# The Role of Simulation within the Life-Cycle of a Process Plant

## Results of a global online survey

February 2015

Mathias Oppelt, Prof. Dr. Mike Barth and Prof. Dr. Leon Urbas
*Siemens AG, Hochschule Pforzheim, Technische Universität Dresden*

# The Role of Simulation within the Life-Cycle of a Process Plant

## Publishers / Authors

Mathias Oppelt, Siemens AG, Karlsruhe

Prof. Dr. Mike Barth, Hochschule Pforzheim, Pforzheim

Prof. Dr. Leon Urbas, Technische Universität Dresden, Dresden

## February 2015



*Please consider the environment before printing this report.*

# 1 Preface

Nowadays there are a lot of discussions and publications about the use of simulation within the process industries. Furthermore in a world of rising complexity it can be expected that simulation will play a key role in finding answers to design, engineering and operational questions. Last year we had the opportunity to discuss this topic with various people from industry, leading to an understanding about how individuals and companies are dealing with simulation. But an industry wide picture of the current use of simulation was still missing and cannot be found in the literature. Publications are focused on the punctual use of simulation within the life-cycle of a process plant.

We therefore decided to extend the research on the use of simulation within the process industries to a very broad level. Besides looking at the status quo, the aim was also to identify a vision for the use for simulation in the future, which is broadly acceptable throughout the industry. A third target was to identify the success factor in using simulation and for realizing the future vision.

Therefore in late spring 2014 work started on a global online survey with the primary goal of answering the following three questions:

- How is simulation used along the life cycle of a process plant today?
- What is the common vision about the future use of simulation?
- How can this vision be reached?

The survey was released in July and ran until end of October 2014, generating 221 responses. We would especially like to thank all participants for their time, input and contributions to this large set of data.

In addition we would like to thank Dr. Romy Müller (TU Dresden) and Dr. Sabine Rass (Siemens AG) for their support during the survey design. For the intensive testing and reviewing of the survey we thank all collogues for their support including the VDI/VDE GMA FA 6.11 members.

Finally, we are grateful to Siemens AG for providing the IT infrastructure to run the survey professionally. Special thanks to Mr. Guide Fey for implementing and hosting the survey.

We are glad to provide you the report for this survey – which all participants made a success – and we are looking forward to further discussions about the use of simulation.

Mathias Oppelt, Prof. Dr. Mike Barth and Prof. Dr. Leon Urbas

SIEMENS HOCHSCHULE PFORZHEIM TECHNISCHE UNIVERSITÄT DRESDEN

# 2 Executive Summary

From July to end of October 2014 we conducted a global survey on the current and future use of simulation during the life-cycle of a process plant. The survey was completed by 221 people (198 from companies and 23 from universities), providing a sound statistical basis for analysis and future research. Within the group of participants 60% work for large companies with more than 1000 employees, 24% work for mid-size companies with 100 to 1000 employees, and 16% work for small companies with 1-100 employees. The majority (40%) work for an owner and operator (O&O) company, followed by 35% who work for system integrators and solution providers (SI), whereas 15% work for equipment manufacturers (EM). The industry split is as follows: 39% chemical industry, 27% oil & gas, 18% energy, 17% petro-chemicals, 16% pharmaceuticals, 14% water and wastewater management, and 13% food and beverage industry (multiple answers possible). The majority of the participants work in engineering (53%), followed by 15% in management (+4% top management), 10% in development, 8% in research, and 6% in production. From a global perspective 34% are working in Germany and 24% in the USA.

Based on these data the following statements about the current use of simulation have been derived:

i. Safety and quality are priorities in process industries.

ii. A majority of decisions made across the plant life-cycle are based on (1) individual experience and (2) on standards.

iii. Simulation can be used to answer engineering and operational questions earlier and with lower risks. Simulation is an accepted technology, even though it is not for free.

iv. Today simulation is most frequently used during engineering, followed by training, then design, and operation. The effort invested early in the life-cycle is currently not utilized in the later phases.

v. Dynamic simulation is the most common kind of simulation across the life-cycle.

vi. Most of the time there is no defined process for the use of simulation; meaning that in more than 50% of the projects, simulation is not used systematically.

vii. Self-developed simulation tools play a significant role across the life-cycle phases.

viii. The wide range of simulation tools are used, with many specific simulation tools. The commercial tools Aspen Plus, Aspen Hysys and Matlab (Mathworks) are the ones with a significant role across the life-cycle. SIMIT (Siemens) plays an important role for engineering and training, and UniSim (Honeywell) for training.

ix. The handling, training effort, modelling efficiency and a reasonable price-performance ratio are critical factors for the selection of a tool.

x. The modelling effort is still high across the life-cycle no matter which phase. The modelling effort does not increase for training and optimization. Are simple models sufficient?

xi. The equipment manufacturers subjectively make the highest modelling effort.

xii. Model reuse and co-simulation is already strongly demanded.

xiii. Simulation is not only for dedicated experts; it is often used by specific domain experts (e.g. automation engineers) as a supporting methodology.

For the picture of the future the following theses have been derived from the survey data:

I. Safety and quality will remain major drivers for the future.

II. Costs and time-to-market are significantly more important in Germany than in the USA.

III. Integrated engineering, simulation and standards are the most relevant technological trends that will change the way of work. Simulation is a valid technology and accepted by the process industries in contrast to Cloud, Big Data and Cyber Physical System (CPS) trends.

IV. Across the whole life-cycle of a process plant, simulation will gain major importance.

V. Modular, flexible and open tool chains as well a continuous use of simulation are critical success factors.

VI. The virtual plant is the future. Thus in future a full virtual representation of the real plant will be created. Simulation models will be the base to make the virtual plant interactive.

VII. A collaboration model needs to be developed between companies to create the models for the virtual plant.

VIII. Collaborative innovation is seen more likely within the USA than in Germany.

IX. Equipment manufacturers will provide simulation models for their equipment in the future.

X. The handling, usability and model reuse are critical success factors (especially in Germany).

XI. Management acceptance is needed to realize a continuous use of simulation.

XII. System integrators are in need of process models, simulation libraries, modeling standards and open interfaces.

XIII. The simulation use cases will come together (first engineering and training then with design then with operation) and enable a continuous use of simulation along the life-cycle of a process plant.

Based on the identified drivers and challenges for the process industries as well as the requirements for the use of simulation and the derived statements about the current and future role of simulation, we identified fields of action to enable an integrated use of simulation along the life-cycle of a process plant. These have been clustered into technical and nontechnical actions. Within the technical actions, the following subcategories have been defined: model reuse, modelling efficiency, integration and usability. The nontechnical actions have been categorized into: workflows, acceptance, education and collaboration.

As a next step, we are interested in developing a technology roadmap towards the integrated use of simulation within the life-cycle of a process plant. This should be carried out together with experts and survey participants in workshops. The outcome of this activity should be an accepted roadmap e.g. called “Simulation within the process plant life-cycle 2030”.

Please get in touch with us if you are interested in participating in such workshops.

# 3 Contents

# 4 Introduction

## 4.1 The Research Motivation

Process plants are very complex environments and are becoming increasingly complex within all classic process industries such as chemicals, pharmaceuticals, oil & gas, food & beverage, water & wastewater, and glass & solar. Therefore the challenges for plant design, engineering, construction, commissioning and operations are increasing as well. In addition to the classic demands to minimize costs and time-to-market and at the same time to increase quality, safety also plays a critical role within process industries. Many process plants are producing hazardous products – either continuously or by batch processes [29]. Thus the highest target for process plants is to operate safely and to avoid dangerous process states. Additionally, process plants should operate continuously in a 24/7 mode for years without any stops. Therefore a process plant is a bad place for engineers to use a trial-and-error methodology to achieve the desired operating mode. The engineers have to get it right from the very start. Furthermore it is well known that errors found early during the design stage can be corrected more easily and more cost efficiently than errors found at later stages.

Throughout the life-cycle of a process plant, decisions have to be made by engineers and operators. One technology which can support the decision making process and capture know-how is simulation. Using simulation it is possible to get questions answered and make decisions on a sound basis.

Simulation can be understood as a virtual experiment to better understand a certain system [47]. The user of simulation will model a system or an aspect of it to investigate a certain question about the behavior. Thus simulation mimics the dynamic behavior of a process or system over time, based on dynamic and mathematical models imitating the reality [11].

Looking at the possibilities provided by simulation on the one hand and on the current use of simulation on the other hand, why is simulation not used continuously throughout the life-cycle of a process plant? Based on various discussions with people from industry it was found that there are people who see huge value in using simulation, but still most of the time simulation is only used at particular points within the life-cycle. To gain a broader understanding of the current use and especially the future vision on the use of simulation, we decided to leave the field of individual discussions and conduct empirical research on a larger scale with a global online survey.

## 4.2 The Plant Life-Cycle and Simulation

The typical life-cycle of a process plant can be divided into the phases of conceptual design, basic engineering, detailed engineering, installation and construction, commissioning, operation and maintenance, and finally modernization [13, 14, 32, 45]. The phases from conceptual design until commissioning can grouped under ‘design and engineering’, while the following phases are 'operations'. Simulation today is already present in various phases of the plant life-cycle. The following four use cases have been identified from the literature and the interviews.

(1) **Design simulation** [5, 17]: Simulation is started with the use of static simulation to design the production process at a steady-state of production. The process layout is the result of this phase. Sometimes dynamic simulations are also used to investigate the transient phases in the production process and to design the startup and shutdown behavior of the plant and to size the process units accordingly. Dynamic simulation is also very helpful for the development of the standard operating procedures.

(2) **Simulation supported engineering and virtual commissioning** [3, 4, 15, 19, 20, 21, 22, 25, 36 and 48]: As the process is designed, the control system engineering is the next step and this can be supported by a simulation system providing a model including the signals and values a controller expects from the real plant devices. The controller (e.g. programmable logic controller, PLC) can either be available as a real controller (the so called hardware-in-the-loop setup) or is replaced by an emulated controller (software-in-the-loop) [46]. As early as possible during this phase it is important that the original controller program is used to test the program which is later deployed within the plant.

(3) **Operator training** [12, 17, 24, 33, 39, 40 and 42]: The purpose of an operator training simulator is to train the plant operation personal with the use of the process control system and the interaction between the control system and the process. Usually for process training very detailed dynamic process simulations are used to mimic the normal production process, but also emergency situations, startup and shutdown behavior and abnormal process conditions.

(4) **Simulation supported plant optimization** [10, 12 and 23]: Simulation is used in a variety of ways during the operation phase, starting from model based predictive controllers up to simulation supported assist systems supporting the operator during a decision process and also providing suggestions on how to run the production process in an optimized manner.

Figure 1 shows these use cases for simulation along the life-cycle of a process plant. But why can simulation not be used continuously throughout the life-cycle, reusing developed models whenever possible. For specific aspects, this idea has been raised in the literature. Some authors [5, 6, 15, 16, 31, 41] are looking at ways to reuse mathematical models from the process design phase in the control optimization phase. Data modelling aspects to use data in more life-cycle phases are investigated in [7, 8, 9, 26]. Others [15, 27, 28] have investigated the digital factory for discrete manufacturing and the role of simulation along the product and production life-cycle. Even though the idea of using simulation continuously across the life-cycle

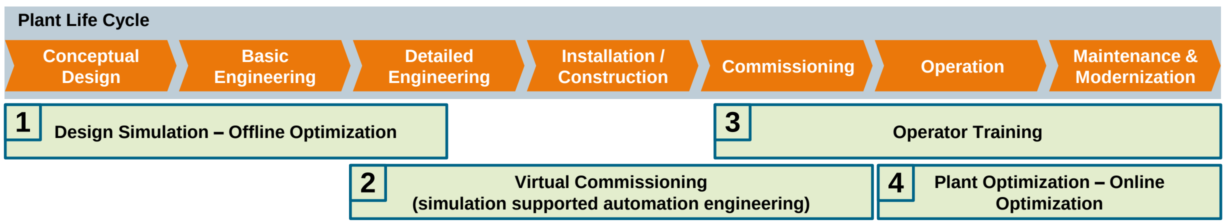



**FIGURE 1: SIMULATION WITHIN THE LIFE-CYCLE OF A PROCESS PLANT**

of production plants has been around for some time it is still not a standard in industry yet.

