TECHNICAL NOTES

Quality Aspects in Simulation Studies for Production and Logistics

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Quality aspects in simulation studies are addressed in a variety of papers and books. In our paper, we intend to provide the simulation practitioner in the field of production and logistics with an easy-to-use procedure to guide him through all phases of a simulation project, from the specification of his needs through the simulation study as such to the potential re-use of models and results. We outline five fundamental quality criteria, provide an extended procedure model for the different project phases, and explain how checklists can be applied for quality improvements. This work is based on the discussions over several years of a special interest group of the ASIM working group "Simulation in Production and Logistics" (Arbeitsgemeinschaft Simulation) and targets to summarise some of the key ideas of simulation experts from industry and academia working in a large variety of application domains of discrete event simulation (DES).

Introduction

Nowadays, a wide range of high-quality discrete event simulation (DES) tools for production and logistics applications are on the market. Simulation is a well-established tool in many industrial application domains (e. g. automotive, aircraft and shipbuilding industry, semiconductor industry, plant engineering and construction, supply chain management, health-care logistics or call centre). These aspects seem sometimes to result in using simulation as a problem solving method like a duck takes to water (see [1]): On the one hand the acceptance of simulation in industrial applications will increase also by new end-users who were put off in the past by statements like "Simulation is an innovative method only used by experts." On the other hand this development obviously provokes certain carelessness using simulation theory and the demand that modelling and simulation is easy, quick and low-cost. Unfortunately, the matter of course in using simulation methods leads to underestimate the time and manpower requirements for a simulation study. Neither statistical verification of the simulation results which is needed for a high-quality planning nor the relevance of the simulation results for the planning task is considered sufficiently. Sometimes a 3-D model of the system which had to be analysed will be sold as *the* result of the simulation study.

In addition, the matter of course in using simulation methods and the standardisation of using simulation on the part of the simulation experts may lead to a non-comprehensible project implementation for clients who do not know anything about simulation (for example: missing transparency with respect to the granularity and quantity of data to be acquired or the modelling level of detail to be chosen). Sometimes new users being non-familiar with the simulation methods adamantly refuse simulation applications.

Therefore the ASIM Working Group "Simulation in Production and Logistics" intends to recollect quality aspects in simulation project implementation. The discussed and published topics "Quality aspects" [2] and "Verification and Validation" [3] are essential for high-quality simulation projects and credible simulation results. In the next section, we briefly discuss some quality criteria in simulation projects and define five fundamental quality criteria. In Section 2, we present a simulation procedure model recommended by ASIM followed by a description of available checklists for a systematic project implementation (Section 3). Finally, a summary concludes the paper.

1 Quality criteria in simulation projects

To ensure a quality-oriented and professional project implementation, the involved project partners have to understand the meaning of the term *quality* in the same manner. "Quality is the totality of features and characteristics of a product or service that bears on its ability to satisfy given needs." "Quality is meeting or exceeding customer expectations." [4], pp. 15. Eppler

([5], pp. 20) discusses the twofold nature of quality defined by subjective (e.g., meeting expectations) and objective indicators (e.g., meeting requirements). The subjective indicators comprehend aspects like "fitness for use" or "satisfy needs" (relative dimension); the objective indicators includes aspects like "error free" or "meeting specification" (absolute dimension).

The definitions above directly show that there are no generic rules to define quality or to measure the degree of fulfilment. The quality of a project in general as well as of a simulation project (simulation study) is defined by different business, company and project-specific requirements. But it also takes into account the opinion of all project partners. Additionally, the definition clarifies that quality in simulation projects includes not only the *quality of the outcomes of the simulation projects* (in terms of correctness, validity, transparency, purpose-orientation, re-usability, acceptability) but also the *process quality* of the project itself. This implies that the results of each project step have to meet these quality requirements.

In the literature there are a lot of information and instructions about how to manage simulation projects successfully [6, 7]. Liebl [8] (pp. 222) describes seven deadly sins of simulation studies:

1. Wrong definition of the study goal
2. Deficient involvement of the sponsor
3. Unbalanced mixture of core competences
4. Inadequate level of detail
5. Selection of the wrong simulation tool
6. Insufficient validation
7. Poor result presentation.

