9. SUMMARY AND FUTURE WORK

The major research work reported as a part of my Dr.ing. work ended in 1991. At that time a version of the SIMMEK simulation package was running on a Macintosh computer, with the functions and facilities reported in the main parts of Sections 3, 4 and 5.

Since then, further development has taken place with SIMMEK, Sections 2.5 and 3.8.

This Section 9 gives a summary of the results achieved up to now in these two stages, giving the setting for some summary remarks on future work.

9.1 Summary of SIMMEK results

9.1.1 The scope of the work

After a long period of studying simulation techniques and tools for use in manufacturing, the following short version of the purpose can be stated. Simulation is used;

* As a decision support tool

* For understanding and learning about complex systems

A lot of different simulation tools are available, with varying facilities and functions. A set of success criteria is defined to applying any of these simulation tools in manufacturing, being;

1	The ability to produce results that are interesting to the user
2	The ability to produce results that cannot be obtained by other methods
3	The resemblance between the modelling facilities and the real world system being modelled
4	The time an inexperienced user has to spend from the time he starts using the tool and till he has a model running
5	The validity and accuracy of results and hence the accuracy of the models

Table 9.1 Success factors in simulation, ref. Table 1.3

The areas of use of simulation in manufacturing may vary a lot within the following description;

Strategic	
Factory planning, including layout, grouping, automation	
Market strategies and product ranges	
Use of subcontractors, outsourcing	
Tactical	
Lot sizes	Job priorities
Sequencing	Logistics rules and systems
Market fluctuations (seasons, trends, etc.)	
Operational	
Rush orders	Scheduling problems
Use of operators	Handling emergencies

Table 9.2 Strategic, tactical and operational use of simulation in manufacturing, ref. Table 1.4

A large research programme was launched at NTH/SINTEF in 1985. The programme was financially supported by the Norwegian Council for Scientific and Industrial Research, NTNF. The research programme was called SIMulering i MEKanisk industri, Simulation in Mechanical Industry, abbreviated to SIMMEK. Its main goals were to investigate and improve existing computer tools or develop new tools for performing analysis of manufacturing systems, based on simulation techniques. Another stated goal was to establish manufacturing simulation as a field of competence at NTH and SINTEF Production Engineering. The ultimate goal was to improve Norwegian industrial companies' competitiveness by giving them the benefits of using simulation as a decision support tool.

It was decided to implement a tool that should as far as possible be useful both in factory planning/automation as one extreme and evaluating weekly schedules as another.

The specification and implementation of the system started as a project within the programme at the beginning of 1987. Late 1988 a first prototype of the simulator was launched. This prototype has been continually developed until the release of the first commercial version in March 1991.

9.1.2. A study in Norwegian companies

In the majority of Norwegian companies they had not heard about simulation of this type at all. But we found that the need for analysis tools was large; a lot of investments and changes is implemented without proper analysis being done, and these changes are often crucial for the survival of a company.

The conclusion was that there is a need and a large potential for simulation tools.

It is also evident that since the typical situation where simulation is thought of as a useful aid, is in machine investment/automation, it is also this type of use that most simulation tools are developed for. Although this was not the case when the survey was performed, simulation tools for this purpose are really excellent today.

The main reason for simulation tools not being widely used, was that the availability of most of the existing or known tools was limited. Programming and simulation expertise were necessary. For most companies the only way to do simulation experiments was to hire a simulation expert from a consultant company for the job. This meant that the experiments were extremely cost expensive. And it took too long time to get the job started; the right consultant company must be found, contracts written and signed and so on. Simulation is often considered as the "method to use if everything else fails", and in that situation, time is the limited resource. This is not a fact that is limited to Norwegian companies [11].

The tool must use advanced facilities in user interaction, i.e., windowing and graphical facilities, so that it will be easy to use and easy to learn to use. No programming should be needed, and manufacturing terms should be used in the modelling of manufacturing systems. The result presentation must be complete, and graphical presentation facilities available.

The need for economical analysis facilities was pointed out by all the industrial managers.

A surprisingly large percentage of the production managers pointed out that simulation in the future may also be used at the operational level.

9.1.3 The SIMMEK tool

Since 1989, I was given the main responsibility to specify and be in charge of the development of the SIMMEK tool. In the first years this work was done in co-operation with Per Aage Nyen and Einar Ramsli. In the last two years, Eirik Borgen was the key person on designing and coding the specifications.

In March 1991, a version 1.0 was available. This version was continuously developed into version 1.5. The description of SIMMEK is not possible to give in short words, see therefore Section 3 for elaborate descriptions. See also references [41, 42, 43, 44].

As any other computer tool, SIMMEK has its advantages and disadvantages. On the positive side the following points are most essential;

* A tool suitable for decision support in strategic, tactical and operational production management
* Includes economical analysis
* Models and results are presented by spreadsheets and graphics, making it quick to model easy to read and interpret easy to post process the data easy to integrate
* No programming or pseudo programming needed

Table 9.3 The SIMMEK system's major advantages, ref. Table 3.1

Most of these points are self explaining, and reference is given to Section 3.

