these disciplines consider to some extent questions of verification and validation of their applications, techniques, and models. Thus, it is necessary and consequent to study, if results from these domains are

useful for the simulation in production and logistics, too. However, only a short insight can be provided here (for more details cp. Rabe et al. 2008).

Operations Research (OR) is an obvious candidate for related disciplines, as simulation is sometimes considered to be an area of research within OR. Examples can be found in Landry und Oral (1993), which show high similarities with the procedure models given above.

Computer science provides a number of models for software development. An early approach was the waterfall model (Benington 1956), which defines the software development process as a sequential process with well-defined steps. The V-model of Boehm (1979) amended the (since then improved) model by aspects of V&V, attaching V&V steps to the activities of the development process. This model has a specific importance in Germany, as it was refined in several steps to the so-called V-model XT. The application of the V-model XT is today mandatory for software development for public authorities in Germany. A comparison of this model with the procedures for modelling and simulation shows that there are structural similarities, but there is no representation of specific simulation-related tasks (e.g., model formalisation, simulation experiments, etc.) in the V-model XT (Bel Haj Saad et al. 2005). Therefore, Bel Haj Saad et al. propose an extension of the V-model XT which allow for its application for simulation purposes.

2.5 Conclusions from Related Work

The overview on the discussed procedure models shows many similarities, but also significant differences. All procedure models for simulation comprise similar basic steps of a simulation study, and consider V&V as a necessary activity. However, the consideration of V&V can range from just naming the relevance to detailed procedure models. The authors of this paper are convinced that verification and validation must accompany the whole simulation project, leading to the following basic requirements for a valid procedure model for V&V:

- Formulation of a Simulation Procedure Model, defining the phases of a simulation study as reference points
- Definition of results that have to be elaborated within the specific phases ("Phase Results")
- Formulation of a V&V Procedure Model that supports the execution of V&V

In the chapter 3, first a Simulation Procedure Model with the Phase Results is defined. Continuing on this ground, a V&V Procedure Model is defined in chapter 4.

3 PROCEDURE MODEL OF SIMULATION WITH V&V

In order to be able to propose a procedure for V&V, it is a prerequisite to understand the position of V&V within the procedure that is applied for simulation. The authors propose a suitable procedure model for simulation including V&V (fig. 2), based on a guideline of the German engineers' association VDI (VDI 2008).

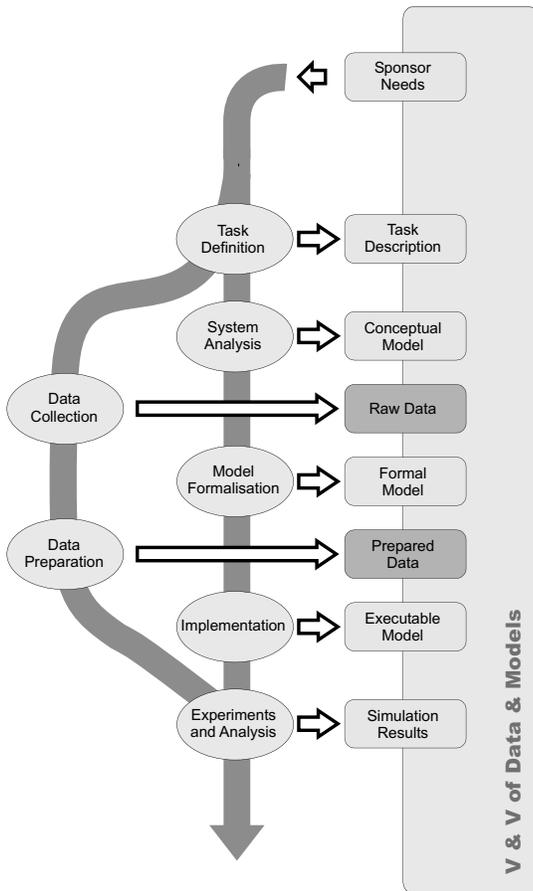


Figure 2: Procedure model for simulation including V&V (cp. Rabe et al. 2008)

Starting from the Sponsor Needs, this procedure model considers only tasks that normally occur after the acceptance of the task and cost plan for a simulation study, not distinguishing between external and internal service providers. Therefore, the proposed procedure starts with the Task Definition, which is considered to be the first analysis step within a simulation study.

