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Markus Olin, Juha Leppävuori, Janne Keränen, Seppo Lahti, Asko Valli, Ari Koistinen, Heikki Hasari, Seppo Leppänen & Tomi Ropanen

Anyone can simulate?

The Q9 operations model to guide execution of simulation projects

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Abstract

Modelling and simulation methods have been developing quickly during the last few decades. In 2005, Tekes launched MASI, a five year programme to develop the knowledge, methods and use of modelling and simulation in the Finnish industry and service sector. Despite the development of simulation tools and public financial support, there are still relatively few simulation service providers on the market, and the benefits of applying modelling and simulation from a business point of view are not yet known. Due to this dilemma, we would like to start by discussing the role of simulation in the competitiveness of Finnish industry. What is the value of modelling and simulation competence? Are we on the right track if simulation methods developed in academia never enter the market or if modelling and simulation companies can only survive with public support?

This report summarises the results of the SISU project, which was part of the MASI programme. The main goals of the project were to develop simulation methods suitable for small and medium-sized enterprises (SMEs); to make an implementation plan to adapt these for industry, and to identify opportunities and create the prerequisites for simulation-based industry. This report mainly emphasises the Q9 operations model, which was developed for the effective execution of simulation projects. Business opportunities for simulation are preliminarily discussed and eleven case studies done within the project are briefly summarised.

The Q9 operations model was developed to guide the execution of simulation projects. In general, new ways to enable quicker, cheaper and more reliable modelling and simulation are needed. The issue here is not only to solve equations correctly and accurately, but more broadly, to identify the equations that need to be solved. This typically requires effective collaboration between different actors in simulation project. Q9 aims to enhance communications and thus helps to search for correct equations.

Preface

Use of simulation in industrial design and resulting business opportunities (SISU) was a Tekes-funded project under the Modelling and Simulation Program (MASI). The research partners were the Helsinki Metropolia University of Applied Sciences and VTT. The goal was to develop business, products, processes and services by means of simulation. This was done through a number of case studies, in which simulation applications were developed for eleven industrial partners financing the project. Case studies provided realistic development and a test environment for the Q9 operations model. Thanks to an active steering group, which members and organisations are listed below, the process was intensively evaluated.

Name	Organisation
Jukka Lahtinen	Etteplan Oyj
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Carl-Gustav Malmberg	Oy Sandman-Nupnau Ab
Tuomas Kallio	Kardex Finland Oy
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Apros	Process Simulation Software (apros.vtt.fi)
CAD	Computer-aided design
CFD	Computational fluid dynamics
COMSOL Multiphysics	Generic partial differential equation solver (www.comsol.com)
DR	Data reconciliation
Enterprise Dynamics	Dynamic simulation software for production and logistic systems (www.incontrolsim.com)
FloWizard	Computational fluid dynamics software (www.ae-solutions.com/engSoftware/ansys/FloWizard.php)
Fluent	Computational fluid dynamics software (www.fluent.com)
LabVIEW	Graphical programming environment (www.ni.com/labview/)
MATLAB	A programming language for technical computing (www.mathworks.com/)
MDR	Measurement Data Reconciliation, see DR

Mixsim	Mix design software (www.mixsim.net)
PIV	Particle image velocimetry, an optical method of fluid visualisation
SolidWorks	3D CAD design software (www.solidworks.com)
SQL	Structured Query Language, a language for managing data in relational databases.
SWOT	Environmental factors upon which an evaluation is based: strengths, weaknesses, opportunities, and threats. The first two are the internal features of the company and latter two are external factors that influence the company.
Validation	A process to check if something satisfies a certain criterion: “Are we solving the right equations?”
Verification	Testing to ensure that the model/system meets certain standards: “Are the equations solved correctly?”

1. Introduction

The development of technology up to its present level has been based on both practice and theory: theory without real-life applications will not affect well-being, and without theory or abstract thinking, any development tends to be slower and more laborious. Major leaps in the development of our technical and theoretical understanding have been based on mathematics; in this regard, the ability to express the theory in the form of partial differential equations has been especially important. The next important step was the development of computers and the application of numerical methods. But digitalisation has also much to offer in communication i.e. people can be in contact with each other very easily and geographical distances have become much less significant. We thus have mathematics, computers and communication, but we need to apply them more efficiently – for our common well-being.

In addition to developing modelling and simulation knowledge and methods, it is equally important to increase their use in the Finnish industry and service sector; this will create a competitive edge for Finnish companies on global markets. Furthermore, the hope is that new business will be catalysed by developing computing tools and know-how based on modelling and simulation.

The MASI program defines the problem as follows: "An important goal of the programme is the utilization of the methods and knowledge created in the research projects. The most advanced companies in Finland are in the international forefront of modelling and simulation know-how and efficient utilization. There is a lot of potential, however, to increase the use of these tools largely in the whole industry and service sector. This situation and future outlook would indicate a fertile ground for new service innovations and new knowledge intensive business services."

MASI's estimated total volume is approximately 92 million euros and Tekes's share of this is 46 million euro. The development of modelling and simulation methods has been highly emphasised in the MASI program. Fortunately, application-oriented SISU project found also a home in the program, for an amount totalling approximately 1 million euros. The main outcome of the SISU project was eleven simulation applications for the industrial participants and Q9 operations model which is a general guideline for executing simulation projects. As a tool, the Q9 can be considered as a model a simulation project itself. Based on our experiences, systematic tools do not always make life easier, but they do create opportunities and reveal pitfalls not visible before the tool (Q9 in our case) was applied.

The report includes a review of work and discussions during the SISU project, reasoning for developing and testing a new Q9 model, experiences from the application of SISU and some considerations for the future. The first chapter introduces the subject, while the second chapter presents the visions for increasing the use of simulation and modelling in the future, along with some preliminary analysis of resulting business models. The third chapter discusses what is preventing these visions from being fulfilled. In the fourth chapter, the SISU project is presented at a general level and the results of case studies are described in the fifth chapter. The Q9 model, applications and experiences are presented and discussed in chapter six. Some future opportunities detected in the area of simulation are presented in chapter seven, and conclusions from the whole SISU project are summarised in last chapter.

Model can be described as a representation of the essential features of the real system by a simplified system of interrelated objects following certain, e.g. mathematical rules, reflecting, and analogous to the real system behaviour. Simulation can be regarded as a repetitious use of these rules (model), for example, to experiment on the system behaviour in different circumstances (different system parameters, initial conditions etc.) using this analogy. In this work modelling and simulation are most often coupled to the application of some computer program.

2. Vision – Increasing the competitiveness of Finnish industry by simulation

At the beginning of the SISU project, its vision was defined: *as a result of the project, new companies that provide integrated simulation and design services for domestic and foreign markets will be established*. The established goal was *to develop a simulation and design method whose usability and costs are also suitable for SMEs*.

The future vision, which includes the systematic application of simulation in the Finnish industry, is presented in the following:

- Modelling and simulation are an essential part of corporate strategy – all decisions from the operative to the strategic level are based on simulations.
- All companies have people knowledgeable about simulation who
  - understand what can be achieved through extensive simulation,
  - communicate with simulation service providers, and
  - understand the risks related to modelling and simulation.
- There is an established network of simulation service providers who
  - understand the application domain, simulation methods and theory,
  - understand the opportunities and limitations of the service,
  - offer fast developing simulation technology to their clients, and
  - commercialise the methods and tools developed at universities.
- Modelling and simulation education is given at all education levels and areas.

Simulation can be interpreted as doing an experiment by computer. The biggest benefits can be achieved when experiments that require money or time can be at least partly replaced by computer simulations, which are cheaper and faster than traditional experiments.

In the SISU project, simulation was applied in R&D, production, selling and marketing. Based on these applications, general views on how simulation could benefit companies are discussed here.

In R&D, experiments and trials are often done and physical prototypes are built when a new process or product is designed. Computer simulations can be used to replace some of these experiments, thus saving time and/or money. Simulations can also lead to new innovations and solutions *through* optimisation or what-if studies, which are safer than physical tests. The return on the investment in simulation is seen in decreased development costs (cost efficiency), better performance of a process or product (competitive advantage), and shorter development time (faster market release).

It is often impossible to make a prototype, for example, in the case of a paper machine, a boat or an aircraft. Then the only possibility to test different solutions is to use simulation, whose real performance does not appear until after the products are in test use. To reduce risks caused by wrong simulation results, simulation methods have to be tested very thoroughly, especially if simulations replace prototyping. On the other hand, simulation can be safely applied to determine critical processes, structures or operations without actually performing these critical operations, e.g. severe accident simulations in nuclear power plants.

In production, especially in the process industry, computational methods like data analysis and process simulation are used in troubleshooting and daily process development. The payback from the investment in these methods come with higher quality of the final product, better process efficiency or increased production. Simulation models could also be of great value in training new personnel.

In selling and marketing, simulation models can be beneficial in visualising complex systems or processes, their behaviour, and the cause-effect relationships. More generally, simulation models can be applied in many contexts that require communication and information sharing.

3. What currently prevents the large-scale application of simulation?

Modelling and simulation represent a rather young area of science, one which has developed rapidly over the past few decades hand in hand with the development of computer technology. In many cases, modelling and simulation require an understanding of mathematics, algorithms and objects or phenomena to be modelled in detail, and therefore, they are usually done by researchers in universities and research organisations.

Researchers often wonder why simulation isn't used more frequently in the industry: it seems to present an open path for greater knowledge with minimal risks and costs, but companies don't seem to see how they could become more competitive by applying simulation.

3.1 Appliers – Industry

What actually prevents simulation from being applied in industry today? The most important factors noted in the SISU project were the lack of knowledge about modelling and simulation opportunities in general, and the questions of how to apply simulation and how to justify broader use of simulation based on economic indicators.

As terms, modelling and simulation are familiar for most, but how do people working in industry actually interpret them? Simulation is generally not taught at schools and colleges, thus the understanding of simulation can be very limited. Modelling and simulation may mean different things to different actors.

For people developing, applying and selling simulation tools, simulation itself may be the area of their interest. Developing new software solutions, algorithms and models may vary from software engineering to scientific work. In many cases, these engineers and researchers work enthusiastically especially in the areas in which they have never worked before.

For people buying or applying simulations, simulation can be seen as a way of seeing how something works. Simulation helps to solve technical problems, but determining how to apply simulation to help companies be more profitable or increase their business is difficult. This might be one reason why many companies do not have systematic guidelines on how to apply simulation today and which areas merit investment in the future.

Instead of having a systematic simulation strategy, modelling and simulation activities are often in the hands of a few specialists at many companies – this is also the case at universities, colleges and research organisations. Once a specialist gets another position at a company, responsibilities related to simulation might not be assigned. In the future, should organisations have a simulation strategy just as they have strategies for personnel and ICT – or should they already have a simulation strategy in place?

3.2 Suppliers – Research organisations and simulation service providers

What prevents increased use of simulation today? This question is considered from the point of view of research organisations and private simulation service providers.

The simulation service business is rather young and as a result, it has not yet established its markets or norms. The majority of today's simulation service providers are still small companies but many have survived for several years and some have been growing constantly. This can be seen an evidence of a market for simulation services, though this definitely lies in highly specialised segments.

The most important issue preventing new simulation service start-ups is the limited market or at least limited knowledge of possible markets. The industry is not familiar with how to apply simulation; in addition, at least before the start-up phase, simulation providers have limited information of available markets – the need and value of simulation services.

Another aspect preventing new simulation service business start-ups is related to people. Running a large-scale simulation project is team work, which includes people from different companies, consultants, scholars, etc. This will put more emphasis on teamwork and on interpersonal and communication skills than merely on professional or scientific competences.

