*Proceedings of the 2009 Winter Simulation Conference*
*M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, eds.*

# VERIFICATION AND VALIDATION ACTIVITIES WITHIN A NEW PROCEDURE MODEL FOR V&V IN PRODUCTION AND LOGISTICS SIMULATION

Markus Rabe
Pascalstr. 8-9
Fraunhofer IPK
Berlin, 10587, GERMANY

Sven Spieckermann
Edmund-Seng-Str. 3-5
SimPlan AG
Maintal, 63477, GERMANY

Sigrid Wenzel
Kurt-Wolters-Str. 3
Universität Kassel
Kassel, 34125, GERMANY

## ABSTRACT

Verification and Validation (V&V) of simulation models have been strongly investigated in the context of defense applications. Significantly less substantial work can be found for applications in 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. The major result of this expert group was the development of a specific procedure model for V&V in the context of simulation for production and logistics, which was documented in a book (in German) and summarized in a paper at the WSC'2008. This paper explains details of the approach, discussing the criteria to be applied when assessing the validity of a model, and providing examples how to conduct V&V with reference to these criteria.

## 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, implies 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 cause 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.

The goal of V&V activities is the assessment of the model's credibility (Rabe, Spieckermann and Wenzel 2008b). As credibility is a question of acceptance, the aim should be to provide a systematic approach that leads to a decision upon acceptance, and to document it in a readable and transparent way. Only by such systematic approach and by structuring it 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 modeling step and its results.

The authors have proposed a suitable procedure model at the 2008 Winter Simulation Conference, and explained its structure and major elements. Therefore, in this paper the major elements of this model are summarized, and the focus is set on the explanation of V&V criteria to be applied as well as the description of V&V activities related to these criteria.

This paper is structured as follows. After a short review of related work in chapter 2, a Simulation Procedure Model is described in chapter 3. In chapter 4, criteria are given for V&V in simulation. Continuing on this ground, a V&V Procedure Model is presented in chapter 5 and exemplary V&V activities are described in chapter 6.

## 2 SUMMARY OF RELATED WORK

There have been numerous research efforts related to procedure models, V&V, and simulation. For an analysis of the related work, different classes of procedure models have been investigated. This chapter gives a brief overview on some literature in the field. Details can be found in Rabe, Spieckermann and Wenzel (2008a and 2008b).

Significant attention has been dedicated to *procedure models for simulation studies*, which to a different extent contain elements for V&V. The focus of these procedure models is to provide guidelines for the professional performance of simulation studies; with quite different level of detail. However, independently of their varying 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 (cp. Banks et al. 2005; Law 2007; Hoover and Perry 1990) as well as in guidelines (cp. USGAO 1979; VDI 2009).

*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. 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 practices are given as a guideline (DMSO 2007a). A procedure model that has significantly influenced the one presented in this paper was introduced 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. Just recently, Skoogh and Johansson (2008) proposed a methodology for input data management that involves data validation and has several aspects in common with the role of data and data validation outlined in the following.

The general context of V&V is, however, much broader than the application domain of simulation in production and logistics, which is the focus of this paper. 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. Candidates are operations research (OR) (cp. Landry and Oral 1993) or computer science (cp. Boehm 1979; Bel Haj Saad et al. 2005).

A comparison of 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 degree of consideration can range from just naming the relevance of V&V to a detailed V&V Procedure Model. This paper is based on the conviction 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 with well-defined intermediate results ("Phase Results")
- Formulation of a V&V Procedure Model that supports the execution of V&V
- Elaboration of V&V activities to be conducted under the systematic framework of the V&V Procedure Model.

## 3 PROCEDURE MODEL OF SIMULATION WITH V&V

In order to propose a procedure for V&V, it is necessary to understand the role of V&V within the procedure that is applied for the simulation study. The authors propose a suitable procedure model for simulation including V&V (Figure 1), based on a guideline of the German engineers' association VDI (VDI 2009).

