Implementation instruction
Process simulation in the automotive and automotive component supply industry

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1 Contents

2 Purpose of the implementation instruction

This implementation instruction is used as a cross-technology and application guideline for internal and external simulation projects. It forms the basis for the acceptance of goods and services, and includes the following:

- general, organisational and technical EDP guidelines,
- standard procedure for simulation projects and guidelines for simulation studies,
- quality requirements and quality management,
- global, non-project-specific input data and requirements,
- data requirement, data management and validation,
- simulation model requirements and validation,
- basic principles of modelling and programming,
- experiment design and evaluation requirements.

The implementation instruction is based on VDI guideline 3633. The VDI guideline is binding for both, client and contractor.[i]

The implementation instruction is supplemented by other client-specific and project-specific documents.

[i] Verein Deutscher Ingenieure: VDI 3633, Sheet 1, Process simulation for logistics, materials flow and production systems; fundamentals, December 1993
Verein Deutscher Ingenieure: VDI 3633, Sheet 2, Performance specification/implementation specification and services description for the simulation study; December 1997
Verein Deutscher Ingenieure: VDI 3633, Sheet 5, Integration of the simulation into operating processes, October 1997

2.1 Differentiation of client and project specific documents

In individual projects, it may be necessary to supplement or further specify the general information given in this document. If the details in the various documents are found to be contradictory, the details in the client-specific section or performance specification are to be considered binding.

2.2 Modifications service

Changes to the form and content of this implementation instruction are carried out only by the VDA (German Association of the Automotive Industry) bodies responsible. Comments and suggested modifications should be addressed to the client. The client can place them as modification requests through the contact person at AG (working group) "Ablaufsimulation" (process simulation).

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Table 1: Overview of modification editors

	Para-graph	Page	Reason for modification	Modification content	V.	Date	Originator
1	All	All	Supplier integration	OEM replaced by AG		24.09.07	
2	5.3	39 et seq.	Integrate supplier	Addition to ZF column		24.09.07	
3	4.4.2 & 5.2	30 et seq. & 39	Handling of various breakdowns	Breakdowns applied per station or protection circuit		24.09.07	
4	5.3.3	42	Project folder structure changed	Picture replaced		24.09.07	
5	All	All	various modifications based on VDA meeting 18.09.07			24.09.07	
6	2.13		Modification request by T. Rooks, Daimler	Include confidence interval, doc. reference footnote		24.09.2007	
7	7.2		Document extended	New concepts added	V1	29.11.2007	
8	5		Addition to paragraph	paint-specific areas	V1.	29.11.2007	
9	6		Addition to paragraph	Plant simulation	V1	29.11.2007	
10	All	All	various modifications based on VDA meeting 03.06.08-04.06.08		V2	06.11.2008	
11	7	38ff	Addition to paragraph	assembly-specific areas	V2.1	04.02.2009	Pöge
12	0	2	Changed contact person at Daimler	Contact person replaced	V2.2	02.12.2009	Pöge
13	0	2	Changed contact person at Opel	Contact person replaced	V2.3	16.06.2010	Pöge
14	0	2	Changed URL for the forum	URL replaced	V2.3	16.06.2010	Pöge
15	2.4	8	Error correction	Names of documents rectified	V2.3	16.06.2010	Pöge
16	4.2.4.2	2	Decision VDA meeting from 4.3.2010, conformity to VDA automotive module library	Chapter 4.2.4.2 on naming of variables changed	V2.3	16.06.2010	Pöge
17	4.3	25	Decision VDA meeting from	Chapter 4.3 regarding Witness	V2.3	16.06.2010	Pöge

	Para-graph	Page	Reason for modification	Modification content	V.	Date	Originator
			16.6.2010	deleted			
18	0	2	Changed contact data at Opel, Daimler and Volkswagen	Contact data changed	V2.4	16.02.2012	Pöge
19	4.2.2	19	Integration of the library concept	Picture of the class library structure adjusted	V2.5	16.02.2012	Pöge
20	4.2.7.1	25	Decision VDA meeting from 14.3.2012	Template for Header of methods defined	V2.5	22.02.2013	Clausing
21	0	2	New contact at Daimler	Contact data changed	V2.6	10.06.2015	Pöge
22	10.2	50	Decision VDA meeting from 12.3.2015	Description Turbulence changed	V2.6	10.06.2015	Pöge
23	10.2	56	Decision VDA meeting from 12.3.2015	Formula Stand Alone Availability (SAA) corrected	V2.6	10.06.2015	Pöge
24	10.2	55	Decision VDA meeting from 2.3.2016	Description OEE changed	V2.6	18.04.2016	Pöge

No. = Serial number **P.** = Number of pages **V.** = Version status (document) of modification

Table 2: Modification history

2.3 Purpose of process simulation

The simulation is used as a planning aid for analysing and planning complex production/logistics systems. It takes account of the impact of stochastic variables on the process under examination. The aim of the simulation study is to cover the planning status or to optimise the process concerned by including the defined target variables. These can have very different values depending on the job definitions.

Use of a process simulation is usually justified when no solution can be found using analytical/mathematical calculations.

Process simulations can also be used to current production control using current process data. Incidental requirements differ from those of planning-related simulation studies and are not currently included in the implementation instruction.

2.4 Acceptance of simulation studies by the client

The requirements for a simulation study can vary according to client and project (please refer to some client/project-specific documents).

However, one general rule applies: a simulation study is considered accepted when all guidelines and specifications have been followed and the results have been accepted by the client through a presentation. The guidelines and specifications are set out in the following documents:

- "Implementation instruction process simulation in the automotive and automotive component supply industry “.
- Supplement "Client-specific addenda to the implementation instruction process simulation in the automotive and automotive component supply industry“.
- Supplement "Project-specific performance specification“.

If the simulation study is used by a system supplier to protect planned investments, but it has not been accepted by the client, then the contractor will, at their own cost and risk, take all necessary action to ensure the requested values.

3 Standard project procedure

The requested process simulations are to be performed on the simulation system described in the company/project specific documents.

If deviations from the specifications in this instruction are necessary in certain cases, these should always be agreed with the client. Additional agreements must be made in writing.

The contractor will analyse the assigned tasks and make a cost analysis based on a rough implementation plan, and taking into account the following project steps:

- Define the scope of services and project plan, determine the data required
- System analysis and data acquisition
- Verification and validation of data and information received
- Set out concepts and responsibilities in writing
- Acceptance by the client
- Simulation model setup, programming if required
- Verification and validation of the simulation model
- Run the simulations and collect statistical data
- Analyse results, execute optimisation loops if necessary
- Document and present the results
- Acceptance by the client and delivery of the specified documents and models.

Depending on project and specification, not all steps may be necessary.

3.1 General representation of project procedure

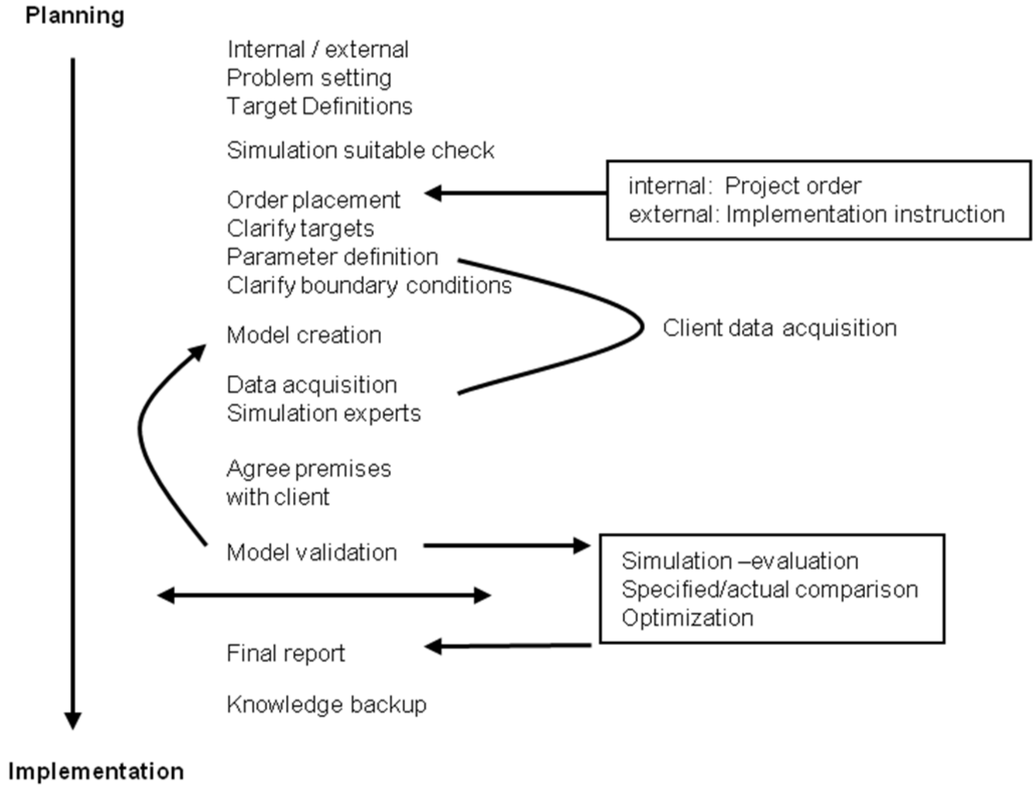

Figure 1: Standard project procedure

For a detailed representation, please refer to the book produced by section 4.5.6 of the Simulation working group ("Arbeitsgemeinschaft Simulation" - ASIM), Simulation in Production and Logistics, concerning the planning and implementation of simulation studies.[ii]

3.2 Task definition

This implementation instruction is binding, and defines the basic requirements for the setup and execution of simulation studies from the point of view of the client.