Simulation methods and tools are being developed at universities and research organisations by researchers. Usually the performance of the methods takes higher priority than the reliability of simulation results. Once a method or tool has reached a certain level of maturity, it should be transferred into some kind of simulation service to be offered for industry. In many cases, these kinds of methods require extensive education and knowledge on the subject, which in practice means that the developers are the only ones who are able to operate it. Similarly, public funding mainly goes to the development of simulation methodologies but is not used to enhance their application in industry, which in turn stalls the incorporation of new methods.

As an expert service, the simulation business is not scalable and thus creates challenges for service providers seeking growth. Some of today's modern Internet-based simulation solutions may help scalability by allowing web-based services, but competent employees are still needed. Limited scalability can also mean limited offshore possibilities and thus be seen as an opportunity for a small country with a high level of education like Finland.

3.3 Education

Simulation is highly professional work and requires education and expertise on application domain and simulation methods. In some areas of education, simulation applications have become an essential part of everyday work and education today. One example is CAD modelling, though it is not necessarily perceived as simulation. However, simulation is still in its infancy in many areas.

Being a modelling and simulation professional involves high education requirements. Modelling and simulation are practical skills. However, these practical skills consist of many different areas of know-how like mathematics, computers (both hardware and software), theories regarding the application fields, the capacity to understand complex systems, and the ability to present results both graphically and by writing. It is generally experts, not students, who are able to understand complex systems and aggregates.

Although there is some teaching of simulation at schools and universities in Finland, simulation is not a part of the general education programme. As a result, most modelling and simulation professionals are trained after graduation.

3.4 Collaboration

The successful application of simulation and adaptation of new technology from academia to industry requires common understanding and a common language between appliers and suppliers. During discussions with people working in this field, the following topics were highlighted:

- Communication: research and industry people use a different language.
- The leap from academia to business is long, and public financial support is limited just near the gully between those two areas.
- The way in which the results are presented: long reports may not be the way to distribute results to busy industry people.
- The reliability of results: this is a big demand in industry while new discoveries are more important in science.
- Solutions arising from research are not necessarily known in industry: how can one look for something that one doesn't know to exists.

4. The SISU project

This chapter briefly describes the SISU project, whose ultimate goal has been to enhance the use of simulation in companies, particularly in small and medium-sized enterprises. A more detailed description of the project is given in Olin et al. (2007a) and Leppävuori et al. (2009), and in various reports of case studies. The results of the case studies are summarised in Chapter 5.

4.1 Background and goals of SISU

The use of simulation in industrial design and the resulting business opportunities (SISU) was a Tekes project under the Modelling and Simulation Program (MASI). The research partners were the Helsinki Metropolia University of Applied Sciences (former EVTEK and Stadia) and VTT, which also coordinated the whole project. Altogether, eleven industrial companies both financed and participated in the project. An operations model called Q9 was developed to facilitate the modelling work.

Briefly, the goals of the project were to provide:

- new simulation and design methods, especially for small- and medium-sized enterprises (SME)
- a detailed plan for taking these new methods into active use in industry
- an assessment of the newly developed business opportunities (economy, technological), and
- potential and real opportunities for new simulation-based business.

4.2 The matrix structure and participants

SISU was organised in a matrix form (see Figure 1). On the one hand, simulation was done for industrial partners in case studies, which were confidential. On the other hand, work was done to achieve the ultimate goal of SISU: to enhance the application of simulation. This part of the work was public and the main outcome of public work is the Q9 model.

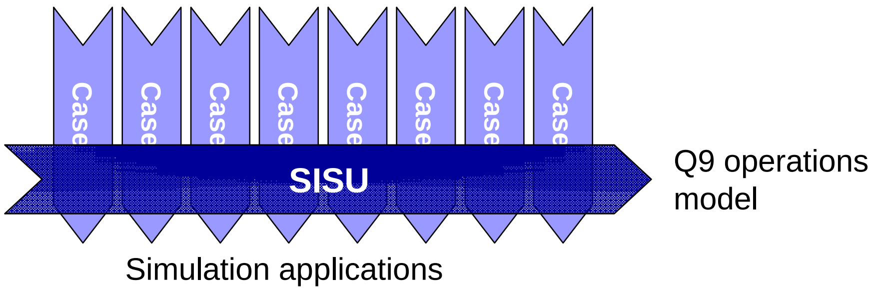

Figure 1. Matrix structure of SISU project.

4.3 Project work programme

The SISU project consisted of several case studies presented more detailed in Chapter 5. The overall work programme was as follows:

- A systematic description was prepared of the new methods to be developed and applied (Olin et al., 2007b).
- The case studies, which all have different timetables, were carried out (Leppävuori et al., 2009).
- The productivity potential of the new simulation and design methods proofed in case studies was analysed. The timetable was case specific. Non-confidential methods are briefly reported in this final report.
- Business opportunities were reviewed.

All SISU project material including reports, summaries of case studies, brainstorming session memos, useful links, etc. are collected on public web pages at https://wiki.metropolia.fi/display/sisu/Home.

5. Case studies

The development of Q9 was based on practical experience obtained from eleven cases studies, in which simulation applications were developed for industrial participants. The results of the case studies are summarised in this chapter.

Case studies were arranged in three groups: product, process and logistics simulation. Each case study produced results on at least two levels: general knowledge for advancing simulation and simulation-related business, and more or less confidential results for industrial participants. The results from the first level were utilised in the development of Q9 and we hope that the case studies yield more practical results within the participating organisations. All the case studies are listed in Table 1 and are described in more detail in the previous project report (Leppävuori et al., 2009).

Table 1. A list of the case studies.

Case study	Partners
Utilisation of the 3D model in simulation and design	EVTEK and Watrec
Validity of process data	EVTEK and Fortum
Behaving PI-diagram	EVTEK and Pöyry
Small-scale biodiesel plant design	EVTEK
MDR – Measurement data reconciliation	EVTEK and Rintekno
Development of 3D design methods	Stadia and Etteplan
Simulation and visualisation to support sales	Stadia and Kardex
Virtual prototypes for transport equipment	Stadia and Sandman-Nupnau
Conceptualisation and pre-design	Stadia ja Sweco Industry
Design tools for electrostatics	VTT and Genano
Particle emissions in a power plant	VTT and Fortum
Simulation of liquid penetration in paper	Metropolia and Metsä-Botnia

5.1 Product simulation

5.1.1 Development of 3D design methods

In the *Development of 3D design methods* case study, the goal was to create a general interface within CAD software to ease parametric design (see Figure 2). Parametric design speeds up customer-based concept design, especially quotations. Correctly designed parametric models, together with modular products, will reduce unnecessary design work. The project was carried out in a realistic application study. The first task was to make a parametric design model of one process equipment used in electric cable production. The equipment was divided into modules and the modules were parameterised. The first interface was done using MS Excel. The modelling of the equipment was done using Catia. The Excel-based design automate was then developed. The customer transferred the system into its Inventor software to check the general applicability of the interface.

5.1.2 Virtual prototype for transport equipment

In the *Virtual prototype for transport equipment* case study, the goal was to make a virtual prototype of a novel trailer (Figure 3) to simulate and optimise its construction. The virtual prototype was modelled using Catia. The project initially used the customer-based concept design as its method. The boundary conditions were the demands set up by the end user and the buyer for the trailer. The demands for the construction came from the operation, environment and auxiliary functions of the trailer. In selecting the construction materials, the main criterion was to optimise the weight of the trailer. From the beginning, the trailer construction was designed to be modular and parametric. These parametric modules can also be used in other similar constructions. New production technologies were sought for the manufacture of the trailer. All steel parts were cut with a laser, thus achieving high accuracy and consistent quality. The original plan was to produce the swing arm of the trailer through casting. The model of the arm was made so that it could be cast using different methods. The idea was to find the most simple and economic casting method, both for the prototype and for the serial production. After thorough consideration of the costs, however, a welded construction of the swing arm was used in the prototype. High-strength steel grades of Ruukki were used in the frame construction of the trailer.

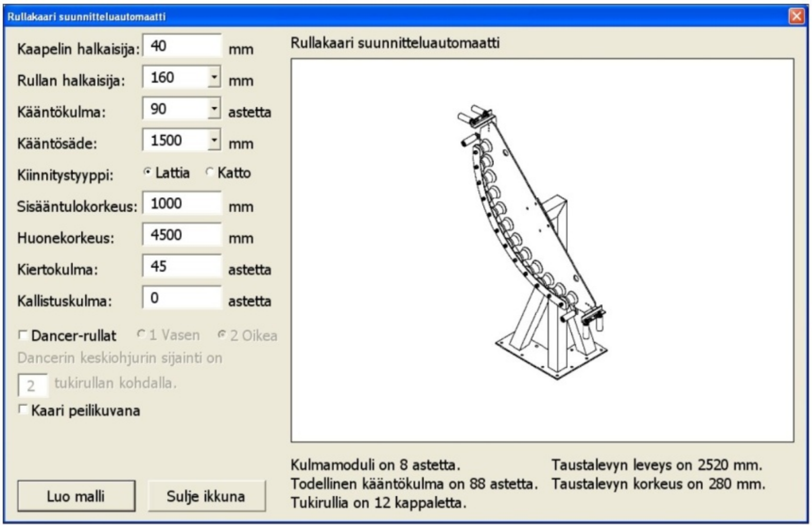

Figure 2. One example of targets in parametric design.

Figure 3. The prototype trailer in its highest and lowest positions.

The motion simulation of the trailer mechanisms was mainly done using 2D simulation. This method is very fast and easy to use. Only a few lines are needed to tie the geometry together for the simulation. As a result, a binding base for dimensioning was created; this base was used when creating the actual 3D model of the trailer. The digital model was used for several tasks, including: collision checking of movable parts, the creation of operational animations and strength calculations. The 2D motion simulation has proved to be a very important and useful method when designing constructions that have movable parts. Once the basic idea was confirmed, it was easy to share the design work of modules between several designers. Motion simulation was used during the project several times, first to define the design parameters and later to check the functionality of the construction. The prototype of the trailer is now ready; it was officially released in November 2008. The prototype has been tested in various situations and the mechanism works as planned. The driving properties have also proved to be very good; the trailer follows the towing car very smoothly and nicely. Due to the changes in legislation, the trailer prototype cannot be used in public traffic when loaded. This is because authorities have not tested the towing bar. The short-term plans for the future include changing the manual lifting/lowering hydraulic system into an electrical system.

5.1.3 Conceptualisation and pre-design

In the *Conceptualisation and pre-design* case study, the goal was to achieve widespread use of the simulation and visualisation at the beginning of the design phase. Through such use, the concept and pre-design would be done more quickly and the quality of the product/project definition would be guaranteed when developing completely new products without any known solutions. The use of simulation in the concept design phase and in classifying ideas is used to make the pre-design phase of new products more efficient (Figure 4). Later in the design phase, the 3D digital prototype is used to simulate and optimise the function of the product. The project started with a brainstorming session in a classroom, resulting in more than thirty different ideas for a foldable chair construction. Five ideas were selected for further design. A simulation model was made for three construction variants. The project was completed by two German exchange students during summer 2007. The results of the project were motion simulations, preliminary strength calculations and a comparison table of the properties of the chair constructions.

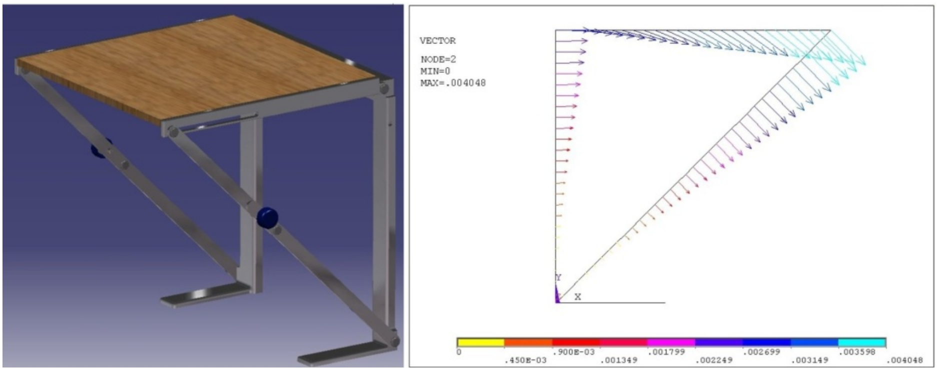

Figure 4. An example of pre-design (in Finnish).

