Credible Simulation Process

SET Level

Simulation-based Engineering and Testing of Automated Driving

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Key Information about the SET Level project

SET Level deals with simulation-based engineering and testing of automated vehicles. In the project, research and development staff of 20 project partners in science and industry are co-operating to form the basis for reliable verification methods and thus for later approval of automated driving functions. It started in 2019 and is funded by the German Federal Ministry for Economic Affairs and Energy programm dealing with new automotive and system technologies ("Neue Fahrzeug- und Systemtechnologien").

SET Level builds upon the PEGASUS cooperation project completed in May 2019. In that project, partners from science and industry developed quality standards and methods for securing autonomous vehicles. The focus was on the context of motorway traffic. SET Level further develops the simulation approaches of PEGASUS on a broader basis and extends the application to the whole traffic environment.

Information about this document

Document title	Credible Simulation Process
Version and release date	v1.1, 13.08.2021
Short description	Description of a process for performing simulation tasks with a focus on traceability and reuse. The process is designed in such a way that it can be integrated and adapted to specific company processes. The elements necessary for quality assurance are available and can also be specifically tailored.
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Changelog

Version	**Date**	**Changes**
1.0	02.07.2021	Initial release
1.1	13.08.2021	Changed license to CC BY-SA 4.0. Replaced figure 5.

Additional important information

The basic principles of the Credible Simulation Process and the associated process framework were developed as a result of the prostep SmartSE project. The detailing and specification for the simulation-based development and testing of automated vehicles in the form presented here took place within the scope of the SET Level project. Further development and maintenance will take place in prostep SmartSE.

Table of Contents

List of Figures

1 Introduction

Virtualization and digitalization are becoming more and more important in development. However, this also means that decisions and releases will be based much more on virtual prototypes (simulation models). This results in:

- The simulation must be integrated into the development processes
- Statements about the reliability of the results must be available
- Traceability and comprehensibility must be guaranteed
- The development will take place on a more cooperative basis with partners, the procedures and infrastructures should therefore be coordinated industry-wide (automotive-wide)

In the following a simulation process is described, which enables and supports these aspects. The description is deliberately kept on a generic level, which can be adopted across companies and must then be concretized in a company-specific and application-specific manner. This described basic sequence of steps shall enable the structured documentation of the information created and used in the simulation process.

This is the basis for the transition from a simulation process to a Credible Simulation Process (CSP).

- Consistent documentation with traceability and quality assurance
- Finding and reuse of information and artifacts (models, infrastructures, etc.)

This description of the CSP is not a simulation handbook or a guideline for the creation of domain-specific models (which effects should be realized and tested, and how should this be done), but a guideline for the implementation of simulation processes with focus on traceability, comprehensibility and completeness of the documentation.

1.1 Target Group

The following target groups can be distinguished according to the type of information they require.

Group 1

These groups of people are addressed here:

- Persons responsible for the simulation
- Persons entrusted with the implementation of simulation environments and integration into company structures
- Persons entrusted with the implementation of simulation-based development and processes
- Persons responsible for virtualization

They need additional know-how and access to company-specific processes, IT infrastructures, as well as simulation and specific domain knowledge.
Their task is the specific implementation and concretization of the CSP for user group 2.

Group 2

- Simulation teams, users

- Model developers

Group 2 does not belong to the direct target group of the CSP. The CSP must be implemented specifically by group 1 for group 2.

1.2 Description of a Generic Engineering Process

A process is a defined sequence of phases (see [1]). This enables reproducibility with consistent quality.
Each phase has inputs (necessary preconditions), the phase itself (what is done), and the output (result).

This structuring and documentation of the necessary information is the basis for traceability and quality assurance.

When implementing processes in companies or domain-specific applications, the "How?" (methods) and "With What?" (tooling) are specifically defined.

1.2.1 Basic Structure of an Engineering Process (Phases)

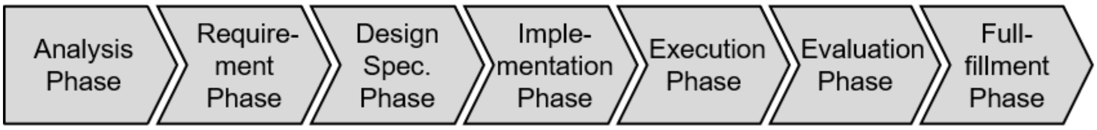

Figure 1: Basic structure of an engineering process

Analysis Phase

- Description of general engineering task
  - Example: Development of an AD driving function based on camera signals
- Description of specific engineering task and objectives
  - Example: Detection of critical occlusions when turning right with pedestrians
- Determination of general requirements and objectives for the solution approach
  - Example: Usage of simulation, consider effect X during the occlusion in your simulation

Requirement Phase

- Further determination of the requirement specification of the solution approach and specification of the requirements of the different elements of the solution approach
  - Example: Consider only aperture angle of the camera in your simulation, the simulation environment should run at least ten time faster than real-time

Design Phase

[1] https://de.wikipedia.org/wiki/Wasserfallmodell, https://de.wikipedia.org/wiki/Vorgehensmodell_zur_Softwareentwicklung

- Determination of how the solution approach will be realized
  - Example: In the camera model, effect X should be modeled with approach Z

Implementation Phase

- Implementation of the solution approach
- Verification of the solution approach
  - Example: Creation and testing of the camera model, integration into simulation environment

Execution Phase

- Application of the solution approach
  - Example: Execution of the simulation

Evaluation Phase

- Evaluation of the results
  - Example: Evaluation of the simulation results

Fulfillment Phase

- Decide if the requirements of the task have been met
  - Example: Based on the simulation results the requirements are fulfilled / not fulfilled

1.2.2 Application of the Process

The process is divided into phases. You can only process a phase completely if all inputs from the previous phase are available in the required form (waterfall model).
In reality, this complete availability of information is usually not given. There are iterations in the phases and across the phases. In larger projects it is necessary, especially for the collaboration of teams, to have stable, defined work statuses and intermediate results.

Approaches to this are:

- The process is run through several times (see Figure 2, pattern stages A, B, C). The output of one run is then the input for the next.
- According to certain criteria (maturity of results, time (e.g. sprints in SCRUM)) the results are frozen (program states, ...) and serve as common basis for the development until the next freeze (see Figure 3).

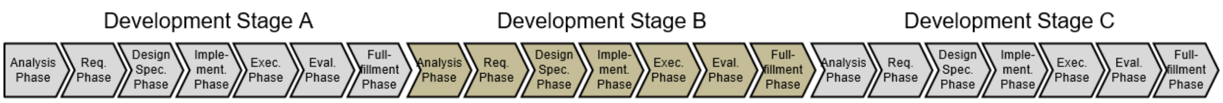

Figure 2: Approach for iteration in engineering processes

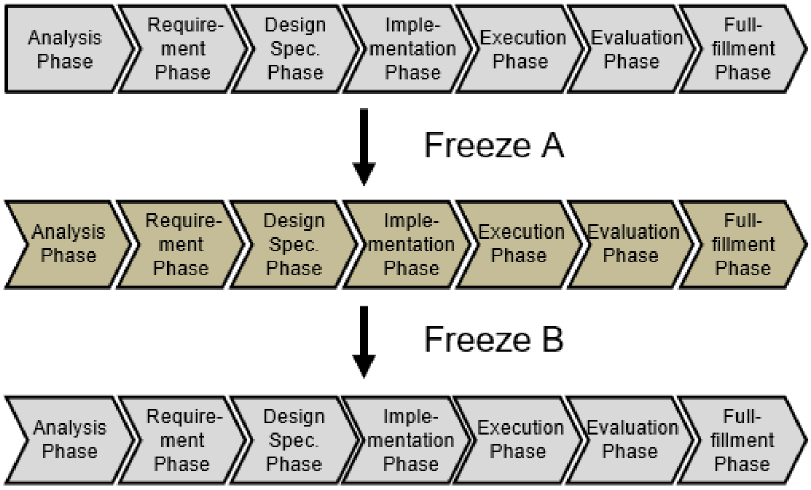

Figure 3: Approach with freezes for iteration in engineering processes

1.2.3 Differentiation between New Application and Variant

If the process is applied to a new application, many infrastructures necessary for the execution of the process (e.g. simulation environment, models) usually have to be created and tested before the actual task can be performed. This means that all steps of the process must be performed.