## 4.3 The Survey Design

At the beginning of the survey design, we formulated the following three major questions, to be answered in as much detail as possible.

1. ***How is simulation used along the life-cycle of a process plant today?***
2. ***What is the common vision about the future use of simulation?***
3. ***How can the vision be reached?***

Before the survey was designed some expert discussions and interviews were conducted to sound out opinions about these questions. In personal discussions, ideas for the survey design and question formulation were generated and tested. The first set of questions were optimized together with survey design experts from the Technische Universität Dresden and the Siemens Global Shared Marketing Services, who later also hosted the survey through their infrastructure. Before the survey was released in July 2014 it was tested with a smaller group of people including the members of the VDI/VDE GMA working group 6.11 to perform a final validation of understandability.

To obtain a global response, the survey was provided in German and English language. To avoid a lack of responses in the summer holiday season the survey was run from July until the end of October 2014. Using international media and forums, the survey was promoted to reach as many people as possible. The publication of the survey was supported by organizations like VDI/VDE GMA, NAMUR and processNet. The following journals and media published notes on the survey: OpenAutomation, atpedition, Process News, Automation.com and PROCESS.

### Survey structure

**Drivers, challenges and trends within process industries**

- Drivers today
- Drivers tomorrow
- Technology trends affecting tomorrow

**Current use of simulation along the life cycle of a process plant**

- Current decision making support
- Role and goals with simulation
- Kinds of simulation and used tools
- Criteria for tool selection
- Effort for simulation
- Reuse of simulation models

**Vision about the future use of simulation along the life cycle of a process plant**

- Relevance of simulation tomorrow
- Scenarios describing tomorrow
- Requirements to enable continuous use of simulation along the life cycle of a process plant

***Color code***

- *Evaluation of today's use/relevance of simulation*
- *Evaluation of future use/relevance of simulation*
- *Evaluation of success factors to reach future vision*

The survey was completely anonymously and structured to evaluate the current role of simulation, the future role of simulation, and the relevant success factors to reach the vision about simulation.

The future was defined as 'within the next six to eight years', because this timeframe extended beyond the next budget cycle but not too far into the future that the respondents would not feel affected by this anymore. No incentives were provided for participation in order to avoid bias.

After the survey was closed the results have been discussed with multiple experts to validate the results and conclusions.

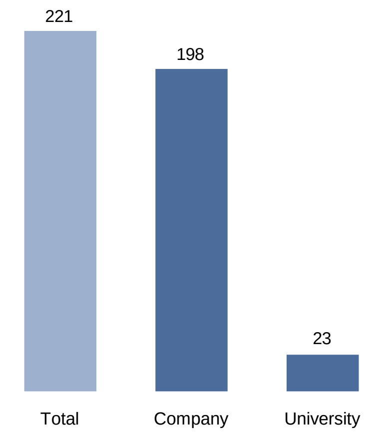



**FIGURE 2: CLASS OF PARTICIPANTS**

## 4.4 The Survey Participants

The survey was completed by 221 people, of which 198 were from companies and 23 from universities (Figure 2), providing a sound statistical basis for analysis and future research. The industry split was as follows: 39% work for chemical, 27% for oil & gas, 18% for energy, 17% for petro-chemicals, 16% for pharmaceuticals, 14% for water and wastewater and 13% for food and beverage sector (Figure 3, multiple answers possible). Within the group of participants, 60% work for large companies with more than 1000 employees, whereas 24% work for medium-sized companies with 100 to 1000 employees, and 16% work for small companies with 1-100

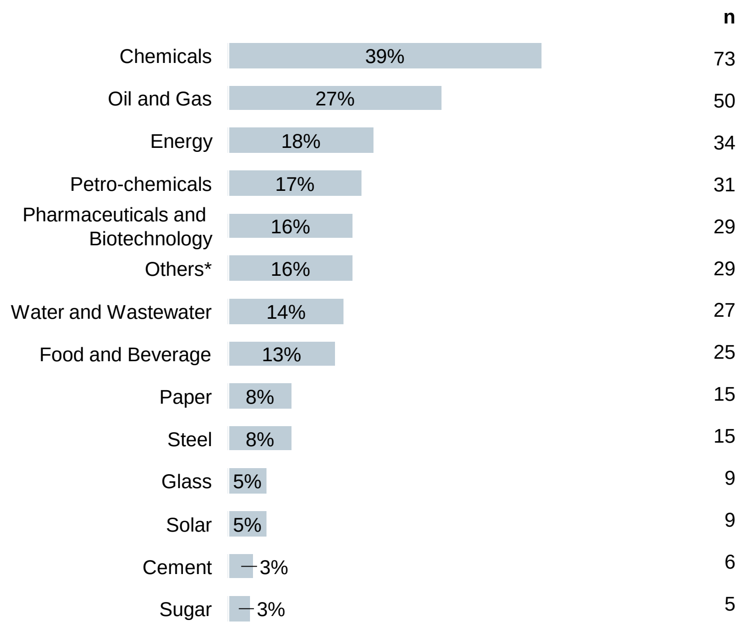



**FIGURE 3: INDUSTRY SPLIT (MULTIPLE ANSWERS POSSIBLE)**

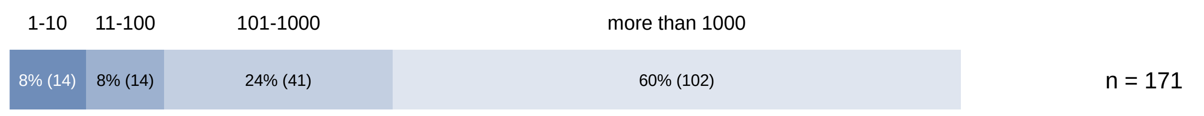
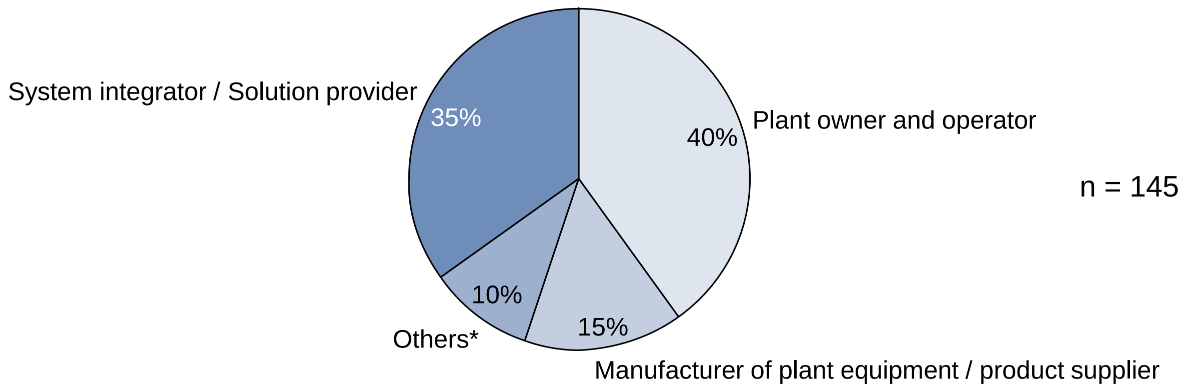



**FIGURE 4: COMPANY SIZE (NUMBER OF EMPLOYEES)**

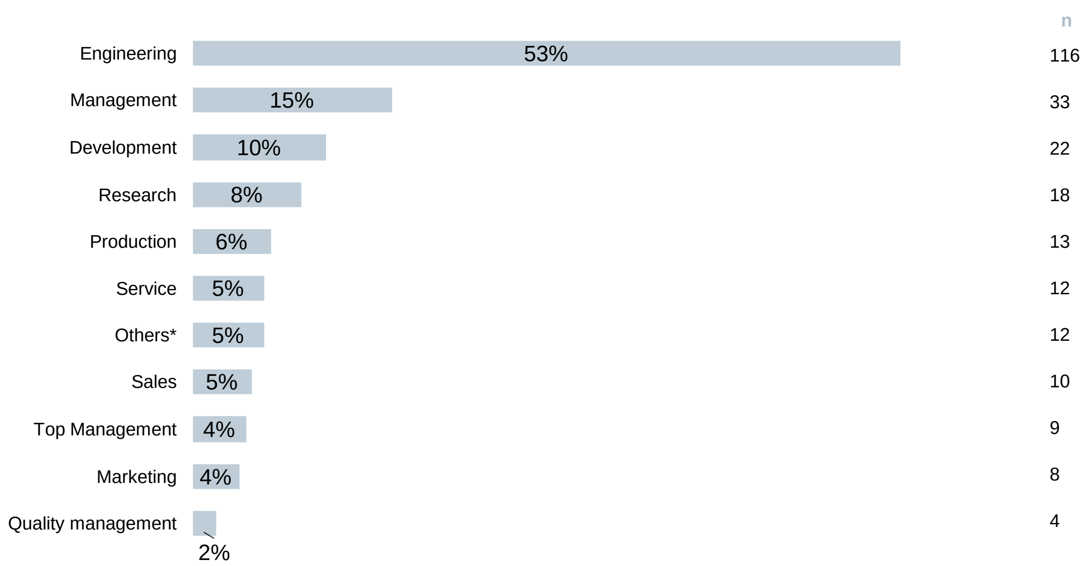



*Others e.g. (Engineering) Consulting, plant manufacturing, EPCM, process licensor, service provider

**FIGURE 5: COMPANY TYPE**

employees (Figure 4). The majority (40%) work for an owner and operator (O&O) company, followed by 35% who work for system integrators and solution providers (SI), and 15% work for equipment manufacturers (EM) (Figure 5). The majority of the participants work in engineering (53%), followed by 15% in management (+4% top management), 10% in development, 8% in research, 6% in production (Figure 6). From a global perspective 34% work in Germany and 24% in the USA (Figure 7).

Across these groups (company or university, country, company size/type, role, industry) significant differences have been evaluated based on the T-test for paired subcategories [43] and the ANOVA (Analysis of Variance) for multiple subcategories [43]. The error threshold was set to 10% to identify significant differences across these groups.




*Others: e.g. (plant) maintenance, technical plant supervision, internal tool and process development, project management

**FIGURE 6: FUNCTION / ROLE OF PARTICIPANTS**

| Country | N |
|---|---|
| Germany | 58 |
| USA | 41 |
| India | 9 |
| Canada | 6 |
| Netherlands | 6 |
| Brazil | 4 |
| Columbia | 4 |
| Australia | 2 |
| Mexico | 2 |
| New Zealand | 2 |
| Nigeria | 2 |
| Norway | 2 |
| Peru | 2 |

| Country | N |
|---|---|
| Saudi Arabia | 2 |
| Sweden | 2 |
| Switzerland | 2 |
| UAE | 2 |
| UK | 2 |
| Argentina | 1 |
| Bahrain | 1 |
| Belize | 1 |
| Botswana | 1 |
| Burkina Faso | 1 |
| China | 1 |
| France | 1 |
| Guatemala | 1 |

| Country | N |
|---|---|
| Indonesia | 1 |
| Iran | 1 |
| Ireland | 1 |
| Kuwait | 1 |
| Austria | 1 |
| Pakistan | 1 |
| Russia | 1 |
| Sambia | 1 |
| Singapur | 1 |
| Spain | 1 |
| Thailand | 1 |
| Venezuela | 1 |
| Overall | 173 |

**FIGURE 7: COUNTRIES OF PARTICIPANTS**

# 5 The Current Role of Simulation

This chapter evaluates the responses about the current status quo of simulation in the life-cycle of a process plant.

The survey first addressed the current drivers in the daily work of the respondents. The statements from the participants indicate that safety and quality are the most dominant drivers within the process industry (Figure 8). These are closely followed by productivity and then costs. For the costs driver there was a significant difference between the USA and Germany, indicating that costs are more important for the participants from Germany. The last group of drivers is formed by sustainability, standards and time-to-market. Interestingly, within the time-to-market driver there was no significant difference between the industries but only between the company types (most important for the EMs, then SIs, and finally for the O&Os).