In contrast to Liebl [8], Robinson and Pidd [9] point out 19 dimensions for simulation project quality. These dimensions include (in an updated version in accordance with [10], pp. 206) model, data, and software-specific criteria as well as characteristics of the model builder himself as credibility, professionalism, expertises and soft skills. Additionally, the client and his organisation ("the commitment of the client´s organization to the simulation project", [10], pp. 206) and the relationship between the involved project partners are taken into account. However, the quality criteria do not have to be fulfilled to the same degree. First of all the project-specific expectations of the customer concerning the organisation of the project, the implementation with of content and technique as well as the usability of the results have to be met. In this context, Robinson [11] developed a simulation quality trilogy concerning the content, the process, and the outcomes of a simulation study.

In a nutshell, the quality in simulation projects is defined by the accuracy and systematic of the project preparation and implementation, adequate participation of the customer, and the consideration of his specific requirements (e.g. number of meetings, scope of presentation, outcomes). From the authors´ point of view, five basic quality criteria are identified which have to be fulfilled within a simulation project for production and logistics tasks:

1. Accurate project preparation
2. Consistent documentation
3. Integrated verification und validation
4. Continuous participation of the client
5. Systematic project implementation

An approach for a consistent documentation and an integrated verification and validation within simulation studies in production and logistics is discussed in more detail in [3] and [12]; the approach of an integrated verification and validation also in [12].

The first, the fourth and the fifth criterion are supported by different checklists on the basis of the simulation procedure model described in the following section. A short description of the checklists as developed by the authors of [2] as well as a list of the available checklists is given in Section 4. More details on the checklists can be found in [2].

2 The extended procedure model

The authors propose an extended procedure model for simulation including Verification & Validation (V&V, see Figure 1), based on a guideline of the German engineers' association VDI [13].

Our procedure model extends the model published in [12]. In particular, we added references to the checklists (depicted as circles in Figure 1) which are discussed in Section 4. These checklists support the work of the project team in all phases of the simulation project and are a fundamental part of our quality improvement philosophy.

In contrast to most other publications on procedure models for simulation projects, we consider the pre-project phase (Project Definition) and the post-project phase (Re-Use) explicitly. Starting from the Sponsor Needs (like, e.g., initial situation, scope of the project, and constraints) the extended procedure model considers only tasks that normally occur after the project

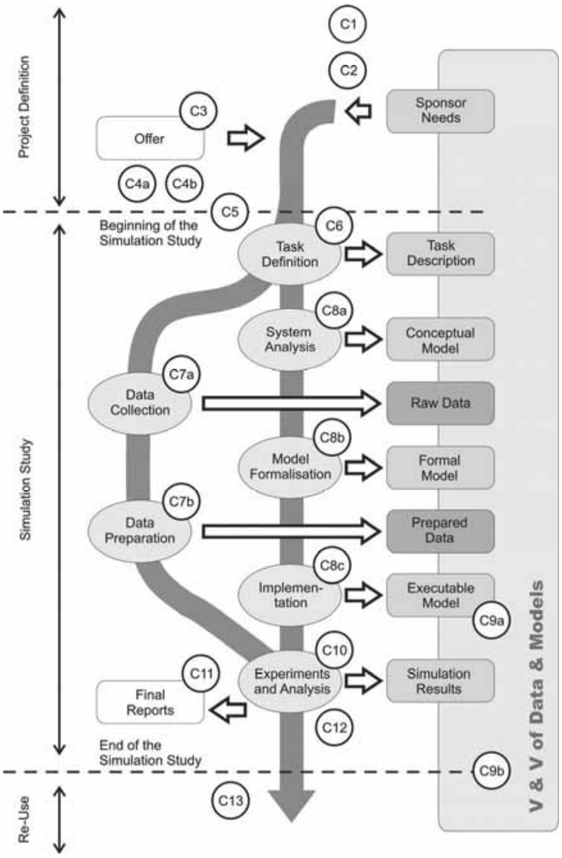

Figure 1. Extended Procedure Model (compare [2]).

sponsor had accepted the task and cost plan in the form of an offer for the simulation study from a simulation provider. We do not distinguish here between external and internal service providers. Therefore, the proposed procedure model starts with the Task Definition, which is considered to be the first analysis step within a simulation study. The Task Definition can be rather coarse in the beginning of the project definition phase and has to be updated with more and more details until a concrete offer finalises this step. This offer will set the frame for the whole simulation project.