[ii] Quality criteria for simulations in production and logistics ", S. Wenzel, M. Weiß, S. Collisi-Böhmer, H. Pitsch, O. Rose; Springer Verlag 2008

3.2.1 Task definition in planning-related simulation studies

Simulation studies are to be carried out in parallel with the planning, i.e. the various stages in the planning process are to be supported by simulations.
Bottlenecks identified during model creation should be reported immediately to the client.
The results are presented, with documentation, at the end of the project.

3.2.2 Simulation studies to support routine operation

<not yet specified>

3.3 Award of contract

The contract will be awarded by the responsible department that defined the subjects to be studied. Before award of contract, discussions are required between client and contractor. A summary of the points discussed and possible agreements are to be recorded in the minutes. At the start of the project, the contractor must appoint a project manager and identify him/her to the client. The project manager will manage the capacities throughout the duration of the project, and will act as contact person for the client. For external award, a project-related implementation instruction must be produced (implementation and performance specification).

3.4 Schedule

If not already defined in the performance specification, a time schedule must be drawn up, with milestones, between client and contractor at the start of the study.

3.5 Definition of target variables / target functions

The exact targets and target variables are to be defined by the client in the client-specific or project-specific performance specification. The aim of the study is to find a configuration in which the parameters are optimised, by starting from the basic model and varying the process parameters. When planning new projects, the planned reference figures and required output values are to be defined.

3.6 System analysis, data collection and preparation

The client is responsible for the accuracy and completeness of the data provided. The data type and data preparation must be set out in the project-specific implementation instruction. The client must make a contact person available, through whom the data will be supplied.

3.7 Data validation

As part of the validation, it is important to carry out a detailed check on the input data (plausibility check). The client should be informed promptly if inconsistent data are found.

3.8 Premises

The client will set out the premises for each simulation study in the project document. If these are found to be incomplete or faulty, additional or different premises will be agreed with the client. The agreed variables are to be recorded in writing. In general, premises are project-specific.

3.9 Concept creation, implementation specification

In general, the modelling should be done after development of a concept model. If creating more complex models, a model description should be produced for the purposes of an IT implementation specification. This will be agreed with the client and, after being approved by the client, will be used as the basis for modelling.
The client will indicate in the project-specific performance specification whether a model description is required.

3.10 Modelling

The following principles are to be applied in the modelling:

- The software specified by the client in the company and project-specific documents is to be used.
- The reference model specified in the company/project-specific documents is to be used. If processes cannot be represented by elements in the reference model, the contractor can use their own elements, or model new ones.
- All incidental variables are represented by separate random data streams, random data streams are managed centrally.
- Central management of all parameters.
- Central acquisition of all statistical values.
- Objects are given meaningful names.
- No encryption of methods, procedures, functions, etc.

- Own reference models can be used only after consulting the client.
- Components that require a license are used only after consulting the client.
- Target-oriented levels of detail to represent processes.

3.11 Model verification

The purpose of model verification is to check the implemented logic and control processes. It may be in the form of animated simulations, or may consist of a sensitivity analysis where trouble-free characteristics (100% availability) are given as the initial parameter set:
deterministic models produce a defined result for given input values. A sensitivity analysis *measures the variations in the result relative to changes in the input values. By itemising the input values, the most sensitive i.e. critical input value can be identified in the area around the given result*.
It must also be ensured that the technical parameter values are set correctly and the input/output characteristics are really produced by the system parameters and not by random processes.

3.12 Model validation

The purpose of model validation is to check whether the characteristics examined for the existing/planned system or handling technology are represented accurately in the simulation model. This particularly applies to the abstract representation of controls, stochastic data, protection circuits, capacities, etc. For existing systems, the simulation values are compared with the real operating values. For new systems, some dialogue between the client and contractor is required in order to examine the model and model validity. Recommendations for the validation process are given in VDI guideline 3633, Sheet 1 and elsewhere. An extract from this guideline is given below:

- The model checking should be problem specific. Depending on the type of simulation project, individual analyses should be made relative to predefined target values, basic data and plausibility tests.
- To simulate existing systems, it is recommended to compare the obtained results with the actual data for the purpose of validation. For new systems where no actual values are available for comparison, an appropriate level of modelling experience and qualifications are required on the part of the user (simulation expert). (Note: In this case, it is important for the planner and simulation expert to work together in collaboration.)

- For the validation, it is helpful to have dynamic representations (and particularly animations) of running processes. In this way, basic structural or parameter errors can often be quickly identified on the screen.
- The time factor, i.e. simulation duration and statistics reset point, is of great importance for the validation process. Not all technical systems are empty at the start of operation: delivery paths, buffers, work stations and other parts of the simulated system may already be occupied (workpieces, conveyors, etc.). This initial state can be represented by initialising the components concerned in the model, or by an initial run of the simulation. To be able to evaluate the overall stability of the model, complete simulation runs that go outside of the actual observation time should also be carried out.
- Settling time: A settled state exists when the mean observed value corresponds to the expected value for an infinite number of observations. The end of the settling phase can be identified when there is stabilisation of the correlation between two successive values measured within one run of the simulation.
- The real simulation time is determined by estimating the frequency of stochastic processes, for example system faults. To do this, the trend selected for the settling time is examined for an assumed distribution (e.g. normal distribution) over a long period. The chi-square test is a useful aid here. The minimum number of values in the trend is determined using a suitable confidence interval (e.g. a safety level of 95% or 98%) and the standard deviation of the trend. For more information, see Chap. 3.13.
- There are project-specific guidelines for the minimum simulation and minimum settling time. They are defined in the client-specific section. Settling time is not taken into account in the evaluation.
- Validation increases the understanding of the system and model, and forms the basis for the quality of the later simulation results.

3.13 Conducting experiments, optimisation

If not already defined in the project-specific performance specification, the variable parameters should be agreed between the client and the contractor before experiments are carried out. They should also agree on which target variables go with which factor in the target function. Depending on the project, the result of the target function is to be minimised or maximised.

The number of runs per experiment should be selected according to the defined confidence interval or confidence level. The confidence interval is the interval into

which the value to be determined (the true value, not the mean value) will fall with the probability of the confidence level (for example, 90% or 95% or 99%, etc.). For calculation of the interval and to determine the required number of runs, please refer to the related documentation.[iii]
The simulation duration and settling time are also to be determined for the experiments. The simulation time must be examined sufficiently in order to determine whether the simulation time is long enough.
The client must be informed immediately of any bottlenecks identified, and optimisation proposals submitted. The results should be interpreted through collaboration between the client and contractor. If there are fundamentally new findings, the target setting should be specified in collaboration with the client. During the revaluation phase, the work should be based on the simulation model.

3.14 Evaluation

Data recorded during the settling time are not included in the results. Results should be registered centrally in tables, global variables or other objects, so that they can be easily exported. The export targets could be databases or Excel files, for example, and are to be specified by the client.
The client should also be informed of results obtained from the simulation, and process optimisation proposals should also be made if necessary. The evaluations stated in the company/project specific documents should also be made for the individual clients.

3.15 Documentation / Overview sheet / Preparation of results

Documentation must be drafted in the language specified by the client. Modifications must be agreed with the client and logged where necessary.
Documentation must contain the following points:

- Aim of the simulations study
- Boundary conditions, premises, possible constraints encountered or unknown parameters accepted, with reasons[iv]
- Parameter and an overview of the data used
- Rough description of the model structure and working method
- Comments on the simulation process
- Results, proposals and alternatives.

[iii] Statistics pocket book, Section C 2.2.2 "Confidence intervals“; Rinne H., Verlag Harri Deutsch, 3rd Edition 2003

The results are to communicated as part of a final presentation with a working simulation model, and an animation if possible.

3.16 Data return

On principle, all project-related data remain the property of the client. All project results are checked and collected by the client with the help of a checklist. The client will supply the checklist to the contractor at the start of the project. Detailed documentation must be provided, and must allow the client to integrate models into their own models. All information must be provided in unencrypted form on a suitable data storage device, without access permissions. The data are forwarded by postal mail. Other means of forwarding can also be agreed with the client.
The directory structure should be created as described in the company/project specific documents for the individual clients.

4 Modelling and programming

4.1 Basic principles

The "modelling" point described in the project procedure model (see paragraph 3 Standard project procedure should be subdivided into the usual substeps for software engineering:
At the ***first modelling stage***, also called the functional part, a formal model (concept model) is developed for the client or user. At the same time, areas of responsibility are clearly identified between planners, users and operators.
At the ***second modelling stage,*** description methods are created for the programmers. These methods must be independent of the programming language. Representation will depend on project size, with program procedure plans, pseudo code, procedure diagrams, or similar.
Only at the ***third modelling stage*** is the simulation created according to the description methods and formal model approved by the client.

4.2 Plant simulation system

4.2.1 General

Module libraries should always be "open", i.e. none of the models, methods or other objects should be encrypted or protected by other forms of technology. The module libraries to be used are stated by the client in the company/project specific documents. Differing standards, for example the contractors own module libraries, must be approved by the project manager.

Use of dialog boxes:
To simplify the model handling, plant simulation dialog windows are to be used, especially for the input/output data and controls. Non-standard controls should be taken out of the project-specific document.

Language:
Starting from Plant Simulation Version 8.1, the modelling language is English.
Note: It may occur that older modules have still been produced in German. However, starting from Plant Simulation Version 8.1, all new developments and modelling must be carried out in English.

Update capability:
All models must be made updateable (see description for VDA Automotive module library or the update function in Plant Simulation).

4.2.2 Structuring

The simulation model should be structured rationally (hierarchy, inheritance...). So that simulation models can be replaced, and to include various users, editors and other persons, a standardised model structure is essential. This also allows the linking of different simulation models. The points described below are managed when using the VDA Automotive module library.