In case of a variant development, it is often possible to reuse existing infrastructure and partial solutions. The task in the steps is then limited to checking whether the prerequisites for the application are covered and, if necessary, adjustments are made. For example: Does the simulation environment cover this parameter range during a parameter variation?

1.3 Introduction and Short Description of the Credible Simulation Process

The basic structure of the CSP and its embedding in the higher-level processes is shown in the following Figure 4:

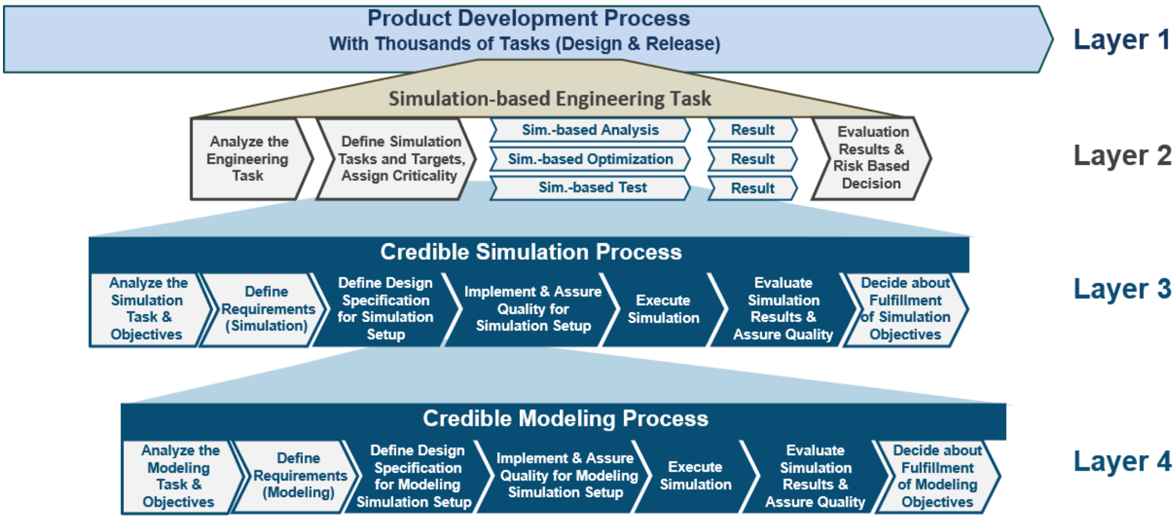

Figure 4: Basic structure of the CSP and its embedding in the higher-level processes

In a product, platform or basic development there are many engineering tasks with corresponding decisions and approvals (Layer 1).

One of the many engineering tasks is the Simulation-based Engineering Task (Layer 2, see [2]): This means that simulation is an essential component for the execution and reliability of the subtasks. In the Simulation-based Engineering Task it is defined with which solution approaches the task is to be processed and what the objectives and the requirements are for the solution approaches. This information and the simulation task itself are input for the CSP. The Simulation-based Engineering Task can include real tests if they are compared to simulations. In the CSP, subtasks like model development can be defined and initiated (Layer 3). The information is then passed on to the Credible Modeling Process (CMP, see [3]) on Layer 4.

All processes listed here have the basic scheme described in Figure 1.

The first two phases in the higher-level process (Layer 2) are run through, then the relevant information is given to the lower-level process (Layer 3) and processed there. The specifications in the second phase "Define Requirements" of the CSP (Layer 3) and the CMP (Layer 4) should be defined in coordination with the parties of the higher-level process. For emphasis, the phases with coordination between the processes and Layers are shown in white.

The description in the CSP is explicitly kept on a generic level, which can be adopted across companies and must then be concretized in a company-specific and application-specific manner. The CSP provides a framework for the usage of methods, but does not specify which methods should be used.

1.4 Credibility of the Simulation

Essential basic elements of credibility are traceability and comprehensibility.
The in the previous sections described basic sequence of process steps enables the structured documentation of the information generated and used in the simulation process.

The requirements for the credibility of a simulation result depend strongly on the specific application and the potential risk of a wrong decision. The higher the requirements for the credibility of a result, the higher the effort for the validation. The effort for the validation should be appropriate to the risk. If, for example, a rough estimation is made in the early phase of a project on the basis of simulation, the potential damage (risk) is manageable. In the CSP the elements necessary for quality assurance are provided. Which quality standards are applied and how they are implemented (ASPICE, ASIL, ...) must be company-specific and application-specific. The CSP does not contain any specific requirements regarding the implementation.

[2] The Simulation-based Engineering Task is another process being defined in the SET Level project, but not yet published.

[3] The Credible Modeling Process is another process being defined in the SET Level project, but not yet published.

2 Credible Simulation Process

The following Figure 5 shows the seven phases of the CSP. Each phase is described in detail in the subsequent text.
Typical applications of the CSP are System Analysis, Optimization and Test. The CSP differs here only in some specific aspects. For better readability, the synonym "test" is used for System Analysis, Optimization and Test.

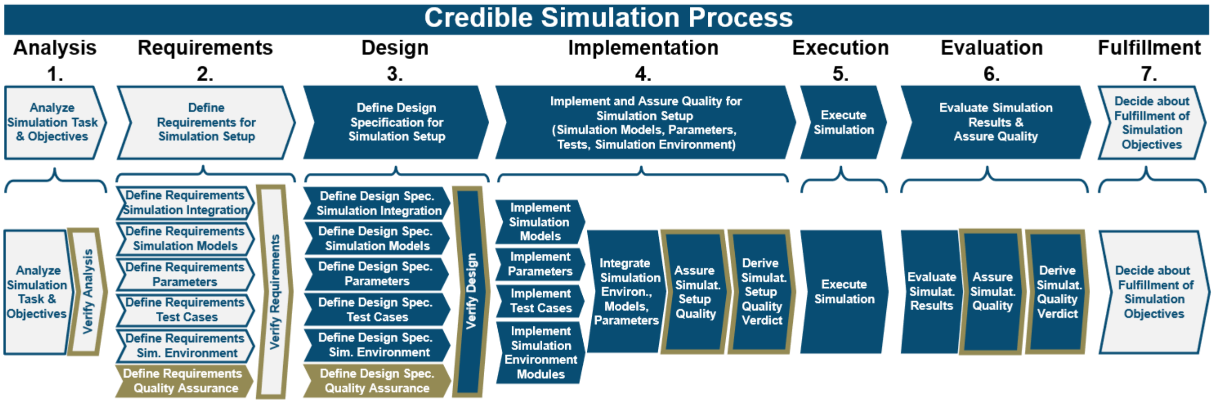

Figure 5: Overview of the Credible Simulation Process

Structure of CSP in Phases and Steps

As shown in Figure 5, the phases in the CSP can have sub-elements called steps. These process steps are used to sub-structure the individual phases. Individual process steps can be processed in parallel or sequentially.