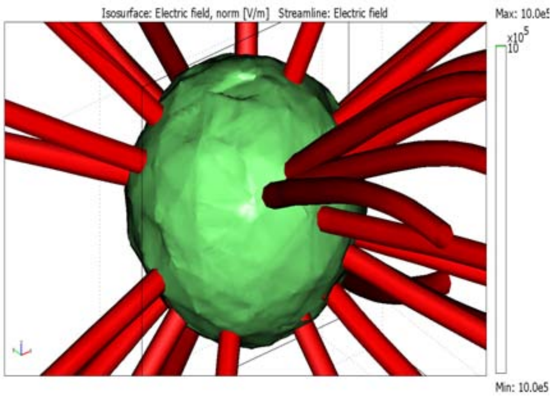

Figure 5. Isosurfaces and force fields of electric field (green) around a mall conifer inside a much bigger box – surfaces of the boxes are outside the area shown. An electric potential of 1 MV is set on the conifer while the surrounding box is grounded.

5.1.4 Design tools for electrostatics

In the *Design tools for electrostatics* case study, the goal was to apply Comsol Multiphysics® in design work for an electric precipitator. Most of the effort has been aimed at finding economical and easily repeatable methods of calculating electric field strength in varying geometrical structures (see Figure 5). Any changes in geometrical structure necessitates additional work with already developed model – the goal was to minimise this work, save the available models in way that facilitates use later on and find estimate the quality of any given design. As a result, the optimised geometry obtained by simulations was taken to production without physical prototyping.

5.2 Process simulation

5.2.1 Utilisation of 3D models in simulation and design

In the *Utilisation of 3D models in simulation and design* case study, the aim was to integrate simulation, CAD and various experimental methods in gas reactor design, problem solving and scale-up. The final target was to have a robust tool for simulation service for the SME industry. The main criteria for use the simulation augmented with these tools in the SME industry are the speed of the problem solution, the reliability and the costs.

The main simulation tool used was the Fluent based CFD-program Mixsim. FloWizard was also tested. A digital prototype printing device was used in the impeller construction. SolidWorks and Catia were used in geometry design. SolidWorks was also used in the vibration analysis of the axis and impellers (Figure 6 and Figure 7). However, it was not possible to use the results of the vibration analysis in the simulation.

In this work, two different laboratory scale vessels were used for the scale up study. These were scaled down from the industrial biogas reactor (6 000 m^3). Two full scale reactors, pulp slurry and fermentation were also used for simulation studies. The main simulation targets were flow fields and relevant macro mixing properties.

In the case studies, the topic was the role of simulation and integrated methods in design, scale-up and problem solving of reactors when fluids are non-Newtonian and impellers are of the non-standard type. Associated problems included process and material problems and malfunctions. The study consisted of many different cases, in which different reactor geometry, impeller types and fluid materials were used.

The analysis methods used were Multiple Reference Frame and Sliding Mesh. The κ-ε model, which is the extension of the standard κ-ε model, was used as the turbulence model. Non-Newtonian power law fluid was used as viscosity model. Gambit was used in generating the grid of the whole reactor. The implementation of process kinetics continues.

Experimental fluid dynamics methods e.g. Laser (PIV) velocimetry measurements and some ad hoc methods were used in laboratory-scale process experiments for partial simulation validations. Because the optical methods still have severe limitations in difficult process conditions, the simple power-draw based method was suggested for partial model validation.

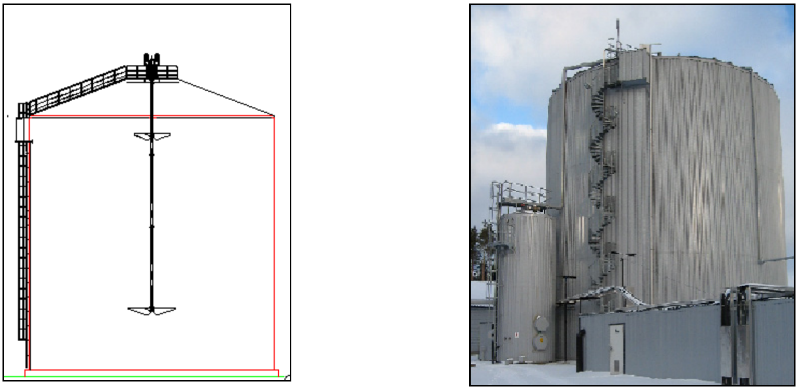

Figure 6. Layout of the Full-Scale Reactor.

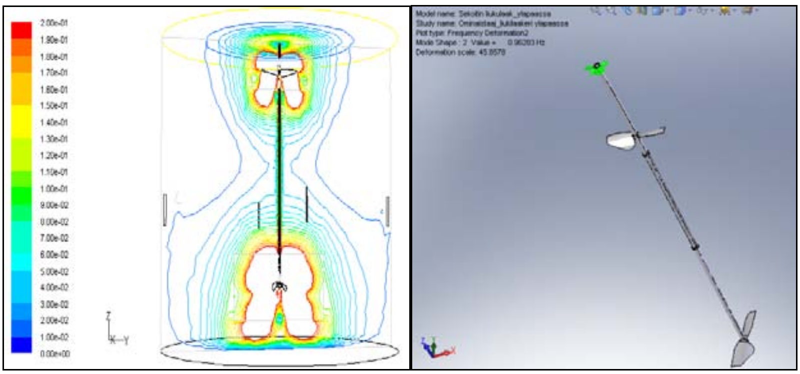

Figure 7. Contours of the velocity magnitude (left). Vibration of the shaft. The most significant specific frequency multiple (right).

5.2.2 MDR – Measurement data reconciliation

In the *MDR – Measurement data reconciliation* case study, the aim was to apply MDR in a power plant environment and to develop a tool for measurement diagnostic and corrections. Stricter environmental rules and demands for more efficient energy use will produce a need for these kinds of tools, which make measurements more precise and reliable.

DR is closely connected with system maintenance, simulation pre-processing and process diagnostics. MDR provides estimates for raw plant data that are consistent with first principles models like material and energy balances or empirical models when small adjustments are made to the available operating data. In addition, MDR also estimates unmeasured variables.

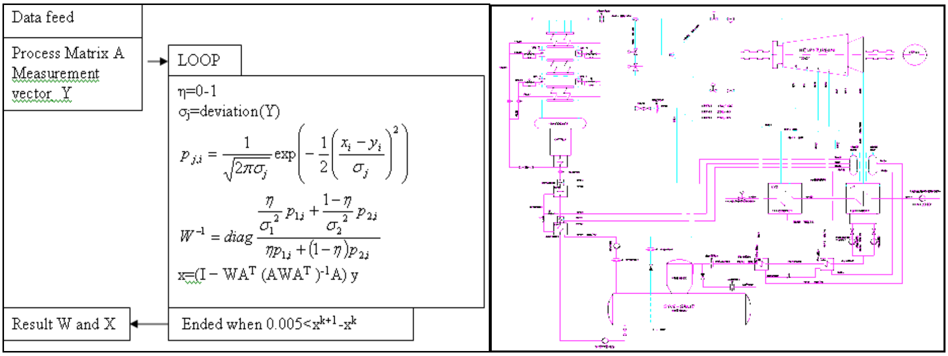

Figure 8. Structure of the basic algorithm (left). Simplified simulation flowsheet of the plant (right).

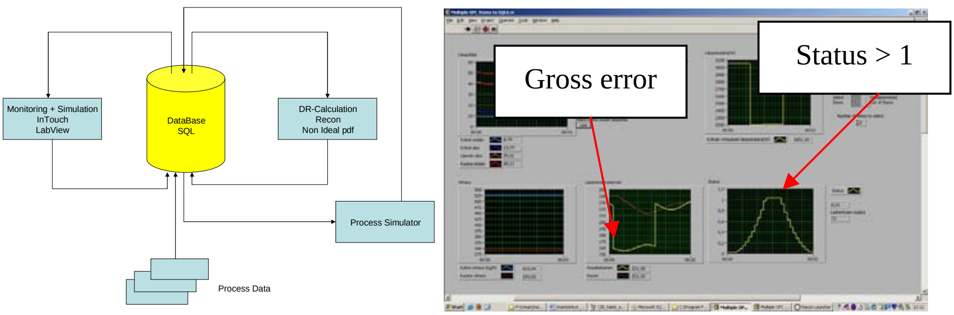

Figure 9. Simulation system for real-time testing (left). Identification of gross error in temperature measurement in heat exchanger (the monitored variable is the overall heat transfer coefficient) in real-time operation.

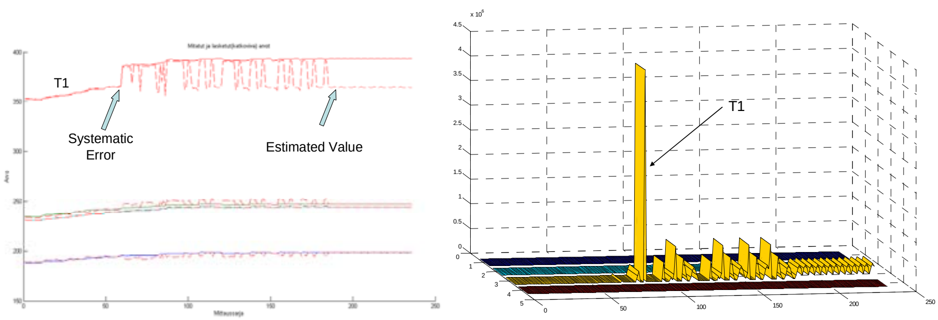

Figure 10. (Non Ideal pdf) Systematic error input to the plant temperature measurement T1 (left). Covariance Matrix of the measurements (right).

Experimental work proceeded from simple unit processes to large and complicated process systems. One difficult problem in power plant tests was the lack of critical measurements. Real-time application was designed and semi-dynamic models have also tested. A simulation system for MDR laboratory testing was made with InTouch and SQL as the database. A LabVIEW platform was also designed using SQL (Figure 8). The algorithms were calculated with MATLAB. On these platforms, automatic gross-error elimination and data warehouse strategies was developed and tested. The LabVIEW system proved more efficient in a real-time test environment than InTouch. A commercial DR program based Gaussian pdf (probability distribution function) was compared with the application, which uses non-ideal Gaussian pdf in the object function. The applicability of these methods for power plant processes was studied by starting with simple process units and after successful trials with more complicated process systems. The emphasis of the tests was to enhance gross error handling.

The benefits of the developed tool compared to reference programs included more efficient gross error treatment, greater changeability better suitability to real time operation and – of course – the fact that no license fees had to be paid. This could be a very important factor in small applications. As a result of the project, a promising product (Figure 9 and Figure 10) with potential for various industrial applications was developed.

5.2.3 Behaving PI diagram

In the *Behaving PI diagram* case study, the aim was to study integrated model-based design. In the plant design department of Pöyry, the process and instrumentation chart and process simulation are separate tasks carried out by different individuals. Balance calculations are transferred manually to the database, which is error prone; automation makes this quicker and more reliable. Another drawback is that simulation updates are not done automatically, when PI-CAD is updated. However, both tasks use the same process database and the same graphics. With greater integration of these tasks, design work could be enhanced. There could be many other potential benefits as well. In this case study, links were created between the process simulator and database and from CAD to the database (Figure 11). The final aim is the close integration of the process CAD and simulator so that simulation becomes invisible to the CAD-user.