Structure of the class library

The Class library in the plant simulation software indicates the model structure, and should be structured in various levels (see Figure 2). The various levels are identified by the structure of the class library, or the folder structure.
The advantages of the specified level structure are in the clear model layout, support for automatic model generation, update capability and compatibility with other models.

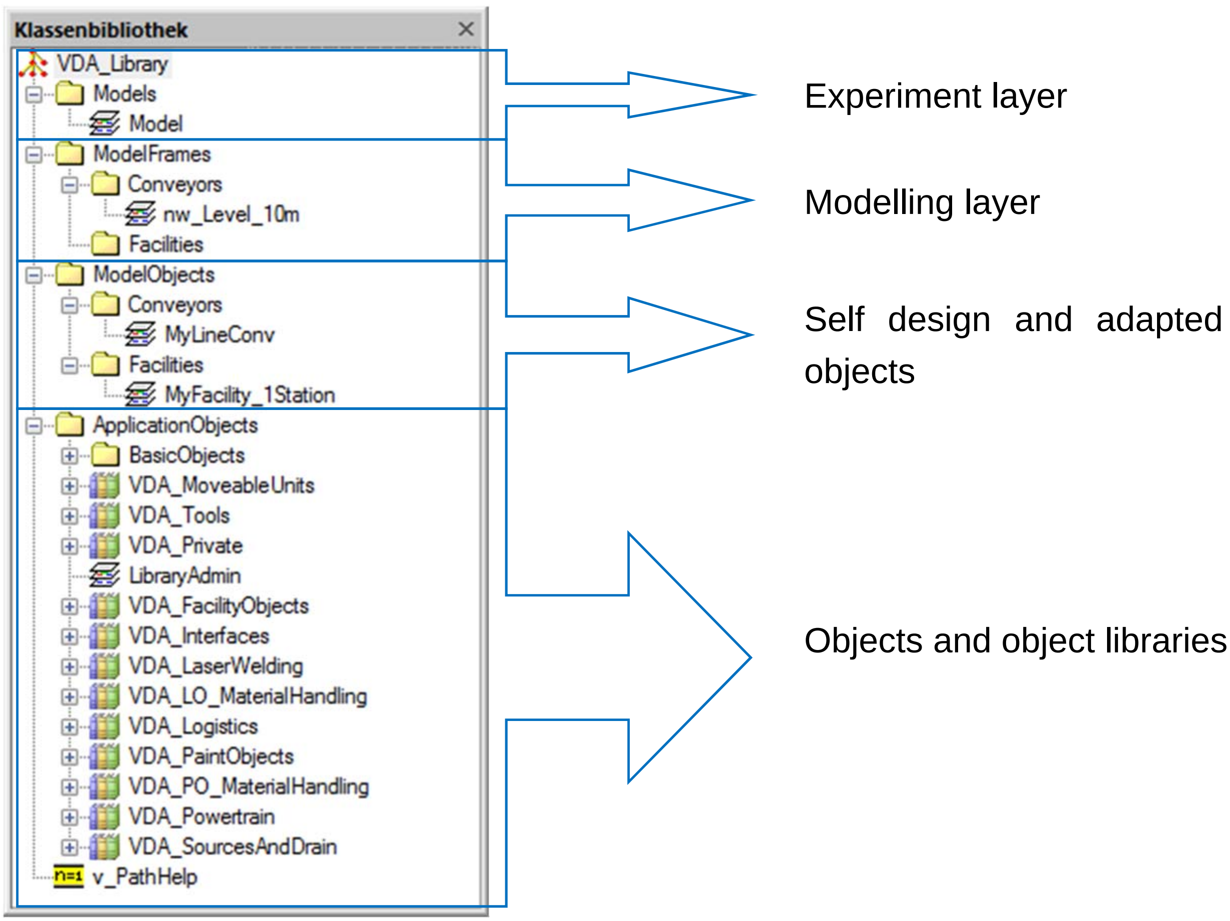

Figure 2: Example of the class library structure

Experiment level

On the experiments level, models (folders & networks) used for carrying out experiments are created, each containing one events manager.
Test models or self-standing partial models can also be managed on this level. All used data are managed on this level.

Modelling level

Models, partial models, networks and objects are organised on the modelling level.
So the model classes are created here. These do not have an events manager and no data are maintained in them.
An exception to this are the self-standing partial models, which can also be imported as objects by external models, and can be switched on or off. They can therefore have their own central data management.
Variations from this method of operation are only allowed if this is specified in the client-specific document.

Modules and module libraries

All basic modules and class modules are managed on the modules and module library level. These modules (classes) are not parameter-based, or have only one basic parameter configuration. The modelling level uses modules from the related modules library.

4.2.3 Data management

As there are numerous possibilities in the data management and parameter settings for simulation models, one of the most important things when building a model is to have uniform and continuous management of all data and parameters.
To ensure automatic model generation, updateability and compatibility with other models, the following rules must be applied:

- Modules and models are not parameter-based, i.e. when they are created, they can be filled out with data (attribute values, structure data, initial values, etc.), but the data for experiments are assigned not through a class but through instances on the experiments level.
- All modules that manage, read or write active data, are located in the main network on the experiments level.
- Parameters must be managed in tables and variables, but not in methods.

In order to apply these rules, depending on the scope of the data management, it is recommended to use an own data network in the root model or build your own networks on the experiments level. The aim is to make the central management of simulation data as clearly arranged as possible.
Random data streams are part of the centrally managed data.

In short, the central data management must allow "two-way parameter configuration" (mutual updating of the parameter data when there are changes in the central management network or in the systems and materials flow modules).
Variations from this method of operation are only allowed if this is specified in the client-specific document.

4.2.4 Networks

Each plant simulation model is made up of networks. When building these networks, the principle applied is that the structure of each network must appear self-explanatory.
The following module types can be used in networks and should therefore be classified:

Data flow modules:
Methods, tables & lists etc. (for control). Particularly:

- Reset: Used only for resetting and deleting statuses,
- Init: Used only for producing an initial state (e.g. data filling),
- global variables (network variables, parameters or constants), configurable once-only by the user, or variable in the course of the simulation. All variables must include comments.

Materials flow modules, interface, BEs:
This refers to the content of the plant simulation class library.

4.2.4.1 Module layout

The following areas should be visually separated from each other within the network:

- BE flow, including background layout (if present),
- initialisation area (Reset / Init),
- controls, methods, tables,
- input/output methods (and sensor methods) should be placed logically with the related modules,
- modules are positioned laterally (in a tree structure) using different symbol sizes, in the order of the call sequence,
- variables, separately configurable and modifiable through the model (for example, while a simulation is running).

4.2.4.2 Module naming / notation

The modules should be given meaningful names, whereas EveryNewWord begins with capitals.

In the case of using information flow objects the following abbreviations of the element type are to be prefixed to the actual name:

Variable:	v_
Method:	m_
Table:	t_
Comment:	c_
CardFile:	cf_
StackFile:	sf_
QueueFile:	qf_
TimeSequence:	ts_
Frame:	nw_

That is to be considered as well at the naming of variables in methods. Counting variables such as „i“ or „j“ may form an exception from this directive. If methods receive arguments, the expression “p_” is to be prefixed to the actual name of the argument.

4.2.5 Colours and symbols

Colours:

The following colour conventions are applied for the modelling modules used:

- green (dark): module, method or variable is to be modified by the user (user input),
- black: standard colour, system parameter,
- blue: comment,
- red: used only to identify particularly important modules, comments, notes, etc. (traffic light colour).

<u>Symbols</u>:

The following symbols for methods are to be used:

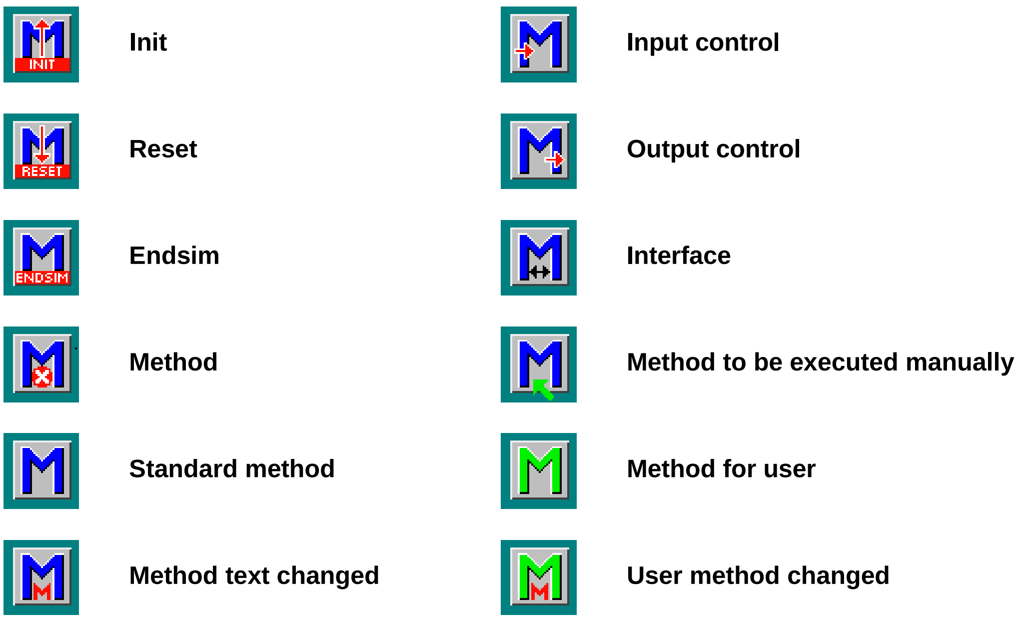

Figure 3: Overview of method illustrations

All objects coloured green, e.g. variables, tables, methods etc. , can be modified or configured by the user.