***Safety and quality are first within process industries***

Next, the survey considered the current support for decisions made along the life-cycle of a process plant (Figure 9). One of the results is that in any phase of the life-cycle about one-third of the decisions are based on the experience of individual people and another third is based upon the use of standards. Minor roles are currently playing the use of security factors, an analysis and the use of simulation. Thus to stay competitive within the future it will become critical to capture and conserve the

***The majority of decisions made across the plant life cycle are based on (1) individual experience and (2) on standards***

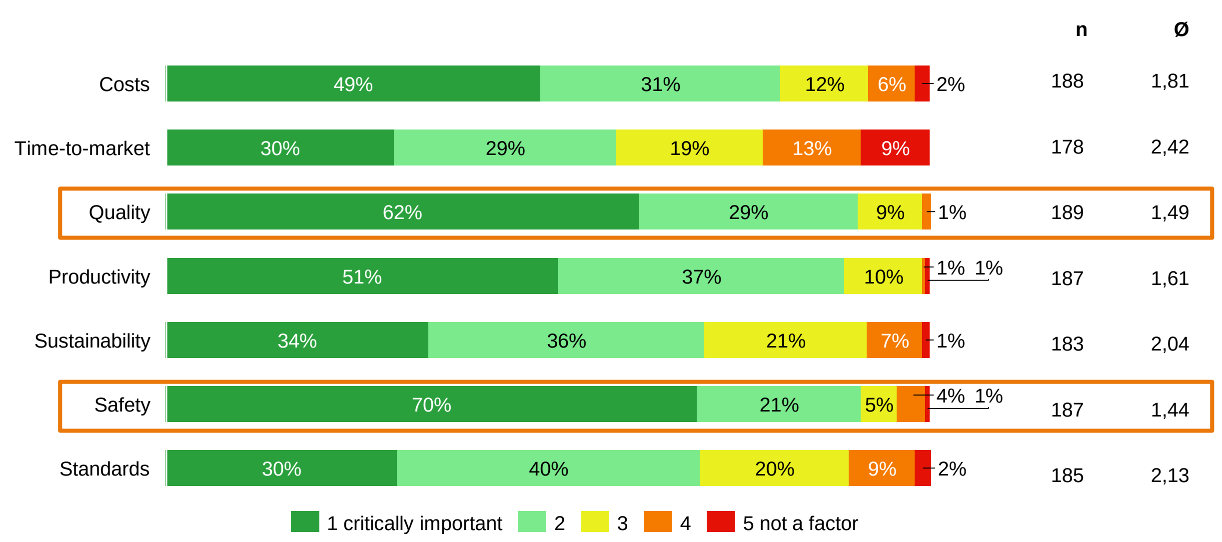



**FIGURE 8: HOW MUCH IS YOUR DAILY WORK DRIVEN BY ONE OF THE FOLLOWING POINTS? (COMPANIES ONLY)**

experience of the workforce and to find and investigate different ways to support the decision making process within a company. Otherwise if the knowledge retires it will become hard to judge on about one-third of the decisions necessary to been made.

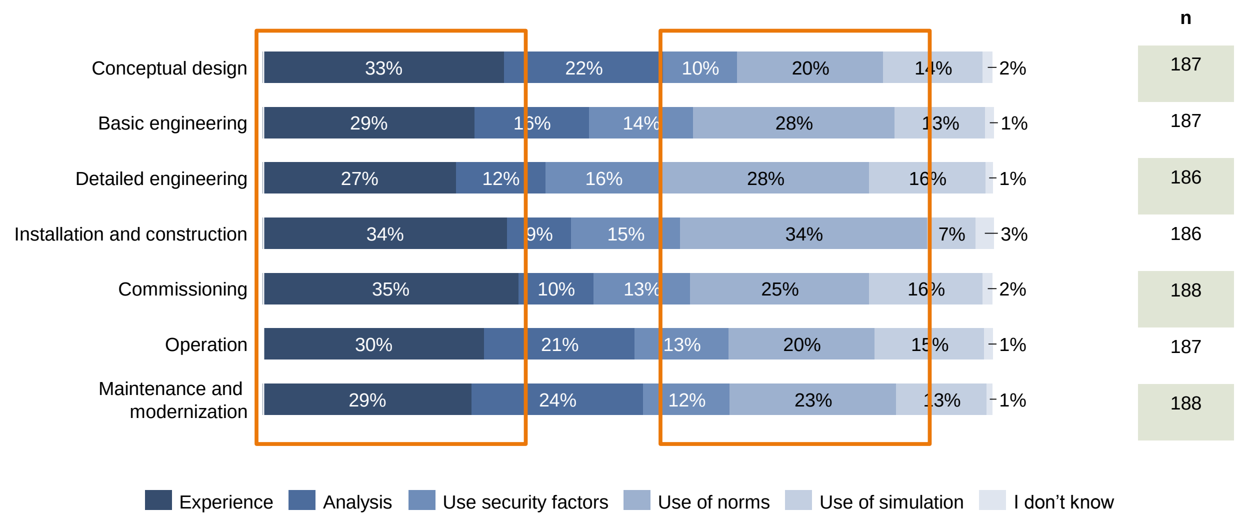



**FIGURE 9: ALONG THE PLANT LIFE CYCLE MANY DECISIONS ARE MADE. HOW IS THE DECISION PROCESS SUPPORTED TODAY? (COMPANIES ONLY)**

Investigating the role of simulation on a scale from 1 (completely agree) to 5 (don't agree at all) the survey participants ranked highest that simulation can answer engineering/operational questions with lower risks (average 1.76/1.86) and earlier (average 1.77/2.03). Followed by the opinion that questions can be answered more reliable (average 2.17/2.21) and with lower efforts (average 2.37/2.29) (Figure 10). Therefore it can be derived that participants see high value in simulation to reduce time and risks during engineering and operations. Another question revealed that simulation would be used by the participants to gain understanding and identify problems (Figure 11). Further the participants would use simulation to support their decisions, leading to the possibility to capture the experience of people within simulation models and to base decisions upon simulation. In addition simulation would be used for validation and testing. Even though simulation might not lower the effort clear value is seen by using it. Clearly simulation is seen as a serious technology to support the business rather than being something to play around with.

***Simulation can be used to answer engineering and operational questions earlier and with lower risks.***

***Simulation is an accepted technology, even though it is not for free.***

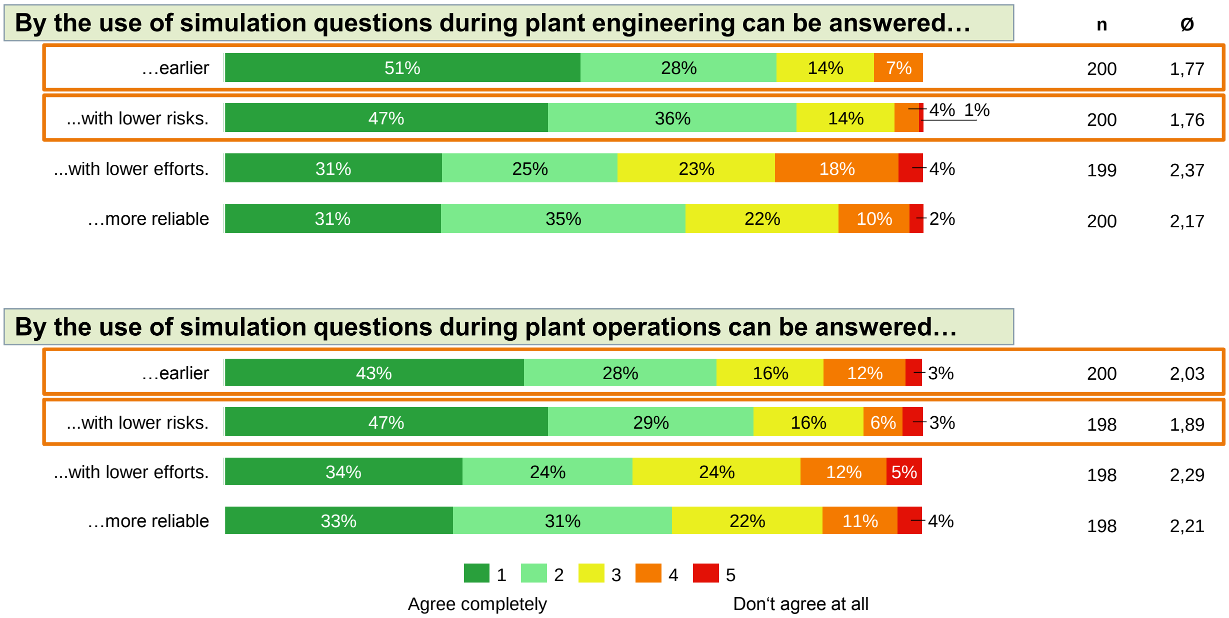



**FIGURE 10: BY THE USE OF SIMULATION QUESTIONS DURING PLANT ENGINEERING/OPERATIONS CAN BE ANSWERED…**

Looking at the current use of simulation along the life-cycle of a process plant it is most commonly used during engineering then training then design and less frequent during the operational phase (Figure 12). This answer could lead to the conclusion that the investment done early within the life-cycle it not fully utilized during later phases of the life-cycle.

*Today simulation is most frequently used during engineering, then training, then design followed by operation. But the effort invested early in the life-cycle is currently not utilized in the later phases.*

The question about the used kind of simulation revealed a strong dominance of dynamic simulation across the whole life-cycle (Figure 13 and Figure 14). During the design phase material flow and static simulation play also a major role. Within engineering the simulation of in- and output signals as well as device feedback signals towards the automation systems and emulations of the control system are used intensively too. The same holds true for training. Within the operations phase dynamic simulation is clearly the strongest kind of simulation.

*Dynamic simulation is the most common kind of simulation used across the life-cycle.*