The phases Data Collection and Data Preparation are intentionally defined in a second path, as they can be handled in parallel with respect to content, time, and involved persons. Therefore, the arrangement of Raw Data in Figure 1 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* [14]. Therefore, the procedure model does not contain a special phase "V&V". But, V&V – both of the data and the models – is an *essential part of the whole simulation study* (see the rectangle on the right of Figure 1). More details about V&V can be found in [15]

The proposed procedure model is characterised by a clear definition of intermediate results, and separate paths for models and data. These phases are depicted as ellipses in Figure 1. A *Phase Result* is assigned to each phase (rectangles in Fig. 1). Phase results can be models, documents, or a combination of both. Only the document "Sponsor Needs" is not really a Phase Result, but the base for starting the simulation study. A detailed description of the procedure model and the necessary documentation is given in [3] and [12].

In addition to the documentation of the phase results, we consider the following documents:

Sponsor Needs

- Definition of the goal of the study
- Due date of the study
- Criteria to judge the successful completion of the study
- Initial situation, expected results, constraints

Offer

- Description of the initial situation
- Description of the goal of the study
- Contents of the study (work packages)
- Scope of the study
- Project management details (teams, meetings, etc.)
- Expected hardware and software environment
- Costs
- Due dates
- Legal issues (terms of payment, nondisclosure agreements, etc.)

Final Reports

- Goal of the simulation study
- Input data
- Modelling assumptions
- Structure of the simulation model
- Control strategies
- Model variants
- Design of experiments

- Simulation results including analysis and interpretation
- Measures of V&V
- Comments about model re-use

It is important to note that not all documents listed above will be required in every simulation study. In addition, the documents will provide the information at different levels of detail. The main purpose is not to generate as much pages as possible but to make transparent all decisions which had to be made during the course of the study.

3 Support utilities for quality criteria compliance

In order to obtain a high quality of all outcomes, intermediate and final, it is essential to consider the aspect of quality during the whole course of a project. This approach is especially expressed by the fifth quality criteria *Systematic Project Implementation* as described in Section 1. Since a consistent and systematic implementation is sometimes difficult to achieve - in particular for companies which use simulation for the first time - assistance has to be provided, e. g., by checklists like the ones developed by the authors of [2]. These checklists cover each phase of a simulation project and are particularly designed for daily and simple use.

The checklists support both customers and simulation experts with a collection of predefined recommendations of activities in each single project phase.

The given recommendations of activities are consciously expressed in an application-independent manner so that they can be used in any industrial branch. This means that the project manager has to decide which recommendation is applicable for the project under consideration when taking into account specific characteristics of the project definition and the given project environment. On the other hand, this means that the given collection of recommendations as published in [11] cannot be exhaustive.

Although it is basically possible to support the systematic project implementation by using simple ticklists, it was the aim of the authors of [2] to provide a dynamic tool which even allows keeping record of organisational data like appointments, responsibilities and remarks. Hence, consistently used checklists can even be used as part of the project documentation. Furthermore, this allows performing a transparent and comprehensible project implementation throughout all phases. Even in case of problems, causes of faults as well as the corresponding responsibilities can easily be tracked.

The tailor-made checklist form (cf. Fig. 2) supports the completion of the five basic quality criteria (see Section 1). The form offers a structured overview of all recommendations of activities for a specific project phase and allows to plan, to implement and to trace each single activity and its potential outcomes in a structured way.

The form consists of several parts for storing different kinds of information:

Header This part of the form contains general information about the project, the specific phase (name of the list; see list of available checklists below), the involved partners and the responsible project manager. He has to take care of a consistent use of all checklists and has to sign each list when closed.