4.2.6 Call records

The purpose of call documentation is to ensure that call chains to various methods are traceable. It should be possible to have an overview of the program chain without opening all methods. Methods can be arranged according to their place in the call hierarchy; Methods on the same hierarchy level are placed beside each other, with those of lower levels placed below.

The call chain is in the methods head, and all methods used as free attributes in modules are documented in a comment in the corresponding network.

4.2.7 Methods programming

4.2.7.1 Methods head

All methods should be given the following head:

```
---------------------------------------------------------------
--|
--|
--|
--| Parameter    :
--| Return       :
--|
--| Called by    :
--| Calls        :

--| Date:                Author  :                Comments (changes):
--|
---------------------------------------------------------------
```

4.2.7.2 Methods documentation

The programmer is required to maintain intelligible and traceable documentation.

4.2.7.3 General notes on programming

As far as possible, methods should be kept short, slight, and structured. Modularisation goes before the creation of nested, conditional instructions.

The modelling language is English.

The parameterisation (hard coding) of experiment data is not allowed in methods. As far as possible, avoid using "waituntil", "repeat-wait-until" loops and execute commands. We recommend using push-pull combinations, in the same way as login/logoff logic.

In "if then/inspect" instructions, the last branch always ends in a debug command.

Operands and variables should be separated by spaces, code blocks should be identified by separators and code passages are separated by blank lines.

In general, standard formatting is used (for example, indenting for conditional instructions).

5 Planning-related simulation in body construction

The purpose of this section is to give more details of the requirements for body construction projects.

5.1 Deviations from the specifications

If running target-oriented simulations and deviations from the specifications in these instructions are necessary in certain cases, these should always be agreed in advance with the client. Additional agreements in writing may also be required.

5.2 Requirement to follow the performance specification

Process simulations must be performed not only according to these instructions, but also the client-specific instructions and the related project-specific performance specification.

5.3 Task definitions

Generally, the aim of the body construction simulation study is to obtain a cost-optimised plan that will ensure the target output.
The targets to be reached are specified in the project-specific section.
Certain production areas are also to be simulated as "stand alone", i.e. the interfaces with the system under examination are represented as drains always ready to receive or sources always ready to deliver. The throughput of an individual SAT production area (Stand Alone Throughput) is defined in the project-specific section. The client must be informed as quickly as possible about any bottlenecks detected during the simulation study.
The simulation can provide information about the following points (for a definition of the operating figures, see paragraph 10.2):

- Throughput in units per hour (Uph) of the entire system, by type or variant where applicable,
- Effective cycle time,
- Overall equipment effectiveness (OEE), or efficiency factor,
- Output of the individual production area (SAT) in jobs per hour, by type or variant where applicable,
- Rate of utilisation of the individual production area,
- Breakdown of protected areas,

- Capacities used in buffers and decoupling sections,
- Required number of transport devices, workpiece carriers, etc.,
- Conclusions on sequence stability.

If the cycle times of concatenated systems differ from each other, then the cycle time to be used in calculations must be specified by the client.
The target variables to be evaluated are set out in the project-specific section.

5.4 Simulation model

The simulation software defined in the company/project specific documents is to be used. The specified reference models and module libraries should also be used.

5.4.1 Levels of detail

The level of abstraction (representation accuracy) depends on the task assignments and the amount of data retrieved. Basically, the model topology should correspond to the production layout. Each workstation and parts store related to the materials flow should be registered as a module.
Individual stations in a protection circuit must be represented by individual modules. Protection circuits and their dependencies are to be included. Lower levels of detail, or "protection circuit level" modelling require approval in writing from the client.
All systems and robots (including those involved in handling) must be included. These stations are especially to be included in mixed assembly or "empty runs“ of the system, in order to identify possible blockages. However, in the case of robot assembly, it is not useful to represent every robot as an individual workstation.
Subassembly sections decoupled by containers are usually considered as availability logistics factors.
Work shift models and rest break rules are to be represented.
The duration of individual simulation runs is to be agreed with the client. The number of simulation runs for each experiment is decided according to safety measures determined stochastically.
A suitable form of representation should be found for representing slip / non-slip conveyors and decoupling sections. In particular, representation of the fault behaviour of buffers and handling systems should correspond to the current planning, or to the real situation.

In addition to the general model, in the assembly areas specified by the client, self-contained stand-alone areas should be examined, i.e. areas where source and drain are always able to supply or remove parts to/from the area.

5.4.2 Modelling

The following information will be helpful in the modelling.

Organisational and logistics factors:

Production employees explicitly shown in the model (assembly workers etc.) are associated with an organisational availability. This should not be mixed up with technical availability. The client's simulation experts should always be consulted when dimensioning the organisational availability of individual production workers and representing them in the model. Details are given in the company/project specific document. In detailed representations of employees, always check whether consultation with the employees' committee is required.

Wastage is normally included in the representation. Details are given in the company/project specific document.

Completely knocked down (CKD) and semi knocked down (SKD) assembly and replacement part assembly are to be included (subject to modifications). Details are given in the company/project specific document.

The underlying working hours model must be implemented. TPM hours (Total Productive Maintenance) are treated as rest breaks in the simulation model.
The client must specify in the project-specific document whether end-plate changes/cutting are to be taken into account.

If the following conditions cannot be met, an additional reduction in availability should be included in the simulation, after consultation with the client:

- regular maintenance and repair work (TPM),
- easy accessibility of systems (for the preparation of containers by the logistics, and for repairs),
- possibility of immediate introduction of replacement parts at discharge points.

Faults:

Since several workstations in one system are usually linked together in one protection circuit for control purposes, this must be represented in the modelling. Two different basic approaches to implementation may be taken, which are either client or project specific. In the first, the availabilities of each station are adapted to the corresponding station element. In the second, the total availability of the protection circuit can be represented by a station of the protection circuit in the simulation model. The other materials flow modules in the protection circuit are configured with 100% availability.
In both cases, when a fault event occurs, all stations in the protection circuit are to be deactivated, then reactivated when the fault has been cleared.
In general, the "component-based availability values " provided by the client are to be used for the calculation.
Faults are to be represented by "number of working hours". However, in certain projects, the client may specify the use of simulation or operating time as reference.
The values used for MTTR (Mean Time To Repair, Mean Time To Recover) and MTBF (Mean Time Between Failures) and the mathematical functions to be used are specified in the project-specific document according to the client.
Major failures are not considered, as normal settled operation is assumed. The details, and particularly the blockage section to which they refer, are to be agreed with the client for the specific project.

Availabilities:

In highly complex arrangements of operating equipment (e.g. machines) a lower availability than the standard can be assumed. In this case, approval is always required from the client.
The basic availabilities stated by the client are to be used for operating equipment liable to blockages. All availability calculations must be documented and delivered at the same time as the simulation model.
In certain configurations, it may be useful to have weighted availabilities. The use of weighting factors must always be agreed with the client. Some example situations are given below:

- Separate process equipment or a separate machine is used to assemble different types, and each is used only for a special type and only one of the two can be used.
- Processes the scope of which are well below the primary processing time,

- Cycle times are very long compared with the cycle times on which the availability values are based.

All availability values are mean values, which in practice are partly subject to considerable fluctuations.

The scrapping of individual parts because a blockage has occurred in individual operating equipment, and subsequent qualification of the system, is not usually part of the simulation. Deviations from this are specified in the company/project-specific documents.

Materials handling systems and decoupling buffers

Normally, all conveyors and decoupling buffers are to be the slip type. Any deviations from this must be documented. Conveyors and decoupling sections are not deactivated for rest breaks or scheduled stoppages. The blockage behaviour of buffers and materials handling systems should be suitably represented in the simulation model. The modelling type and method is to be agreed with the client, and documented.

Machining and cycle times:

Configuration is always based on the planned cycle time. In special cases, the cycle time determined by simulation can be used for critical stations (off-line robot simulation). However, this is only allowed after consultation with the client.

Control strategies:

All controls that affect materials flow must be represented as closely as possible to the real situation.

5.4.3 Statistics

The statistics required to determine the values described in paragraph 5.3 are to be collected centrally in the simulation model, in order to simplify data exports to an external location, for example a database.

6 Planning related simulation in the paintshop area

This purpose of this section is to give more details of the requirements for projects in the paintshop planning.

6.1 Deviations from the specifications

If running target-oriented simulations and deviations from the specifications in these instructions are necessary in certain cases, these should always be agreed in advance with the client. Additional agreements in writing may also be required.

6.2 Requirement to follow the performance specification

Process simulations should be carried out according to these instructions, as well as the client-specific instructions and the performance specification that defines the project concerned.

6.3 Task definitions

In general, the purpose of the simulation study in the paintshop area is to allow a cost-optimised plan that will obtain the target output and secure the processes. The target values to be obtained are specified in the project-specific section.

The simulation can provide information about the following points (for a definition of operating figures, see paragraph 10.2):

- Output in units per hour (Uph), by type or variant where applicable
- System cycle times
- Overall equipment effectiveness (OEE), or efficiency factor
- Throughput of the individual production area (SAT) in jobs per hour, by type or variant where applicable
- Useable capacities required in the buffers (clearing storage buffer, sorting storage buffer) and decoupling sections
- Number of handling aids required (skids), workpiece carriers, etc.
- Sequence stability data
- Average colour block size and colour block size distribution at input to the filler and top coat lines, averaged over all colours and for each colour
- Operating rate of retouching workstations: mean value and time elapsed
- Impact of retouching rates on throughput and the operating rate of workstations

- Throughput times for the overall system and defined sub-areas; minimum, mean and maximum values, with histograms
- Car body history.

The points to be evaluated are defined in the project-specific section.

6.4 Simulation model

The simulation software defined in the company/project specific documents is to be used. The specified reference models and module libraries should also be used.