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 procedure model is characterized by the consequent definition of intermediate results, and the separate paths for models and data. The model path is structured into Task Definition, System Analysis, Model Formalization, Implementation, and finally Experiments and Analysis (ellipses in Figure 1).

A Phase Result is assigned to each phase (rectangles in Figure 1). 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 deliberately 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.

As V&V has to be conducted during all phases of the modeling process, V&V – both of the data and the models – is arranged along the whole simulation study (see the rectangle on the right of Figure 1). 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 modeling process.

Verification and Validation imply tests, which in turn require a subject of testing. Therefore, V&V is always performed with the results of a modeling 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. 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 detail by Rabe, Spieckermann and Wenzel (2008a) and have been given in a summarized form by Rabe, Spieckermann and Wenzel (2008b).

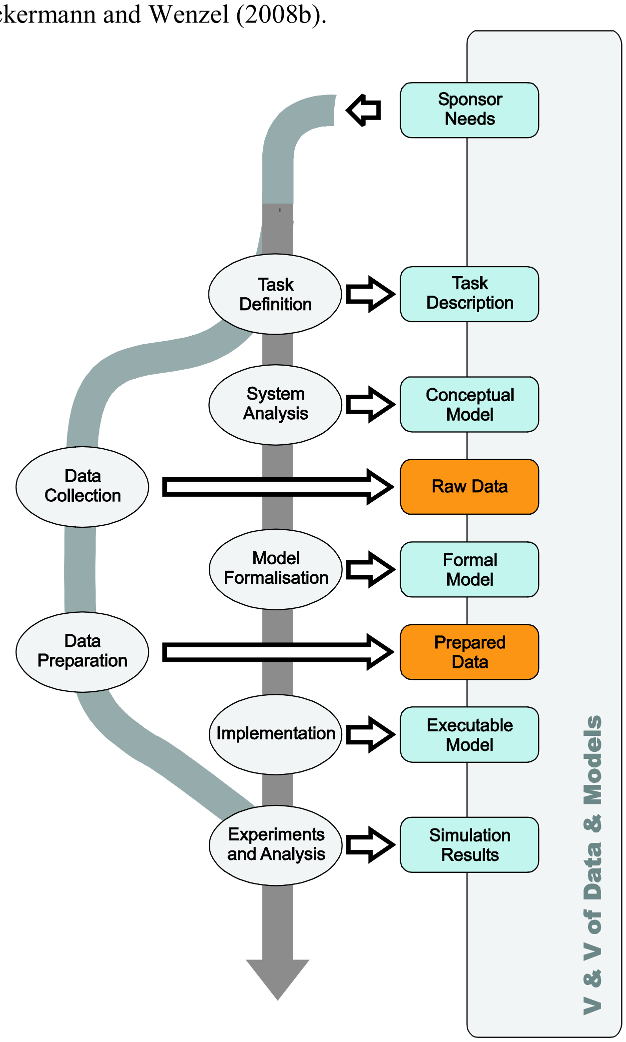


Figure 1: Procedure model for simulation including V&V (cp. Rabe et al. 2008b)

## 4 VERIFICATION AND VALIDATION CRITERIA

Each model represents the original system under study for a given set of questions and goals. Therefore, validity can only be considered in this given context. As Box (1987) states in a very illustrative way, "Essentially, all models are wrong, but some are useful". Consequently, validation analyzes if the model is an acceptable representation of the real system for the given goals (Kleijnen 1999).

The validity of a simulation model is closely correlated with its credibility. Credibility, however, is based on a subjective impression and is defined by the user on the basis of his or her own acceptance criteria. Balci (1990, p. 28) defines a hierarchy of credibility assessment stages for evaluating the acceptability of simulation results, dependent on the procedure model applied for the simulation study. In Balci et al. (2000) more than 400 indicators for credibility assessment are given, which can be structured at the highest level into

- Requirements Credibility,
- Application Credibility,
- Experimentations Credibility,
- Project Management Quality,
- Cost, and
- Risk.