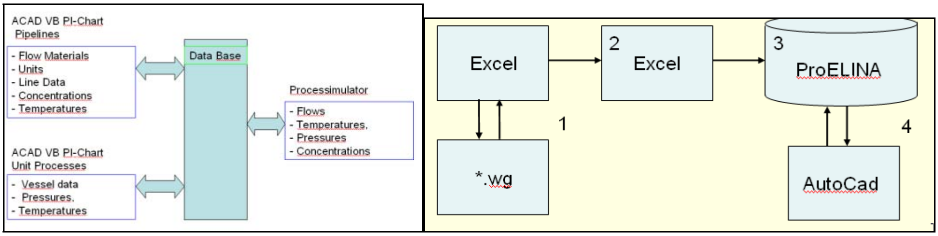

Figure 11. Structure of the data transfer between Simulation and PI-Chart (left). Data transfer application between the Simulator and PI-CAD (right).

5.2.4 Small-scale biodiesel plant design

In the *Small-scale biodiesel plant design* case study, the aim was to support biodiesel plant design. The study was focused on a process development and simulation of biodiesel in small and medium-scale production from waste vegetable oils, starting with batch processes; the final target was to achieve a continuous process. The other objectives were to identify the methods to enhance continuous washing process and the breakdown of emulsions, which are formed in product washing. These problems have an impact on process structures and unit processes.

Experiments were done on the new enzymatic catalysts and process purification efficiency was increased. As a result, purer biodiesel and glycerol by-product were achieved. With these new enzymes, the process can be considered a second generation process.

In the project field analysis, methods were tested to observe the state of esterification reimpact. The project was done in co-operation with the Universities of Valencia and Frankfurt. A small-scale automated pilot process was built in to the project (Figure 12 and Figure 13).

The efficient use of the side products e.g. glycerol, is a prerequisite of the economy of the small and medium-scale biodiesel process. There are various promising alternatives e.g. conversion to butanol by fermentation or gasification and the Fisher-Tropsch process (Figure 14); preliminary studies on such alternatives were done in this project.

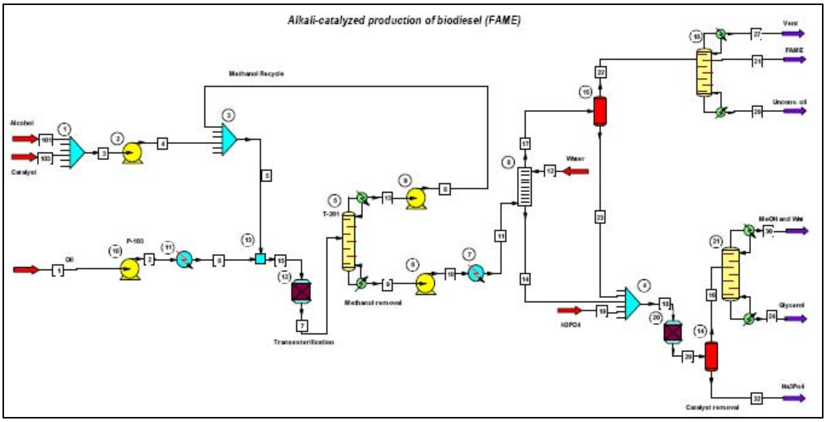

Figure 12. Simulation flowsheet of BD-process (alkali-catalyzed transesterification).

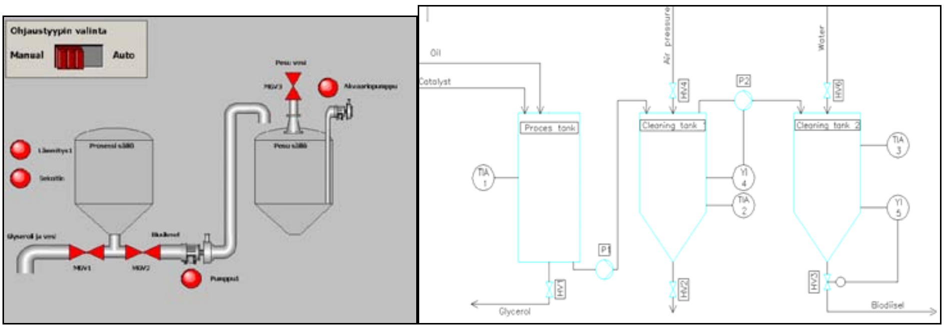

Figure 13. Main operation interface (left) and instrumentation (right) of the pilot process.

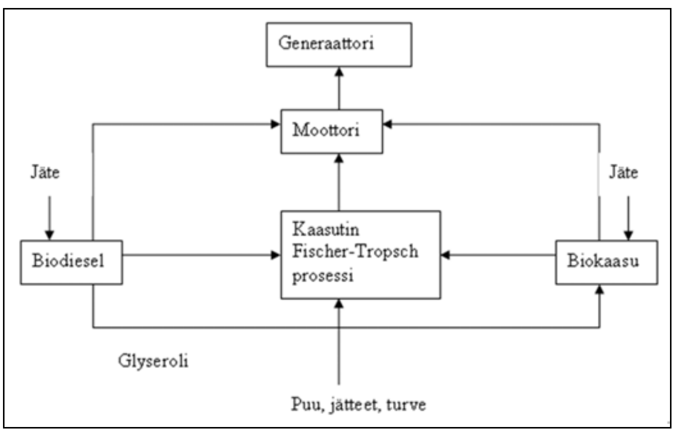

Figure 14. Integration of small and medium scale biodiesel production (In Finnish).

5.2.5 Particle emissions in a peat power plant

In the *Particle emissions in a peat power plant* case study, the aim was to apply the dynamical process simulation tool Apros to calculate flow rates, temperatures and pressures. The effect of all these factors was then calculated on particle emissions in a peat drying process, which utilises the combustion gas of the power plant itself. The Apros tool (see a public example in Figure 15) was partially successful in answering the questions posed by power plant operators. The biggest advantage of using Apros as opposed to studying the minute-based process data from the plant itself is that cause and effects are clearly distinguishable. It is relatively straightforward to calculate correlations and some more advanced measures between analysed process parameters, but it is difficult to reason out the causes from all that data. The other important advantage is to study the plant in states which are rarely or never encountered in the typical use of the plant. It may sometimes even be dangerous to run the plant in certain conditions, which are safely demonstrated by Apros.

5.2.6 Simulation of liquid penetration in paper

In certain paper making processes, such as the coating process, liquid must be added to the paper structure. This addition of liquid reduces the mechanical strength of the paper, thus limiting the speed of the process. As this phenomenon is difficult to examine through direct measurements, a decision was made to approach it via simulation. The fibre properties that have an effect on the final paper processing can be modified by developing pulping process. The objective was to utilise the simulation results to develop resource-efficient production processes.

In the *Simulation of liquid penetration in paper* case study, the Lattice-Boltzmann method was chosen for fluid dynamic simulations, because it is known as the only feasible model to describe flow phenomena in such a microscopically complex medium as paper. The computer code used for simulations was programmed at the Department of Physics of the University of Jyväskylä, where the X-ray tomography of the paper samples followed by the 3D-model construction of the fibre network was done. The simulations required quite heavy computing and the code was run in parallel using the Louhi and Murska supercomputers of the CSC – IT Center for Science. Some results are shown in Figure 16.

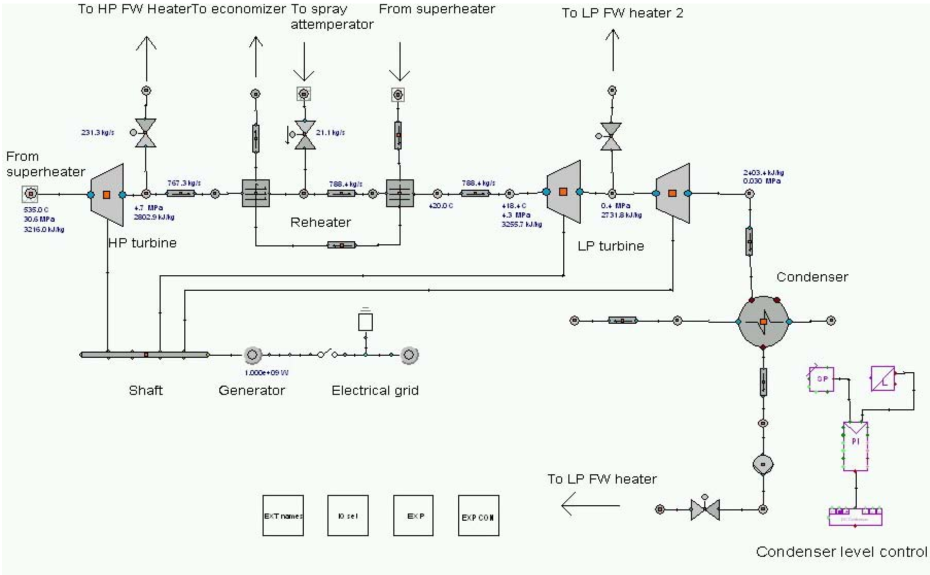

Figure 15. An example of public results on the application of Apros (our case study results are restricted and not presented here).

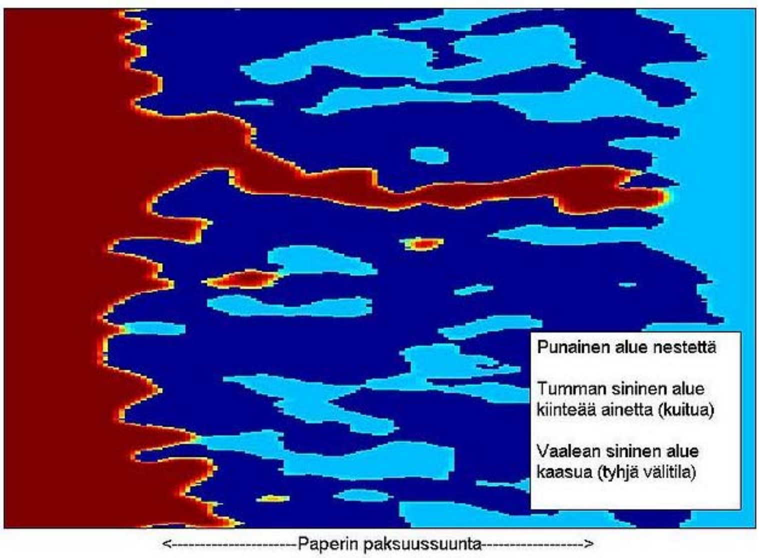

Figure 16. A sample result from Lattice-Boltzmann: in the cross-section, the liquid front is penetrating the paper from the left. The channelling through the fibre network is taking place in the picture. Red represents liquid, dark blue is fibre and light blue is gas (void volume).

5.3 Logistics simulation

In the logistics simulation group, the *Simulation and visualisation as a support for sales* case study was carried out. The goal was to develop simulation methods for visualising the planned logistical solutions offered to customers. This study on the use of simulation and visualisation to sell complex automated storage systems was launched with Kardex in October 2006. In the first stage, a checklist was designed for the customer parameters needed for simulation and testing. Parameters for modelling storage automata and functional modelling of storage systems were also studied. Enterprise Dynamics software, supplemented with a functional model for Kardex storage automation, was used for simulations. An example worksheet of the tool applied is shown in Figure 17.

Models to evaluate the overall performance of the customer system and the profitability of the automation investment were created in co-operation with Kardex. A model of customers' operational environment was built and utilised to compare various solution alternatives. The possibility of simulating the effect of the often rapid changes in the operational environment was examined.