6.4.1 Detail

The level of abstraction (representation accuracy) depends on the task assignments and the amount of data retrieved. The model topology should always correspond to the production layout. In general, the simulation models in the paintshop area are based on a representation of the handling technology (systems always include handling technology), where each handling and/or building level is usually represented by a separate network.
Areas where the supply of vehicle bodies to workstations is time-critical are to be represented in detail at the level of individual handling elements. This is typically the case with the retouching area.
Individual workstations in the retouching area must be represented by individual modules. Protection circuits and their dependencies are to be included.

6.4.2 Modelling

The following information will be helpful in the modelling.

Organisational and logistics factors:

The real working hours models must be implemented. This is particularly important as the working hours models and clearing storage buffers are adjusted to each other for the individual process steps.
Cleaning hours are to be represented in the same way as rest breaks in the working hours models.
TPM hours (Total Productive Maintenance) are treated as rest breaks in the simulation model.
Wastage is normally included in the representation. Details are given in the company/project specific document.
CKD and SKD assembly and replacement part assembly are to be included (subject to modifications). Details are given in the project-specific documents according to the client.

Faults and availabilities:

Systems which are usually represented by handling technology elements (pre-treatment, cathodic immersion painting, filler line, top coat line, etc.) are always represented with their fault characteristics. In the case of connective handling systems, it may be useful to concentrate on the important nodes. Materials handling elements, including electric suspension tracks or Power and Free (P&F) systems in the VDA automotive module library have their own blockage mechanisms.
Faults are to be represented by number of working hours or, if the modules do not allow this, by number of operating hours. However, in certain projects, the client may specify that simulation time is to be used as reference.
The values to be used for MTTR and MTBF, and the functions to be used, are defined in the project-specific document according to the client.
Major blockages are not considered, as normal settled operation is assumed. The details, and particularly the fault section to which they refer, are to be agreed with the client for the specific project.

Materials handling systems and decoupling buffers

Normally, all conveyors and decoupling buffers are to be the slip type. Any deviations from this must be documented. Conveyors and decoupling sections are not deactivated for rest breaks or scheduled stoppages. The fault behaviour of buffers and handling systems should be suitably represented in the simulation model. The modelling type and method is to be agreed with the client, and documented.

Handling aids:

Skid circuits are usually represented along with the stacking/unstacking processes.

Gaps:

Colour changes in the filler and top coat can cause cycle losses due to lengthened cycle times or intervals. They must be represented, as they affect the possible throughput depending on the size of the colour block.

Storage buffers:

The clearing storage and sorting storage buffers in the paintshops perform an important technical function, and must therefore be represented along with their controls.

Clearing buffers ensure removal from the process lines, but may cause changes in the vehicle body sequence.

Sorting storage buffers are used first of all to produce the largest possible colour blocks. These have a crucial effect on the throughput of the painting lines and the dimensioning of the retouching areas.

Retouching areas:

The paintshop retouching area is very important, as the process in this area is highly dynamic due to colour-dependent retouching rates. Large colour blocks for colours with high retouching rates cause a temporarily increased retouching requirement, so that the temporary storage of vehicle bodies is often necessary in order to prevent blockages. If there are long distances between the storage buffers and the workstations, it becomes difficult to supply the vehicle body to the workstation at the correct time.

The retouching rates are to be represented in the simulation model using a statistical process. The bases for the data are the retouching rates that occur during assembly, which depend both on vehicle type (optional) and on colour (see Figure 4). If the VDA

Automotive module library is used, the user will find the appropriate function in module *SetCarState2*.

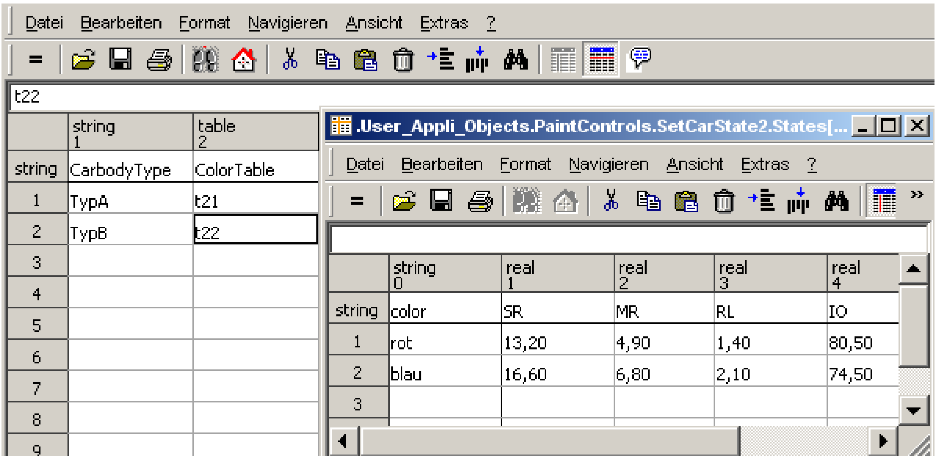

Figure 4: Possible data structure for paintshop retouching rates

<u>Fill level monitoring:</u>

There are usually one or more process lines running into the clearing storage buffer. The buffer is used to clear the process lines at the start of rest break, at the end of a shift, or if there is a blockage in the systems downstream in order to prevent irreparable damage to vehicle bodies through overshooting of the process time. To ensure that process lines will always be cleared, the total number of vehicle bodies in the process line and the clearing storage buffer should not exceed the total capacity of the clearing buffer. The fill level must therefore be monitored for each combination of process line and clearing buffer in the simulation model, and the input to the process line must be blocked if maximum capacity of the clearing storage buffer is reached. In certain cases, specific overshoots may be allowed during the shift, and must then be represented after agreement with the client.

<u>Control strategies</u>:

All controls that affect materials flow must be represented as closely as possible to the real situation. The controls for the colour sorter and retouching area are of particular importance. The positions of metering and detection points should also be taken into account.

Handling/cycle times:

A constant cycle time is assumed in automated systems.
If the retouching area is being modelled in detail, then distribution functions (e.g. delta functions) should be used for the handling times. If the basis data are available, colour-related distribution functions should also be used.

6.4.3 Statistics

The statistics required to determine the values described in paragraph 6.3 are to be collected centrally in the simulation model, in order to simplify data exports to an external location, for example a database.

7 Planning related simulation in the assembly area

This purpose of this section is to give more details of the requirements for assembly planning projects.

7.1 Deviations from the specifications

If running target-oriented simulations and deviations from the specifications in these instructions are necessary in certain cases, these should always be agreed in advance with the client. Additional agreements in writing may also be required.

7.2 Requirement to follow the performance specification

Process simulations should be carried out according to these instructions, as well as the client-specific instructions and the performance specification that defines the project concerned.

7.3 Task definitions

Generally, the aim of the assembly simulation study is to obtain a cost-optimised plan that will ensure the target output.
The targets to be reached are specified in the project-specific section.
The client must be informed as quickly as possible about any bottlenecks detected during the simulation study.
The simulation can provide information about the following points (for a definition of the values, see paragraph 10.2):

- Output in units per hour (Uph) of the entire system, by type or variant where applicable,
- Effective cycle time,
- Overall equipment effectiveness (OEE), or efficiency factor,
- Capacities used in buffers and decoupling sections,
- Required number of transport devices, workpiece carriers, etc.,
- Conclusions on sequence stability.
- Security of supply to drains or assembly line sections
- Overview of station operating rate (working, blocked, waiting, out of order, transferring)

If the cycle times of concatenated systems differ from each other, then the cycle time to be used in calculations must be specified by the client.
The target variables to be evaluated are set out in the project-specific section.

7.4 Simulation model

The simulation software defined in the company/project specific documents is to be used. The specified reference models and module libraries should also be used.

7.4.1 Detail

The level of abstraction (representation accuracy) depends on the task assignments and the amount of data retrieved. The model topology should always correspond to the production layout. Any line section or workstation related to materials flow must be represented as a module.
All line sections, individual workstations and transport sections that can be physically occupied by a vehicle body must be included. These stations are to be included especially in the case of mixed assemblies or empty runs of the system, in order to anticipate bottlenecks or to be able to determine the number of transport devices required.
Sub-assembly sections decoupled by containers are usually considered as availability logistics factors.
Where assembly areas that apply different work shift models and rest break rules, these must be represented. TPM hours (Total Productive Maintenance) are treated as rest breaks in the simulation model.
The duration of individual simulation runs is to be agreed with the client. The number of simulation runs for each experiment is decided according to safety measures determined stochastically.
A suitable form of representation should be found for representing slip / non-slip conveyors and decoupling sections. In particular, representation of the blockage behaviour of buffers and handling systems should correspond to the current planning, or to the real situation.
In addition to the general model, in the assembly areas specified by the client, self-contained stand-alone areas should be examined, i.e. areas where source and drain are always able to supply or remove parts to/from the area.

7.4.2 Modelling

The following information will be helpful in the modelling.

Organisational and logistics factors:

Explicitly modelled production employees (assembly workers etc.) are associated with an organisational availability. These should not be mixed up with the technical or organisational availability of a line section or workstation. The client's simulation experts should always be consulted when dimensioning the organisational availability of individual production workers and representing them in the model. Details are given in the company/project specific document. In detailed representations of employees, always check whether consultation with the employees' committee is required.

Wastage is normally included in the representation. Depending on the simulation requirements and level of detail, it may be necessary to represent a production sequence using vehicle specifications. This particularly applies when there are restrictions regarding the gaps between vehicle bodies with particular specifications/equipment in the sequence. Details are given in the company/project specific document.