The general status of SIMMEK today can be summarised by stating that it is extremely fast to learn to use, and to create the first models in. But it is still limited in what can be modelled, and how fast the models can be changed.

Concerning programming, it is still true that the so-called programming free tools like SIMAN and Witness, need pseudo programming to be able to model a plant, and thus more time is required to learn to use. On the other hand, this makes them more flexible in what can be modelled.

On the negative side, SIMMEK has what could be called lacks of facilities compared to other existing packages. The most important of them are;

*	No animation
*	No programming facilities
*	Modelling limitations
*	Slow in changing large set of parameters
*	Available only on Macintosh
*	No integration possibilities

Table 9.4 The major disadvantages of SIMMEK, ref. Table 3.16

The lack of programming facilities is the most severe lack of a tool like SIMMEK. This limits what can be modelled. At least it limits what can be modelled without a lot of abstraction and “tricky modelling”. But some phenomena must be simplified and not modelled, and in several cases this is crucial for the validity of the model.

The last three points, slow in changing large set of parameters, available only on Macintosh, and no integration possibilities, have certainly been solved with the new version of SIMMEK, SIMMEK-II, made outside the work presented in this report.

Concerning the integration aspects, speaking of the new version of SIMMEK-II, as well as any other simulator, there is still a lot of research work to be done to be able to make a *smart* transformation of data.

9.1.4 Model validation in SIMMEK

Model validation has been given special concern in the development of SIMMEK, because the consequences of making invalid models are severe and mainly of two types;

* Wrong conclusions
* Increased costs

These consequences will in turn lead to;

* Reduced use of simulation

We have developed a system where the user is guided all the way through the modelling phases, and with excellent means of model validation at all stages of a simulation study. The following list shows the different facilities and aids in the sequence that they are normally used, starting with how validity is secured in modelling;

*	Use of statistical packages for testing input
*	Check of input values

*	Input by pointing and referring
*	Check of model logic
*	Aggregated schemes of input values
*	On-line checks during simulation runs
*	Monitoring

Table 9.5 SIMMEK; How validity is secured in modelling, ref. Table 4.3

This is in the core of model validation. As we now go on to how validity is secured and assisted in experimenting and result analysis, please remember that the validation is cyclic, and many facilities are used more than once during an experiment. The facilities are;

*	Advanced trace
*	Statistical tests
*	Graphical visualisation
*	Automatic use of replications

Table 9.6 SIMMEK; How validity is secured in experimenting and analysis, ref. Table 4.4

9.1.5 Result presentation and analysis in SIMMEK

The results in SIMMEK are organised along two axis; one axis giving the different categories of results, the other giving what could be called the time scope of the results. These two tables show the general set of results in SIMMEK. Along the first axis we have results in four categories;

1	Economical and market service results for the total model (Ex; Net profit, value of WIP, delivery performance)
2	Product results. Per production order or per product type (Ex; Throughput time, no of pieces in stock, turnover)
3	Resource results (Ex; Utilisation rate, queue)
4	Experimental facts (Ex; Simulation time, warm up time)

Table 9.7 Results along the category axis, ref. Table 5.5

Along the second axis there are five major points. These factors concern the simulation time span over which they are captured, as well as the degree of detail of the results;

1	Estimated expected values These "results" are calculated before the simulation. Resources; It shows the expected load for the resources Products; The minimum TPT (if no queues anywhere)
2	Average results/values from one replication This is the most used and detailed information. It shows the results averaged over one replication
3	Detailed results/values from one replication Gives a more detailed and also chronological picture of one replication for some of the results concerning resources and products (Ex; Every TPT measured, the utilisation *profile* for the resources)
4	Average results from many replications All the results from 2, averaged over more than one replication
5	A trace of all events from a selected period of one replication

Table 9.8 Results along the time scope axis, ref. Table 5.6

All these results are produced into Excel spreadsheets, making it easy to post process them, compare, and create charts.

9.1.6 Cases with SIMMEK

The SIMMEK tool has up to this date been used at a number of different industrial companies. It has also been applied to very different areas like modelling the transportation of salmon from the fish farms to the end customer. In Section 6.2 there is a list of the models/experiments made with SIMMEK that I am aware of. As the tool is now available to a commercial market, there are, of course, many applications that I am not aware of.

SIMMEK has also been used in several presentations and lectures. The purpose is then to illustrate some effects of certain topics or phenomena within production management. It has also extensively been used in students' project and diploma work, see Table 6.9.

One example is Raufoss AS. Situated at Raufoss, it is one of Norway's leading manufacturing companies. Its main products are ammunition and military equipment as well as aluminium and plastic parts for the automotive industry. Raufoss produces bumpers and chassis parts for many of the leading car manufacturers in Europe and the USA.

The goals of the simulation experiment at Raufoss were many, but from the company the two most important ones were the following;

* See the effects of reduction of set-up times

* Find "optimal" lot sizes

In other words, it was a simulation experiment trying to find a better way of operating an existing system, hence it was simulation used for a tactical purpose.