These categories can then be fine-structured in several levels of detail. As an example, Application Credibility can be divided into

- Credibility of the conceptual model,
- Credibility of the design,
- Credibility of the implementation,
- Credibility of the integration
- Credibility of the data
- Quality of the product, and
- Quality of the application documentation.

Robinson (2006) discusses the requirements to a conceptual model, referring to Willemain's (1994) five quality attributes for an effective model: Validity, Usability, Value to the Clients, Feasibility, and Aptness for the Client's Problem. Eppler (2006) discusses information quality criteria in knowledge-intense products and processes independently of simulation, and assembles a comprehensive list of criteria that form a basis for the evaluation of validity of the data to be used and can therefore be used as acceptance criteria.

Thus, acceptance criteria do not only comprise V&V criteria, but also more general requirements to the quality of the product, the process, and the project (cf. Balci 2003). This shows the strong relation to the overall quality of the simulation project, which has also to be evaluated with respect to credibility as well as the technical and social competence of the person that conducts the modeling (cp. e.g. Robinson and Pidd 1998).

In general, V&V will not lead to a complete and formal prove of a model's validity. However, the confidence in the simulation model can be increased, reducing both to the user and the simulation expert the perceived risk with respect to the model's application. In this context, it should be clear that "the process of verification and validation is no one of trying to demonstrate that the model is correct, but is in fact a process of trying to prove that the model is incorrect" (Robinson 2004, p. 214). Therefore, it is quite helpful to define a set of V&V criteria (cf. Pohl et al. 2005). As a matter of risk analysis, the consequences of non-perceived faults of the model on the usability of the model should be analyzed with respect to the V&V criteria. The more risk is seen in not meeting one of the criteria, the higher should be the confidence that is correlated with this criterion.

Due to the goal-oriented setup of V&V, providing a generally valid set of criteria is not possible. Taking into consideration the very broad set of criteria to be found in literature, the authors propose a set of essential criteria that form a pragmatic base for the use in production and logistics projects (Table 1). This set is the basis for the procedures and guidance provided in the following chapters. These criteria cover generally all information and data to be used within a simulation study. However, they partially own focal points in their concrete use.

Criteria to ensure the *correctness* of a model mainly assess content and structure of the models, documents, information, and data. These include mainly completeness and consistency, not withstanding that also accuracy and currency have some meaning in this context. The *suitability* of the results for the targeted application can also be proven through accuracy and currency as well as through the criteria applicability, plausibility, and clarity. For the *practicability* of a project on the levels of organization, techniques, and model theory the major criteria are feasibility and accessibility.

Table 1 names in the first column the V&V criterion and correlates it in the second column with its general focus. Different facets with respect to the content are listed in the last column.

Table 1: V&V Criteria for Simulation in Production and Logistics

| V&V Criterion | Scope of V&V | |
|---|---|---|
| | **Focal Points** | **Examples** |
| **Completeness** | Correctness of Content and Structure | • Does the structural review point out missing requirements and information?<br>• Which level of conformity does exist between requirements and model? |
| **Consistency** | Correctness of Content and Structure | • Is the semantic context free of contradictions?<br>• Are the structures of the documents, information and model free of contradictions?<br>• Is the terminology consistent? |
| **Accuracy** | Correctness of Content and Structure as well as Suitability of the Results for the Application | • Is the model free of visible faults and carefully built?<br>• Is the level of detail appropriately chosen?<br>• Are the scope of information and the granularity of data adequate?<br>• Are the random distributions sufficiently precise and close enough to reality? |
| **Currency** | Correctness of Content and Structure as well as Suitability of the Results for the Application | • Are the information and data valid with regard to content and time?<br>• Is the model valid with respect to the given task? |
| **Applicability** | Suitability of the Results for the Application | • Is the model usable and convenient for the intended purpose?<br>• Does the effort related to the model correspond to the given task?<br>• Is the model performance adequate?<br>• Is the benefit for the user distinguished? |
| **Plausibility** | Suitability of the Results for the Application | • Is the procedure, the background of information, and the model context traceable?<br>• Are the results free of contradictions? |
| **Clarity** | Suitability of the Results for the Application | • Are the phase results understandable or comprehensible to the target groups?<br>• Is the model building process understandable for the user?<br>• Is the wording well-defined?<br>• Are the documents readable and understandable? |
| **Feasibility** | Practicability | • Can the requirements be technically realized?<br>• Are the required project objectives achievable?<br>• Is the project plan realizable in time? |
| **Accessibility** | Practicability | • Is there a continuous and unobstructed way to get to the needed information?<br>• Are the information and data sources reliable?<br>• Are time and effort for the process of information acquisition acceptable? |