If the following conditions cannot be met, an additional availability reduction should be included in the simulation, after consultation with the client:

- regular maintenance and repair work (TPM),
- easy accessibility of systems (for the preparation of containers by the logistics, and for repairs),

Faults:

All systems and line sections that demonstrate failure behaviour in the real situation must be associated with the corresponding faults in the simulation. In this case, it may be necessary to assign several fault profiles to one simulation element, in order to represent the real conditions (for example, Andon breakdown and technical problems that may have different MTTR profiles). This is company and/or project specific and must be agreed with the client. If different assembly sections and stations have a problem at the same time, the modelling can be made as described in the "Faults" section of paragraph "Body Construction“.

Faults are to be represented with reference to the number of working hours. However, in certain projects, the client may specify the use of simulation or operating time as reference.
The values used for MTTR (Mean Time To Repair, Mean Time To Recover) and MTBF (Mean Time Between Failures) and the mathematical functions to be used are specified in the project-specific document according to the client.
Major blockages are not considered, as normal settled operation is assumed. The details, and particularly the fault section to which they refer, are to be agreed with the client for the specific project.

Availabilities:
For the availability calculation, the basic availabilities stated by the client (if available) are to be used for operating equipment liable to blockage. Otherwise, the availability will be determined in agreement with the client, using the existing data or empirical values/estimates. This also applies to the distribution of total losses between individual blockage profiles. All availability calculations must be documented and delivered at the same time as the simulation model.
In certain configurations, it may be useful to have weighted availabilities. The use of weighting factors must always be agreed with the client. Some example situations are given below:

- Separate process equipment or a separate machine is used to assemble different types, and each is used only for a special type and only one of the two can be used.
- Processes the scope of which are well below the primary processing time,
- Cycle times are very long compared with the cycle times on which the availability values are based.

All availability values are mean values, which in practice are partly subject to considerable fluctuations.
The scrapping of individual parts because faults have occurred in individual operating equipment, and subsequent qualification of the system, are not usually part of the simulation. Deviations from this are specified in the company/project-specific documents.

Materials handling systems and decoupling buffers
Normally, all conveyors and decoupling buffers are to be the slip type. Any deviations from this must be documented. Conveyors and decoupling sections are not deactivated

for rest breaks or scheduled stoppages. The fault behaviour of buffers and materials handling systems should be suitably represented in the simulation model. The modelling type and method is to be agreed with the client, and documented.

Machining and cycle times:
Configuration is always based on the planned cycle time. In special cases, the cycle time determined by simulation can be used for critical stations (off-line robot simulation). However, this is only allowed after consultation with the client.

Variant / type dependent cycle times:
Depending on task assignments, calculation of type/variant specific cycle times may be required for individual objects. For this purpose, data are provided in the form of worksheets, and the calculation methods are also supplied by the client.

Control strategies:
All controls that affect materials flow must be represented as closely as possible to the real situation.

7.4.3 Statistics

The statistics required for calculating the values described in paragraph 7.3 are collected centrally in the simulation model, in order to simplify data exports to an external location, for example a database.

8 Planning-related simulation in logistics projects

The purpose of this section is to give more details of the requirements for logistics planning projects.

8.1 Deviations from the specifications

If running target-oriented simulations and deviations from the specifications in these instructions are necessary in certain cases, these should always be agreed in advance with the client. Additional agreements in writing may also be required.

8.2 Requirement to follow the performance specification

Process simulations should be carried out according to these instructions, as well as the client-specific instructions and the performance specification that defines the project concerned.

8.3 Task definitions

<not yet specified>

9 Factory simulation

The purpose of this section is to give more details of the requirements for plant simulations.

9.1 Deviations from the specifications

If running target-oriented simulations and deviations from the specifications in these instructions are necessary in certain cases, these should always be agreed in advance with the client. Additional agreements in writing may also be required.

9.2 Requirement to follow the performance specification

Process simulations should be carried out according to these instructions, as well as the client-specific instructions and the performance specification that defines the project concerned.

9.3 Task definitions and/or study objectives

Study objectives can be divided into two general themes. In the first, simulation studies are used to determine the decoupling variables between two subsections required due to faults or different working hours models (see paragraph 9.3.1). In the second, plant simulations are used to examine various themes in the job control environment (see paragraph 9.3.2).

9.3.1 Determining the decoupling variables between two sections

The purpose of this classic study type is to determine the buffer capacity required in order to decouple sections from each other (body construction from paintshop, paintshop from assembly). Correct decoupling should ensure that a section is supplied with vehicle bodies irrespective of the current status of the sections upstream or downstream. The required buffer size will depend, for example, on the availability (technical / logistical / organisational) and the working hours model of the sections concerned.

9.3.2 Studies related to job control

Job control studies are becoming increasingly important for body construction, as more and more parts and modules are delivered "Just in Sequence" (JiS) to the assembly

lines. The JiS process assumes that vehicles bodies arrive at the assembly line in the planned sequence order. Breaches of the planned sequence can only be compensated within very narrow limits. In certain conditions, if these tolerance limits are exceeded, the lines may even have to be stopped.
The plant simulation should determine the sequence stability that results from different input factors. Sequence stability can be affected by the following input factors:

- Plan job list (number of body variants, number of colour variants, model mix restrictions),
- Section working hours models,
- Job control strategy (keyword: early and late job allocation (baptism), etc.),
- Variations in number of pieces/production schedule at section level,
- Variant mix restrictions on supply to assembly line,
- Body turbulence at section level (see paragraph 10.2 for a definition of "turbulence"),
- Size of the sorting buffer (before assembly, usually a high-bay storage facility) between two sections.

Another possible study objective is to reduce the vehicle body/job throughput times for individual sections or for the whole plant. Lower throughput times usually mean less stock in circulation.

9.4 Simulation model

The simulation software defined in the company/project specific documents is to be used. The specified reference models and module libraries should also be used.

9.4.1 Job lists

This paragraph is only relevant for sequence stability studies related to jobs or vehicle bodies (see paragraph 9.3.2).
To be able to carry out a sequence stability study, a job list with the planned job sequence must be loaded into the simulation model. The job list can be read in from an external source, or created in the simulation model itself by using a job generator. The external source may consist of a historical job list, a list actually in use, or one created for planning purposes using an external job generator.
The creation of a planning job list depends on the following parameters:

- Assembly structure (linear production only, but also parallel assembly, body construction, etc.): In the case of parallel structures, a separate list must be created for each assembly, or the overall list must be divided up.
- Variety of variants:
    - Number of types or derivatives,
    - Number of body variants by type or derivative,
    - Number of colours per body variant and type or derivative,
- Number of related assembly variants, if any: An assembly variant is related if it is part of the variant mix restrictions, or the construction activities in the assembly process,
- Assembly variant mix restrictions,
- Piece number scenarios..

The possible job structure should be expressed in a string, which could appear as follows:

"Type_Bodyvariant_Colour_Assemblyvariants__Ordernumber“.

In the case of a vehicle body of type AAA, left-hand drive body variant with sliding roof and antenna, colour blue, air conditioning assembly variant, engine XXX and order number 123456789, the job string would appear as follows:

"AAA_0LH0SRANT_BLUE_ACSXXX__123456789“.

If the VDA Automotive module library is used, the job data should be entered in the Premid attribute of the BE job (Type Table, row 1). All data records must have the same byte length and the same of type information should always be inserted at the same location.

9.4.2 Modelling

Two flows are to be represented for sequence stability studies: the vehicle body flow and the information/work flow. If the aim of the studies is only to determine the size of decoupling storage buffers, then the paragraph 9.4.2.1, "Information flow and job control", is not relevant and can be skipped.

9.4.2.1 Information flow and job control

This paragraph is only relevant for sequence stability studies related to job control and/or vehicle bodies (see paragraph 9.3.2).
In the simulation model, the information flow should be represented as follows:

- Load the planned job lists (assembly start sequence) into the job control,
- If necessary, calculate the body/shell construction start sequence from the job control,
- Load the jobs from the information flow into the materials flow source, implementation in BEs. If using the VDA Automotive module library, the job data for each BE must entered in the Premid attribute,
- Vehicle body flow control, if necessary. This is only necessary if jobs are interchangeable (i.e. one job can be assigned to another vehicle body) or a variant is being developed. In both cases, there are interfaces (information points) between the vehicle body and job flows,
- Control of the transfer sequence from sorting storage for assembly.

The parameters are determined by comparing the planned job list with the job sequence calculated in the simulation (or even in the real situation). These parameters are usually client-specific.

9.4.2.2 Materials flow

The following information will be helpful in the modelling.

<u>Detail:</u>
In plant simulations, whole assembly areas or sections can be represented by suitable abstract elements or details. For example, a suitable abstract element could be the "VerwAnl" module in the ".User_Appli_Objects.MaterialFlow.Facilities" folder in the VDA Automotive module library. The level of detail is decided according to various premises. Entire assembly areas or sections can always be represented by abstract elements, provided individual elements in these areas are not going to be modified,

data are available for parameter configuration, and no job control decisions (for example, job swaps) are made inside the area represented.

The sources for configuration data might be, for example, a detail model or (better) real data. If real data are used for the parameter configuration, all real processes are represented in the simulation model and the simulation is thus made to match the real situation as closely as possible. On the other hand, in detailed simulation models, not all processes are usually represented, particularly special processes with manual intervention. If the base data are not available for an abstract representation, or new planning structures are being studied, or the processes inside an area are to be examined (for example, supply of JiS or JiT parts), the detailed form of representation should be selected.

Sections that connect handling technology elements, and decoupling storage or sorting buffers should always be shown with a sufficient level of detail so that branch points, capacities and controls are represented realistically.

Assembly (assembly line) can usually be represented as a drain, using a cycle time & availability working model (but also where effective cycle time = cycle time / availability). This is always the case, unless the JiS and JiT supply and fitting of parts is to be shown in detail.

In principle, any combinations of abstract elements and detailed areas are possible. This would be suitable, for example, if no modifications are being considered for an existing paintshop area and sufficient actual data are available for parameter configuration, but the body construction is being completely re-planned. In this case, the paintshop area is represented in detail by an abstract element and the body construction is represented in detail.