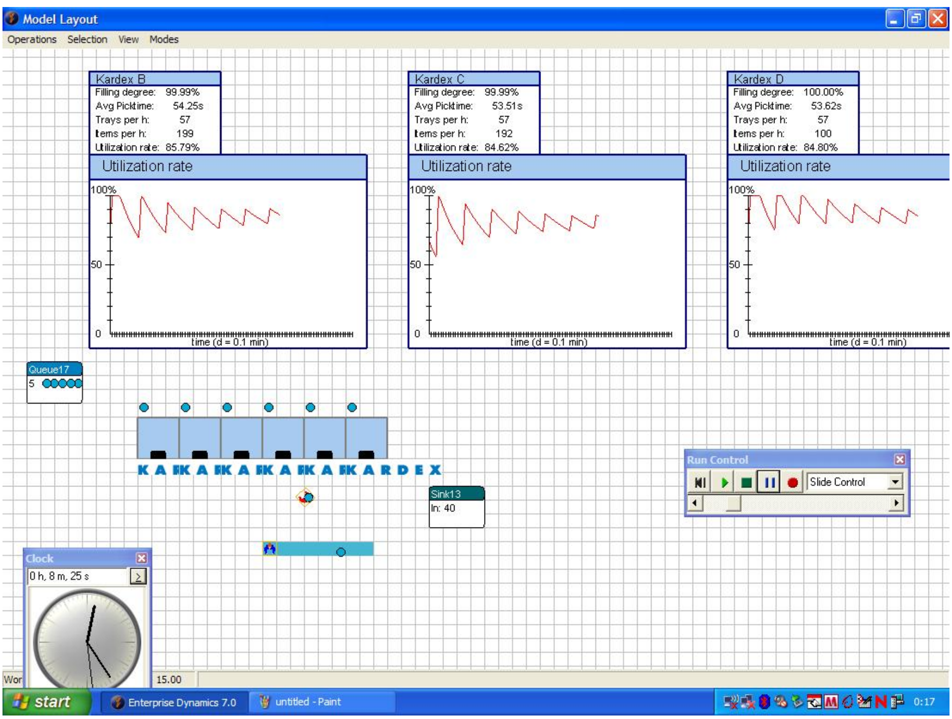

Figure 17. A screenshot of an automated storage simulation.

6. The Q9 operations model

Why is football so popular all around the world? One reason may be that it is a game with simple rules, which nonetheless allows for very complicated matches. The rules are easy to learn and people from different countries are ready to play without any additional knowledge. In football, there are different actors, who know their different roles and are ready to perform them. What about rules and roles in simulation: are they clear enough to allow smart solutions to complicated problems to emerge?

This chapter presents the Q9 operations model first at the conceptual level and later in detail. The actors and their different roles in the simulation business are described as well as their first experience applying Q9.

Could a Q9 type operations model help to navigate the ocean of simulation and avoid navigation errors? Could Q9 help actors to leave their own comfort-zone and thus avoid the typical pitfalls caused by a lack in communication? Could it also help in discussions between parties and make it a continuous process?

6.1 Conceptual description

Q9 involves applying a well-known and frequently applied strategic approach for orienteering in the solution space. Quite often the starting point is some problem (Q9: PROBLEM; see Figure 18), which is natural because that is just how many of us see the world: full of totally or partly unresolved problems. In many cases problems are good starting points, because they are often quite concrete and a solution (Q9: SOLUTION) may already be available. In this context, PROBLEM and SOLUTION refer to abstract objects, meaning mainly that we are able to describe them: we have an idea about how to solve them.

During the course of the SISU project, it appeared useful to go one step further in the hierarchy towards impact or vision (Q9: IMPACT). Problems often result from unattained impacts or something that prevents our vision (Figure 19).

6. The Q9 operations model

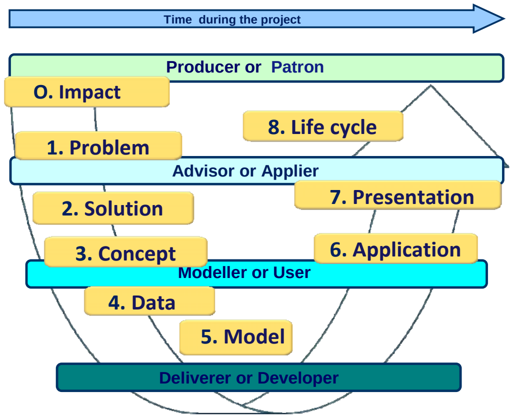

Figure 18. Actors of a simulation and phases of Q9 shown in the same figure.

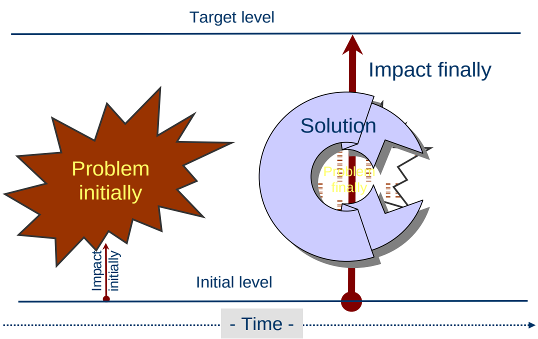

Figure 19. Impact, problem and solution. Often in this order: problem, solution and then impact.

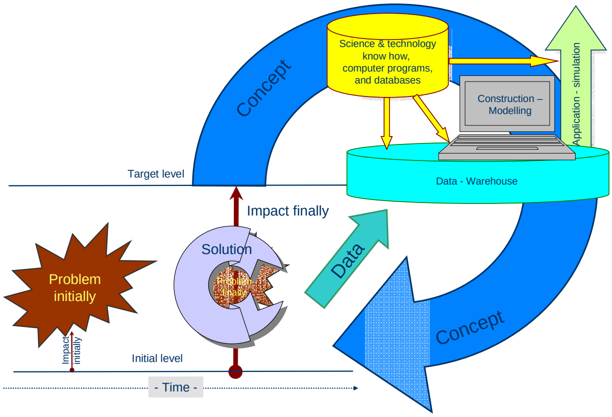

Figure 20. Concept as an interface: customer's problems and the modeller's work.

By including IMPACT, the Q9 can be used more generally, because many actors have visions or expectations of certain impacts but do not see the solutions available: problems are required in order for there to be solutions! In any case, the IMPACT-PROBLEM-SOLUTION triangle, which often comes in the order PROBLEM-SOLUTION-IMPACT, forms the hard core of the Q9.

These issues above are often quite abstract and the next thing is to make the problem solving more tangible through conceptualisation. (Q9: CONCEPT, Figure 20). The proper conceptualisation requires collaboration between the problem owners (PATRON), problem solvers (APPLIER), real modellers (USER) and model developers (DEVELOPERS) (Figure 21).

All modelling needs information (Q9: DATA, Figure 22), which is the most basic resource for simulation, like cement for the building industry. A tool (Q9: MODEL, Figure 21) must be available to solve all the necessary equations and to apply all the data gathered.

Model must be used (Q9: APPLICATION, Figure 22) to solve the PROBLEM and yield results, which must be presented (Q9: PRESENTATION, Figure 23) in a way that enables communication between different actors.

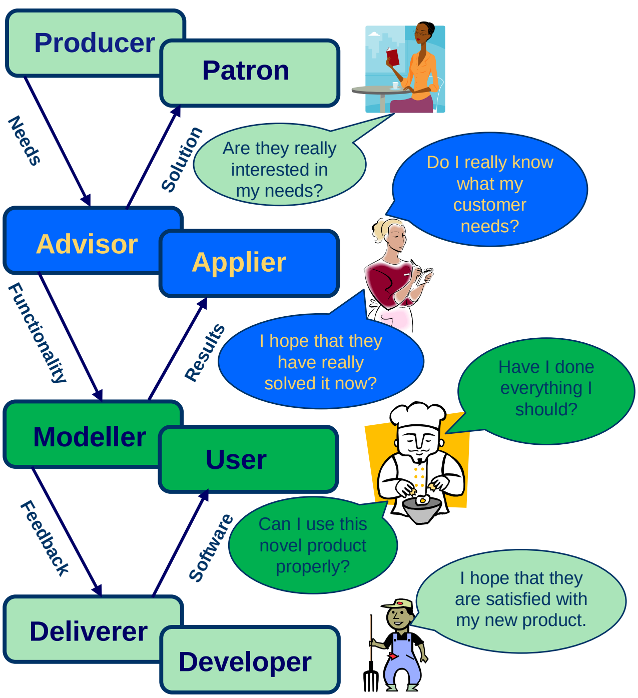

Figure 21. Actors of modelling and simulation based problem solving.

6. The Q9 operations model

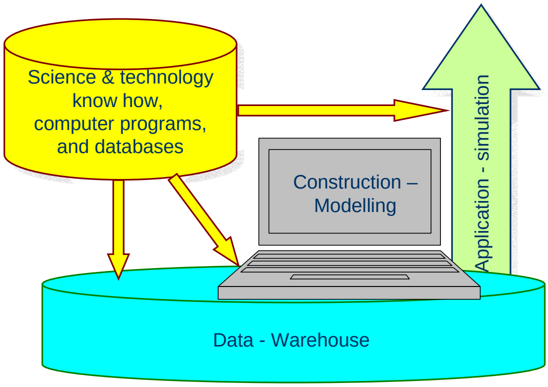

Figure 22. Data handling, model construction and application in same figure.

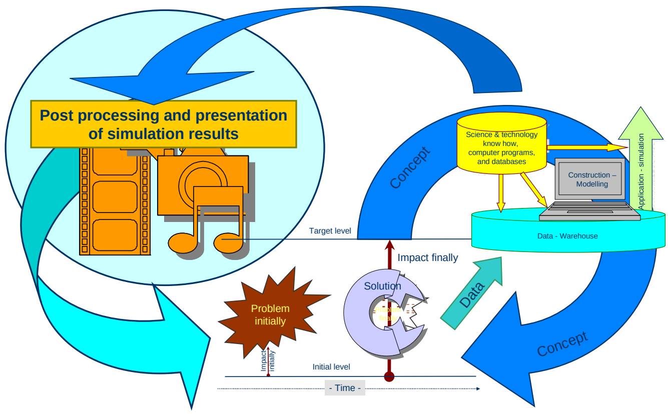

Figure 23. Post processing and presentation are essential links to the applier and patron.

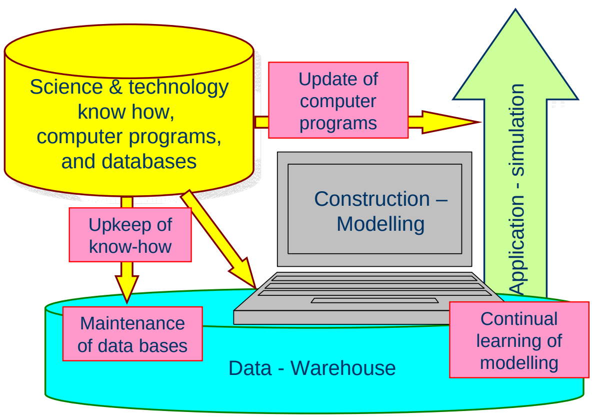

Figure 24. Model maintenance includes many topics and goes over several life cycles.

The last topic to be considered is the life cycle (Q9: MAINTENANCE, Figure 24), because quite often same processes are iterated and it is helpful if this was originally planned.

Everything listed briefly below followed by a practical example e.g. through the MASI programme itself (Figure 25):

1. Identify the situation (IMPACT): well-being through simulation
2. Find the obstacles (PROBLEM): insufficient know-how in application
3. Formulate a way out (SOLUTION): set of operations to enhance know-how
4. Make the solution realistic (CONCEPT): collect operations in a public research program
5. Collect information (DATA): which organisations have the know-how needed for the program, what they know
6. Construction (MODEL): set up the program
7. Actual execution (APPLICATION): run the research program
8. Results (PRESENTATION): collect all the results and present them in a way that helps gain impact and solve the problem
9. Future (LIFE CYCLE): at least certain parts of the research program need continuation or something else to do after the program.