## 5 PROCEDURE MODEL FOR V&V

Based on the procedure model for simulation in production and logistics including V&V (Figure 1), 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. The procedure model proposed by the authors was presented at the 2008 Winter Simulation Conference (Rabe, Spieckermann, and Wenzel 2008b). Therefore, here only the essentials are given that are the basis to understand the V&V activities that are given in the next chapter. Especially, aspects of documentation and V&V planning, which have been described in the mentioned paper, are not discussed here.

As discussed above, at each point of time during a simulation project all documents and models can be analyzed 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 modeling constraints, in order to achieve an efficient and pragmatic application.

From the precious discussion within 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

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.

### 5.1 Systematic of the V&V Procedure Model

The proposed V&V Procedure Model is shown in Figure 2. It takes into account the principles given by the simulation procedure (Figure 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 modeling 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 results with respect to data cannot be clearly related to the modeling 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.

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 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.

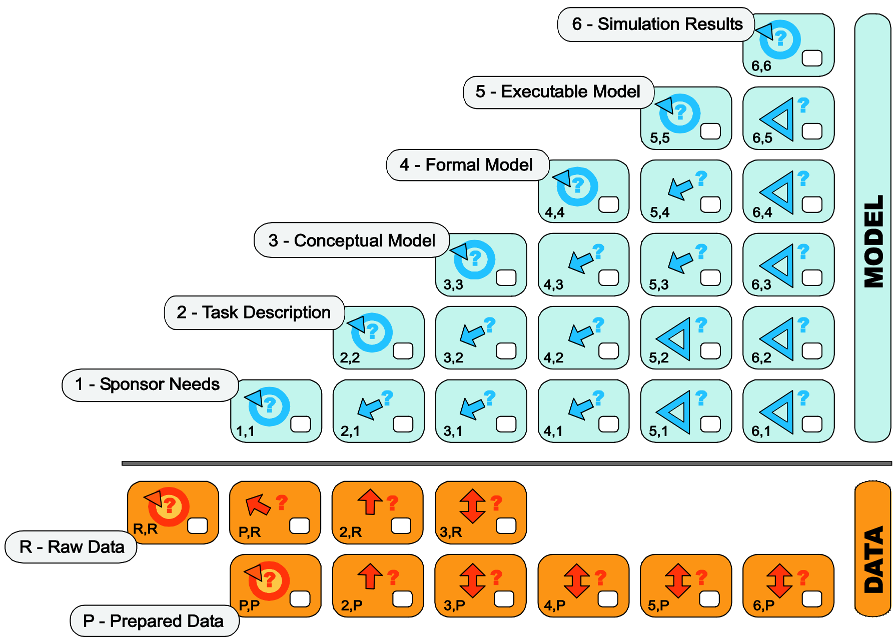


Figure 2: Procedure model for V&V of simulation in the production and logistics domain (Rabe, Spieckermann and Wenzel 2008b)

## 5.2 Classification of V&V Elements

The circle in some of the V&V Elements given in Figure 2 stands for an intrinsic test, i.e. the document is analyzed 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. The 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 modeling 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 modeling and the data phases of the simulation process model are to a certain degree independent, the test of a data document "against" a modeling 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 modeling 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).