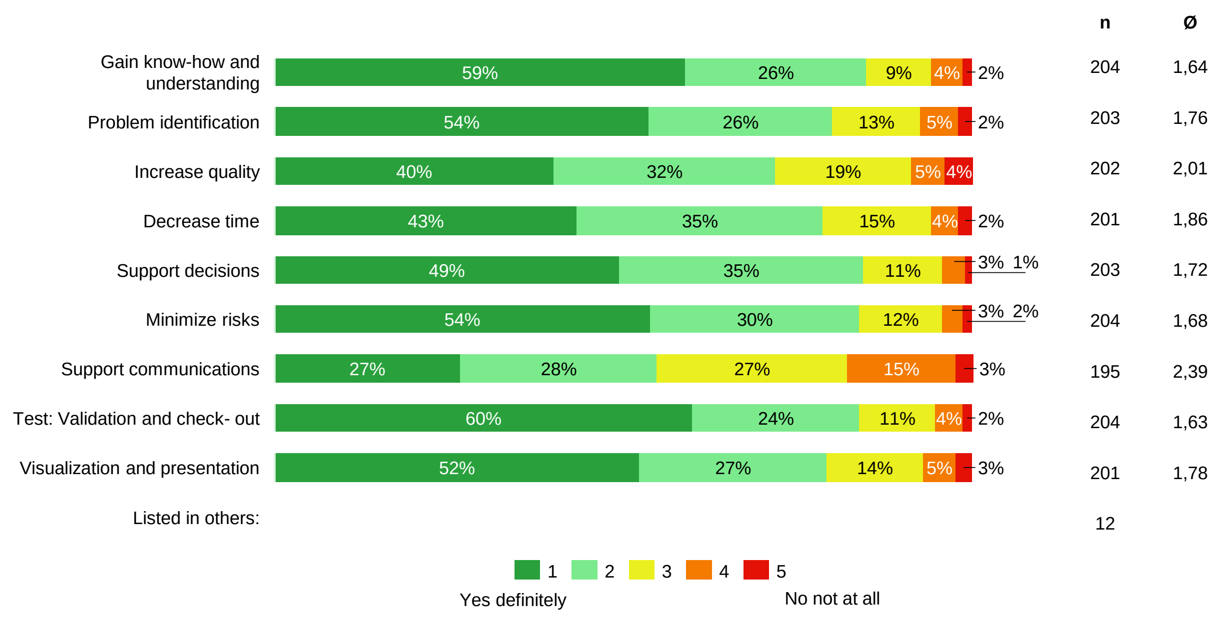



**FIGURE 11: A SIMULATION CAN SUPPORT DIFFERENT TASKS. WOULD YOU USE SIMULATION FOR ONE OF THE FOLLOWING TASKS?**

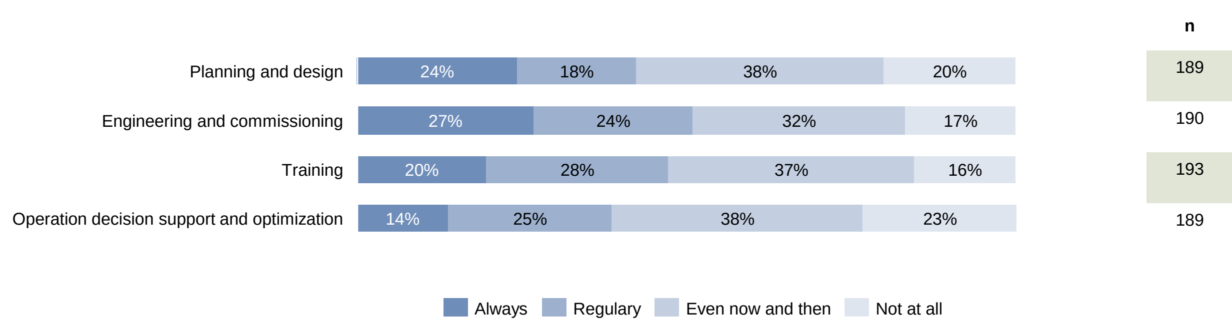



**FIGURE 12: HOW OFTEN IS SIMULATION CURRENTLY USED WITHIN EACH PHASE?**

Looking at how simulation is currently used, the answers show that the use of simulation depends most of the time on individuals, no matter in which phase (always 50% or more) (Figure 15). On the other hand, almost 1/3 of the participants say that simulation is an integrated part of their normal engineering workflow within the design and engineering phase.

***Most of the time there is no defined process for the use of simulation; in more than 50% of the projects simulation is not used systematically.***

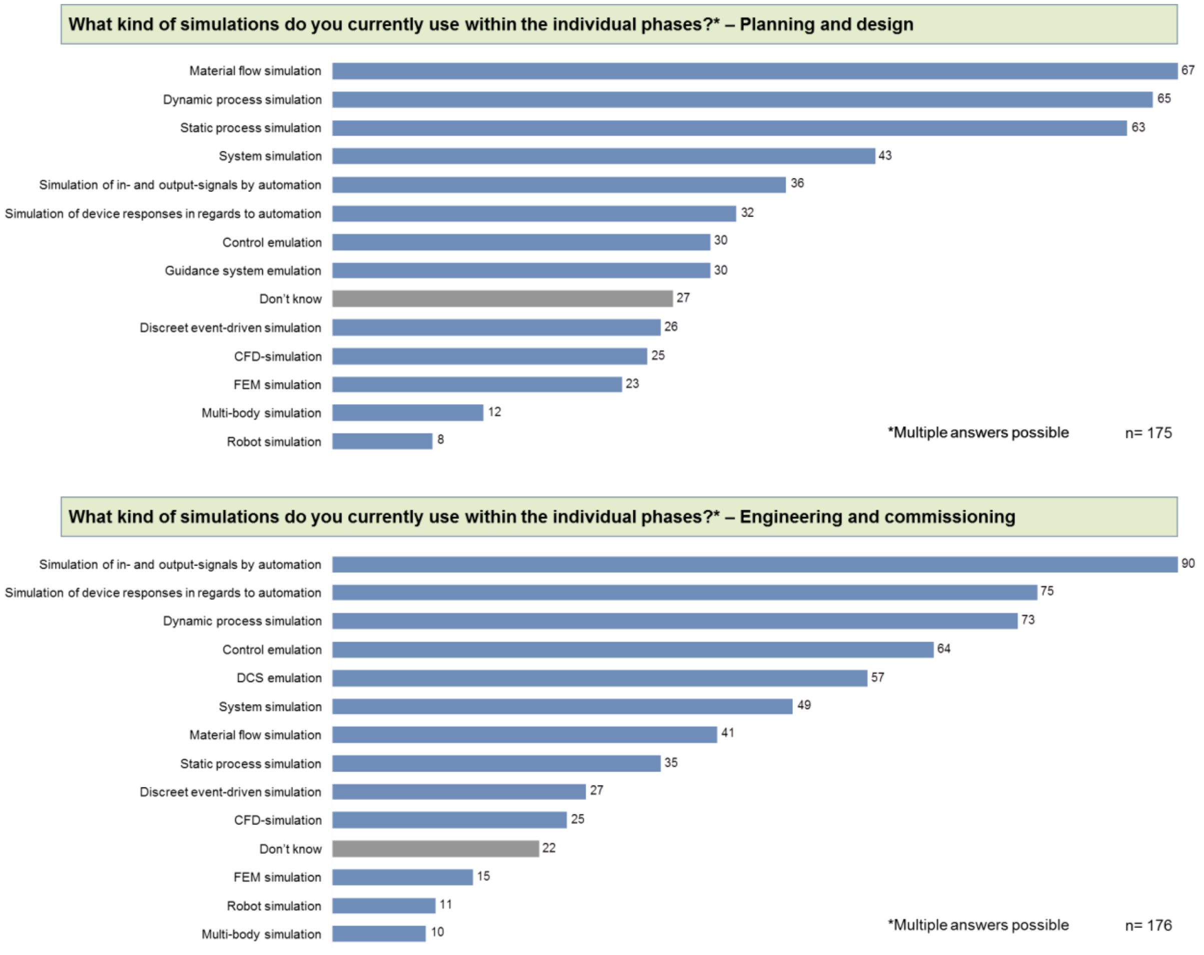



**FIGURE 13: WHAT KIND OF SIMULATIONS DO YOU CURRENTLY USE WITHIN THE INDIVIDUAL PHASES? (1/2)**

Investigating the tools currently used by the participants shows that self-developed tools play a major role, with 14% or more across all different simulation use cases (Figure 16). Furthermore, the field of the used simulation tools is very diverse with many specific simulation tools. The commercial tools Aspen Plus, Aspen Hysys and Matlab (Mathworks) (always above 9%) have a significant role across the life-cycle. For engineering and training SIMIT (Siemens) plays a significant role (6%) and for training UniSim (Honeywell) (8%).