6.2 Actors and their different roles

The very first observation in the SISU project was that it is beneficial to define the roles of different actors in the field of simulation and modelling. Actually, the roles are not very different compared to other fields, which can be seen from Figure 4, where simulation roles are named and comparable roles in restaurant business are shown in small pictures. Figure 26 shows both the actors and their roles and outlines the relationships between them.

6.2.1 Management: Producer – Patron

Simulation or modelling work is typically observed from the modeller's perspective. However, like any other people, modellers too must earn an income, either indirectly, e.g. via some state organisation like a university, or directly from a real client or customer. Direct customers typically get their main incomes from some source other than simulation, and therefore their main interest also lies in their own business. In order to develop their production or processes, even small companies have a technology department or personnel. Modellers typically communicate with these people. But technology departments must give good reasons to management to receive funding for simulation or other research work.

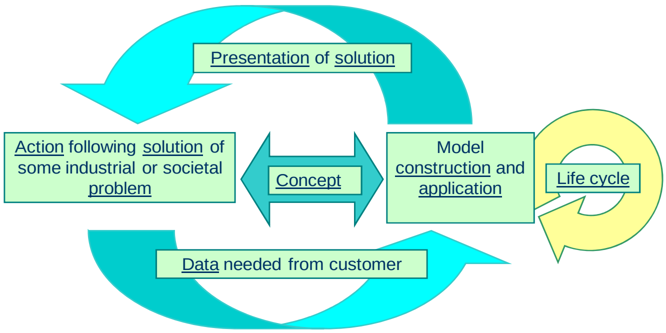

Figure 25. Process chart of the proposed Q9 operations model for simulation.

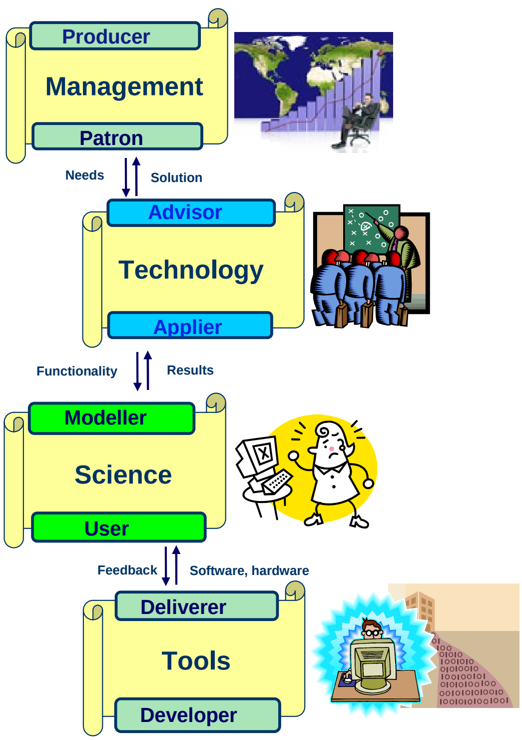

Figure 26. Actors and their roles in a simulation project.

The first actor in the Q9 operations model is the administration of the ordering company. However, it should be noted that simulation projects typically consist of smaller sub-projects, which may again have sub-topics, and the entity assigning resources to any simulation work may be held as a first-level actor (just for this work).

The first level actor may be referred to by many names, but MANAGEMENT is adopted in this report. MANAGEMENT's first role is the PRODUCER (that's how we *assume* that they think of themselves) or the final user of the model, but to other actors in the Q9 model they may seen as a PATRON i.e. an actor who gives orders to others. MANAGEMENt is producing something and selling it, but in order for these to have IMPACTS, it may have some needs or PROBLEMS that need to be solved.

As a PRODUCER, MANAGEMENT gives or sets needs (goals) for TECHNOLOGY (defined in the next section), which provides some solution in the role of the ADVISOR to the PATRON. In our restaurant case (Figure 4), the restaurant customer is a PATRON who orders something from the headwaiter, the ADVISOR.

6.2.2 Technology: Advisor – Applier

An actor who solves technological or R&D problems is called TECHNOLOGY. This actor has two roles:

- As an ADVISOR, it receives *needs* from the PRODUCER and provides *solutions* to the PATRON; they support MANAGEMENT and operate by financing coming from there
- As an APPLIER, it gives *functionality* (demands) to SCIENCE, from which it expects *results*.

Typically TECHNOLOGY operates with several SCIENCE actors, even when only a single problem needs to be solved. However, this is left out of our simplified description and figures.

6.2.3 Science: Modeller – User

An actor who utilises computer software and solves problems by modelling, but who do not necessarily develop software, is called SCIENCE. This actor typically has much interest in applied sciences along with customer knowledge and computational know-how.

The roles of SCIENCE are those of MODELLER and USER:

- As a MODELLER, it gets *functionality* (demands) from the ADVISOR and give the *results* to the APPLIER. It supports TECHNOLOGY and operates through financing that comes through TECHNOLOGY.
- As a USER, it gives *feedback* to TOOLS and expects both *software* and *hardware* in return.

Typically SCIENCE is a university, research institute or a research-oriented private company. And like TECHNOLOGY, SCIENCE typically has several customers and operates with several TOOLS.

6.2.4 Tools: Deliverer – Developer

Tools of numerical science consist both of hardware and software, and therefore, an actor working at that level is called TOOLS:

- As a DELIVERER, it gets *feedback* from the USER and gives *software* and *hardware* to the MODELLER. It supports SCIENCE and gets financing through SCIENCE.
- As a DEVELOPER, it gives *new ideas* to information technology.

Typically TOOLS is a software house or computer producer.

6.3 Process description

Like production, the simulation business needs both resources and processes. Processes are sketched in Figure 24**,** briefly reviewed in Table 2, and discussed here in detail. Phases of the simulation process are taken from Ulgen et al. (1996).

Table 2. Phases and required actions of Q9, typically applied iteratively.

	Phases	Brief description
1	Impact	A benefit to be obtained or something catastrophic to be avoided.
2	Problem	Problem description. Job to be done.
3	Solution	Actions planned to tackle the problem. A detailed project plan.
4	Concept	Verbal or visual description of the model. Basic selections for the tactics.
5	Data	Utilities to implement the concept: limitations, required data, preliminary planning of prints, etc.
6	Model	Building of the model, comparisons and validity checks.
7	Application	Applying the model (made during phase 6) to solve the problem (phases 1–3).
8	Presentation	Presentation and documentation of the results fulfilling needs of stakeholders.
9	Life cycle	Will the model be needed in the future? Update and development requirements of the model in the future.

6.3.1 Impact

The first level driving force for the simulation project is a future vision or desired impact. In this report, the term IMPACT is adopted. Impact might refer to a benefit to be obtained or something catastrophic to be avoided: the key thing here is the will to do something. Examples of industrial impacts may be

- developing a new product,
- decreasing environmental emissions, or
- proving that a product is working in the promised way – to support marketing.

Typically, problems are encountered on the path from the present-day situation to the desired impact. It is remarkable that impacts and visions exist without any associated problems.

IMPACTS are entities belonging to or owned by MANAGEMENT, which have to be understood as any human entity with specific goals: the customer, R&D the department, the project manager, etc.

6.3.2 Problem definition

In this report, the PROBLEM is an entity closely connected to the IMPACT: it prevents the desired impacts from taking place. The PROBLEM and solution in this case are independent, and solutions to the problem may or may not exist. At least while defining the PROBLEM, it might be good to ignore all existing and proposed solutions. For any given IMPACT, there are probably many PROBLEMS and resolving these problems generates more sub-PROBLEMS.

Main tasks in this phase are:

- finding and identifying problems,
- describing them in a systematic way,
- listing and organising the problems in some systematic way,
- including all problems in the list, not only those that appear to have solutions through a simulation or without it, and
- associating PROBLEM with a certain IMPACT.

Problems are entities belonging to or owned partly by the MANAGEMENT and TECHNOLOGY actors. However, MANAGEMENT here refers to any human organisation with problems which should be solved by some other TECHNOLOGY organisation.

6.3.3 Solution

SOLUTION in this context is usually something that totally or partly solves the problem. The solution can be a result of some software tool, but usually the solution is something broader. ACTORS who face PROBLEMS may be in one of many possible situations:

- No solution is available, but it is possible to live with the problem.
- At least one solution is known to exist, but there is no motivation or resources to apply it.
- Several solutions exits, but it is difficult to choose between them.
- Some solutions appear to exist, but they are not ripe enough to se applied.

For any PROBLEM, a set possible SOLUTIONS may be sketched out; some SOLUTIONS include simulations at least as part of the SOLUTION, while some do not. When simulation is applied, the solution typically appears as a project with a project plan.

Three first phases and their relationship are sketched in Figure 19. IMPACTS, PROBLEMS and SOLUTIONS occur constantly in any human activity but

PROBLEMS follow from IMPACTS and SOLUTIONS are needed for problems. IMPACTS are typically documented in internal MANAGEMENT reports; PROBLEMS are quite often formulated not in written form except perhaps some slide shows of meeting memorials but verbally (discussions in meetings); and the SOLUTION is likely to be documented as a project plan that is often written is co-operation between TECHNOLOGY and SCIENCE. Therefore, it is highly recommendable to include descriptions of both the IMPACT and the PROBLEM in the project plan.

For the actors SCIENCE and TOOLS, it may be difficult to understand why TECHNOLOGY and MANAGEMENT are not applying simulation or some other scientifically based method to solve the PROBLEMS, while the subsequent actors then wonder why there are no solutions for their problems. Therefore, communication between different actors is of the utmost importance, but this communication must be very effective and smart due to limited resources. This is addressed in more detail in the next chapter.

6.3.4 Concept

Concept and conceptual level modelling are frequently used expressions whose meanings may vary. In this report, CONCEPT is an interface between upper (M&T – MANAGEMENT and TECHNOLOGY) and lower (S&T – SCIENCE and TOOLS) level actors. It is via CONCEPT that all actors can discuss the following: M&T'S main duty is to carry out business while S&T is, in our case, more or less interested in simulation and making business by it. Even when this actor division is continued within any project, the supervisor (M&T) is interested in obtaining specific results without doing the actual work, while workers (S&T) are more interested in doing the work than in obtaining the results (of interest to the supervisor).

The CONCEPT as an interface or glue between impacts (M&T) and simulation (S&T) are sketched in Figure 27, where those two entities are quite distant from each other (bottom) initially, but are much closer after a concept has ultimately emerged between them (top).

The CONCEPT includes a description of the data, model, application and presentation at an accuracy level that can be achieved without actually gathering the data and by writing a complete set of equations, the finalised inputs for computed codes, etc. The CONCEPT is a living object designed to enhance the communication between actors.

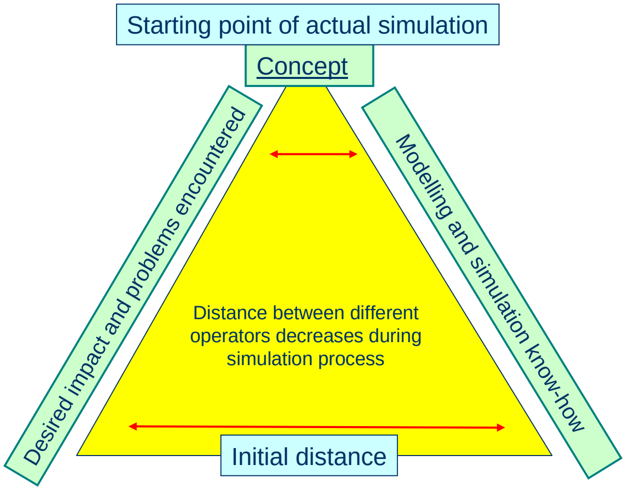

Figure 27. The concept glues the impact and simulation models: initially they can be quite distant from each other, but in a successful simulation project they will ultimately be combined into a single compact entity.