Structure of a Process Step

The process steps are all structured according to the following scheme:

- **Title**
  Title and short description of the step
- **Process Execution**
  Description of what should be done in this step
- **Inputs**
  List of required information
- **Outputs**
  Listing of the work results that are required in the further steps.
- **Credibility Documentation**
  Procedure Documentation with Quality Assurance
  Rationale/Reasons (for xyz)
- **Roles**
  Nominated (responsible) persons
- **Required Expertise**
  Optional, usually only notes
- **Used Infrastructure, tools, methods**
  Optional, usually only hints

- **Comment**
  Optional, additional comment

Usage of the CSP

The CSP is a recommendation that should be applied when deriving a concrete company or domain specific CSP. The role is then replaced by Life Cycle Information. Here it is documented in which life cycle (Drafted, Defined, Validated, Approved, Archived, Retracted) this part of the process is currently in and who (role) releases this cycle. The specifications for the roles are exemplary. The role descriptions and names are to be adapted company-specifically. The listing in Appendix A is only intended to serve as an example.

The "Required expertise" and "Used infrastructure, tools, methods" are optional. The items listed are to be regarded as examples.

2.1 Analyze Simulation Task & Objectives (Analysis Phase)

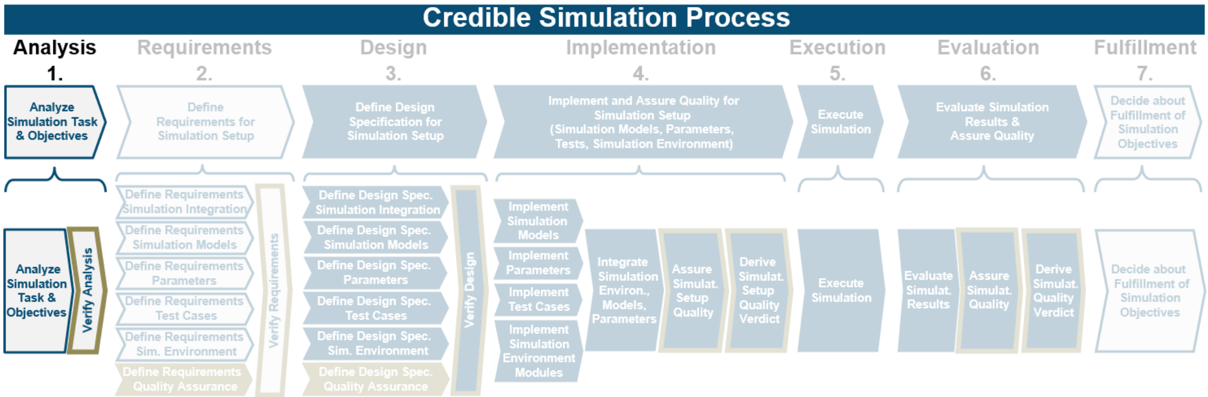

Figure 6: Focus on phase 1 of the Credible Simulation Process

Phase 1 "Analyze Simulation Task & Objectives" contains information and a description of the engineering task of the higher-level engineering process as well the general requirements and objectives, e.g. KPI and other criteria, for the simulation task. In phase 2 "Define Requirements for Simulation Setup", the requirements for the simulation task are further detailed and assigned to the elements of the simulation setup. The input information in phase 1 of the CSP is a copy of the relevant information of the corresponding part of the higher-level engineering process. In this process phase 1, the information from the higher-level engineering process is further specified and detailed with regard of the needed information in the following phases of the CSP. This includes the description of the developed product (e.g a car), the specific engineering task and its relevant environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …), development objectives, KPI and criteria. The content handled in this phase may be extended, but there must be no inconsistencies with the content of the higher-level engineering process, otherwise a change request must be issued for the higher-level engineering process. It is a coordination process between phase 1 of the CSP and the higher-level process. The result of the coordination is documented in both for seamless traceability. "Master" is the higher-level process. If a higher-level process is not explicitly present, the assumptions are described in CSP phase 1.

Differentiation between task and objectives:

Simulation task:

- What has to be simulated, description of the task; the focus is more on the "What"

– Example: Simulate a road crossing with a vehicle turning right and a pedestrian crossing then further details for clarification

Simulation objectives:

- Finding out how critical this situation of pedestrians crossing is
- Here it must be determined what is critical

In practice, the following aspects can be assigned to both tasks and objectives:

- Parameter ranges
- Effects that are to be considered (weather, occlusion, effects of components, functions)

The higher-level process defines the criticality of the simulation task as input. The criticality of the simulation task means: How critical is the influence of the result on the decision in the higher-level process? What potential damage can occur if the decision, based on the result of the task, is wrong?
Typically, not the criticality itself is given as input, but the according (company or domain) specific quality process or quality aspects which must be fulfilled. Also, a decision in an early stage of the development can have a big impact, e.g. if a wrong setting of a sensors is chosen.

Process execution:

- Further specification and clarification of the simulation task and objectives (general requirements and objectives, e.g. KPI and other criteria)
- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- General project information
- Engineering task, development objectives and specifications of higher-level engineering process
- Description of product, the requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Simulation task and objectives
- Explanation why simulation was chosen as solution approach for the engineering task
- Quality aspects derived from the criticality of the decision of engineering task

Outputs:

- Specific, detailed description of product, requirements, environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task

- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Result of analysis verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer
- Simultaneous Engineering Team

Required expertise:

- Domain expert

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.1.1 Analyze Simulation Task & Objectives

Phase 1 "Analyze Simulation Task & Objectives" contains information and a description of the engineering task of the higher-level engineering process as well the general requirements and objectives, e.g. KPI and other criteria for the simulation task (see also 2.1).

Process execution:

- Further specification and clarification of the simulation task (general requirements and objectives, e.g. KPI and other criteria)

Inputs:

- General project information
- Engineering task, development objectives and specifications of higher-level engineering process
- Description of product, the requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Simulation task and objectives
- Explanation why simulation was chosen as solution approach for the engineering task
- Quality aspects according to the criticality of the decision of the engineering task

Outputs:

- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer
- Simultaneous Engineering Team

Required expertise:

- Domain expert

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.1.2 Verify Analysis

In step 2 "Verify Analysis" of phase 1 the outputs and credibility documentation of phase 1 are verified and the result is documented. Verification can be, for example: Are all objectives selected appropriately? Has the procedure documentation been checked? A formal verification is often necessary from the point of view of quality assurance.
If the results are needed for quality gates or similar predefined by a (company specific) quality process, they have to be prepared in this step.

Process execution:

- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- Simulation task and objectives
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)

- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Quality aspects derived from the criticality of the decision of engineering task
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task

Outputs:

- Result of analysis verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Quality Expert
- Simultaneous Engineering Team

Required expertise:

- Domain expert, Quality assurance

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.2 Define Requirements for Simulation Setup (Requirement Phase)

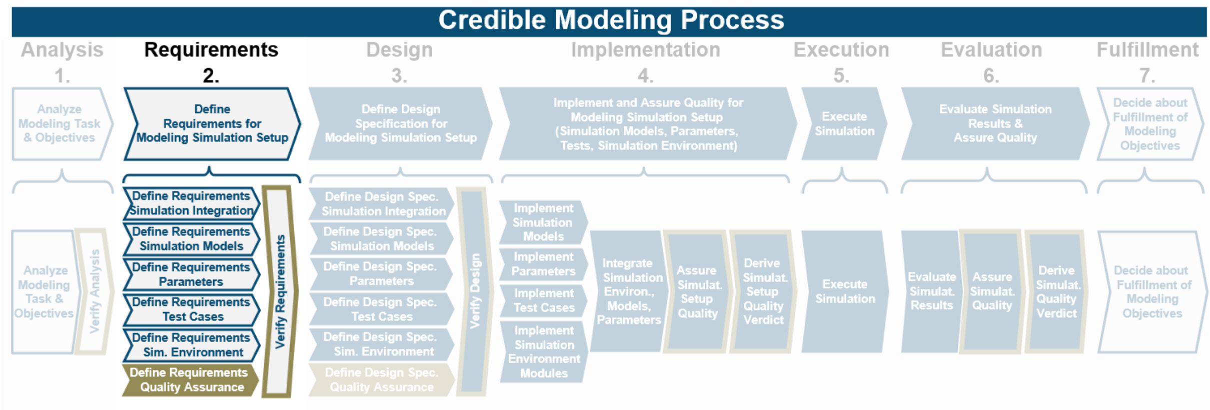

Figure 7: Focus on phase 2 of the Credible Simulation Process

In phase 2 "Define Requirements for Simulation Setup" the requirements from phase 1 "Analyze Simulation Task & Objectives" are further detailed. An essential step is the clarification of the general conditions, relevant assumptions and requirements that the simulation has to fulfill. That also means that it should be clarified what (e.g. which effects) should be considered, what neglected and why. The requirements of the simulation task are broken down into the individual requirements for the simulation integration, models, parameters, test cases, simulation environment and quality assurance.