Work Area This major part of each checklist contains all recommended activities for each project phase as well as the corresponding organisational

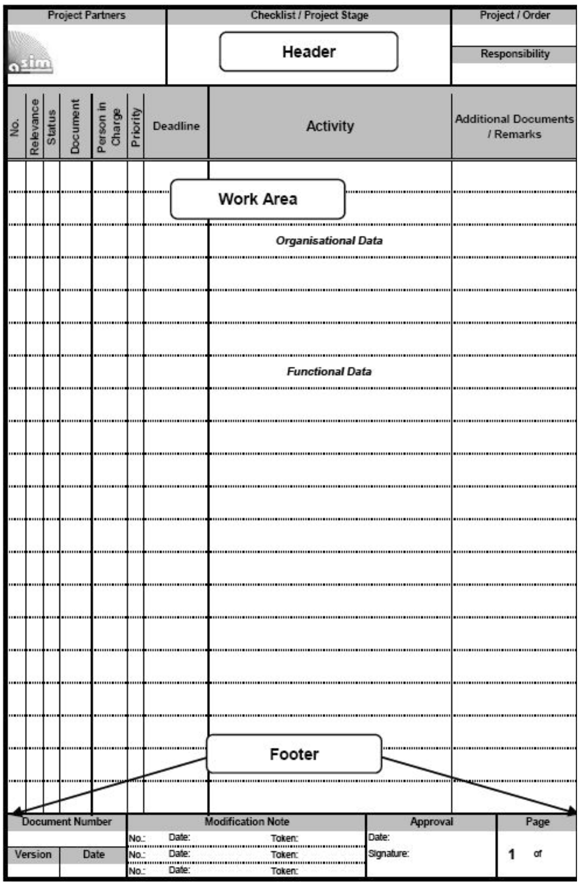

Figure 2. Checklist form – total view (see [2]).

information (see example in Figure 3). The activities are grouped into organisational and functional items in order to provide a guideline for the specific project phase. Each given recommendation has to be rated as relevant for the project or not. If relevant, a responsible person for the activity has to be assigned and a priority indicator as well as a deadline has to be specified. During the project the current status of each activity has to be tracked in the checklist. Relevance, status and priority should be depicted by symbols easy to understand. A reference to a part of the documentation which has to be prepared during the project should be given in the column *Document*. These documents should be written according to the proposed documentation structure for simulation projects in [2]. The proposed document identifier *Dx,y* indicates the document number *x* and the chapter number *y*. Documents that extent the recommended standard documentation should be referenced by an acronym (see example "*oD*" in Figure 3). Of course, the list of recommendations can be enhanced with project specific items by the project team.

Footer The lower part contains organisational data regarding the checklist itself. Besides the document and the page number, the version and the date of publishing have to be given here in order to fulfill the requirement of traceability. It is obvious that any change to a recommended activity has to be noted down together with an identification code of the initiator. Finally, when all activities have been done and the project phase is completed, the checklist has to be closed by the signature of the project leader. In case that a certain project phase has to be passed through

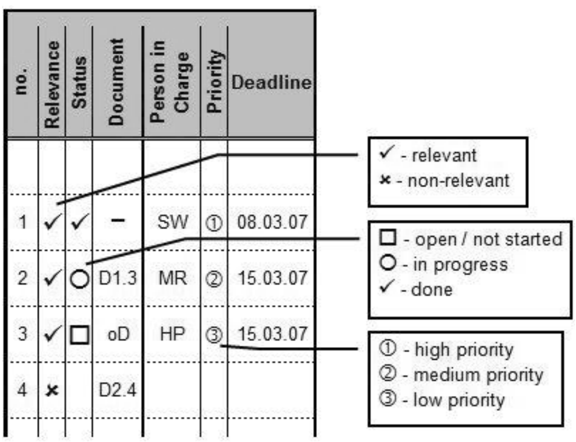

Figure 3. Organisational information in the work area of a checklist (see [2]).

another time because an iteration is necessary a new form of the same corresponding checklist shall be used.