The proposed procedure model is characterised by the consequent definition of intermediate results, and the separate paths for models and data. The procedure of the model path is structured into Task Definition, System Analysis, Model Formalisation, Implementation, and finally Experiments and Analysis (ellipses in fig. 2).

A *Phase Result* is assigned to each phase (rectangles in fig. 2). Phase Results can be models, documents, or a combination of both. In the following, for simplification the term document is used for the Phase Results in general. The document “Sponsor Needs” is no Phase Result, but the base for starting the simulation study.

The phases Data Collection and Data Preparation (with the results Raw Data and Prepared Data) are intentionally defined in a second path, as they can be handled in parallel with respect to content, time, and involved persons. Therefore, the graphical arrangement of Raw Data does not indicate that they can only become available after the conceptual model. Raw Data does not need to be completely collected before the elaboration of the Formal Model. The same applies to the Prepared Data, analogously. The procedure model just defines that Data Preparation requires Data Collection to be done, and that for the use of the Executable Model the Prepared Data have to be available.

V&V has to be conducted *during all phases of the modelling process* (Banks 1988). Therefore, the procedure model does not contain a special phase “V&V”. But, V&V – both of the data and the models – is *arranged along the whole simulation study* (see the rectangle on the right of fig. 2). Even the Document “Sponsor Needs”, whose development is not subject of the simulation study, should be validated before starting the Task Definition, with respect to consistency and structural completeness.

Thus, V&V is not at all a task that is conducted at the end of a project. Especially, it should never be considered as a procedure that is iterated after the implementation until the model seems to operate, correctly. In contrast, V&V has to accompany the simulation project from the start until the very end, and specific V&V Activities are indispensable within each single phase of the modelling process.

Similarly, V&V may (and should) not be applied only at the end of a modelling phase. When a suitable, comprehensive intermediate status has been achieved, the results should be validated, immediately, in order to detect faults, early, and to limit the implications of such faults on the further effort for modelling.

Verification and Validation imply tests, which in turn require a subject of testing. Therefore, V&V is always performed with the *results* of a modelling phase. In the procedure model this is indicated by arranging the “V&V of data and models” along the documents which are the Phase Results (fig. 2). Thus, a careful documentation of these results is an important prerequisite for a consequent application of V&V. Even in those cases where the test is conducted with a running computer model (e.g., supported by animation), the assumptions and preconditions must be available as a document, allowing for the systematic check if the model is compliant with this description.

According to this high importance of the Phase Results, the authors propose a generic document structure for each of the Phase Results, which are published in Rabe et al. (2008). According to the limited space available, these document structures are only summarized here. Table 1 shows the highest level of these structures.

From table 1 it is obvious that several headlines appear in similar form in more than one Phase Result, especially in the “core modelling” area of conceptual, formal, and executable model. This does not mean that the documents should have the same content, but it mirrors the evolution of the models from the concept to the full executable status. Differences between these descriptions occur on the detailed level, as described by Rabe et al. (2008).

4 PROCEDURE MODEL FOR V&V

Based on the procedure model for simulation in production and logistics including V&V (fig. 2), the procedure for the V&V itself can be defined. The considerations given in the previous chapter already imply that this procedure model for V&V must support all phases of the simulation procedure model. In addition, the procedure model should list and structure the single steps that are necessary for V&V, and provide guidelines for the execution of these steps.

In general, at each point of time during a simulation project all documents and models can be analysed with respect to all other documents and models that have previously been created. This approach, however, will in most cases be neither acceptable in terms of time consumption, nor economically feasible. On the other hand, the execution of activities for V&V just “by accident” can never be acceptable. For a systematic procedure it is essential that a dedicated decision procedure is applied to identify those activities that are necessary and economic for the specific project. For this purpose, a *V&V Procedure Model* is necessary. This procedure model can be used to establish and monitor process quality at the simulation service provider itself as well as for the communication between the service provider and the customer. In the latter case, it can be used as a common guideline. The scope and the level of detail of this procedure model need to be adapted to specific modelling constraints, in order to achieve an efficient and pragmatic application.