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill
- Break down of the requirements of the simulation task into the individual requirements of the simulation integration, models, parameters, test cases and simulation environment
- Definition of requirements for quality assurance
- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance

  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.1 Define Requirements for Simulation Integration

In step 1 "Define Requirements for Simulation Integration" of phase 2 the framework conditions, the relevant assumptions and the requirements that the simulation must fulfill are clarified. Also, the requirements of the simulation task are broken down into the individual requirements for the simulation integration elements. This is an iterative process between all steps of phase 2.

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill
- Break down of the requirements of the simulation task into the individual requirements for the simulation integration

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)

- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Specific quality requirements for the simulation integration

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.2 Define Requirements for Simulation Models

In step 2 "Define Requirements for Simulation Models" of phase 2 the framework conditions, the relevant assumptions and the requirements that the simulation must fulfill are clarified. Also, the requirements of the simulation task are broken down into the individual requirements for the simulation models. In the case of usage of the models in several projects or with partners olso IP-protection has to be considered. This is an iterative process between all steps of phase 2.

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill

- Break down of the requirements of the simulation task into the individual requirements for the simulation models

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for simulation models
- Specific quality requirements for the simulation models

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.3 Define Requirements for Parameters

In step 3 "Define Requirements for Simulation Parameters" of phase 2 the framework conditions, the relevant assumptions and the requirements that the simulation must fulfill are clarified. Also, the requirements of the simulation task are broken down into the individual requirements for the parameters. This is an iterative process between all steps of phase 2.
In this process step the requirements have to be clarified for:

- Quality assurance of the parameters or the chain from the data source to the parameter
- The implementation aspects, when for example material data is processed for the data input of the models
- Parameter structures that are used according to model structures
- The infrastructure for handling different parameter sets (parameter management)

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill
- Break down of the requirements of the simulation task into the individual requirements for the parameters and handling of parameters

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for parameters
- Specific quality requirements for the parameters

Credibility documentation:

- Procedure documentation with quality assurance

- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.4 Define Requirements for Test Cases

In step 4 "Define Requirements for Simulation Test Cases" of phase 2 the framework conditions, the relevant assumptions and the requirements that the simulation must fulfill are clarified. Also, the requirements of the simulation task are broken down into the individual requirements for the test cases. This is an iterative process between all steps of phase 2.

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill
- Break down of the requirements of the simulation task into the individual requirements for the test cases (or optimization see introduction)

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for test cases (the test cases or optimization criteria targeting the simulation objective)
- Specific quality requirements for the cases

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.5 Define Requirements for Simulation Environment

In step 5 "Define Requirements for Simulation Environment" of phase 2 the framework conditions, the relevant assumptions and the requirements that the simulation must fulfill are clarified. Also, the requirements of the simulation task are broken down into the individual requirements for the simulation environment. This is an iterative process between all steps of phase 2.

Process Execution:

- Clarification of framework conditions, the relevant assumptions and the requirements that the simulation must fulfill
- Break down of the requirements of the simulation task into the individual requirements for the simulation environment

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)

- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
  - Part of design specifications can be included
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for simulation environment
- Specific quality requirements for simulation environment

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Project management environment, product data management, quality engineering

Comment:

2.2.6 Define Requirements for Quality Assurance

In this process step the requirements for the quality assurance are specified, including company and domain-specific quality assurance requirements or requirements for quality standards such as ASPICE or ASIL.

Process Execution:

- Definition of requirements for quality assurance

Inputs:

- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance

Outputs:

- Requirements for quality assurance

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Quality Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Quality engineering

Comment:

2.2.7 Verify Requirements

In step 7 "Verify Requirements" of phase 2 the outputs and credibility documentation of all steps of phase 2 are verified and the result is documented. Verification can be, for example: Are all outputs of the steps consistent? A formal verification is often necessary from the point of view of quality assurance.
If the results are needed for quality gates or similar predefined by a (company specific) quality process, they have to be prepared in this step.

Process execution:

- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- Engineering task, development objectives and specifications of higher-level engineering process
- Specific, detailed description of product, requirements and environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Detailed explanation why simulation was chosen as solution approach for the engineering task
- Requirements for the simulation task and the according environment (comes from higher-level process)
    - Part of design specifications can be included

- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task
- Company specific regulations regarding quality assurance
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements

Outputs:

- Result of requirements verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project engineer, development engineer, Quality expert
- Simultaneous Engineering Team

Required expertise:

- Domain expert, Quality assurance

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.3 Define Design Specification for Simulation Setup (Design Phase)

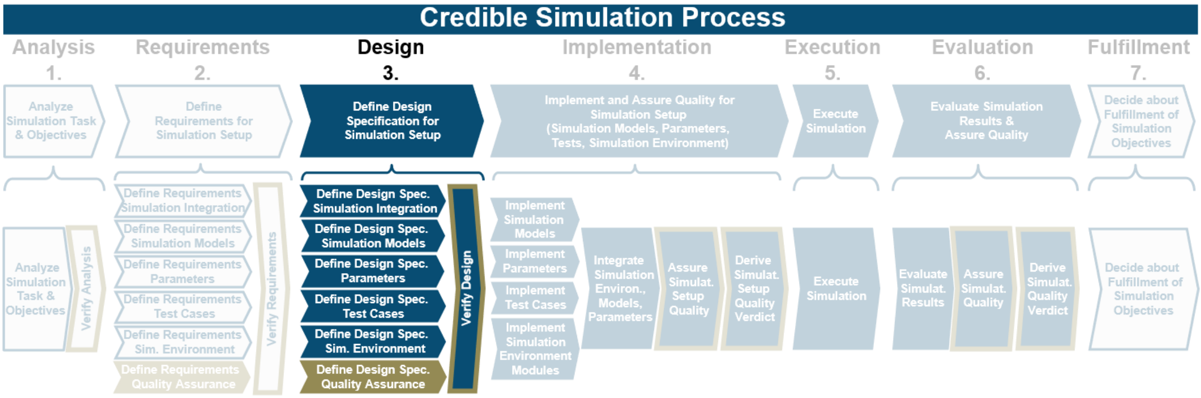

Figure 8: Focus on phase 3 of the Credible Simulation Process

In this process phase, the design specification (how is it realized?) for the simulation task is determined from the requirements, as well as the design specifications for the corresponding simulation integration, models, parameters, test cases, simulation environment and quality assurance. The design specification must contain consistent, coordinated design requirements for all artifacts, models, tools, parameters with interfaces, versions, etc. Important is also the documentation why the respective type of realization was chosen. Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks.

Process Execution:

- Definition of design specification for simulation integration, models, parameters, test cases and simulation environment
- Documentation of reasons for design specifications
- Definition of design specification of quality assurance of the simulation setup and its elements (which methods and test sets are used to check the quality of the simulation environment and its elements in its specific operating range (which is larger than the range used in the actual tests))
- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment

- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification for simulation integration (also design specification for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Design specification models
- Design specification parameters
- Design specification test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Design specification simulation environment, including design specification of workflow, data flow
- Design specification for quality assurance
  - Quality design specifications regarding the simulation and the simulation setup are part of the design specification for quality assurance
  - Specific quality design specifications for the individual elements (models, parameters, test cases, simulation environment) are part of the design specifications for the elements
- Result of design specification verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- Quality Assurance
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:
Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks.
With the help of conceptual implementations, implementation approaches for aspects that the model has to perform can be tested and evaluated in advance.
They also serve to explain why the design specifications are defined in this way.