***Self-developed simulation tools play a significant role across the life-cycle phases.***

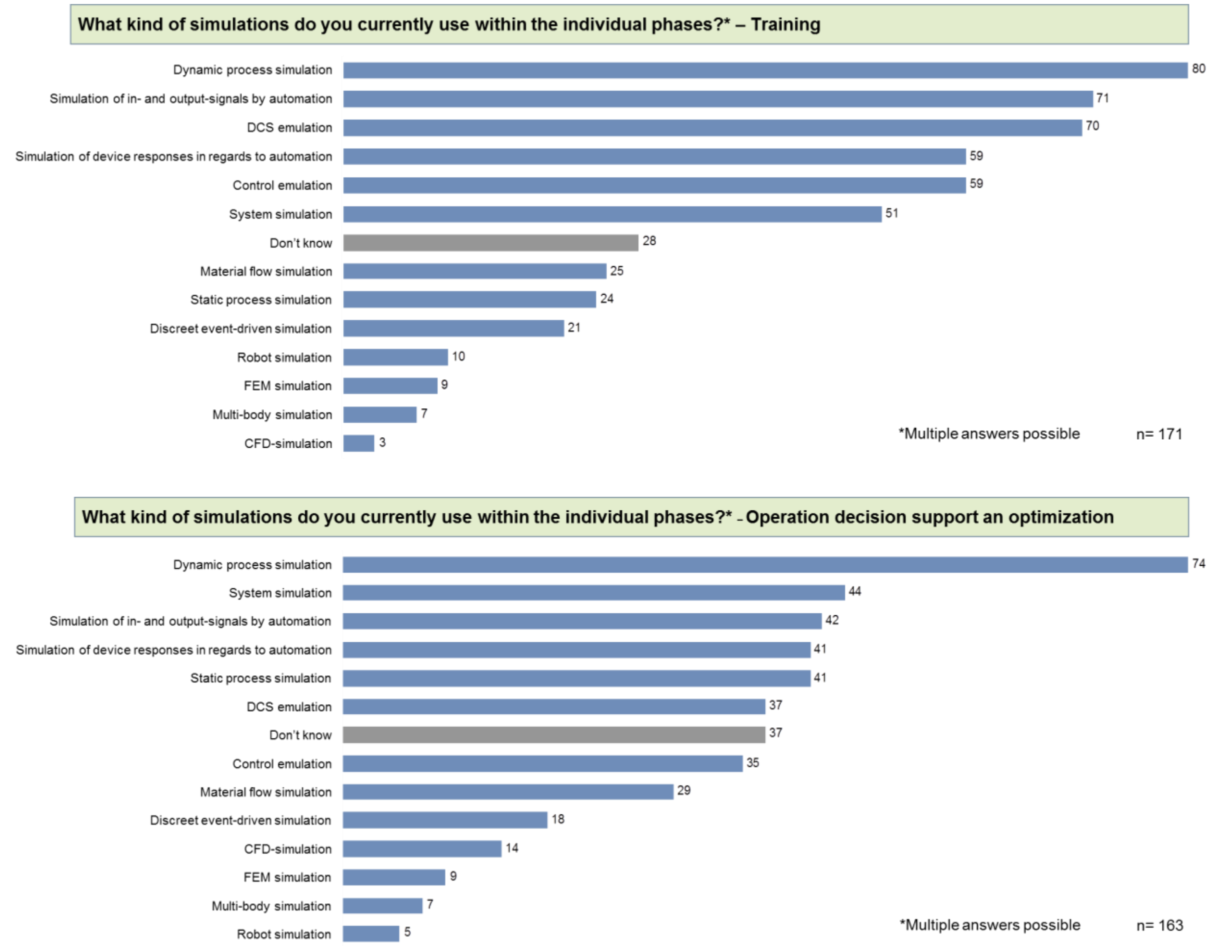



**FIGURE 14: WHAT KIND OF SIMULATIONS DO YOU CURRENTLY USE WITHIN THE INDIVIDUAL PHASES? (2/2)**

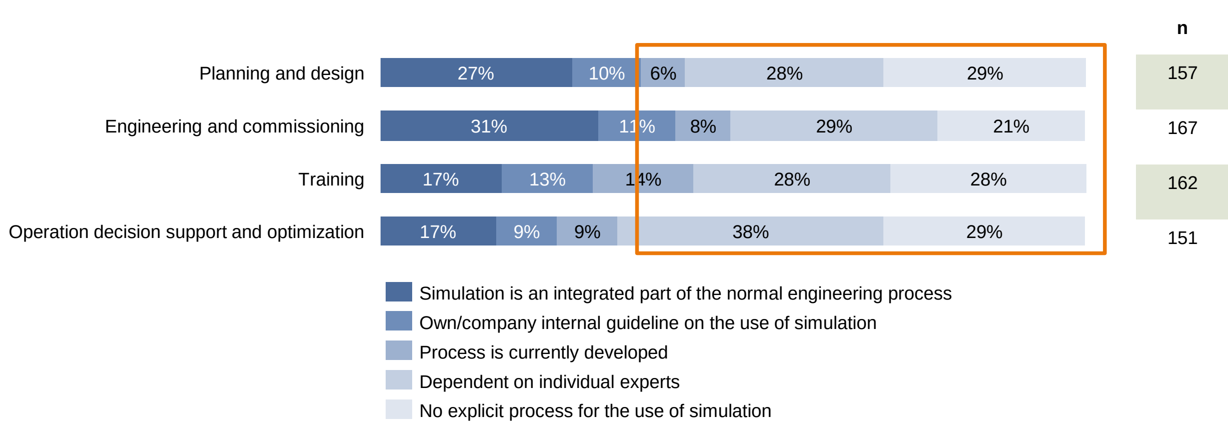
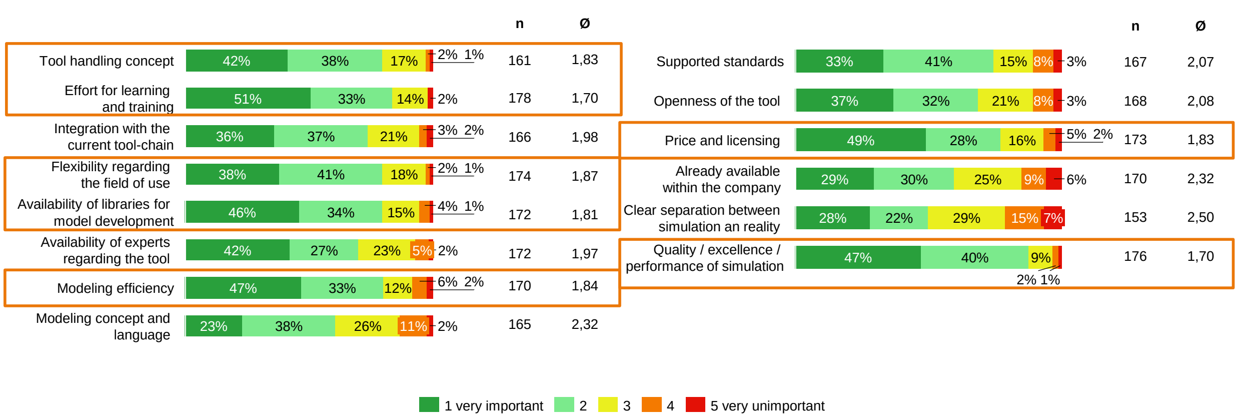



**FIGURE 15: WHICH PROCESS SUPPORTS YOUR CURRENT USE OF SIMULATION?**

| | Planning and design | n | Engineering and commissioning | n | Training | n | Operation decision support and optimization | n |
|---|---|---|---|---|---|---|---|---|
| Aspen Plus (AspenTech) | 17% | 46* | 11% | 32* | 11% | 21* | 22% | 34* |
| Aspen HYSYS (AspenTech) | 13% | 35* | 10% | 29* | 9% | 18* | 15% | 24* |
| ASSETT, K-SPICS (Kongsberg) | 1% | 3* | 1% | 4* | 2% | 3* | - | - |
| CHEMCAD (Chemstations) | 4% | 11* | 3% | 9* | 3% | 5* | 2% | 3* |
| COCO Simulator (AmsterCHEM) | 1% | 3* | 1% | 2* | 1% | 2* | - | - |
| Dymola (Dassault Systems) | 2% | 6* | 3% | 9* | 3% | 6* | 3% | 4* |
| IDEAS (Andritz) | 1% | 3* | 2% | 7* | 2% | 4* | 1% | 1* |
| INDISS (RSI) | 1% | 3* | 2% | 6* | 2% | 4* | - | - |
| Matlab (Mathworks) | 16% | 42* | 10% | 31* | 10% | 20* | 16% | 25* |
| MiMiC (Mynah Technologies) | 1% | 3* | 3% | 8* | 2% | 4* | 1% | 2* |
| Omegaland (Yokogawa) | 2% | 4* | 1% | 4* | 2% | 4* | 1% | 2* |
| OpenModelica (OpenSource) | 2% | 6* | 3% | 9* | 2% | 3* | - | - |
| ProSim Plus, ProSim DAC (ProSim) | 2% | 4* | 1% | 3* | 2% | 3* | 3% | 4* |
| SIMIT (Siemens) | 3% | 8* | 6% | 17* | 6% | 12* | 3% | 5* |
| SimulationX (ITI) | 2% | 5* | 2% | 5* | 1% | 1* | 1% | 1* |
| SimSci (Schneider Electic, ehemals invensys) | 3% | 8* | 3% | 8* | 3% | 6* | 2% | 3* |
| SimSci DYNSIM (Schneider Electic, ehemals invensys) | 2% | 5* | 4% | 11* | 3% | 6* | 1% | 2* |
| SimSci DYNSIM Checkout (Schneider Electic, ehemals invensys) | 2% | 4* | 2% | 7* | 2% | 4* | 1% | 1* |
| TrySim (Cephalos GmbH) | 1% | 2* | 2% | 5* | 2% | 4* | - | - |
| UniSim (Honeywell) | 5% | 12* | 5% | 15* | 8% | 16* | 3% | 4* |
| Virtuos (ISG Industrielle Steuerungstechnik) | 1% | 3* | 2% | 7* | 2% | 4* | 1% | 2* |
| WinMOD (Mewes & Partner) | 2% | 6* | 4% | 13* | 3% | 6* | 4% | 6* |
| Within system specific tools | 2% | 6* | 7% | 20* | 5% | 10* | 5% | 8* |
| Self developed tool | 14% | 37* | 14% | 41* | 16% | 31* | 17% | 27* |

## Figure 16: Which simulation tools do you currently use?




## Figure 17: From your perspective: What are the most important criteria when choosing a simulation tool?

Important criteria for choosing a simulation are especially the effort for learning and training, and the overall handling concept (Figure 17). In addition, the flexibility in using the tool is important as well as the modelling efficiency. The availability of libraries with simulation components is critical. The performance of the simulation and the price are relevant factors too. Least important are the availability within the company and the clear separation between reality and simulation. But for the last point there is a significant difference between the different roles within a company. Participants from research and development ranked this point as significantly less important than participants from management. Therefore the separation between simulation and reality is especially important during the real plant operation phase and it must be always be clear whether the user is dealing with a simulation or the reality.

***Subjectively, the equipment manufacturers report the highest modelling effort.***

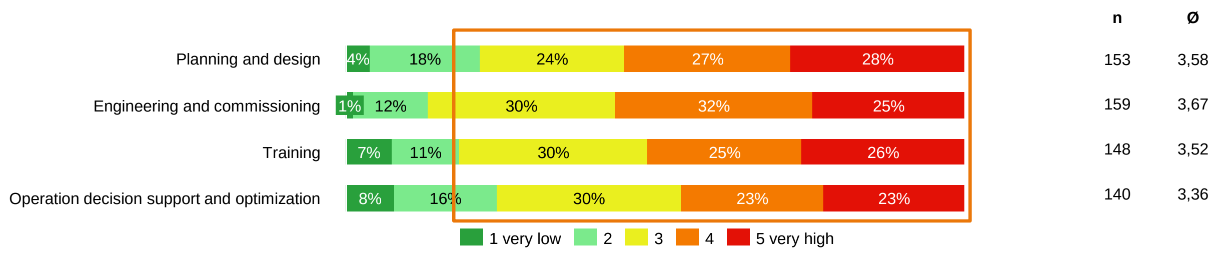



**Figure 18: What is the effort (time and costs) to use simulation within the phases?**

The effort for the use of simulation is still quite high across the life cycle, no matter in which phase. On a scale from 1 (very low) to 5 (very high) the subjective effort (time and money) to use simulation is quite high in all phases (averages: design 3.58, engineering 3.67, training 3.52, operations 3.36) (Figure 18). Also for training and optimization the modelling effort does not increase. This was a surprise. Does it mean that simple models are sufficient for training too?

Interestingly, there is a significant difference between the company types, with the EMs having the highest subjective modelling effort. During the design and engineering phase the EM showed a significant higher effort then the O&O as well as the SI (average design/engineering: O&O 3.15/3.50, SI 3.75/3.64, EM 4.22/4.32). We believe that a lack of process know-how makes it harder for the EM to build up sufficient models. A difference in the tools or the kind of simulation that is used could not be found in the data.

***Model reuse and co-simulation is already in strong demand.***


**FIGURE 19: DO YOU HAVE/SEE THE NEED TO INTEGRATE MODELS DEVELOPED IN ONE SIMULATION TOOL INTO ANOTHER SIMULATION TOOL?**

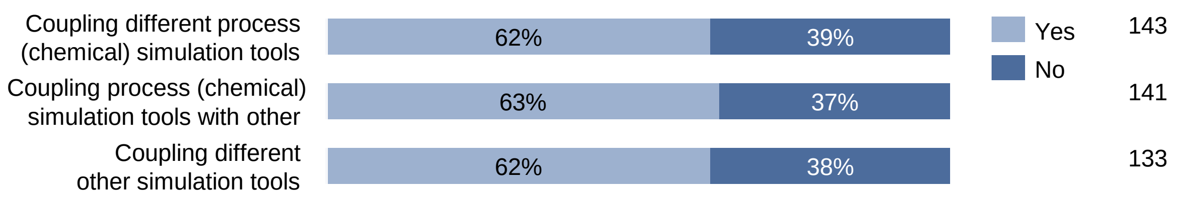



**FIGURE 20: DO YOU HAVE/SEE THE NEED TO COUPLE DIFFERENT SIMULATION TOOLS?**

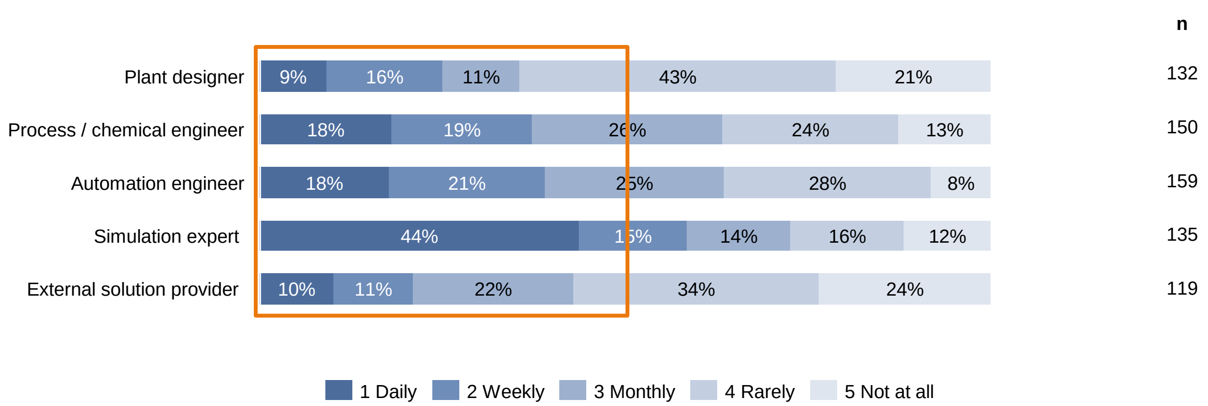



**FIGURE 21: HOW OFTEN ARE WORKING THE FOLLOWING PERSONS WITH SIMULATION AT YOUR COMPANY?**

*Simulation is not only for dedicated experts; it is often used by specific domain experts (e.g. automation engineers) as a supporting methodology.*

In addition, the survey investigated the need to reuse simulation models once these have been developed. First, the participants indicated a high demand for the integration of models developed within one simulation tool into another simulation tool (Figure 19). Further, about two-thirds of the participants need to couple different simulation tools. On the one hand they want to couple process simulation tools with other simulators (vertical coupling), but on the other hand they also want to couple on the same level e.g. process simulation tool (horizontal coupling) (Figure 20).

The current users of simulation were also evaluated with the result that simulation is not only for dedicated experts and is commonly used by experts from specific domains like automation engineering (Figure 21).

# 6 The Future Role of Simulation

The investigation of the future role of simulation began with a set of questions to identify relevant future drivers (Figure 22). Regarding the challenges, the participants indicated that safety and quality will remain the most important driver in the future. Other drivers like winning qualified personnel, costs pressure and time pressure, environmental protection or limited resources are following in the ranking. Interestingly, regarding cost and time pressure there is a significant difference between responses from Germany and the USA, and participants from Germany find these significantly more important.