The following 18 checklists are available in [2]. Each checklist can be identified either by a name or by an acronym built of a "*C*" plus a number and potentially a further attribute. Figure 1 in Section 2 illustrates how the checklists relate to the activities in the Extended Procedure Model:

- C1 Contractor's Project Preparation
- C2 First Meeting
- C3 Proposal Preparation
- C4a Proposal Selection
- C4b Tool Selection
- C5 Kick-off-Meeting
- C6 Problem Definition
- C7a Data Collection
- C7b Data Preparation
- C8a System Analysis
- C8b Model Formalisation
- C8c Implementation
- C9a Model Approval
- C9b Project Approval
- C10 Experimentation
- C11 Final Documentation
- C12 Final Presentation
- C13 Subsequent Use

A representative example of a checklist for an early project phase is given in Figure 4. Checklist *C2 – First Meeting* contains recommendations for organisational and functional activities which should be performed by the project participants – contractors and potential simulation experts – when they meet for the first time to discuss the intended simulation project in detail.

An example of an organisational recommended activity is "*Define date, location and group of participants; invite in time*"; no. 1 in checklist *C2 – First Meeting* (cf. Fig. 4). Although it is a very simple advice and seems to be obvious, it is even more important to note it down in a checklist so that it cannot be forgotten.

A very important example of a functional recommended activity for the first meeting between contractor and simulation expert is "*Clarify and define budget allowances*", No. 18 in Figure 4. Although not technical, this activity impacts the next steps of the simulation expert in case he is requested to prepare a

Project Partners							Checklist / Project Phase
asim							C2 – First Meeting
No.	Relevance	Status	Document	Person in Charge	Priority	Deadline	Activity
							Organizational Data
1			–				Define date, location, and participants; invite in time
2			oD				Distribute documents for preparation of meeting
3			oD				Determine person for minutes; write minutes in time
4			–				Approve minutes, determine recipients, distribute minutes
5			–				Plan for second meeting, update/extend list of participants
6			–				Define next steps, e.g., write offer, plan on-site visit
							Functional Data
7			D1.1				Ask for approval for problem description; add details (if necessary)
8			D1.2				Define system limits (plan on-site visit, if necessary)
9			D1.2				Define goals / research questions for study
10			D1.2				Ask for approval for outline of expected results and for form of presentation
11			D1.2				Discuss potential solution approaches and determine appropriate approach
12			D1.2				Outline project milestones and ask for approval
13			D1.2				Discuss intended application of results and models
14			D1.3				Define work packages and discuss whether additional partners are needed
15			D1.3				Determine third party reporting requirements
16			D1.3				Determine non-disclosure agreement requirements
17			D1.3				Clarify / determine time restrictions for the project
18			D1.3				Clarify / determine budget restrictions
19			D1.3				Define modeling and project approval criteria
20			D1.3				Define form and amount of documentation, define form of results
21			D1.3				Check / define hardware and software constraints
Document Number				Modification Note			Approval

Figure 4. Extract of Checklist C2 – First Meeting (see [2]).

quotation for the simulation project. The example in Figure 4 shows that the recommended activities are ordered logically within the two groups. The users of the checklist just have to follow the list deciding which recommendations are relevant for the specific project. In the next step, they have to decide about the persons in charge, the priorities and the deadlines for the relevant activities. Of course, it is possible to add further activities individually based on the project and its characteristics. While the decisions for relevance, persons in charge, priorities and deadlines for organisational items can mostly be taken by one party before the project phase starts, most of the decisions regarding the functional items have to be taken by all involved parties during the project phase – here: during the first meeting.

For a further support of contractors and simulation experts in order to achieve high quality level simulation projects, the authors of [2] advise to use methods which allow, e. g. a systematic selection of proposals or simulation tools based on assessment criteria and procedures. These methods were adopted from design methodology and support objective results in decision processes; see also [16].

4 Summary

Simulation is a well-established decision and analysis tool in industry and academia. Nevertheless, it is still important to foster a high-quality attitude of all partners in simulation projects.

In our paper, we provided several methods to achieve this goal, namely fundamental quality criteria, an extended procedure model, and problem-specific checklists. Based on our experience, these methods can be practically applied and they are helpful to initiate and implement simulation projects at a high quality level.

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