Conceptual implementations can be:

- Modeling approaches from literature, they do not have to be implemented
- Prototypical implementations; these can also take place in other modeling languages, tool environments (these prototype implementations can also be used afterwards for test purposes)

Conceptual models can be used for testing aspects of the developed model.

2.3.1 Define Design Specification Simulation Integration

In this process step, the design specification for the simulation integration is determined from the requirements. It is defined how the models and their parametrization are implemented in the simulation environment, how the elements interact with each other, and how tests and simulation are initialized, performed and evaluated.
This step 3.1 Design Specification Simulation Setup should be the first in Phase 3 "Define Design Specification for Simulation Setup". In this step further requirement specifications and also design specifications for the models, parameters, test cases and the simulation environment are defined. In practice, this is an iterative process of the steps in Phase 3. Step 3.1 Design Specification Overall Simulation Setup is the bracket over the other steps in Phase 3.

Process execution:

- Definition of design specification for simulation integration (models, parameters, simulation environment, and their interaction)
- Definition of design specification for quality assurance for integration requirements (simulation setup, models included)
- Documentation of reasons for design specifications

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)

- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification for simulation integration (also design specification for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Specific quality design specifications for the simulation integration (i.e. integration tests)

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer, Test Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Domain Expert, Test Environment Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.3.2 Define Design Specification Simulation Models

In this process step, the design specification for the simulation model is determined from the requirements. Important here is the documentation why the respective type of realization was chosen. Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks.

There are two kinds of inputs for this step. Firstly, the information about the simulation setup in which the model should finally run. This information is needed to clarify and give background information for the design specification. Secondly, the information about the requirements for the specific simulation setup in which the model has to be developed and the specific model assurance has to be performed. As an output also the specific subset of the design specification of the other steps of phase 3 has to be provided (simulation integration, parameters, test cases, simulation environment). This information is needed for clarification for the implementation of the model. This is an iterative process between all steps in phase 3. The results are documented in the specific steps.

Process execution:

- Definition of design specification for simulation model and according sub-models (structure, interfaces, design specification of models)
  - This also includes, for example, processing sequences
- In the case of usage of the models in several projects or with partners also IP-protection has to be considered
- Definition of design specification of quality assurance for model, sub-models i.e. tests
- Check if available parameters fit chosen design
- Create necessary subset of information for model implementation from the outputs of the other steps of phase 3

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification for models
- Design specification for model specific simulation set up
- Subset of information needed for model implementation from the design specifications of the other elements (simulation integration, parameters, test cases, simulation environment)
- Specific quality design specifications for the models

Credibility documentation:

- Procedure documentation with quality assurance

- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks. With the help of conceptual implementations, implementation approaches for aspects that the model has to perform can be tested and evaluated in advance. They also serve to explain why the design specifications are defined in this way.

Conceptual implementations can be:

- Modeling approaches from literature, they do not have to be implemented
- Prototypical implementations; these can also take place in other modeling languages, tool environments (these prototype implementations can also be used afterwards for test purposes)

Conceptual models can be used for testing aspects of the developed model.

2.3.3 Define Design Specification Parameters

In this process step, the design specification for the parameters is determined from the requirements. Here it is important to know how the quality assurance of the parameters or the chain from the data source to the parameter is realized and how the quality of the parameters is determined. The implementation aspects are important when for example material data is processed for the data input of the models, parameter structures are used for model structures, or the infrastructure for handling different parameter sets has to be defined.
As an output also the specific subset of the design specification of the other steps of phase 3 has to be provided (simulation integration, models, test cases, simulation environment). This information is needed for clarification for the implementation of the parameters. This is an iterative process between all steps in phase 3. The results are documented in the specific steps.

Process execution:

- Definition of design specification for parameters
- Linkage to data sheets, measurements, material data
- Definition of design specification of quality assurance for parameters
- Create necessary subset of information for parameter implementation from the outputs of the other steps of phase 3

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification for parameters
- Design specification for parameter specific simulation set up
- Subset of information needed for parameter implementation from the design specifications of the other elements (simulation integration, models, test cases, simulation environment)
- Specific quality design specifications for the parameters

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Expert, Simulation Environment Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.3.4 Define Design Specification Test Cases

In this process step, the design specifications for the test cases are determined from the requirements. In some cases, predefined test cases are already committed. Here it is important that the corresponding requirements for the models and simulation infrastructure are consistent.
As an output also the specific subset of the design specification of the other steps of phase 3 has to be provided (simulation integration, models, parameters, simulation environment). This information is needed for clarification for the implementation of the test cases. This is an iterative process between all steps in phase 3. The results are documented in the specific steps.

Process execution:

- Definition of design specification for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Description of tests in a complete and executable form
- Definition of design specification of quality assurance for tests
- Create necessary subset of information for test cases implementation from the outputs of the other steps of phase 3

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Design specification for test case specific simulation set up

- Subset of information needed for test case implementation from the design specifications of the other elements (simulation integration, models, parameters, simulation environment)
- Specific quality design specifications for the test cases

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer, Test Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Domain Expert, Test Environment Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.3.5 Define Design Specification Simulation Environment

In this process step, the design specification for the simulation environment is determined from the requirements. This includes design specifications for structure, interfaces, modules, workflow and data flow.

Important here is the documentation why the respective type of realization was chosen. Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks.

There are two kinds of inputs for this step. Firstly, the information about the simulation setup in which the (software) modules, workflow and data flow should finally run. This information is needed to clarify and give background information for the design specification. Secondly, the information about the requirements for the specific simulation setup in which the module has to be developed and the specific model assurance has to be performed.

As an output also the specific subset of the design specification of the other steps of phase 3 has to be provided (simulation integration, models, parameters, test cases). This information is needed for clarification for the implementation of the simulation environment. This is an iterative process between all steps in phase 3. The results are documented in the specific steps.

Process execution:

- Definition of design specification for simulation environment (structure, interfaces, design specification of modules)
- Definition of design specification of workflow and data flow
- Definition of design specification of quality assurance for overall simulation environment and elements

- Create necessary subset of information for simulation environment implementation from the outputs of the other steps of phase 3.

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Result of requirements verification

Outputs:

- Design specification simulation environment (structure, interfaces, design specification of modules)
- Design specification of workflow and data flow
- Design specification for simulation environment specific simulation set up
- Subset of information needed for simulation environment implementation from the design specifications of the other elements (simulation integration, models, parameters, test cases)
- Specific quality design specifications for the simulation environment

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

Conceptual implementations can be used for design specification decisions. They are handled in separate sub-tasks. With the help of conceptual implementations, implementation approaches for aspects that the module has to perform can be tested and evaluated in advance. They also serve to explain why the design specifications are defined in this way.

Conceptual implementations can be:

- Approaches from literature, they do not have to be implemented
- Prototypical implementations; these can also take place in other programming languages, tool environments (these prototype implementations can also be used afterwards for test purposes)

Conceptual "modules" can be used for testing aspects of the developed module.

2.3.6 Define Design Specification for Quality Assurance

In this process step the requirements of the quality assurance are transformed into design specifications, including company and domain-specific quality assurance requirements or requirements for quality standards such as ASPICE or ASIL.

Process Execution:

- Definition of design specification of quality assurance
- Define additional design specification for quality assurance of the setup elements (model, parameters, simulation environment, etc.)