Parameter configuration:

Like the central management of the standard materials flow parameters, the control parameters for the job data are also to be managed centrally for models with job controls.

If abstract elements are used to represent larger areas or sections, these elements are to be defined using the following parameters:

- Cycle time
- Availability
- Working hours model
- Fill level characteristics or limits (minimum/maximum),

- Turbulence histograms and minimum throughput times, throughput time histograms (net times) or another suitable method for representing the vehicle body turbulence.

As an alternative to cycle time and availability, the effective cycle time can be used (effective cycle time = cycle time / availability).

Organisational and logistics factors:

Organisational factors are not usually taken into account in plant simulations. On the other hand, the logistics factors for JiS and JiT parts supply can be very important for assembly. This could be the case, for example, when jobs are included in assembly only if it is certain that selected JiS and JiT parts can be delivered on time for fitting on the assembly line. If the supply process is important, then it should be suitably represented in the model.
In principle, there are two ways of representing this in the model. In the first, the supply process and fitting at the assembly line can be represented. In the second, the appropriate equipment features can be temporarily blocked through a random process. The proportion of JiS and JiT parts is given either by the actual or planned data.

Validation:

As far as possible, validation is to be performed by loading a real "Start of Assembly“ job list and then comparing the figures in the simulation model with the data from the real plant, over the same period from which the real list was derived. The validation figures are the ones described in paragraph 9.4.3, but should at least be the sequence and filling characteristics of the sections and storage buffers.

9.4.3 Statistics

All statistical data are to be collected centrally into the simulation model, in order to simplify data exports to an external data location, such as a database.
In addition to the data discussed in the above paragraphs, the following values are typically examined as part of the plant simulation:

- Job sequence stability figures:
    - Sequence characteristics for determining the job sequence stability when vehicles bodies enter the assembly line. Definition of the measurement variable varies from client to client, and also partly within the ordering company itself. Evaluation often depends on type and variant.

    - Other client-specific measurement variables, for example cumulative backlog.
    - Sequence characteristics at other measurement points, for example at the output from the body construction section. These also vary from client to client.
    - Measured turbulence diagrams (for a definition, see 10.2) for individual areas or sections. Measurement of velocities is appropriate when areas are modelled in detail. The basis for measurement can be either the physical vehicle bodies or jobs.
- Throughput figures:
    - Minimum, average and maximum throughput time for defined areas (e.g. one section, or the entire plant).
    - Throughput time histogram.
    - The throughput times can be measured either as gross or net. In the gross method, the throughput time is calculated as the difference between two absolute time stamps, and in the net method, all scheduled stoppages are deducted between the two measurement points. The scheduled stoppages could be, for example, rest breaks and hours outside of work shifts.
    - Throughput times can be measured relative to types and/or variants.
    - The basis for measurement can be either physical vehicle bodies or jobs.
- Filling characteristics, particularly those of storage buffers between sections, or inside one section.
    - Filling characteristics are often measured according to variants.
- Section-based throughputs.
    - Filling characteristics are often measured according to variants.

10 Appendix

10.1 Abbreviations

German designator	*English designator*	*Abbreviation*	*Unit*
Taktzeit	Cycle time	CT	[s]
Fertigung auf Basis von importierten Einzelteilen	Completely Knocked Down	CKD	-
Fertigung auf Basis von importierten Baugruppen	Semi Knocked Down	SKD	-
Ausfallzeit	Down Times (Machine breakdowns)	DT	[s]
Durchlaufzeit	lead time	DLZ	[s]
Gesamtanlageneffektivität: Wirkungsgrad einer Fertigung bezogen auf IO-Teile	Overall Equipment Efficiency	GAE/OEE	[%]
Anzahl produzierte Einheiten pro Stunde	Units per hour	Uph	[n/h]
-	Just in Sequence	JiS	
-	Just in Time	JiT	
mittlerer Störabstand	Mean Time Between Failures	MTBF	[s]
mittlere Stördauer	Mean Time To Repair, Mean Time To Recover	MTTR	[s]
Netto-Kapazität eines Fertigungs-bereichs, ohne Verkettungsverluste zu vor- oder nachgelagerten Fertigungsbereichen	Stand Alone Throughput measured in Units per hour (Uph)	SAT	[n/h]
Aufwand für vorbeugende Instandhaltung	Total Productive Maintenance	TPM	[s]

10.2 Concepts

Plant section

In this document, this term refers to a production area in the automotive industry, for example body construction, the paint shop, or the assembly line.

Turbulence

Turbulence defines how much the measured sequence deviates from the planned sequence.

Body planning sequence (specified sequence)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Body sequence identified (actual sequence)	15	11	14	12	13	9	10	7	6	8	3	5	4	2	1
Advanced = too early Delayed = too late	0	3	-1	0	-2	1	-1	1	1	-2	2	-1	-1	0	0

Figure 5 shows an example with 15 vehicle bodies, measured at the input to assembly. In the measured sequence on the second row, there are 10 bodies that differ from the sequence on the top row. Four bodies arrive too late (delayed), and 6 too early (advanced). The size of the advance/delay varies.

Body planning sequence (specified sequence)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Body sequence identified (actual sequence)	15	11	14	12	13	9	10	7	6	8	3	5	4	2	1
Advanced = too early Delayed = too late	0	3	-1	0	-2	1	-1	1	1	-2	2	-1	-1	0	0

Figure 5: Example of turbulence in 15 vehicle bodies arriving at assembly

The turbulence diagram based on

Body planning sequence (specified sequence)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Body sequence identified (actual sequence)	15	11	14	12	13	9	10	7	6	8	3	5	4	2	1
Advanced = too early Delayed = too late	0	3	-1	0	-2	1	-1	1	1	-2	2	-1	-1	0	0

Figure 5 is shown in Figure 6.