6.3.5 Data

All models include at least some data, which may be such an integrated part of the computer code applied that it is almost unnoticeable. In any case, it exists there, buried deep within the files. In addition to the data in computer code, some input is always needed. In this report, DATA refers to any parameter value, figure, sketch, database, literature, project plans, meeting memos, etc. that is needed when a simulation project is executed. Therefore, DATA is an entity existing even without the MODEL (defined in the next chapter). It is possible to collect and maintain DATA even without model construction or development.

The documentation of DATA appears very differently from handwritten notes to really large relation databases, but according to the authors' experience, it is generally organised poorly. In addition, even when the DATA is in good order, it may not be relevantly documented when the model is finally presented and reported.

6.3.6 Model construction

In the simplest case, the model construction is done in the previous phase by introducing the model with some relevant input. On the other end, the model is constructed at the conceptual level, starting from the phenomena and processes and continuing via mathematical formulations to the creation of suitable solution methods and model outputs. It may take years or decades to construct the final model that in the end aims solving a problem on a path to the vision. Naturally, the target and visions may even change over the years.

In this report, the MODEL refers to the construction of a specific calculation tool, which ultimately yields a solution that can be applied to the problem specified earlier. It is possible to construct the MODEL without any real data, e.g. analytical solutions of differential equations. Therefore, the MODEL is an entity that can stand alone, but the suitable DATA and a smart APPLICATION make the MODEL a useful simulation tool.

The MODEL is documented both in written documents and in input and output files, which after a while may consume gigabytes or more disk space, and there may be many versions of them. Systematic naming and logging are, therefore, very recommendable.

6.3.7 Application of calculation tools

In this report, the APPLICATION of the model (simulation) refers to the use of the MODEL to solve the PROBLEM.

Even more systematic naming and logging of calculation cases than in the MODEL phase are recommendable during the APPLICATION, where the MODEL is often applied systematically to produce the needed results, which will form the basis for the PRESENTATION. The documentation of the application should be based on the systematic plan of model that applies.

COMPARED to the DATA and MODEL phases, which are independent entities that can be developed as such based throughout the CONCEPT, the APPLICATION is a very dependable entity that:

- is based on CONCEPT, DATA and MODEL;
- is done to obtain a SOLUTION; and
- PRESENTATION is based on results the from APPLICATION.

The model construction described in the previous chapter can be tedious (though interesting) work, There is a risk of using all resources before the model can be applied. This is very undesirable situation in which the project fails to deliver the desired impact.

6.3.8 Presentation of the solution

In this report, PRESENTATION refers to both the way the SOLUTION is presented to the MANAGER and all other ways in which the results obtained by the APPLICATION are presented In order to ensure that the PRESENTATION is done correctly, some post processing of the results is usually needed. Sometimes, this post-processing is very hard task and necessitates a return to the APPLICATION, MODEL and DATA. Iteration steps are, therefore, arising even during the PRESENTATION. Unfortunately, in many projects the resources are exhausted after the MODEL or APPLICATION. This may be one of the main reasons why simulation projects fail to achieve their goals.

PRESENTATION is also a dependable entity that is closely associated to almost every other phase. CONCEPT and PRESENTATION are both interfaces between MANAGER & TECHNOLOGY and SCIENCE & TOOLS.

6.3.9 Life cycle

In this report, LIFE CYCLE refers to all the actions needed to maintain the simulation tools developed during a project. These include:

1. Keeping detailed documentation on everything that could be needed later.
2. Saving and naming the files produced in any phase for later use.
3. Saving the applied installation files of all software, if considered to be important.
4. Planning maintenance and agreeing on the costs stemming from saving and/or updating the files.
5. Deciding how long the maintenance will be carried out.
6. Deciding how quickly the simulation should be started later.
7. All other actions needed (security, annual updates).

When a simulation project ends and the results are presented and accepted by MANAGEMENT, none of the actors may be considering the future utilisation of the recently developed simulation. Therefore, few people (if any) work on the documentation and other preparations needed to eventually reuse the models. In many cases, there is a time lag of years or even decades before the same simulation is important again. It may even be difficult to open the documents created some years ago due to new software versions or the use of software that is no longer available.

6.4 Q9 questions

The nine phases discussed in Section 6.3 can be generalised for everyday situations. Consider the following example:

1. Impact – a bigger home is needed
2. Problem – a suitable house in not available
3. Solution – construct the house yourself
4. Concept – a detached 150 m^2 house, low energy consumption, etc.
5. Data – site and construction materials
6. Model – contact all the professionals needed, make detailed plans
7. Simulation – actual construction of the house
8. Presentation – furnish the house and ask your friends to visit
9. Life cycle – everyday life and continual reconstruction and refurnishing.

In everyday life, it looks simple, but in business, things tend to be more complicated, especially in terms of planning a simulation project. However, it is not easy to provide guidance, for example, on how to go through all nine phases. After some long hard work and many discussions during the SISU project, participants decided ask questions instead of using guidance in each phase. There were two reasons behind this decision:

1. There is probably nobody – and definitely no one on the SISU project team – with the competence to guide participants through all kinds of modelling and simulation projects.

2. Answers to questions are the flexible part in the Q9 operations model while phases and actors are fixed.

Q9 questions are presented in a matrix form (Table 3). The questions can be classified into four groups:

1. AIM: Why? What? When?
2. WAY: How?
3. POSITION: Where are we?
4. FUNCTIONALITY: How it is working?

Table 3. Q9 questionnaire – one example set.

PHASE	AIM	WAY	POSITION	FUNCTIONALITY
1 IMPACT	Desired impact or vision?	Who defines?	How fixed the desired impact is?	Are the problems revealed?
2 PROBLEM	Job to be done!	How should the problem be formulated?	Where are we in the formulation?	Does the formulation suggest possible solutions?
3 SOLUTION	What needs to be solved? Timetable? Resources? Why?	How should the project plan be written?	Where are we in the writing of project plan?	How does the plan work in terms of solving the problem?
4 CONCEPT	What are the model alternatives? What are the model concepts? Why?	How should model concepts be described?	Where are we in the model conceptualization?	Does the concept support model development?
5 DATA	What data the model concept needs? Why?	How to get the needed data?	Is the data needed available or does it experiments?	How good data we have?
6 MODEL	Which models should be built? Why?	How should models be built? Which tools should be used?	Where are we in the model realization?	How does the model work in terms of solving the problem?
7 APPLICATION	What questions should the model answer to? Why?	How should model testing be guided?	Where are we in the model testing?	Are the results reliable and model cost-efficient?
8 PRESENTATION	To whom will the results be presented and why?	Which type of prints and articles are most working?	Have all the questions been answered?	Are the result documents easily understandable?
9 LIFE CYCLE	Is the model needed in the future? How often?	How can the model be maintained?	Have we plan for model maintenance?	How easy is it to reuse?

Below there is a more detailed discussion of the sub-classes of questions (see also Table 3). The actual form of the Q9 questions depends on the phase, the field of simulation and probably on some other conditions depending on the case. Naturally, all these questions are repeated until a satisfactory state is reached. The phases may also be carried out iteratively, which may make execution of the complete Q9 operation model quite tedious, but hopefully fruitful.

Table 3 shows a version of the full Q9 questionnaire. The questions are not fixed. The relative importance and weight of a certain phase and certain question types may instead vary during a simulation project.

6.4.1 AIM: Why? What? When?

Examples of questions related to the AIM are given below

- What is included in the phase under consideration?
- Why are only these aspects included?
- What aspects are not included? Why?
- Who will need data from this phase?
- To whom the outcome will be presented?
- Who provides the data needed?

6.4.2 WAY: How?

The next question set concerning the WAY of doing may be started by asking

- How can the content of the phase be documented?
- How is the data arranged?
- How is the communication organised?
- How can necessary items be constructed?

6.4.3 POSITION: Where are we?

After knowing or at least being aware of *what, why and how,* it is good to assess how close the phase is to completion. Position information reports on the progress for the requirements of project management and steering.

- Where are we in terms of our timetable?
- How much is lacking?
- Is everything already done?
- When will the next milestone be reached?

6.4.4 FUNCTIONALITY: How it is working?

After *what, why, how, where and when,* the interest may lie in the usability of what has already been achieved:

- How does the completed job actually work?
- Is the job done reliable and understandable?
- Does the job done open new possible solutions and ways of working?
- How simple it is to maintain the completed job?

6.5 How to apply Q9

The primary goal of the application of Q9 is to have a model of the simulation project that enables the evaluation and guidance of the project, and improves results, making them more easily available. The Q9 operations model can be applied in many ways: by doing a very quick check list type analysis or by holding many meetings to discuss the topics. On the other hand, Q9 may be applied by the project manager of a simulation project, or by the modeller himself to enable better understanding of the meaning or of his/her role. It may also be applied by an industrial customer who is interested in ordering a simulation project that fulfils his/her needs or by the producer of a simulation software in order to more fully understand the demands of his/her product.

At a glance, Q9 may look like just another stiff “methodology”, but after a closer look, it is clearly an operations model that can guide the simulation project without limiting actions themselves. It is possible to do a rapid analysis of a small simulation project in just a few hours – or to test much larger projects before any other actions. On the other hand, Q9 may be applied by all the partners in a large project before, during and even after the actual execution.

It is possible and even recommendable to apply Q9 operations model in a hierarchical way. Q9 can be applied for whole project as well as each single subprojects and steps within a project. It is probable – and has often been observed – that a solution may not follow a single path; instead, it may consist of different paths, which form still narrower paths for solving sub-problems.

We have identified how different actors in simulation business can use Q9 in their work. Depending on the actor, the viewpoint of simulation differs. Next, Q9 from the point of view of the project manager, modeller, customer and producer is described.

The project manager is often more interested in project goals and timetables than in the details of the simulation work. Q9 offers support for both:

1. Goals, customer needs and problems, the impact of the work and other related aspects are explicitly discussed and documented.
2. Q9 enquires into the state and performance during each phase.

A project manager can apply the Q9 analysis as a model of his or her project; at very beginning, it helps him/her to analyse the situation and write the project proposal. During the actual execution of the project, the manager can apply Q9 analysis as a guiding and resourcing tool.

The modeller may be more interested in the model problems and problem solving than in the presentation of the results. Q9 helps give the modeller answers to the important questions, rather than pinpointing the difficulties of simulation.

The customer needs results that meet quality standards and deadlines. Results needs to be understood together with the risks involved.

Q9 offers an analysed process model:

- Before starting the project, Q9 can be used to select from among different solution paths.
- In the project planning, it is a helpful analysing tool (setting milestones, deliverables and demands).
- After the project, the provided results and solutions can be interpreted.

The software producer will have more information from the other participants. All decisions include risk and a deeper understanding of the risk involved will improve the decision process.

During the project, Q9 was implemented in PowerPoint and Excel platforms and a Wikipedia-type platform was discussed. Each platform has advantages and disadvantages, which are summarised in Table 4.

6.6 Q9 experience and conclusions

The Q9 operations model was created during the SISU project and was, therefore, originally not applied in all case studies of SISU. Only the *Liquid penetration of paper's structure* case study started during the prototyping phase of Q9. On the other hand, all samples cases have been thoroughly investigated in the Q9 framework and project reporting has also been based on the Q9 structure. Therefore, it is possible to estimate the applicability of this kind of general model and its benefits, on the basis of case studies too.

Table 4. Observed and potential advantages and shortcomings of different implementation platforms of the Q9 operations model.