## 6 EXEMPLARY V&V ACTIVITIES

The V&V Procedure Model described above contains 31 V&V Elements. All these elements are described in detail by Rabe, Spieckermann and Wenzel (2008a) in German. Obviously, this paper does not provide enough space to present this detailed work. Therefore, a set of V&V elements has been selected in such a way, that examples for all different types of V&V elements are discussed as well as both the modeling and the data part of the simulation procedure model are considered:

- The intrinsic V&V of the Sponsor Needs as an example for intrinsic elements on the modeling side
- The intrinsic V&V of the Raw Data as an additional example for the data side
- The V&V of the Conceptual Model with respect to the Sponsor Needs and the Task Description as examples for the "simple arrow" elements
- The V&V of Prepared Data in relation to the Conceptual Model as an example for the "double-sided arrow" elements
- The V&V of the Executable Model and the Simulation Results in relation to the Task Description under usage of the Prepared Data as examples for the "triangle" element

*Intrinsic V&V of the Sponsor Needs* (V&V element (1,1) in Figure 2) ensures the correct and suitable representation of the planned tasks and intended project objectives. Therefore completeness, consistency, accuracy and currency of the phase result documentation have to be checked. This implies e. g. to ask whether the Sponsor Needs comprise all bullet points mentioned in the proposed document structure or whether the given requirements are free of contradictions, exactly defined and not obsolete. For checking the suitability it has to be thoroughly considered whether the described solution approach and methods as well as the project objectives sufficiently fulfil the intended purpose of the study (applicability). The precondition is that the project activities with all participating project partners (internal and external) have been planned. A further important objective of this V&V element is the question, whether simulation is the right technology to achieve the goals and tasks of the study. Additionally, plausibility and clarity of the Sponsor Needs determine the suitability of the Sponsor Needs for the task to be done. Plausibility implies e. g. a project plan free of contradictions and a reasonably justified specification of the scope of the project. According to the V&V criterion clarity the description of all relevant project aspects relating to non-ambiguity and comprehensibility to the target groups need to be checked. Last but not least the feasibility of the specified Sponsor Need has to be considered. On the one hand this comprehends the review of the planned way to conduct the project under the given organizational, financial and technical constraints. On the other hand it has to be made sure that the complexity of the task and the scope of the system allow for the use of simulation and that well-defined buy-off criteria specify the success of the project.

*Intrinsic V&V of the Raw Data* (V&V element (R,R) in Figure 2) also has the formal aspect of checking if the documentation for completeness and consistency. However, there is a specific emphasize on feasibility and availability with respect to organizational issues: if regular updates of the Raw Data are needed throughout the project, a suitable process needs to be in place or prepared to ensure these updates. A second organizational issue has its roots in possible standards and regulations for interfaces and data exchange, which IT departments in some large companies have implemented. In such cases, it is part of element (R,R) to check whether these standards are met by the project. Additional V&V activities relate to the plausibility, consistency, and applicability of the raw data themselves. In this context, it needs to be checked if collected data have been collected without measurement errors, if generated data do really match the constraints given for the generation, if attribute values are within the specified range, etc. To conclude with, the documentation itself might specify plausibility and consistency checks. In that case, V&V also has to make sure that these checks have been executed.

*V&V of the Conceptual Model with respect to the Task Description* (V&V element (3,2) in Figure 2) deals on the one hand with the complete, consistent and accurate transformation of all specifications designed in the Task Description into the Conceptual Model. On the other hand applicability, currency, plausibility and feasibility of the Conceptual Model have to be checked with respect to the specified task, the planned use of the model, the defined solution approach and the model requirements. Therefore, the documentation of the Task Description as well as the description of the planned or real production or logistics system is part of the V&V investigation. The implementation of the specification designed in the Task Description demands that all specified processes and structures, system elements, structuring requirements (e. g. partial models, sub model building) as well as organizational and system load specifications are adequately considered (completeness). The consistency check should answer the questions whether the structures of the conceptual model sufficiently and unambiguously correspond to the system to be modeled. Additionally, the appropriateness of the level of detail chosen for the conceptual model and the specified output values have to be checked taking in consideration the problem definition and the system as given (accuracy). The accuracy check also comprehends whether the acceptance and buy-off criteria will be measured. According to the V&V criterion applicability the usability and suitability of the Conceptual Model have to be checked with respect to the requirements on the model building process, the scope of the planned use of the model and the estimated model performance. The last one is also a V&V objective for the technical feasibility check.