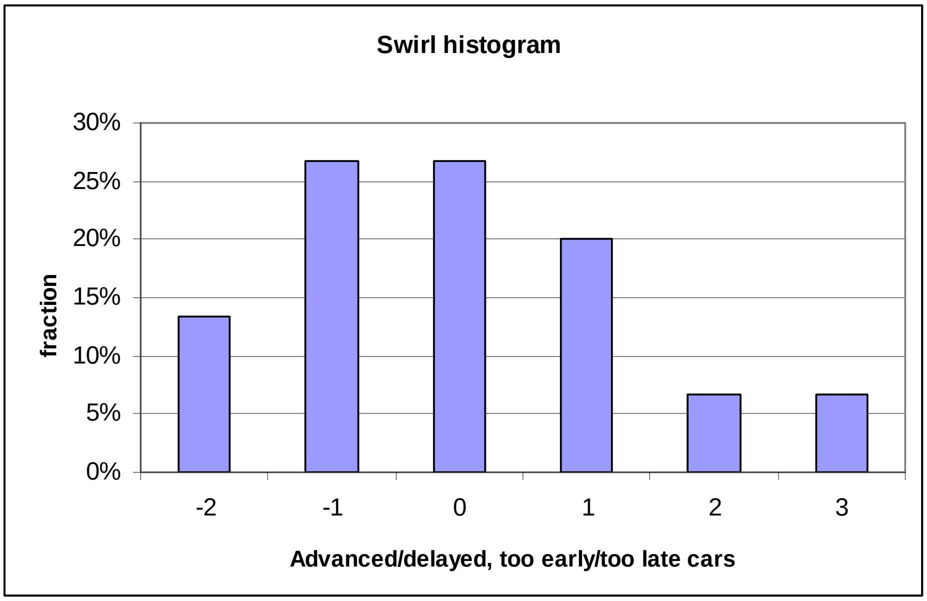

Figure 6: Turbulence diagram based on the example

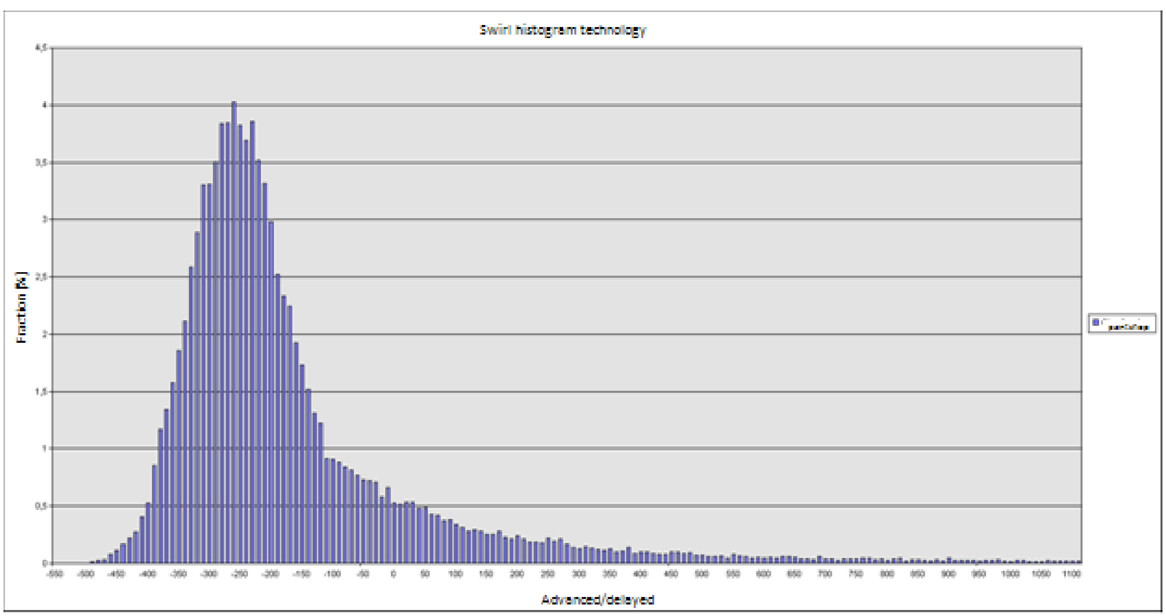

Figure 7: Typical turbulence measured at an paintshop area

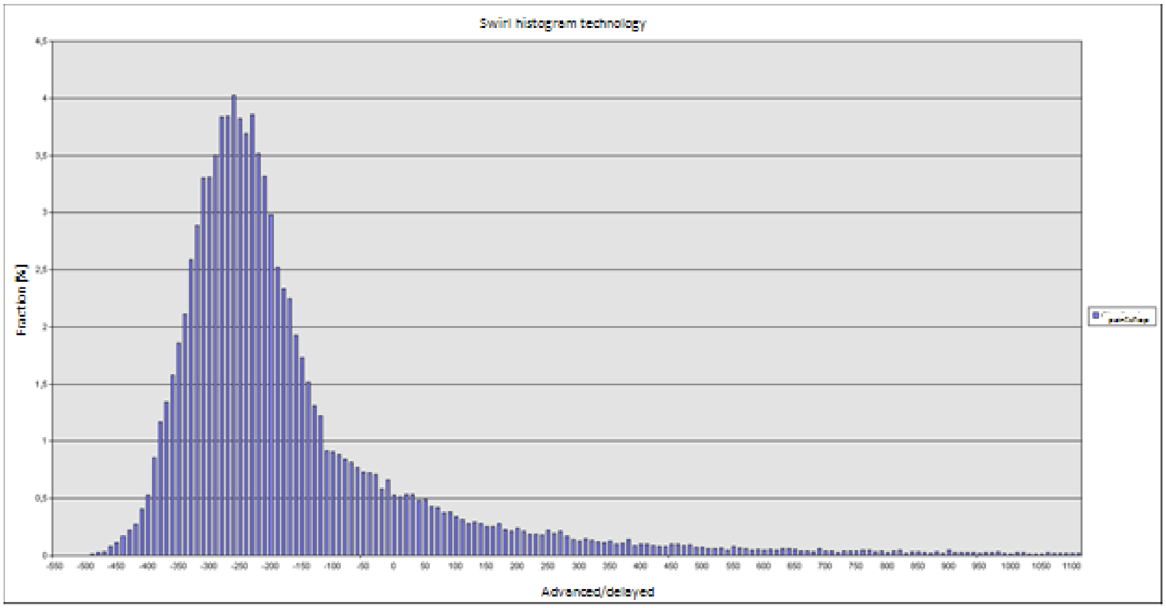

Figure 7 shows typical turbulence measured at the paintshop area. If more than 1100 vehicle bodies arrive too late, these are no longer shown.

General rule for all turbulence diagrams: the total of all products (early/late)*ratio is always equal to zero:

$$\sum_{i=\max.Advanced}^{\max.Delayed} (Advanced/Delayed)_i \times fraction_i = 0$$

The turbulence measurement can be based either on the number of physical bodies or the number of jobs.

Cycle time

Cycle time is the total time starting from the end of one working cycle to the end of the next (or from one positioning stop to the next positioning stop on a conveyor). It includes insertion time, process time (robots/workers) and extraction time, but without blockage/waiting times, downtimes or timeouts.

Operating time

The operating time of a system is the same as working hours, but without all scheduled stops such as rest breaks, time outside of work shifts, or group meetings. TPM times are not usually included in the operating time. See also Figure 8.

System availability

System availability (technical) is the percentage of the system operating time, minus technical downtimes and setup/adjustment times, relative to operating time (see above) when there are no faults.

For individual systems or protection circuits, the ratio can also be expressed mathematically:

$$System\_availability = \frac{produced\_units_A \times cycle\_time}{operation\_time} \times 100\% ,$$

where $produced\_units_A$ is the number of parts produced by a system, taking into account technical faults, and setup/adjustment procedures. The cycle time used for calculation is specified in the project-specific section. System availability corresponds to Stand Alone Availability (SAA) when the appropriate system boundaries are set.

Organisational losses

Organisational losses are the percentage of the theoretically possible throughput, which can occur at a station due to worker performance, parts shortages (supply logistics), power outages, condition of raw parts etc., and which are not caused by the machine itself.

For individual systems or protection circuits, the ratio can also be expressed mathematically:

$$Organisational\_losses = 100\% - \frac{produced\_units_O \times cycle\_time}{operation\_time} \times 100\% ,$$

where $produced\_units_O$ is the number of parts produced by a system when there are organisational losses only. The cycle time used for calculation is specified in the project-specific section.

Efficiency factor N (uptime) or operating ratio

The rate of utilisation of a plant is deduced by taking account of the technical and organisational losses, particularly losses due to concatenation with other production areas. The rate of utilisation (operating ratio) is the percentage ratio of the actual number of pieces produced, considering the above loss factors, relative to the theoretically possible number of pieces (without losses).

$$N = \frac{produced\_units_{A,O} \times cycle\_time}{operation\_time} \times 100\% ,$$

where $produced\_units_{A,O}$ is the number of parts produced by a system, taking into account technical faults, setup/adjustment procedures, and organisational losses. For concatenated systems, concatenation losses automatically occur in the simulation. The formula therefore applies both to individual systems and protection circuits and to concatenated systems. The cycle time used for calculation is specified in the project-specific section.

Quality rate

The quality rate is a measure of the number of pieces lost due to detects or parts that require reworking. It consists of the percentage number of fault-free parts produced relative to the total number of parts produced.

$$Quality\_Rate = \frac{produced\_units_{iO}}{total\_prod.\_units} \times 100\%$$

$$= \frac{total\_prod.\_units - units\_rework - units\_scrap}{total\_prod.\_units} \times 100\%$$

Where $produced\_units_{iO}$ is the number of parts produced without defects. In certain conditions, reworked parts are considered as parts produced without defects. If this is the case, the calculation variant given in the project-specific document is to be used.

Overall Equipment Efficiency (OEE)

Overall equipment efficiency expresses the ratios of net throughput and possible net productive time, allowing for system availability, concatenation losses and quality rate. A time-based representation is shown in Figure 8.

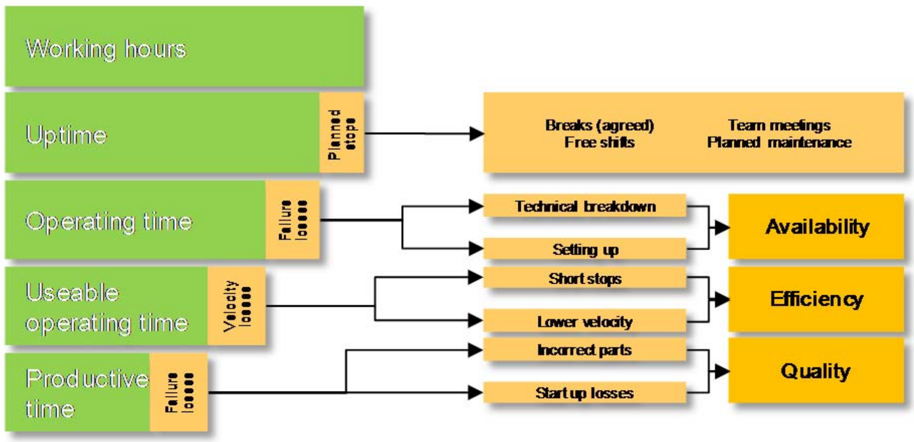

Figure 8: OEE time frames, process-oriented system and maintenance management, TÜV publisher

For OEE there is no generally accepted definition. If the OEE has to be one of the key performance indicators in a specific project the formula to be used has to be provided by the client.

Output in number of pieces per hour (uph, jph)

The output is normally expressed in units / jobs per hour (uph / jph). This figure indicates average output of a system or production unit, deducting scheduled stops. Technical availabilities, setup times and organisational losses are included in the calculation.

$$Output = \frac{produced\_units_{A,O,IO}}{operation\_time[s]} \times 3600,$$

where $produced\_units_{A,O,IO}$ is the number of parts produced by the production unit, with technical faults, setup/adjustment procedures, and organisational losses, and allowing for quality rate. For concatenated systems, concatenation losses are included automatically. The formula therefore applies both to individual systems and protection circuits and to concatenated systems.

Stand Alone Throughput (SAT)

Stand Alone Throughput represents the average number of pieces that could be produced by a system or production area during scheduled operating time, if there were no concatenation losses occurring in the production areas upstream or downstream. The technical and organisational losses occurring inside the system or production area are also included. The SAT value is normally expressed in units per hour (uph).

Stand Alone Availability (SAA)

SAA represents the technical availability of a station, protection circuit or production area. It is the percentage time for which this area is operating without technical faults. It applies to the area when operating without concatenated production areas upstream or downstream and is determined on the basis of "busy time“. Mathematically, it is expressed as follows:

$$SAA = \frac{produced\_units_A \times cycle\_time}{operation\_time} \times 100\%$$

where $produced\_units_A$ is the number of parts produced by a system, allowing for technical faults and setup/adjustment procedures. Blockages and waiting times (e.g. concatenation losses) are not taken into account. SAA corresponds to system availability when the appropriate system boundaries are set.

Mean Time To Repair, Mean Time To Recover (MTTR)

MTTR is the average downtime, i.e. the length of time a fault lasts in a station or protection circuit. It usually includes the time required to identify the fault, travel time of the repair technician to the fault source, and the time to complete the repair.

Mean Time Between Failures (MTBF)

MTBF is the average operating time between from the end of one fault until the start of the next one, in a station or protection circuit.

Technical availability (V):

The formula below expresses the mathematical relation between availability and the fault parameters "average fault duration" and "mean time between faults".

$$\mathrm{V} = \frac{MTBF}{MTBF + MTTR}$$