Platform	Advantages	Shortages
PowerPoint	Planned to present and discuss topics, thus supporting the communication between different actors	A page includes a only small amount of text: it is not easy to present answers to the full Q9
	The project model can readily expand in publishable form	Collaboration between different actors is complicated compared to e.g. wiki
	All actors have PowerPoint or a similar program already installed on their computers	Forming and maintaining links to various documents needed is difficult
Excel	Easy to write enough text on sheet for the main question set	Too much text on one sheet makes the meeting like working more difficult
	Easier to form links and maintain them than PowerPoint	Excel is not flexible enough to present results without post-processing
	Like PowerPoint, everybody has access to Excel or a similar spreadsheet application	Forming and maintaining the links to various documents needed is difficult
Wikipedia	Structured but yet flexible way to carry out the Q9 analysis	Easy access from everywhere enabling access to crackers as well
	Automatic version control	So flexible that the utilisation after a while is not going after any methodology
	Easy access everywhere, thus allowing effective collaboration	
	Planned to link documents to one other	

After many trials and learning sessions, the project group itself learned to apply the Q9 operations model. At the beginning, it was astonishing how difficult it was to learn to work systematically and to distinguish the different levels. The definitions appeared to be very important: a “problem” at the project level is totally different than a “problem” in model construction. At the project level, a problem is something that prevents the customer to achieve the desired impact. The model construction problem refers to any obstacle in the constructing the actual model. Both problems are important, but it is unlikely that the paying customer is truly interested in some technical problems related to modelling: instead, they are definitively interested in solving company problems.

During the project, we applied different versions of Q9 on the public funded (KYT2010, www.ydinjatetutkimus.fi/) research projects in the area of bentonite research, which is part of the final disposal studies of used nuclear fuel in Finland. Altogether four different topics were covered by the Q9 analysis:

- the glacial erosion of bentonite buffer,
- the wetting of bentonite,
- the bentonite-cement interaction, and
- Comsol MultiPhysics applications in bentonite studies.

The main observation was that the application of the Q9 operations model resulted in better overall performance for the projects; otherwise, the main focus would have been on model construction itself. The important topic of model data was studied in more detail after the Q9 analysis.

The Q9 operations model is the main achievement of the SISU project and therefore it's future was carefully analysed at the end of the project. In order to enhance the application and further develop the Q9 model, we propose that:

- wiki pages be maintained, including all SISU documents and Q9 User Manuals, and
- new projects that emphasise social and economical aspects more than in SISU be considered.

It is definitely not possible to increase the use of simulation in Finland by merely inventing new operations models like the Q9. As developers of Q9, we hope that our model will aid in the development of successful simulation projects for both the private and public sectors. All these potential success stories will enhance the simulation applications more than any operations model – but during the process, better operations models will also be created and applied.

The Q9 operations model together with social media applications (like wiki) seems to be a promising platform for future simulation business. To date, the visual appearance of Q9 has been done by researchers and the main emphasis has been the contents of the model. Further development on graphical design together with an ad agency would be needed, including:

- wiki pages.
- continuation: social and economical aspects more emphasised than in SISU.
- In simulation business, it is essential to be familiar with the customer's visions, problems and proposed solutions. Co-operation with simulation software *suppliers* and knowledge of their products (historic, existing and planned) are also critical.

7. Opportunities for modelling and simulation

Simulation will probably become an essential part of our everyday lives, because computers are already included in most of our daily equipment. Some of the work cannot be done without help of simulations, while other work can be facilitated considerably through simulations.

Simulation aims to provide understanding and even solutions for some of the major challenges for humanity, e.g.:

- Climate – or more generally, global change – is one of the main modelling enterprises all over the world; experimenting with it is simply impossible and too risky even if possible.
- Safe nuclear power and the final disposal of used nuclear fuel must be based on modelling and simulation instead of experiments, at least at a full scale, for quite understandable reasons.

Significant funding will probably be destined to scientific research of the challenges in the coming years. They could also provide business opportunities for certain modelling and simulation areas on global markets. For example, climate change has already established new businesses in areas such as solar and wind energy, carbon trading, CO_2 capture and storage, biomass and biofuels, energy efficiency, consulting, etc.

It is very difficult to imagine how humanity will apply the ever-increasing computational capability to new applications. The present situation may be compared to the 1980s when personal computers were new and the following questions were imminent:

- Should anybody really have their own computer?
- Why *are* computers needed at home?
- A PC may be a useful for a technology enthusiast, but what will it do for me?

Many people now own several computers, and they are not only using them for calculation (Excel) and documentation (Word), but also for communication, listening to music, watching TV, etc. Most of the people in the western countries have cellular phones that are becoming more and more like computers with built-in connections to everywhere.

An increasing amount of simulation applications in our daily lives may change both how we live and how we do business in the future. It has been said that making major decisions without simulations could be considered naive in the next decade.[1] An example of simulation-based decision making can already be seen today: GPS navigators and map services on the Internet allow people to compare different route options before deciding which way to go. In the future, applying simulation could be as common as using mobile phones or the internet today. We just don't imagine that we are using simulations.

What will be the role of simulation in a ubiquitous world, when everybody is online all the time and accessible everywhere? What new business opportunities for simulation will emerge in this ubiquitous society? What are the risks for Finnish simulation service providers when every motivated and talented engineer in India has access to internet everywhere? These questions raise fears among Finnish simulation actors, but they also represent business opportunities on local and global markets. Examples of everyday simulation businesses can be found in the online game industry (e.g. Habbo hotel) and among service providers (www.reittiopas.fi).

Only about 150 years ago, the quickest interactive communication between Asia and Europe took several months. Communication has been much faster for many years, but during the last few years alone, software development and changes in social behaviour have enabled truly efficient interactive communication between human beings. Simulation is an application in which these developed communication methods may be beneficial in many ways, but utilisation is trailing behind other human activities. We could even argue that modellers are often not very good at using their computers for anything other than computing.

[1] http://www.iftf.org/system/files/deliverables/SR1121_simulation_memo.pdf

In any case, the following assumptions are made.

- Any single modeller is only a member of a bigger network.
- Many modellers may *work* on same problem simultaneously even over long distances.
- Plenty of computing power *is* available – what is more important, however, is how to use that power.

During the SISU project, interactive networking was tested by using wiki pages to collect all the material produced, and to make it easily available for other interested individuals and organisations.

Social media applications for simulation can provide new business opportunities for both networking service providers and organisations that applying these services. One example of a social media application for simulation is Simupedia (www.simupedia.com).

The application of the computational power of present and future computers will be one of humanity's most important technological resources. Even experimental apparatus and industrial production will be increasingly based on computer applications and simulation *methods* will be an essential part of them. These can be seen as resources that accumulate over time. After this accumulation, they can be seen almost like brands with their own value.

Therefore, the application of simulation will take many forms in the future. It can be simple, fast and almost go unnoticed by the user, or be highly specialised heavy computation done by specialists. In both cases, the exchange of information and communication between people with different backgrounds are needed to support the development and maintenance of simulation applications and simulation-based business. Forums like wiki-pages along with a Q9-like operations model could provide tools for that.

The case studies carried out in SISU resulted in a number of applications that are in use in industry, a few beta-level solutions that may have market potential, and a number of simulation-trained engineers on the labour market.

8. Summary and conclusions

The goal of the SISU project was to develop business, products, processes and services by means of simulation. A systematic operations model, Q9, and eleven simulation applications were developed for industry.

Success stories are often based on three elements: visions, know-how and resources (see figure 28). During the execution of SISU, all these elements were investigated with the help of Q9. First, it was observed that current know-how in simulation was sufficient for at least the purposes of SME. Second, SME companies are not ready to pay for simulation work without public support even though the necessary resources are available in Finland. We believe that success stories and the demonstrated benefits of simulation for SMEs will increase interest. According to our experience, operations models like Q9 are an essential part in creating such success stories.

Figure 28. The relationship between visions, know-how and resources: all three are needed for success stories. The authors' assessment of the result when only two of the prerequisites are fulfilled is given on the sides of the triangle.

8.1 Visions

This report was written according to the Q9 operations model, and therefore, it starts with a chapter on vision in which the impact of simulation is discussed. Currently, it appears that there are no clear visions on how increasing the quantity of simulations would shape society and industry.

One example of a vision may clarify our thinking, that of multi-storey houses (six to nine storeys) made out of wood. What are the requirements for such buildings in Scandinavia and Southern Europe, and how do they change with climate and culture? How should they be marketed? (Simulation can actually help here!) What if we could model the complexity of the structures needed to estimate the future potential business? What kinds of requirements are set by different legislations? What properties are universal? Can this be adapted to business in the long term by using simulations?

8.2 Know-how

Simulation and modelling are typically learning processes in which the information accumulates over time to individuals. This information contains both technical knowledge and non-technical know-how. One can learn technical knowledge related to simulation and the application domain through education and training. Non-technical knowledge – best practices, communication, pitfalls, project management – is more difficult to study and the available education is more limited. The Q9 operations model can assist individual modellers and organisations in this area.

Education on modelling and simulation at colleges and universities is limited in Finland. To ensure high competence in modelling and simulation in the future, simulation education – as well as international networking – is important at all levels, starting today.

Many of the obstacles to the modelling and simulation business are related to people as opposed to technology. Simulation will be increasingly based on team work and such collaboration requires good social and psychological skills. Modelling and simulation are more like tools for exercising a profession than a profession itself. On its own, a simulation business might be difficult to establish, but when it is connected with knowledge from a specific field of application, it may be easier. In any case, during the SISU project, we found that Finland unquestionably has the technological know-how needed to support SMEs.

8.3 Resources

A modelling and simulation-based development cycle may be more cost effective than a traditional one based on up scaling done through prototypes, pilot plants and production; in some cases, simulation may even be the only option. However, simulation needs resources as well, and at least some of these resources differ from traditional ones. The following will be needed:

- more efficient computers and related know-how,
- software products, their licenses and capable users, and
- management capable to operate in this new environment.

Therefore, the large-scale utilisation of simulation is one of many investments that a company needs to make, and the profits attained through better products and decreased costs will come later.

Small and medium enterprises may have particular difficulties in funding simulation. The following is a list of some strategic options:

- Increasing income at least partly through the results obtained from simulation.
- Collaborating with other small companies: simulation companies or companies tackling the same problems.
- Focusing on strategic things and applying simulation there according to their limited resources (Q9 may be helpful).

All companies, including bigger and internationals, may collect international know-how and then grow, and focus on certain business areas with simulation resources.

Society is often the most important resource when changing to an operations model in which simulation is applied as a strategic tool. Funding for simulation development and education is of course of the utmost importance. Funding research work on “How can a simulation to be done?” may be almost as essential as mathematical developments. It is important to be familiar with human, social and networking aspects and further develop them.

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Title

Anyone can simulate?
The Q9 operations model to guide execution of simulation projects

Abstract
In 2005, Tekes launched MASI, a five-year programme on modelling and simulation to develop the knowledge, methods and use of modelling and simulation in the Finnish industry and service sector. There are still relatively few simulation service providers on the market, and the benefits of applying modelling and simulation from the business point of view are not yet known. Due to this dilemma, we would like to start by discussing the role of simulation in the competitiveness of Finnish industry. What is the value of modelling and simulation competence? Are we on the right track if simulation methods developed in academia never enter the market or if simulation companies can only survive with public support? This report summarises the results of the SISU project, which was part of the MASI programme. The main goals of the project were to develop simulation methods suitable for small and medium-sized enterprises (SMEs); to make an implementation plan that can be adapted for industry, and to identify opportunities and create the prerequisites for simulation-based industry. This report mainly emphasises the Q9 operations model, which was developed for the effective execution of simulation projects. Business opportunities for simulation are preliminarily discussed and eleven case studies done within the project are briefly summarised.

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This report summarises the results of the SISU project carried out between 2006 and 2009 by VTT and the Metropolia University of Applied Sciences. The main emphasis is on the Q9 operations model, which was developed for effective execution of simulation projects. Business opportunities for modelling and simulation are preliminarily discussed and eleven case studies done within the project are summarised. The aim is to highlight the opportunities and obstacles of modelling and simulation. The authors would like to challenge the reader to prove, disprove or modify the ideas presented in this report in order to catalyse a public discussion on the benefits of modelling and simulation, especially from the point of view of business. Would your company be more profitable if it doubled or halved its simulation budget?

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