***Safety and quality remain major drivers for the future.***

***Costs and time-to-market are significantly more important in Germany than in the USA.***

Another question concerned the expectations regarding particular technological trends (Figure 23). Within the evaluated trends, three major groups can be found. The first includes integrated engineering and working processes [44], simulation-driven solutions and products for plant engineering, and standards for interfaces and architectures. These technological trends will most likely change the daily work of the participants in the future. The second group, with less impact, includes simulation-driven solutions and products for the plant operation and modularization of plants. And the group of trends which are expected to change the daily work the least includes data-driven solutions and products (big data), cloud and web-driven solutions and products and cyber physical systems. For simulation it can be concluded that it is an

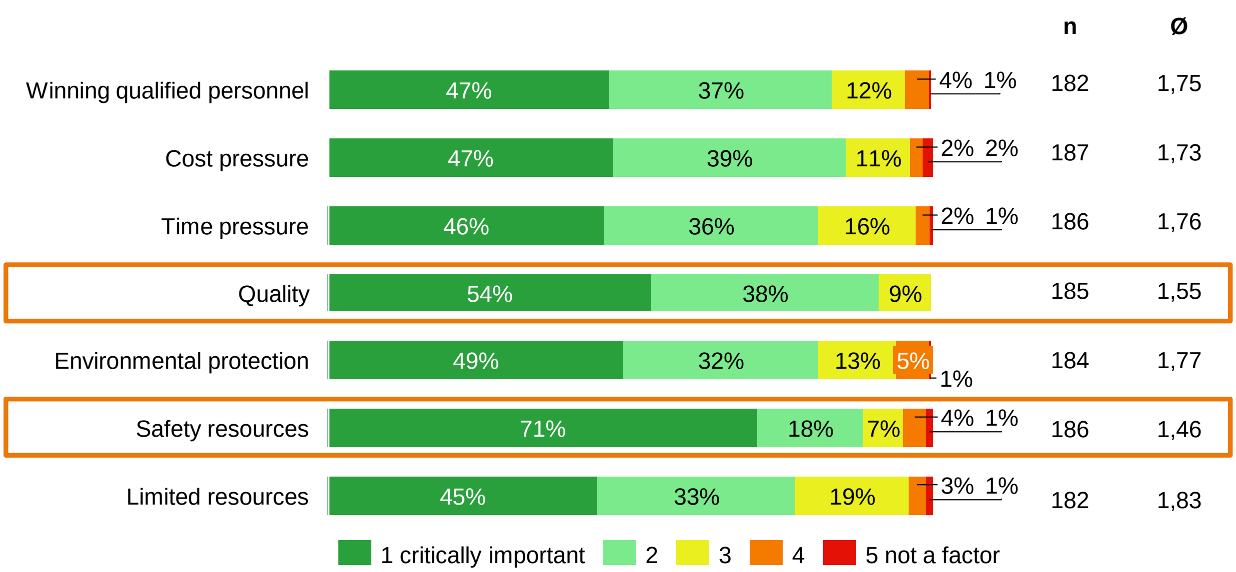



**FIGURE 22: HOW IMPORTANT DO YOU ANTICIPATE EACH OF THE FOLLOWING CHALLENGES WILL BE FOR YOU IN 6-8 YEARS? (COMPANIES ONLY)**

accepted technology within the process industries in contrast to cloud technology, Big Data and Cyber Physical Systems [2].

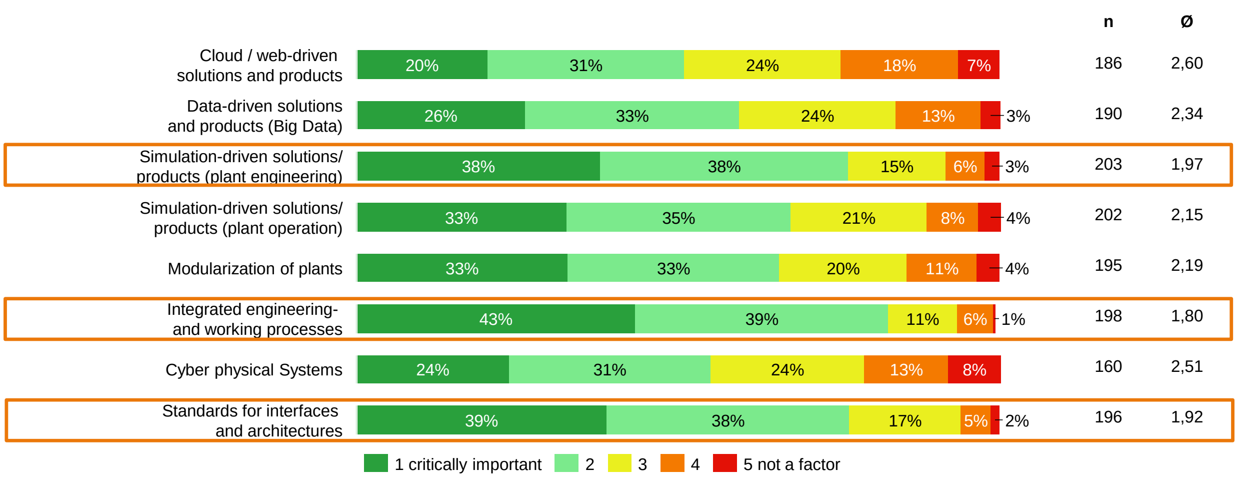



**FIGURE 23: HOW IMPORTANT DO YOU EXPECT THE FOLLOWING TECHNOLOGY TRENDS WILL BE TO YOUR DAILY WORK IN 6-8 YEARS?**

***Integrated engineering, simulation and standards are the most relevant technological trends that will change the way we work.***

***Across the whole life-cycle of a process plant, simulation will gain major importance.***

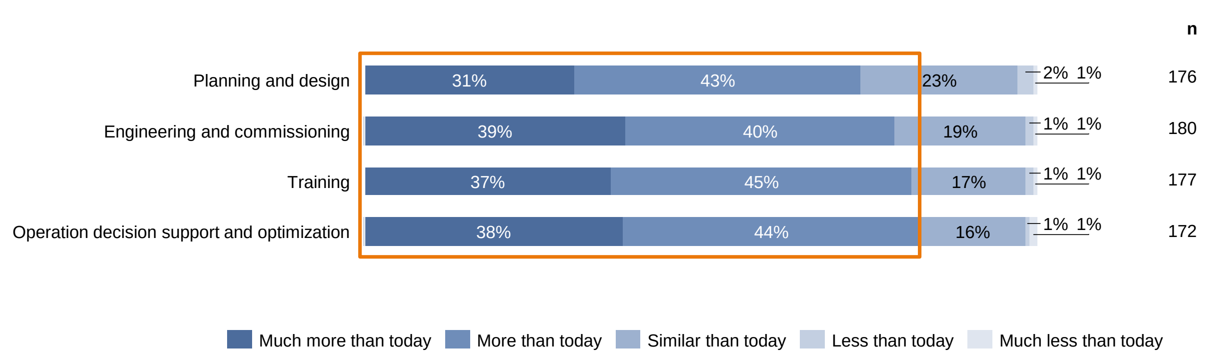



**FIGURE 24: FROM YOUR POINT OF VIEW: WHAT WILL BE THE RELEVANCE OF SIMULATION IN 6-8 YEARS?**

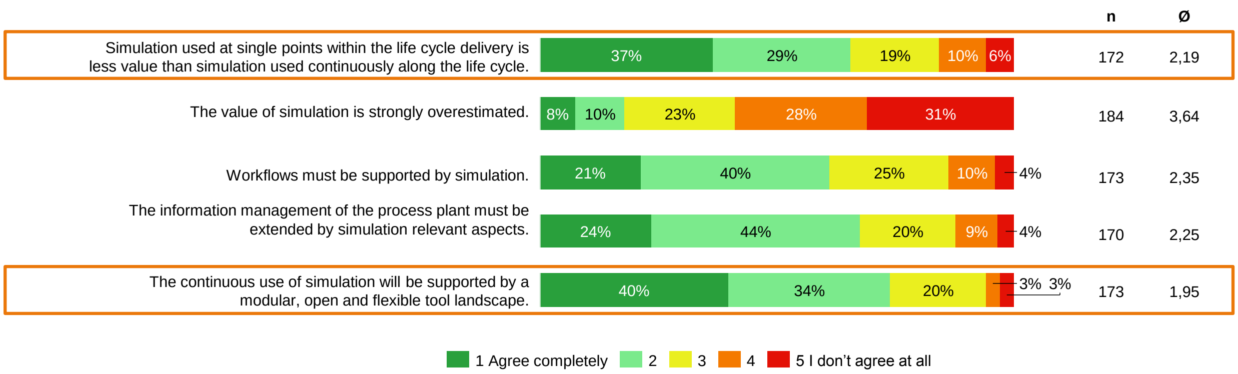



**FIGURE 25: HOW MUCH DO YOU AGREE WITH THE FOLLOWING STATEMENTS?**

The following question evaluated the relevance of simulation within the future (Figure 24). Clearly in all phases of the life-cycle simulation will gain more or much more importance than today according to the participants.

Investigating statements about the future (Figure 25) indicated that an important functionality to enable a continuous use of simulation across the life-cycle of a process plant is a modular, flexible and open tool landscape. The majority of the participants also agreed that using simulation at a single point within the life-cycle delivers less value than simulation used continuously along the life-cycle. Further, it will be important to extend the information management with simulation relevant aspects and to adjust the workflows to support simulation.

***The virtual plant is the future.***

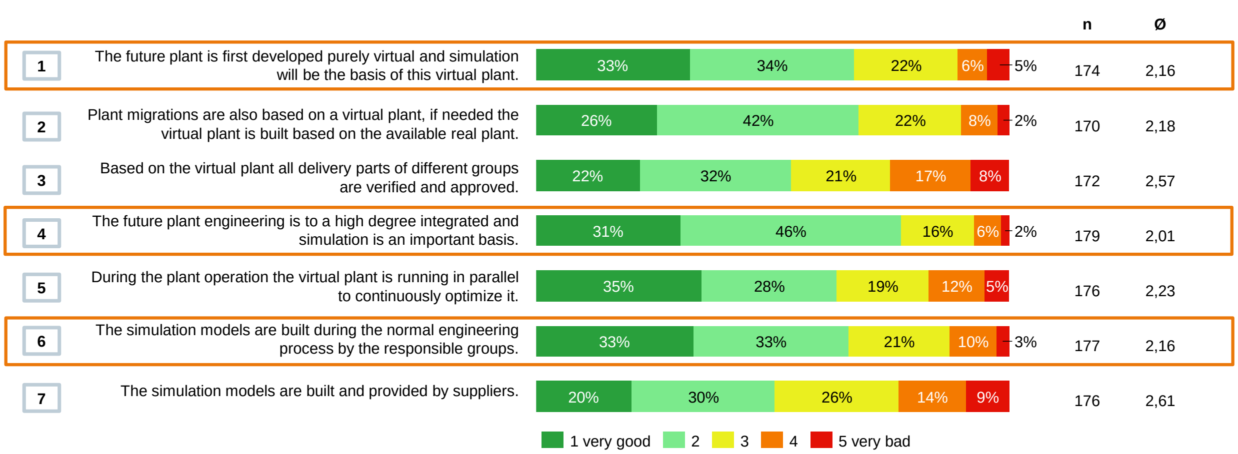



**FIGURE 26: THE FOLLOWING SCENARIOS DESCRIBE THE USE OF SIMULATION WITHIN THE LIFE CYCLE OF A PROCESS PLANT IN 6-8 YEARS. HOW WELL DO THEY DESCRIBE YOUR EXPECTATIONS?**

A set of scenarios were evaluated by the participants (Figure 26). The scenario that the future plant engineering will be highly integrated and simulation will provide an important basis was ranked highest. This is closely followed by the scenario that in future plants will first be