Inputs:

- Requirement specification for quality assurance

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models
- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance

  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements

- Result of requirements verification

Outputs:

- Design specification for quality assurance (can be test, review, etc.) for the simulation and the simulation setup

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Quality Expert

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- Quality Assurance

Used infrastructure, tools and methods:

- Quality engineering

Comment:

2.3.7 Verify Design Specification

In step 7 "Verify Design Specification" of phase 3 the outputs and credibility documentation of all steps of phase 3 are verified and the result is documented. Verification can be, for example: Are all outputs of the steps consistent? A formal verification is often necessary from the point of view of quality assurance.
If the results are needed for quality gates or similar predefined by a (company specific) quality process, they have to be prepared in this step.

Process execution:

- Verification of the outputs and credibility documentation
- Documentation of the result

Inputs:

- Requirements for simulation integration (also requirements for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Requirements for models

- Requirements for parameters
- Requirements for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Requirements for simulation environment
- Requirements for quality assurance
  - Quality requirements regarding the simulation and the simulation setup are part of the requirements for quality assurance
  - Specific quality requirements for the individual elements (models, parameters, test cases, simulation environment) are part of the requirements for the elements
- Design specification for simulation integration (also design specification for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Design specification models
- Design specification parameters
- Design specification test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Design specification simulation environment, including design specification of workflow and data flow
- Design specification for quality assurance
  - Quality design specifications regarding the simulation and the simulation setup are part of the design specification for quality assurance
  - Specific quality design specifications for the individual elements (models, parameters, test cases, simulation environment) are part of the design specifications for the elements

Outputs:

- Result of design specification verification

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project engineer, development engineer, Quality expert
- Simultaneous Engineering Team

Required expertise:

- Domain expert, Quality assurance

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.4 Implement and Assure Quality for Simulation Setup (Simulation Models, Parameters, Tests, Simulation Environment) (Implementation Phase)

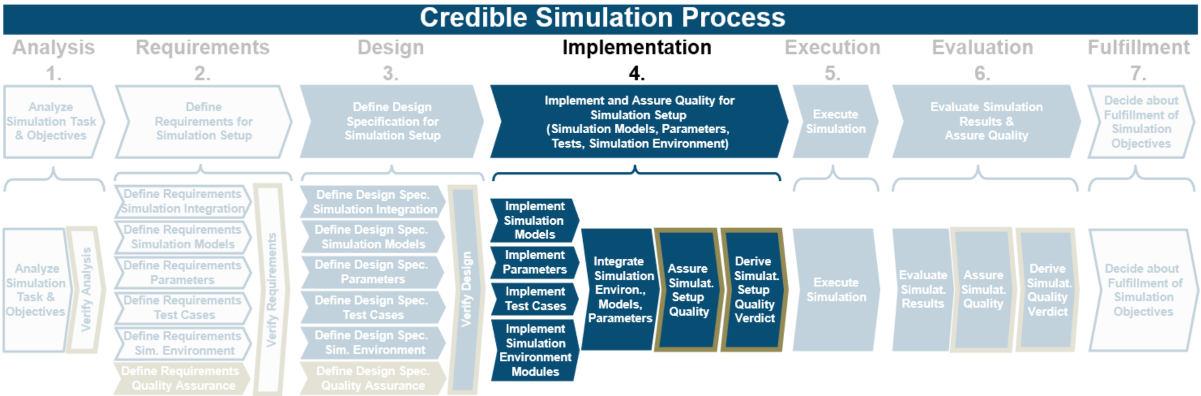

Figure 9: Focus on phase 4 of the Credible Simulation Process

In this process phase, the different parts of the simulation setup (models, parameters, test cases, simulation environment) are implemented and their functionality verified both individually and in their interaction in the simulation setup. Phase 4 is an iterative process.

Quality assurance is carried out over the specified parameter space, assured fidelity. Finally, a quality verdict about the simulation setup is performed.

Process execution:

- Implement simulation models, parameters, test cases and simulation environment modules
- Assure quality of simulation models, parameters, test cases and simulation environment modules
- Integrate elements (modules, workflow, ...) of simulation environment and perform quality assurance
- Integrate simulation environment, models and parameters to simulation setup
- Parametrization of simulation setup (solver settings, …)
- Implement and execute integration tests
- Assure quality for simulation setup (simulation environment with integrated models and parametrization) with tests and quality assuring methods
- Provide quality information about simulation setup according to the criticality of the decision of simulation task
- Assess quality information of models, parametrization, test cases and simulation environment according to the criticality of the simulation task
- Derive quality verdict about simulation setup

Inputs:

- Design specification for simulation integration (also design specification for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Design specification models
- Design specification parameters
- Design specification test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Design specification simulation environment, including design specification of workflow and data flow
- Design specification for quality assurance
  - Quality design specifications regarding the simulation and the simulation setup are part of the design specification for quality assurance
  - Specific quality design specifications for the individual elements (models, parameters, test cases, simulation environment) are part of the design specifications for the elements
- Result of design specification verification

Outputs:

- Implemented, integrated, qualified and documented simulation setup (models, parameters, simulation environment) according to requirement & design specifications
- Test cases targeting the simulation objective (or optimization, analysis criteria targeting the simulation objective)
- Quality information about simulation setup
- Quality verdict about simulation setup

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert, Quality Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.1 Implement Simulation Model(s)

In this process step, the simulation sub-models are implemented and integrated to the simulation model. Quality assurance is performed, both individually for the sub-models and in their interaction as simulation model. There are two kinds of inputs for this step. Firstly, the information about the simulation setup in which the model should finally run. This information is needed to clarify and give background information for the implementation. Secondly, the information about the design specification and requirements for the specific simulation setups in which the model and sub-models has to be developed and the specific model assurances has to be performed. The quality assurance within the "target" simulation environment is carried out in step 6 of phase 4.

Process execution:

- Implement simulation sub-models
- Integrate sub-models to model
- Quality assurance of the sub-models
- Quality assurance of the model

Inputs:

- Design specification for models
- Design specification for model specific simulation set up
- Subset of information needed for model implementation from the design specifications of the other elements (simulation integration, parameters, test cases, simulation environment)
- Specific quality Design Specifications for the models

Outputs:

- Implemented and documented models and sub-models according to requirement and design specifications
- Specific quality assurance of model and sub-models according the simulation environments the model and sub-models are developed and simulated in

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.2 Implement Parameters

In this process step, the parameter structures, the infrastructure for handling different parameter sets, and the processing of material data to model parameters is implemented. Necessary infrastructure for quality assurance of data and parameters is implemented and quality assurance performed.

Process execution:

- Implement infrastructure for parameter handling, i.e. parameter sets, parameter structures, processing of data, quality assurance
- Quality assurance for parameters

Inputs:

- Design specification for parameters
- Design specification for parameter specific simulation set up
- Subset of information needed for parameter implementation from the design specifications of the other elements (simulation integration, models, test cases, simulation environment)
- Specific quality design specifications for the parameters

Outputs:

- Infrastructure for parameter handling
- Parameter (sets)
- Quality assurance of parameters

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer, Test Engineer, IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert

- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment, material-, test database

Comment:

2.4.3 Implement Test Cases

In this process step, the test cases are implemented and quality assurance is performed. Preferably, the implementation should be done in a non-proprietary language (for reuse). Alternatively to the test cases the optimization or analysis functionality is implemented.

Process execution:

- Implement test cases (or the optimization or analysis functionality) according to the simulation task
- Assure quality of test cases

Inputs:

- Design specification for test cases (the test case or optimization or analysis criteria targeting the simulation objective)
- Design specification for test case specific simulation set up
- Subset of information needed for test case implementation from the design specifications of the other elements (simulation integration, models, parameters, simulation environment)
- Specific quality design specifications for the test cases

Outputs:

- Test cases according to simulation task (the test case or optimization or analysis functionality targeting the simulation objective)
- Quality assurance of test cases

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- Test Engineer

Required expertise:

- Test Domain Expert, Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.4 Implement Simulation Environment Modules

In this process step, the simulation environment modules, workflow and data flow are implemented and integrated to the simulation environment. Quality assurance is performed, both individually for the modules and in their interaction.