In addition to the V&V element (3,2) *the V&V of the Conceptual Model with respect to the Sponsor Needs* (V&V element (3,1) in Figure 2) has to ensure the adequate consideration of the intended goals and constraints described in the Sponsor Needs (integrated as first chapter of the Task Description) within the Conceptual Model. Therefore, the external partners named in the Sponsor Needs should be involved in designing and aligning the Conceptual Model. With regard to the V&V criteria completeness and consistency you have to ask e.g. if the functionality of the system is fully taken into account as given in the Sponsor Needs, including the system's processes and structures, or if there are any comprehensible and well-grounded differences. However, the most important criterion in this context is the applicability, which has to be checked by different questions like: Does the Conceptual Model represent the Sponsor Needs appropriately in scope and level of detail? Are the specified output values, analysis approaches and measuring points appropriate to achieve the kind of results requested in the Sponsor Needs? Are the Conceptual Model and the simulation model implementation specified therein adequate for the intended model usage?

The first step of the *V&V of Prepared Data in relation to the Conceptual Model* (V&V element (3,A) in Figure 2) is the comparison of the respective documentations. The Conceptual Model as well as the Prepared Data Documentation include a data specification down to attribute level. Hence, both descriptions need to be consistent and applicable. Also, the Prepared Data need to be checked for completeness with respect to the model elements and structures specified in the Conceptual Model: Basically, all data (possibly) required by the elements should be available or it should be possible to make them available throughout the further progress of the project. Furthermore, the concepts and the data allow for a first estimate of the model performance during runtime. This enables to assess whether the given performance requirements are feasible or not.

A significant difference of the *V&V of the Executable Model in relation to the Task Description* (V&V element (5,2) in Figure 2) with respect to the V&V elements described so far is that it is based on the outcome of three phases of the simulation procedure model (hence the triangle in Figure 2). Here, main V&V tasks are to make sure that the Executable Model matches the Task Description with respect to model structure, control rules, visualization, animation, modeling conventions, hardware and software requirements, interfaces, output etc. In order to perform some of these checks the model needs to be actually executed, in almost all cases requiring Prepared Data. Thus, the element (5,2) has most similarity with the “outdated” old V&V understanding of starting validation once the model has been fully implemented.

*The V&V of the Simulation Results in relation to the Task Description* (V&V element (6,2) in Figure 2) makes sure that the results fulfill the requirements given in the Task Description with respect to criteria such as completeness, consistency, accuracy, applicability, and clarity. It needs to be verified e.g. that all required experiments are part of the experiment design and that the experiments have been performed in accordance with this design. Also, output variables and simulation period need to be compliant to the Task Description and the results have to be presented in a clear manner. Of major importance in this V&V element is to validate that the simulation experiments and the results meet the purposes given in the Task Description. Finally, the buy-off criteria specified in the Task Description have to be checked.

## 7 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 presents a procedure model, which

- increases the probability to recognize (early) if the task description, models, or result analysis could lead to invalid conclusions,
- structures the steps to be done for V&V into a well-defined framework of V&V elements, thus providing the possibility to prove all activities at any later point of time, and
- provides exemplary advice how to conduct V&V activities within different V&V Element types as defined by the procedure model.

From the ASIM simulation society as well as from the last Winter Simulation conference, 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. Tutorial material has been prepared for the dissemination in university education as well as in courses for professional simulation managers and experts. The first tutorial had been conducted in

October 2008 during the ASIM conference on simulation in production and logistics in Berlin (Germany) with significant attendance and very good resonance. Currently, the authors consider to provide a book in English that represents and extends the content summarized above, because the extensive description of the V&V Procedure Model is still available in German, only.