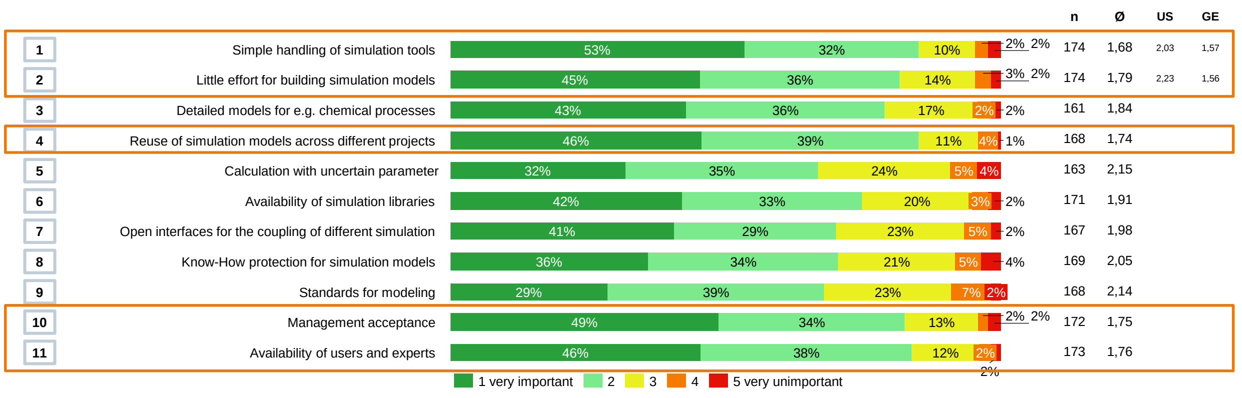



**FIGURE 27: WHAT ARE THE MOST RELEVANT REQUIREMENTS TO ENABLE A CONTINUOUS USE OF SIMULATION ALONG THE LIFE CYCLE OF A PROCESS PLANT?**

developed virtually and simulation will be the basis for this virtual plant. The option that the simulation models will be built during the normal engineering process by the responsible groups is ranked high too. Lower in the rankings was that plant migrations will also be based on a virtual plant and if this is not available the virtual plant will be built. Very diverse responses were received for the scenario that during the plant operation the virtual plant will run in parallel to continuously optimize it. This scenario got the most votes for describing the future "very well", but on average it was only number four. The last two scenarios ranked by the participants are the one that the virtual plant is used to verify and approve all deliveries of the different groups and that the simulation models are built and provided by the suppliers. But especially the last point showed a significant difference between the different types of company. The EM ranked this scenario much higher than an O&O participant, indicating that the EM is willing to provide models for their equipment.

***Management acceptance is needed to realize a continuous use of simulation.***

***A collaboration model between companies to create the models for the virtual plant needs to be developed.***

***System integrators are in strong need for process models, simulation libraries, modeling standards and open interfaces.***

Another interesting aspect was found when looking at the scenarios addressing some kind of collaboration, e.g. using the virtual plant for approval and validation of the deliveries and the building of simulation models by the suppliers. There is a large difference between participants from the USA and participants from Germany, and these scenarios are seen as more likely by participants from the USA. One action derived from this evaluation is that collaboration models around the virtual plant need to be developed for the future; currently there are no collaboration models across companies to provide and exchange simulation models. This is essential to make the continuous use of simulation successful and to enable the model development by the most appropriate party/company involved in the design, engineering and commissioning of a process plant.

***Equipment manufacturers will provide simulation models for their equipment in the future.***

***"No simulation no success"***

*Survey participant*

Investigating the most relevant requirements to allow a continuous use of simulation along the plant life-cycle delivered the results shown in Figure 27. The handling, usability, model reusability and modelling efficiency are important criteria for success. In addition it was shown that the acceptance by management is another very important factor for success. The availability of simulation libraries, open interfaces and know-how protection are relevant too, but significantly more relevant to SIs than O&Os. We believe this is because an SI does not have the detailed process knowledge to hand and would gain considerably if they could directly use good models (e.g. of a chemical process) to validate their control system design without the need to develop such models themselves.

***"Simulation will be in continual use. Models will be refined automatically based on real time data."***

*Survey participant*

From the survey results it could be seen that the future use of simulation should be a continuous one along the life-cycle. Thus the cases of single simulation use need to growth together (Figure 28). The results suggest it is most likely that the engineering and training simulation will merge first and start using a common model base. Then the design will join, and finally the operation simulation. The biggest challenge will be to bring down the barriers between

***"As companies develop corporate responsibility and accountability programs and/or regulations force change, companies will need to seek ways to minimize impact on all social, environmental and economic levels. Simulation will by conformity provide an expected outcome to ensure that many unintended outcomes will best be answered and benchmarks may be set."***

*Survey participant*

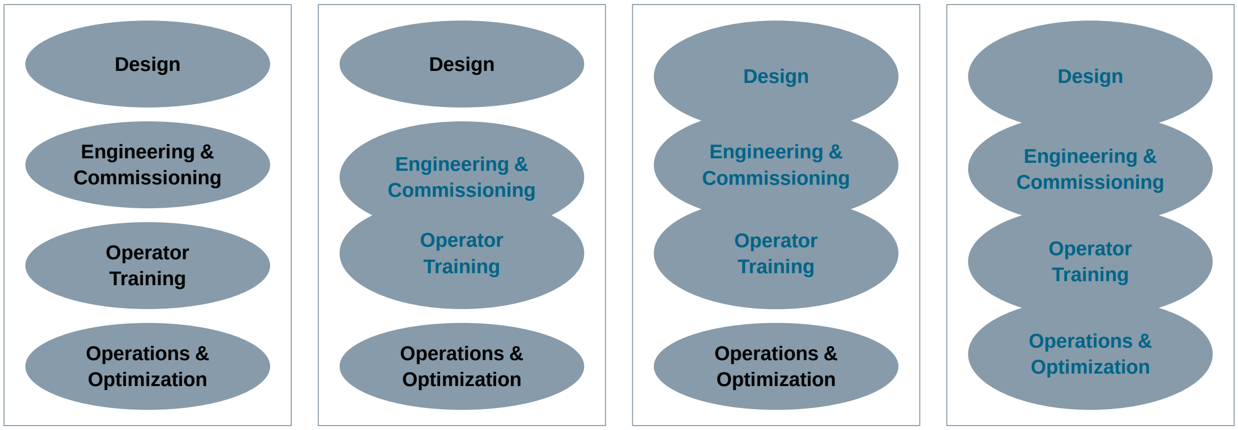



**FIGURE 28: THE SIMULATION USE CASES WILL GROWTH TOGETHER**

engineering and operations if one set of people and companies have the responsibility for designing, engineering and building a plant and another set of people and companies are then responsible for operating it. Each handover of responsibilities will be a major hurdle for a continuous use of simulation.

***The simulation use cases will growth together and enable a continuous use of simulation along the life-cycle of a process plant.***

# 7 Enabling the Integrated Use of Simulation

Based on the drivers and challenges for the process industries as well as the requirements for the use of simulation and the survey results about the current and future role of simulation, we identified possible fields of action to enable an integrated use of simulation along the life-cycle of a process plant. These actions will be described briefly here as a basis for further discussions. The target is to develop a commonly accepted technological roadmap for the continuous use of simulation within the life-cycle of a process plant. The actions have been clustered into technical and non-technical actions. Within the technical actions the following subcategories have been defined: model reuse, modelling efficiency, integration, and usability. The non-technical actions have been categorized into: workflows, acceptance, education, and collaboration.

## 7.1 Workflows

The following four actions were derived: (1) workflows, (2) iVComm (integrated virtual commissioning), (3) iCAPE (simulation integrated computer aided process engineering), (4) iO&M (simulation integrated operations and maintenance). (1) addresses the need to generally change existing workflows within companies to make simulation a standard within the future, without major additional efforts. (2) looks at the development of an integrated virtual commissioning workflow as standard within each automation project [36]. (3) addresses the need to extend the integration of workflows into the design and planning phase to enable an integrated computer aided process engineering. Finally with action (4) the integration of simulation into the operations and maintenance workflow should be developed.

## 7.2 Acceptance

The acceptance action field holds the action to gain acceptance from the management of the company for the use of simulation technology. The generation of success stories was added to support the management acceptance but also the general acceptance and trust in the use of simulation.

## 7.3 Education

A common methodology and terminology should be developed to ease the understanding of other simulation systems. This will also have great benefits in the technological action fields e.g. in terms of data and tool chain integration. In addition it is necessary to extend the education curricula towards the integrated use of simulation by using simulation technologies as standard e.g. within the training of process and automation engineers.

## 7.4 Collaboration

The need to develop a collaboration model between companies to realize the virtual plant was already formulated in summary about the future role of simulation and this action was added to the collaboration action field. In addition, a common model development guideline for simulation models delivered by the EM needs to be created.

## 7.5 Model reuse

Technically very essential will be the reuse of models which have been developed earlier in the life-cycle of the plant. First action would be to develop a co-simulation standard that is accepted by both vendors and users, followed by (or combined with) a standard for model exchange between different simulation tools (An analysis of co-simulation work can be found in [36]). A way to create a simulation or a virtual plant in a modular fashion (plug-and-play) based on available engineering or operation models needs to be developed. This plug-and-play functionality will also demand a commonly accepted modelling standard for simulation.

## 7.6 Modelling Efficiency

To drive down the effort for the use of simulation, the modelling efficiency needs to be improved. First the automatic generation of simulation models from existing data based on the latest information from the engineering or operating phase is needed [3, 4, 20, 21, 34, 37 and 38]. Usually, this includes the integration of various heterogeneous information models, the application of transformation mechanisms and a manual enrichment of simulation-specific information.

Second, libraries for devices as well as for processes need to be developed and provided ready-to-use. Managing simulation models across the life-cycle is also a challenge that has to be addressed. Finally the management of change in simulation models will be also a critical factor for success which could for example be achieved by a specialized model and simulation version control systems.

## 7.7 Integration

As it is expected that the vision will not be realized with a completely new set of tools that require users to change their complete IT infrastructure it is necessary to work on possible tool chain integration. The simulation should be deeply integrated both in engineering workflows as well as operating workflows to support the decision in a seamless way. Along the life-cycle of plants, many different information silos are created which can all be valuable for an integrated use of simulation. The heterogeneity of the data sources in terms of syntax and semantics requires further data integration concepts.

The sharing of simulation models across organizational boundaries can provide high-quality models. However, the domain experts demand a way to protect their critical knowledge. For the subsequent use of simulation within operations it is necessary to provide a secure online interface between the simulation system and the real plant operation.

## 7.8 Usability

Finally it is important to work constantly on the usability to create benefits also for non-simulation-experts. An important aspect is the provision of the prediction uncertainty so that the simulation results can be assessed. This is an important criteria for humans in their decision making process during plant operations, with backing from simulation decision support systems. Therefore concepts for the integration of simulations into the plant operations have to be developed further.

# 8 Future Work and Next Steps

Based on the survey results we are interested in developing a technology roadmap (e.g. [1, 18, 30 and 49]) towards the integrated use of simulation within the life-cycle of a process plant. This should be done together with experts and survey participants by organizing workshops to develop the roadmap. The outcome of this activity should be an accepted roadmap, for example with the title “Simulation within the process plant life-cycle 2030”.

The authors appreciate input and support. Please get in touch with us if you are interested in participating within the workshops (E-mail: oppelt.mathias@siemens.com).

Planned timeline: Summer/Autumn 2015

Planned location(s): Germany and/or USA

# 9 About the Authors

**Mathias Oppelt** is Product Manager at Siemens AG. He is responsible for simulation in context of process control system and the simulation system SIMIT. In addition he is co-chairman of the GMA FA 6.11 "virtual commissioning" and external doctoral student at the institute for automation at the Technische Universität Dresden. Mathias Oppelt graduated from Hamburg University of Technology (TUHH) with a Diploma (Dipl.-Ing.) in Mechatronics Engineering and from the Northern Institute of Technology Management (NIT) with a Masters in Technology Management (MTM).