There are two kinds of inputs for this step. Firstly, the information about the simulation setup in which the (software) modules, workflow and data flow should finally run. This information is needed to clarify and give background information for the design specification. Secondly, the information about the design specification and requirements for the specific simulation setup in which the modules and workflow have to be developed and the specific module and workflow assurance has to be performed. The quality assurance with the "target" model and test cases is carried out in step 6 of phase 4.

Process execution:

- Implement simulation environment modules
  - Development and quality assurance of singular modules (separate (sub) simulation tasks) including workflow and data flow
- Integrate elements (modules, workflow, ...) of simulation environment and perform quality assurance

Inputs:

- Design specification simulation environment (structure, interfaces, design specification of modules)
- Design specification of workflow and data flow
- Design specification for simulation environment specific simulation set up
- Subset of information needed for simulation environment implementation from the design specifications of the other elements (simulation integration, models, parameters, test cases)
- Specific quality design specifications for the simulation environment

Outputs:

- Implemented and documented modules and simulation environment, workflow and data flow according to requirement and design specifications
- Quality assurance of modules and simulation environment
- Specific quality assurance of modules and simulation environment according to the prescribed models

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.5 Integrate Simulation Environment, Models, Parameters

In this process step the models with their parametrization and tests (or the optimization or analysis functionality) are integrated in the simulation environment. Integration tests are implemented and performed according to the specific quality design specifications. Phase 4 is an iterative process between steps 1 to 6, specially step 5 and 6. The results of this iterative process are documented in the according steps.

Process execution:

- Integrate simulation environment, models and parameters to simulation setup
- Parametrization of simulation setup (solver settings, …)
- Implement and execute integration tests

Inputs:

- Design specification for simulation integration (also design specification for the assembly and interaction of the elements of the simulation setup, execution and evaluation, including operation range)
- Specific quality design specifications for the simulation integration (i.e. integration tests)
- Implemented and documented models and sub-models according to requirement and design specifications
- Infrastructure for parameter handling
- Parameter (sets)
- Test cases according to simulation task
- Implemented and documented modules and simulation environment according to requirement and design specifications

Outputs:

- Implemented, integrated and documented simulation setup according to requirement and design specifications

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.6 Assure Simulation Setup Quality

In this process step quality assurance (i.e. tests) for the simulation environment with integrated models and parametrization is performed. Quality information about models and simulation environment according to the criticality of the decision of the simulation task is provided. This can be domain or company specific.

Process execution:

- Assure quality for simulation setup (simulation environment with integrated models and parametrization) with tests and quality assuring methods
- Provide quality information about model and simulation environment according to criticality of decision of simulation task

Inputs:

- Implemented, integrated and documented simulation environment according to requirement and design specifications
- Design specification of quality assurance (for model, parameters, simulation environment and integration; can be (integration-)test, review, etc.)
- Quality assurance of elements of simulation setup

Outputs:

- Quality assurance for simulation setup according to requirement and design specifications
- Quality assurance results

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer, (Quality Engineer)
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- IT Expert - Integration, IT Expert - Coupling Simulation Environment with PLM

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.4.7 Derive Simulation Setup Quality Verdict

An assessment of the quality of the simulation setup and according models, test cases, parametrization and simulation environment is carried out (according to the criticality of the simulation task). This can be domain or company specific.

Process execution:

- Assess quality information of models, parametrization, test cases and simulation environment according to the criticality of the simulation task
- Derive quality verdict about simulation setup

Inputs:

- Quality information of model and sub-models
- Quality information of test cases
- Quality information of modules and simulation environment
- Quality assurance for simulation setup according to requirement and design specifications
- Quality assurance results

Outputs:

- Quality information of simulation setup (models, parameters, test cases, simulation environment)
- Quality verdict about simulation setup

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Quality Engineer, Simulation Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert
- Quality Domain Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment, PLM

Comment:

2.5 Execute Simulation (Execution Phase)

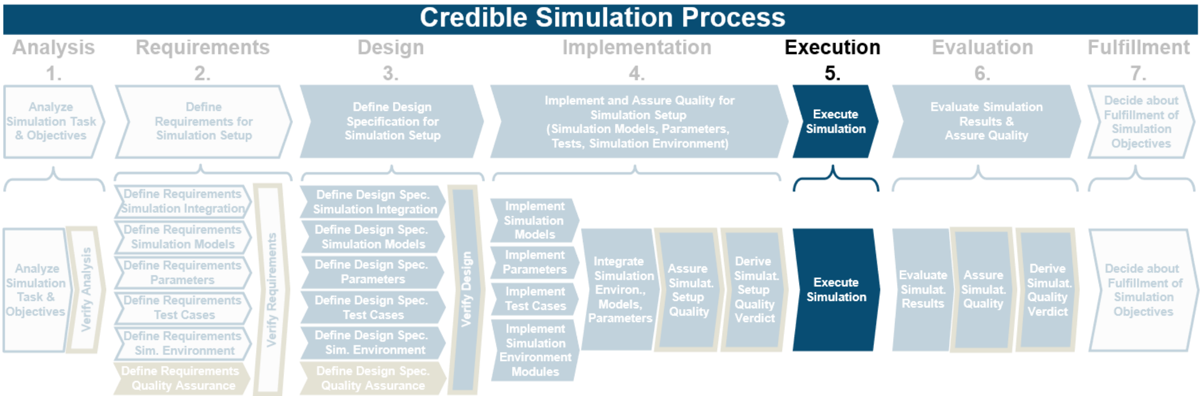

Figure 10: Focus on phase 5 of the Credible Simulation Process

In this process phase the simulation itself as well as simulation experiments relevant for the following evaluation and quality assurance are carried out. Single simulations, a given set of simulations or iterative simulations can be performed here. Phase 5 and 6 are an iterative process, results are documented in the according phases.

Process execution:

- Execute simulation according to simulation task

Inputs:

- Implemented and documented models, parameters and simulation environment according to requirement and design specifications
- Test cases according to simulation task (the test case or optimization or analysis functionality targeting the simulation objective)

- Quality information of simulation setup (models, parameters, test cases, simulation environment)
- Quality verdict about simulation setup

Outputs:

- Simulation results
- Quality information of simulation experiments (e.g error estimations or confidence range)

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer

Required expertise:

- Modeling Domain Expert, Simulation Environment Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.5.1 Execute Simulation

Phase 5 "Execute Simulation" has has no sub-steps, therefore no additional aspects are provided.

2.6 Evaluate Simulation Results & Assure Quality (Evaluation Phase)

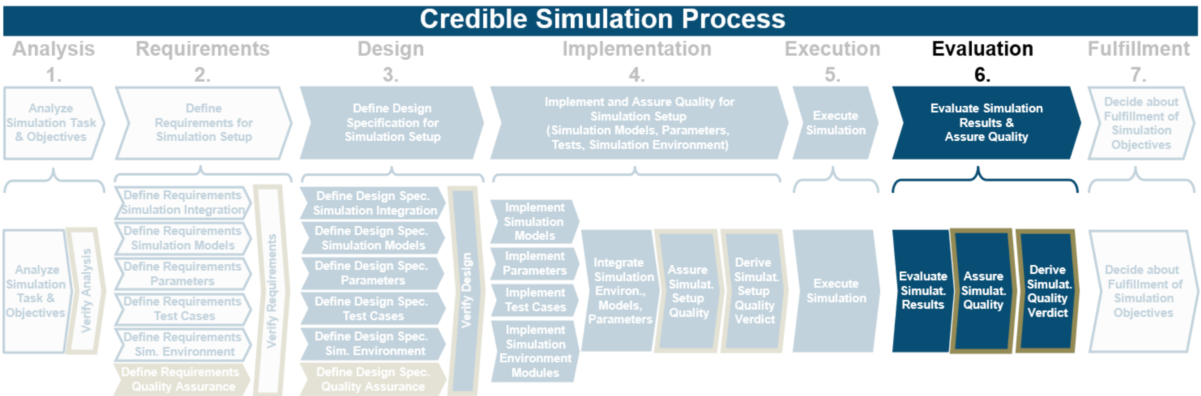

Figure 11: Focus on phase 6 of the Credible Simulation Process

In this process phase, the simulation results are evaluated, processed and quality assurance is performed. It is important here that there should be two types of statements: the results in comparison to the target values (value too large/small) and an indication of the confidence range (statement quality). Phase 5 and 6 are an iterative process, results are documented in the according phases.