From the chapters 2 and 3 of this paper, the following requirements and constraints can be deduced for a V&V Procedure Model:

- V&V must be performed in an integrated way, i.e. all actions and procedures related to either verification or validation are discussed in one single approach
- V&V is a process that accompanies the whole simulation study

Table 1: Overview on document structures to be used for the description of Phase Results

Sponsor Needs	<ul style="list-style-type: none"> • Initial situation • Scope of the project • Constraints
Task Description	<ul style="list-style-type: none"> • Goal and task description • Description of the real world system to be analysed • Required information and data • Expected use of the model • Solution method and procedure • Requirements on model configuration and modelling
Conceptual Model	<ul style="list-style-type: none"> • Task specification and system description • Conceptual Modelling of the system structure • Conceptual Modelling of the sub-systems • Systematic listing of the required model data • Re-usable components of the model
Formal Model	<ul style="list-style-type: none"> • Task specification and system description • Formal Modelling of the system structure • Formal Modelling of the sub-systems • Systematic listing of the required model data • Re-usable components of the model
Executable Model	<ul style="list-style-type: none"> • Task specification and system description • Computational Modelling of the system structure • Computational Modelling of the sub-systems • Systematic listing of the required model data • Re-usable components of the model
Simulation Results	<ul style="list-style-type: none"> • Assumptions • Experimental design • Results from experiments
Raw Data	<ul style="list-style-type: none"> • Relation to task description and amending organizational constraints • Data entity types (one by one) • Plausibility checks across entity types
Prepared Data	<ul style="list-style-type: none"> • Relation to raw data, expected use of the data, and organizational constraints • Preparation of data entities (for each entity type) • Plausibility checks across entity types

- The basis of V&V are documented Phase Results according to the procedure model for simulation with V&V
- In the production and logistics domain, V&V must take special care of the data

In the following sections, the characteristics of the procedure model that was developed on the background of these requirements and constraints are presented as an overview. Additionally, a more detailed level of so-called *V&V Elements* is introduced. Finally, the documentation of the V&V process is discussed.

4.1 Systematic of the V&V Procedure Model

The proposed V&V Procedure Model is shown in figure 3. It takes into account the principles given by the simulation procedure (fig. 2) and is, therefore, separated into two major sections representing the model path and the data path. The lower part of the procedure model relates to data collection and preparation; the upper part relates to modelling and simulation. Thus, the eight rows of the V&V Procedure Model represent the results of the phases defined by the simulation procedure model.

In order to conveniently refer to the Phase Results, they are enumerated from 1 (Sponsor Needs) to 6 (Simulation Results). The Sponsor Needs are included, even not being a Phase Result of the simulation study itself, as it has to be referenced as an important document in the structure of the V&V process.

The results with respect to data cannot be clearly related to the modelling phases, as explained above. In order to avoid any misinterpretation, they are not characterized by numbers. Instead, the letters “R” (Raw

Data) and “P” (Prepared Data) are assigned to these documents.

Each row of the V&V Procedure Model consists of *V&V Elements*, which are indicated by rectangles. The V&V Elements comprise a set of possible *V&V Activities*. In order to establish a unique relation to the V&V procedure, each V&V Element is denoted by two indices:

- The first index defines the Phase Result which is validated by the activities of this V&V Element
- The second index defines the Phase Result which is used as the reference for the V&V with respect to this V&V Element

Thus, the index (1,1) indicates that the Phase Result “1” (Sponsor Needs) is tested with reference to the Phase Result “1”, i.e. with respect to itself. The index (3,2) indicates that the Phase Result “3” (Conceptual Model) is tested with reference to Phase Result “2” (Task Description).

In the following section, the V&V Elements are described in more detail. For the sake of simplicity, the V&V Elements are called “elements” in the remaining text, as long as this does not reduce the clarity of description. A very detailed description of each element and the related activities is to be found in Rabe et al. (2008).

The V&V Procedure Model establishes a causal – and in parts a timely – relationship among the V&V Elements and the phases of the simulation procedure model. The arrangement of the Phase Results (from Sponsor Needs to Simulation Results) defines a time axis in the upper part of the model, which leads from left to right. From the lower part of the procedure model, the elements from (2,R), (2,P) and all elements shown to the right of these elements can only partially be related to this time axis, since Data