Siemens AG, Oestliche Rheinbrueckenstr. 50, 76187 Karlsruhe,
E-mail: oppelt.mathias@siemens.com, Tel: +49 (721) 595-2178

Prof. Dr.-Ing. **Mike Barth** is Professor for the Engineering of Mechatronic Systems at Pforzheim University. His research interests include the engineering of automation systems - especially the field of simulation based methods. Prof Barth is spokesman of the task force GMA FA 6.11 "Virtual Commissioning" and member of scientific advisory board of the renowned scientific journal atp edition - Automatisierungstechnische Praxis.

Hochschule Pforzheim, 75175 Pforzheim
E-mail: mike.barth@hs-pforzheim.de, Tel: +49 (7231) 28 6475

Prof. Dr.-Ing. habil. **Leon Urbas** is head of the Chair of Process Control Systems Engineering at Technische Universität Dresden. His research interests include formal information and simulation models in automation, their application in model driven methods for engineering support systems and integrated highly efficient workflows for human-computer-collaboration in automation engineering. These technology oriented topics are supported by research in human-centered automation, in particular process visualization and operation across control rooms and shop floors, usability engineering in supervisory control and human performance modelling. Prof Urbas is spokesman of the task force GMA FA 5.16 "Middleware in industrial automation", member of the board of the processNet working group PAAT and Editor-in-Chief of the journal atp edition - Automatisierungstechnische Praxis.

Technische Universität Dresden, 01062 Dresden
E-mail: leon.urbas@tu-dresden.de, Tel: +49 (351) 463-39614

# 10 References


[1] Abele, T. (2006): Verfahren für das Technologie-Roadmapping zur Unterstützung des strategischen Technologiemanagements. Dissertation. Heimsheim: Jost Jetter Verlag (IPA-IAO Forschung und Praxis, 441).

[2] Acatech (2013): Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4.0.

[3] Barth, M. (2011): Automatisch generierte Simulationsmodelle verfahrenstechnischer Anlagen für den Steuerungstest. Dissertation. Düsseldorf: VDI Verlag GmbH (Fortschritt-Bericht VDI, Nr. 438).

[4] Barth, M.; Fay, A. (2013): Automated generation of simulation models for control code tests. In: Control Engineering Practice 21, p. 218–230.

[5] Bausa, J.; Dünnebier, G. (2006): Life Cycle Modelling in the chemical industries: Is there any reuse of models in automation and control? In: 16th European Symposium on Computer Aided Process Engineering and 9th Int. Symposium on Process Systems Engineering, p. 3–8.

[6] Bayer, B.; Marquardt, W. (2003): A Comparison of Models in Chemical Engineering. In: Concurrent Engineering: Research and Applications 11 (129).

[7] Belkius, B.; Holm, T.; Tetzner, T. (2010): Nutzen integrierter, gewerkübergreifender Modellierung industrieller Anlagen. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2010. VDI Berichte.

[8] Bergert, M.; Diedrich, C. (2008): Durchgängige Verhaltensmodellierung von Betriebsmitteln zur Erzeugung digitaler Simulationsmodelle von Fertigungssystemen. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2008. VDI Berichte.

[9] Biffl, S.; Schatten, A.; Zoitl, A. (2009): Integration of Heterogeneous Engineering Environments for the Automation Systems Lifecycle. In: 7th IEEE Int. Conf. on Industrial Informatics (INDIN),p. 576–581.

[10] Bohlmann, S.; Becker, M.; Balci, S.; Szczerbicka, H. (2013): Online Simulation Based Decision Support System for Resource Failure Management in Multi-Site Production Environments. In: Proceedings of the 18th IEEE International Conference on Emerging Technologies and Factory Automation.

[11] Bungartz, H.J.; Zimmer, S.; Buchholz, M.; Pflüger, D. (2013): Modellbildung und Simulation. Eine anwendungsorientierte Einführung. 2. Aufl.: Springer-Verlag Berlin Heidelberg.

[12] Cox, R. K.; Smith, J. F.; Dimitratos, Y. (2006): Can simulation technology enable a paradigm shift in process control? Modeling for the rest of us. In: Computers and Chemical Engineering 30, p. 1542–1552.

[13] PAS PAS 1059:2006-02, 02.02.2006: Planung einer verfahrenstechnischen Anlage - Vorgehensmodell und Terminologie.

[14] DIN EN 62381 (IEC 62381:2012), April 2013: Automatisierungssysteme in der verfahrenstechnischen Industrie – Werksabnahme (FAT), Abnahme der installierten Anlage (SAT) und Integrationstest (SIT).

[15] Dores Cardoso, L.; Assis Rangel, J. J.; Teixeira Bastos, P. J. (2013): Discrete Event Simulation for integrated Design in the Production and Commissioning of Manufacturing Systems. In: Proceedings of the 2013 Winter Simulation Conference, p. 2544–2552.

[16] Eggersmann, M.; Wedel, L. von; Marquardt, W. (2004): Management and Reuse of Mathematical Models in the Industrial Design Process. In: Chem. Eng. Technol. 24 (1), p. 13–22. DOI: 10.1002/caet.200406114.

[17] Engl, G.; Kröner, A.; Pottmann, M. (2010): Practical Aspects of Dynamic Simulation in Plant Engineering. In: 20th European Symposium on Computer Aided Process Engineering - ESCAPE20.
[18] Frauenhofer Institut für System- und Innovationsforschung ISI (ed.) (2012): Produkt-Roadmap Lithium-Ionen-Batterien 2030. Karlsruhe.
[19] Gu, F.; Harrison, W. S.; Tilbury, D. M.; Yuan, C. (2007): Hardware-In-The-Loop for Manufactoring Automation Control: Current State and Identified Needs. In: Proceedings of the 3rd Annual IEEE Conference on Automation Science and Engineering, p. 1105–1110.
[20] Hoffmann, P.; Schumann, R.; Maksoud, T. M. A.; Premier, G. C. (2010): Virtual Commissioning of Manufacturing Systems a Review and new Approaches for Simplification. In: Proceedings 24th European Conference on Modelling and Simulation.
[21] Hoyer, M.; Schumann, R.; Hoffmann, P.; Premier, G. C. (2008): Virtuelle Inbetriebnahme mit Model-CAT. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2008. VDI Berichte.
[22] Hoyer, M.; Schumann, R.; Premier, G. C. (2005): An Approach for Integrating Process and Control Simulation into the Plant Engineering Process. In: European Symposium on Computer Aided Process Engineering 15.
[23] Kain, S.; Heuschmann, C.; Schiller, F. (2008): Von der virtuellen Inbetriebnahme zur Betriebsparallelen Simulation. Herauforderungen im Anlagenbetrieb und Nutzenpotentiale der betriebsparallelen Simulation. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2008. VDI Berichte.
[24] Klatt, K.-U. (2009): Trainingssimulation. Erfahrungen und Perspektiven aus Sicht der chemisch-pharmazeutischen Industrie. In: atp (1-2), p. 66–71.
[25] Ko, M.; Ahn, E.; Park, S.C. (2013): A concurrent design methodology of a production system for virtual commissioning. In: Concurrent Engineering: Research and Applications 21 (2), p. 129–140. DOI: 10.1177/1063293XI3476070.
[26] Körtgen, A.-T.; Nagl, M. (2011): Tools for consistency management between design products. In: Computers and Chemical Engineering 35, p. 724–735.
[27] Kuehn, W. (2006): Digital Factory - Integration of Simulation enhancing the Product and Production Process towards operative Control and Optimization. In: Int. J. of Simulation 7 (7).
[28] Lüder, A.; Rosendahl, R.; Schmidt, N. (2013): Validation of behavior specifications of production systems within different phases of the engineering process. In: Proceedings of the 18th IEEE International Conference on Emerging Technologies and Factory Automation.
[29] Mersch, H.; Behnen, D.; Schmitz, D.; Epple, U.; Brecher, C.; Jarke, M. (2011): Gemeinsamkeiten und Unterscheide der Prozess- und Fertigungstechnik. Interdisziplinäre Aspekte der Produktionsmodellierung. In: at - Automatisierungstechnik 59 (1), p. 7–17.
[30] Möhrle, M.G.; Isenmann, R. (ed.) (2008): Technologie-Roadmapping. Zukunftsstrategien für Technologieunternehmen. 3rd edition: Springer-Verlag Berlin Heidelberg.
[31] Morbach, J.; Wiesner, A.; Marquardt, W. (2009): OntoCAPE - A (re)usable ontology for computer-aided process engineering. In: Computers and Chemical Engineering 33, p. 1546–1556.
[32] NAMUR Arbeitsblatt NA 35, 24.03.2003: NA 35 - Abwicklung von PLT-Projekten.
[33] NAMUR Arbeitsblatt NA 60, 11.04.2006: NA 60 - Management von Trainingssimulatorprojekten.
[34] Oppelt, M.; Drumm, O.; Lutz, B.; Wolf, G. (2013): Approach for integrated Simulation based on Plant Engineering Data. In: Proceedings of the 18th IEEE International Conference on Emerging Technologies and Factory Automation.
[35] Oppelt, M.; Urbas, L. (2014): Integrated Virtual Commissioning as Part of the Automation Engineering Process. In: Proceedings 40th Annual Conference of IEEE Industrial Electronics Society - IECON 2014.

[36] Oppelt, M.; Wolf, G.; Urbas, L. (2014): Capability-Analysis of Co-Simulation Approaches for Process Industries. In: Proceedings of the 19th IEEE International Conference on Emerging Technologies and Factory Automation.

[37] Oppelt, M.; Wolf, G.; Drumm, O.; Lutz, B.; Baudisch, T.; Wehrstedt, J.C. et al. (2014): Automatische Generierung von Simulationsmodellen für die virtuelle Inbetriebnahme auf Basis von Planungsdaten. Vorstellung eines generischen Konzepts und einer prototypischen Implementierung. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2014. VDI Berichte.

[38] Oppelt, M.; Wolf, G.; Drumm, O.; Lutz, B.; Stöß, M.; Urbas, L. (2014): Automatic Model Generation for Virtual Commissioning based on Plant Engineering Data. In: Proceedings of the 19th World Congress of the International Federation of Automatic Control.

[39] Patle, D. S.; Ahmad, Z.; Rangaiah G. P. (2014): Operator training simulators in the chemical industry: review, issues, and future directions. In: Reviews in Chemical Engineering 2 (30), p. 199–216.

[40] Schaich, D.; Hanisch, F. (2010): Einsatz von Operator-Training-Simulatoren (OTS) über den Lebenszyklus von Anlagen. In: VDI Wissensforum GmbH (ed.): Tagungsband Automation 2010. VDI Berichte.

[41] Schopfer, G.; Yang, A.; Wedel, L. von; Marquardt, W. (2004): CHEOPS: A tool-integration platform for chemical process modelling and simulation. In: International Journal Software Tools Technology Transfer (6), p. 186–202.

[42] Schulze, K. (2014): Trainingssimulation in der Prozessindustrie. Umfrageergebnisse zur Anwendung von Trainingssimulatoren. In: atp edition (1-2), p. 66–72.

[43] StatSoft, Inc. (2013): Electronic Statistics Textbook. Tulsa, OK. Online verfügbar unter http://www.statsoft.com/textbook/.

[44] Tauchnitz, T. (2013): Integriertes Engineering - wann, wenn nicht jetzt! Notwendigkeit, Anforderungen und Ansätze. In: atp edition (1-2), p. 46–53.

[45] Urbas, L. (2012): Process Control Systems Engineering. Unter Mitarbeit von A. Krause und J. Ziegler. 1. Aufl. München: Oldenbourg Industrieverlag GmbH.

[46] VDI-Guideline 2206, June 2004: VDI 2206: Design methodology for mechatronic systems

[47] VDI-Guideline 3633, Part 1, December 1993: VDI 3633: Simulation von Logistik-, Materialfluß- und Produktionssystemen.

[48] VDI-Guideline 4499, Part 2, May 2011: VDI 4499: Digital Factory.

[49] Wehnert, T.; Winzenick, M. (2011): Technologie-Roadmap Automation 2020+ Energie. Zukunftsmärkte für die Automationstechnologien. In: atp edition (5), p. 46–54.