Process execution:

- Post processing and quality evaluation of simulation results
- Visualization of simulation results according simulation task requirements
- Provide quality information about simulation experiments according to the criticality of the decision of the simulation task
- Check quality against chosen quality standard
- Derive quality verdict about simulation result

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Simulation results
- Quality information of simulation experiments (e.g error estimations or confidence range)
- Quality verdict about simulation setup
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task

Outputs:

- Simulation results and quality of results post processed
- Quality verdict about simulation result

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer, Quality Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert, Quality Expert

Used infrastructure, tools and methods:

- Modeling, simulation, test, post processing, visualization environment

Comment:

2.6.1 Evaluate Simulation Results

In this process step the post processing of simulation results and for the quality of results is performed. That often means the visualization of simulation results according to the simulation task requirements.

Process execution:

- Post processing of simulation results and quality of results
- Visualization of simulation results according simulation task requirements

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Simulation results
- Quality information of simulation experiments (e.g error estimations or confidence range)

Outputs:

- Simulation results and quality of results post processed

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Development Engineer, Simulation Engineer, Quality Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert, Quality Expert

Used infrastructure, tools and methods:

- Modeling, simulation, test, post processing, visualization environment

Comment:

2.6.2 Assure Simulation Quality

In this process step quality assurance for the simulation task and result is performed. Quality information about the simulation experiments is provided, according to the criticality of the decision of the simulation task. As input the results from process step 6 of phase 4 "Assure Simulation Setup Quality" and step 7 of phase 4 "Derive Simulation Setup Quality Verdict" are used:

- Quality assurance for simulation setup according to requirement and design specifications
- Quality assurance results

- Quality verdict about simulation setup (models, parameters, test cases, simulation environment)

Main focus is then the influence of the specific settings (parameters, operating points, solver settings, …).

This can be domain or company specific.

Process execution:

- Provide quality information about simulation experiments according to the criticality of the decision of the simulation task

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Implemented, tested and documented models, parameters and simulation environment according to requirement and design specifications
- Quality information of simulation setup (models, parameters, test cases, simulation environment)
- Simulation results and quality of results post processed

Outputs:

- Quality information of simulation results

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer
- (Quality Engineer)

Required expertise:

- Modeling Domain Expert, Simulation Environment Expert, Quality Domain Expert

Used infrastructure, tools and methods:

- Modeling, simulation and test environment

Comment:

2.6.3 Derive Simulation Quality Verdict

An assessment of the quality of the simulation task and result is carried out. This can be domain or company specific.

Process execution:

- Check quality against chosen quality standard

- Derive quality verdict about simulation result

Inputs:

- Analyzed simulation task and objectives (including KPI and other criteria)
- Quality information of simulation experiments (e.g error estimations or confidence range)
- Quality information of simulation results
- Quality verdict about simulation setup
- Specific quality aspects for the simulation task derived from the criticality of the decision of engineering task

Outputs:

- Quality verdict about simulation result

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Simulation Engineer, Quality Engineer
- IT Engineer

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert, Quality Domain Expert

Used infrastructure, tools and methods:

- Quality engineering

Comment:

2.7 Decide about Fulfillment of Simulation Objectives (Fulfillment Phase)

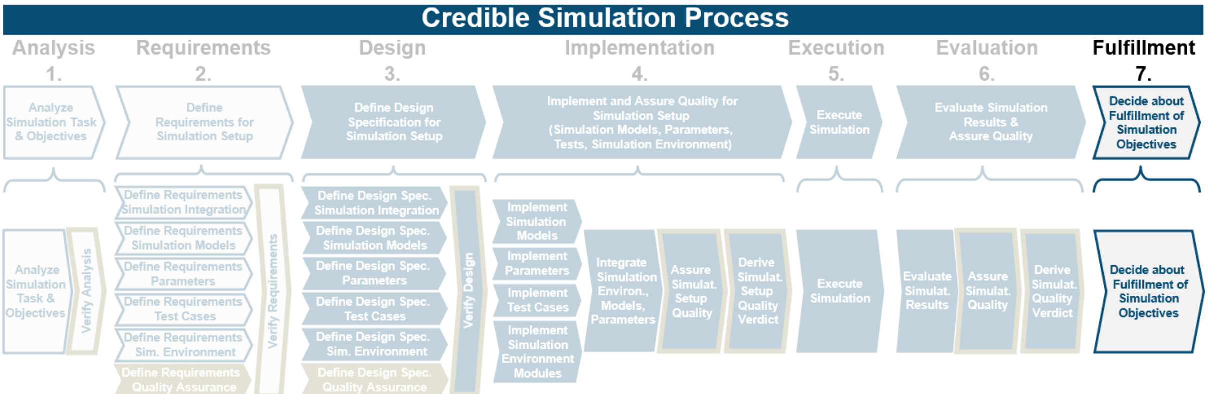

Figure 12: Focus on phase 7 of the Credible Simulation Process

In this process phase the decision is made whether the requirements and objectives of the simulation task have been fulfilled. This is done in coordination with the higher-level process (Simulation-based Engineering Task). Further information available in the higher-level process can also be taken into account (e.g. results of other test tasks), as cross information of other test tasks of the engineering process can be useful input.

Process execution:

- Decide about fulfillment of simulation objectives

Inputs:

- Simulation results and quality of results post processed
- Quality verdict about simulation result
- Specific, detailed description of product, requirements, environment (meant is the environment of the real product, e.g. for car -> road, climate zone, user group, frequency of use, …)
- Analyzed simulation task and objectives (including KPI and other criteria)
- Requirement specifications of phase 1 "Analyze Simulation Task & Objectives" and 2 "Define Requirements for Simulation Setup"
- Criticality of decision of specific engineering task (see phase 1 "Analyze Simulation Task & Objectives")

Outputs:

- Decision about fulfillment of simulation objectives

Credibility documentation:

- Procedure documentation with quality assurance
- Rationale / Reasons

Roles:

- Project Engineer, Development Engineer, Simulation Engineer, Quality Engineer
- Simultaneous Engineering Team

Required expertise:

- Product Domain Expert, Modeling Domain Expert, Simulation Environment Expert, Quality Domain Expert

Used infrastructure, tools and methods:

- Project management environment, product data management

Comment:

2.7.1 Decide about Fulfillment of Simulation Objectives

Phase 7 "Decide about Fulfillment of Simulation Objectives" has no sub-steps, therefore no additional aspects are provided.

Appendix A: Roles

- Project Engineer
  - Places order for the Credible Simulation Process
- Development Engineer
  - Provides technical input from the commissioning project
- Simultaneous Engineering Team
  - Team of experts (development, manufacturing, simulation, sales, ...)
- Simulation Engineer
  - Simulation and modeling expert
- Quality Engineer
  - Responsible for and expert for quality assurance
- Test Engineer
  - Expert for test and release, does inspections
- IT Engineer
  - Expert in IT and data management
  - Interface to IT infrastructure