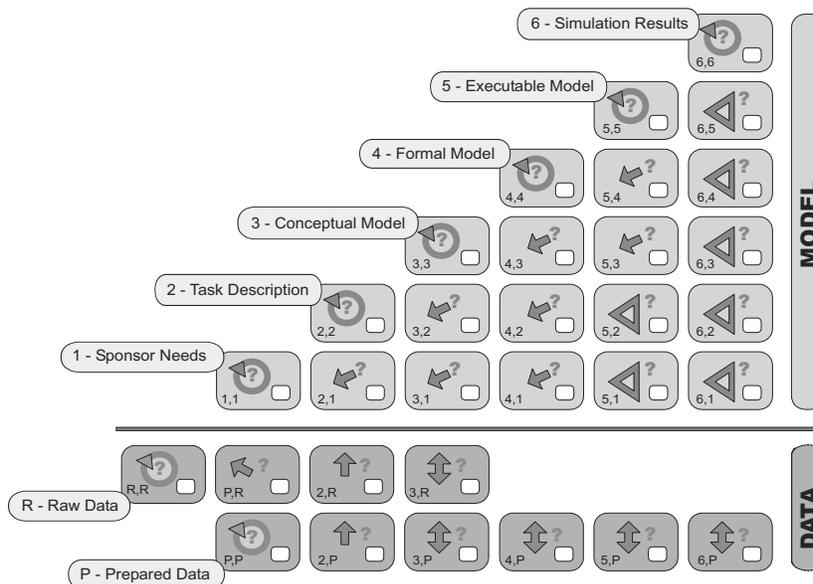


Figure 3: Procedure model for V&V of simulation in the production and logistics domain (cp. Rabe et al. 2008)

Collection and Data Preparation are not strictly aligned with the other phases of the simulation procedure model (as discussed earlier). The three elements (R,R), (P,P), and (P,R) have no relation to this time axis, but only among each other (as for the latter two, data preparation must have been accomplished).

For simplification and readability, the time axis does not at all indicate iterations, which are obviously necessary. However, it should be clear that this simplification in the graphical representation of the procedure model in no way denies the necessity for such iterations:

- V&V can (and should!) not only be executed at the end of one phase, but when ever a suitable intermediate state is achieved. This helps to identify problems, early, and to reduce the implications. The V&V of intermediary states can in principle relate to all results achieved at that point of time, and therefore does not show substantial differences with respect to V&V done at the end of the phase. Therefore, the separate definition of procedures for V&V in intermediary states is not necessary.
- Negative validation results in one phase may have their roots in problems induced by other phases, leading to the necessity to revise this (preceding) phase. In this case, for a complete V&V all V&V Elements based on this previous result need to be reconsidered, and tests repeated if it cannot be assumed that the change has no implications on the test results.

4.2 Classification of V&V Elements

The circle in some of the V&V Elements given in figure 3 stands for an intrinsic test, i.e. the document is analysed with respect to itself, and only to itself. Such *Intrinsic V&V Elements* always have an index with two identical digits (or letters), as both the first and the second index indicate the same Phase Result.

A simple arrow indicates the test of a Phase Result with respect to the results of a previous phase. Coming back to the example given in section 4.1, the simple arrow in element (3,2) stands for the reference from the Conceptual Model to the Task Description, asking if the requirements defined by the latter document are correctly mirrored by this Conceptual Model. The arrow indicates the direction of this relation.

The third type of V&V Elements provides a relationship between the Phase Results of modelling and the results of data collection and preparation. Therefore, these elements are indexed by one letter and one digit, and represent tests in combination of both documents. As the modelling and the data phases of the simulation process model are to a certain degree independent, the test of a data

document “against” a modelling document or vice versa has no meaning. None of the documents can be fully derived from the others, even if this can be the case for some parts of the documents. Therefore, there is no direction of the relationship, and the element is indicated by a double-sided arrow.

The last type of V&V Elements, which is marked by a triangle, stands again for the test of one Phase Result (of the modelling domain) to another one. But, for the tests of this fourth type the availability of the Prepared Data is a precondition, and the test is conducted using these prepared data. Negative results can have their roots in any of the three Phase Results used for the test. This type of V&V Element is applicable in the two last phases, only (Implementation as well as Experiments and Analysis).

4.3 V&V Documentation

The results of the V&V Activities conducted for each V&V Element have to be documented, carefully, as this is the only way to review the validation activities at a later time (Conwell et al. 2000). This leads to a set of reports for each phase of the simulation study, which can be used for detailed credibility assessment of the simulation study. In addition, these reports might be exploited in case of a change in the targets of the simulation study, in order to decide if the model is valid for the modified Task Description. Similar to further accompanying documents (proposals, project plans, meeting minutes, decisions on assumptions, status reports) these reports can be related to the Phase Results according to figure 3.