## ACKNOWLEDGMENTS

The work reported has been conducted within the community of the "Arbeitsgemeinschaft Simulation" (ASIM), which is the simulation society of the German-speaking regions in Europe. The working group "Simulation in Production and Logistics" (SPL) within ASIM has initiated an expert group on validation in the year 2003, with members from industry, simulation service providers, and research institutions. The results presented would not have been achievable without the high personal commitment of the members of this expert group, and additional support by further members of ASIM. The authors would like to express their specific gratitude to Stefan Heinrich (Audi AG) and Simone Collisi-Böhmer (Siemens AG) for their careful review of the results from the industrial point of view, to Axel Lehmann (Universität der Bundeswehr München) for his extremely helpful hints about related work in the defense domain and in computer science, and to Tobias Schmuck (Universität Erlangen) for his very work-intensive contributions to the description of the V&V Elements.

## REFERENCES

Balci, O. 1990. Guidelines for successful simulation studies. *In Proceedings of the 1990 Winter Simulation Conference*, ed O. Balci, R.P. Sadowski, and R. E. Nance, 25-32. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Balci, O., W. F. Ormsby, J. T. Carr III., and S. D. Saadi 2000. Planning for verification, validation, and accreditation of modeling and simulation applications. *In Proceedings of the 2000 Winter Simulation Conference*, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 829-839. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Balci O, R. E. Nance, J. D. Arthur, and W. F. Ormsby 2002. Expanding our horizons in verification, validation, and accreditation research and practice. *In Proceedings of the 2002 Winter Simulation Conference*, ed. E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, 653-663. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Balci, O. 2003. Validation, verification, and certification of modeling and simulation applications. In Proceedings of the 2003 Winter Simulation Conference, ed. S. Chick, P. J. Sanchez, E. Ferrin, and D. J. Morrice, 150-158. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Banks J, J. Carson II., B. Nelson, and D. Nicol 2005. Discrete-event system simulation. 4th ed. Upper Saddle River: Prentice-Hall.

Bel Haj Saad S, M. Best, A. Köster, A. Lehmann, S. Pohl, J. Qian, C. Waldner, Z. Wang, and Z. Xu 2005. Leitfaden für Modelldokumentation. Final report Studienkennziffer 129902114X. Neubiberg: Institut für Technik Intelligenter Systeme ITIS.

Boehm, B. 1979. Guidelines for verifying and validating software requirements and design specifications. In Proceedings Euro IFIP'79, ed. P. A. Samet, 711-719. Amsterdam: North-Holland.

Brade, D. 2003. A generalized process for the verification and validation of models and simulation results. Dissertation, Neubiberg: Universität der Bundeswehr.

Box, G.E.P. 1987 Empirical model-building and response surfaces. New York: John Wiley & Sons.

Davis, P. K. 1992. Generalizing concepts and methods of verification, validation, and accreditation (VV&A) for military simulations.Santa Monica: RAND.

DMSO 2007. Key concepts of VV&A. Defense Modeling and Simulation Office, Recommended Practices Guide. http://vva.dmso.mil (visited 7.3.2007).

DMSO 2007a. VV&A Recommended practices guide. Defense Modeling and Simulation Office. http://vva.dmso.mil (visited 7.3.2007).

Eppler, M.J. 2006. Managing information quality, 2nd ed. Berlin, Heidelberg; Springer.

Hoover, S., and R. Perry 1990. Simulation: A problem-solving approach. Reading: Addison-Wesley.

Kleijnen, J.P.C. 1999. Validation of models: statistical techniques and data availability. In: Proceedings of the 1999 Winter Simulation Conference, ed. P.A. Farrington, H.B. Nembhard, D.T. Sturrock, and G.W. Evans, 647-654. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Landry, M., and M. Oral (eds) 1993. Special issue on model validation. European Journal of Operational Research 2:161-258.