The structure of this *V&V Document* should on one hand mirror the V&V Procedure Model, and on the other hand follow the time axis and therefore the columns of this model. Thus, the authors recommend to structure the documentation of the V&V firstly according to the phases of the modelling process (1 to 6) into six chapters, and then to establish sections for each chapter. One section represents the intrinsic test, and the other ones the tests related to all previously established Phase Results. For the V&V of data, two additional chapters are required, which report all tests involving the data as given by the two lower rows of the V&V Procedure Model. For transparency, it seems adequate to mark these chapters with “R” and “P”, according to the related V&V Elements.

Within each section, the V&V Activities performed for this V&V Element should be documented, including the description of the tests conducted, the results achieved by the test, and a conclusion about the credibility implications from the test results. Especially, the following aspects should be considered in the documentation:

- subject of the test
- skipped tests (with justification for skipping them)
- V&V techniques applied

- experts that have set up the V&V plans and conducted the tests
- version indication of the Phase Results as used for the test
- results of the test and credibility statement

In this manner, a *V&V Report* is generated for each V&V Element. As an essential issue, it must be possible at any later point of time to uniquely identify and reconsider this documentation. This applies to the activities conducted for the specific V&V Element as well as to the results achieved by the execution of these activities.

4.4 Systematic Planning of V&V

For the definition of concrete activities necessary for a V&V Element in a specific simulation study, the experience and competence of the simulation experts is decisive. By a systematic procedure model, this competence can be supported, but never be replaced: “The whole [V&V] process has elements of art as well as of science” (Kleijnen 1995). Thus, the V&V Elements have to be specifically adapted for each simulation study. This adaptation has to be conducted in a structured way, and as early as possible; in any case *before* the start of the phase that this V&V Element is related to.

For the complete V&V process the V&V Procedure Model provides a suitable structure. The attempt to propose a similar structure in detail for each of the V&V Elements is likely to fail, taking into account the huge size of the potential problem space. However, this may not lead to the conclusion that the V&V Activities of a given

element do not require a concise plan. In this context, some papers use the term “V&V Plan” (see Balci et al. 2000; Pohl et al. 2005), which typically includes the following points:

- subject of the test
- V&V techniques to apply
- responsibilities for the conduction of the tests
- prerequisites for the tests
- point of time for the conduction of the tests (in time or in relation to progress in the study)
- estimated effort for the conduction of the tests

Of course, also the V&V Plans have to be included in the documentation of the V&V.

V&V techniques to be applied are not discussed in this paper, as there is comprehensive literature available (cp. Balci 1998). An overview of some important V&V techniques useful for the phases of the simulation study are shown in figure 4.

5 CONCLUSIONS AND OUTLOOK

The quality-oriented application of simulation for production and logistics tasks requires that the significance of V&V is acknowledged, and the related activities are budgeted as an important part of the simulation study. In joint efforts, the members of the project team have to assure that models are sufficiently accurate, that the estimation of their credibility can be re-assessed at any time, and that the V&V activities are defined, systematically. Therefore, this paper proposes a well-structured procedure model, which

Phase	1	2	3	4	5	6	R	P
V&V Techniques								
Animation					X	X		
Cause-Effect-Graph			X	X	X			
Comparison to other Models					X	X		
Desk Checking	X	X	X	X	X	X	X	X
Dimensional Consistency Test				X	X	X	X	X
Event Validity Test					X			
Extreme Condition Test				X	X	X		
Face Validity	X	X	X	X	X	X	X	X
Fixed Value Test				X	X	X		
Historical Data Validation					X			
Internal Validity Test					X	X		
Monitoring					X	X		X
Predictive Validation					X			
Review	X	X	X	X	X	X	X	X
Sensitivity Analysis					X	X		X
Statistical Techniques					X	X	X	X
Structured Walkthrough	X	X	X	X	X	X	X	X
Submodel Testing			X	X	X			
Trace Analysis					X			
Turing Test					X			X

Figure 4: Typical use of V&V Techniques for the Phase Results of a simulation study (index according to fig. 3)

- increases the probability to recognize (early) if the task description, models, or result analysis could lead to invalid conclusions, and
- structures the steps to be done for V&V as well as the documentation of V&V results, thus providing the possibility to prove all activities at any later point of time.

From the ASIM simulation society, the authors have received very positive feedback on the proposed procedure models. First evaluations have been conducted at the authors' companies and institutions within running simulation projects. The next steps will be the broad promotion of the systematic V&V approach for simulation in production and logistics as well as the dissemination in university education as well as in courses for professional simulation managers and experts.

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