Law, A. M. 2007. Simulation Modeling and Analysis. 4th ed. Boston: McGraw-Hill.

Pohl, S., S. Bel Haj Saad, M. Best, D. Brade, M. Hofmann, T. Kiesling, T. Krieger, A. Köster, J. Qian, C. Waldner, Z. Wang, Z. Xu, and A. Lehmann 2005. Verifizierung, Validierung und Akkreditierung von Modellen, Simulationen und Förderationen. Final report Studienkennziffer E/F11S/ 2A280/ T5228. Neubiberg: Institut für Technik Intelligenter Systeme ITIS.

Rabe, M., S. Spieckermann, and S. Wenzel 2008a. Verifikation und Validierung für die Simulation in Produktion und Logistik – Vorgehensmodelle und Techniken. Berlin: Springer.

Rabe, M.; S. Spieckermann, and S. Wenzel 2008b. A new procedure model for verification and validation in production and logistics simulation. *In Proceedings of the 2008 Winter Simulation Conference*, ed. S. J. Mason, R. Hill, L. Moench, and O. Rose, 1717-1726. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Robinson, S. 2004. Simulation: The Practice of model development and use. Chichester: John Wiley & Sons.

Robinson, S. 2006. Conceptual modeling for simulation: Issues and research requirements. *In Proceedings of the 2006 Winter Simulation Conference*, ed. L.F. Perrone, F.P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R.M. Fujimoto, 792-800. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Robinson, S., and M. Pidd 1998. Provider and customer expectations of successful simulation projects. Journal of the Operational Research Society. 49 (1998) 3: 200-209.

Sargent, R. G. 1982. Verification and validation of simulation models. In Progress in Modelling and Simulation, ed. F. E. Cellier, 159-169. London: Academic Press.

Skoogh, A. and B. Johansson 2008. A Methodology for input data management in discrete event simulation projects. *In Proceedings of the 2008 Winter Simulation Conference*, ed. S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, and J. W. Fowler, 1727-1735. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

USGAO 1979. Guidelines for model evaluation. PAD-79-17. Washington D.C.: U.S. General Accounting Office.

VDI 2009. Richtlinie 3633 Blatt 1 „Simulation von Logistik-, Materialfluss- und Produktionssystemen“. Berlin: Beuth.

Willemain, T.R. 1994. Insights on modeling from a dozen experts. Operations Research 42 (1994) 2: 213-222.

## AUTHOR BIOGRAPHIES

**MARKUS RABE**, Ph.D., is head of the corporate logistics and processes department of Fraunhofer IPK. He is responsible for business process planning, factory planning and simulation and head of the Berlin Demonstration Center for Simulation in Production and Logistics. Markus Rabe is member of several conference program committees and chaired the conference “Simulation in Production and Logistics” in 1998, 2000, 2004, and 2008. More than 130 publications and editions report from his work. His e-mail address is <markus.rabe@ipk.fraunhofer.de>.

**SVEN SPIECKERMANN**, Ph.D., is Chief Executive Officer at SimPlan AG, Maintal, Germany, mainly working as a senior consultant and project manager in simulation projects for several industries. Since 1992, he has been participating in over 200 simulation projects. Additionally, he has been giving lectures in simulation at the Technical University of Braunschweig since 1995 and at the Technical University of Darmstadt since 2008. He has published several papers on simulation, simulation-based optimization and related topics. His e-mail contact is <sven.spieckermann@simplan.de>

**SIGRID WENZEL** is professor and managing director of the Institute for Production Engineering and Logistics, University of Kassel, and head of the Department of Production Organization and Factory Planning. In addition to this, she is a board member of the Arbeitsgemeinschaft Simulation (ASIM), spokesperson for the ASIM working group Simulation in Production and Logistics and head of the Committee Modeling and Simulation of the Association of Engineers Society for Materials Handling, Materials Flow and Logistics Engineering (VDI-FML). You can reach her by e-mail at <s.wenzel@uni-kassel.de>.