The conclusion from this project can be summarised as follows;

As a conclusion, the Raufoss study proved that it was possible to model a large manufacturing plant with SIMMEK
The results were close enough to be able to conclude about the effects of a reduction of set-up times and batch sizes
The results showed potentials of improving inventory turnover by 30 %
As anticipated, SIMMEK is more suitable for making comparisons than for predictions
A list of improvements needed in SIMMEK was created. Some of these are already implemented
SIMMEK is useful for learning personnel working in a plant more about the plant
It was seen as unlikely that this personnel could use the tool without external, expert help with the modelling
They were able to play with existing models themselves

Table 9.9 Conclusions from the Raufoss case study, ref. Table 6.8

Many of these conclusions are confirmed by a number of other case studies, see Table 6.9 for details.

Connected to the Raufoss project, a set of algorithms to improve the speed of performing simulation experiments were developed. These algorithms were developed to run a large set of results to identify result elements that were outside a specific range.

The efficiency of the algorithms can be measured in two ways. By using the algorithms, the time to set-up a new experiment was reduced to one fifth of the original. The algorithms were far more reliable in checking and finding the "right parameter to change next", i.e., using the algorithms is a more systematic result study than a manual one.

The negative aspects of using such algorithms are closely related to this last statement. The algorithms do not check what it is not told to check. Therefore some obvious "out of range results" were not spotted.

Some of the assumptions and conditions made limits to the applicability of the algorithms. The scheduling principles were very simple, mainly First Come First Serve. An improvement in this scheduling, and allowing differences in time between batches of the same product type would probably improve the results.

In short, the main conclusion is that these algorithms are most time saving when running a series of experiments changing a set of parameters equally between each simulation run. The time may be reduced to one fifth on this part of the experiment.

9.2 Summary of SIMMEK-II results

In 1992, there was launched a follow-up project of SIMMEK. This project was also funded by Norwegian Council for Scientific and Industrial Research, NTNF. Main partners were Teknologisk Institutt, Kongsberg, Stavanger EDB (a software company), and SINTEF.

As I have only been supervising this project, the work completed within this project should not be considered as a part of my Dr.ing. work. More details on this work can be found in Borgen [12] and [45].

The possibilities of using a simulation tool as an operative tool in evaluating detailed production plans/schedules are very promising. This research will be followed by several research tasks within our research group at NTH and SINTEF. These achievements can be summarised in the three following points, see Borgen [12];

*	All input can be given in the Excel format
*	Data can be received from an MRP II computer based production management system, or any other system that can produce Excel files
*	Available on both PC - MS/DOS and Macintosh

Table 9.10 The new SIMMEK versions

The effects of these achievements are obvious. SIMMEK-II is now available for “all” who are in possession of a personal computer. It can be used for operational decisions in production management. And it is very quick and easy to make changes for a whole set of parameters at once.

9.3 Future work

9.3.1 Discrete event simulation in production management

It is important to remember that simulation is still unknown to the majority of industrial companies. Another large number of companies know of simulation as a possible aid in production management, but have found the tools not applicable in their situation.

I see the following topics as the ones that effort should be put into to enlarge the number of companies and situations where simulation may come to use.

Improving facilities of existing tools

* Closer to manufacturing and production management in modelling
* Covering more manufacturing planning and control phenomena
* Easier modelling/updating of sequences of parameters
* Covering human behaviour (learning curves, peak performance, etc.)
* Guided and reliable use of statistics
* Facilities to model with uncertain specifications,
  i.e., One-of-a Kind production

More integration facilities

* Accepting input from
  - Process plans
  - Production plans (Master Production Schedule and schedules)
  - Sales
  - Costs accounting
  - Data acquisition facilities
* Transformation of values to statistical parameters/distributions
* Giving output as suggestive plan/schedule iterations
* Facilities to import uncertain specifications,
  i.e., One-of-a Kind production

More automated/computerised functions

* Transformation of values to statistical distributions (as above)
* Automated use of replications/long runs for improved reliability

Speed up the learning, modelling and simulation time

* Use of tutorials in learning
* Easier modelling (see above)
* Faster computer processing (parallel, more true object orientation, etc.)

Table 9.11 Future detailed research areas of DES in manufacturing, ref. Table 2.4

It must be stressed that these topics are chosen for the purpose to make better tools for the users, and not for the reason of making the tools easier to promote from a commercial point of view. To explain what is meant by this we can take the example of animation. Concerning this topic there are number of tools available with excellent animation facilities (SIMAN/CINEMA, Witness, etc.). The animation facilities in these tools are more than good enough for use in real cases; visualisation and verification/validation. Any improvement here may make the tools easier to promote, but will not make the tools necessarily better in use.

9.3.2 SIMMEK-II

Concerning the future development of SIMMEK-II, the possibilities of further development is dependent of the reception of the package in the Norwegian market, as well as possibilities for funding research work in the area of simulation in production management.

As virtual manufacturing will become increasingly important in the future, with shorter life cycles of products, modelling and simulation of manufacturing processes and products will come more into focus.

I see specially two areas, in combination, which will be of future interest with SIMMEK-II.

First is the area of one-of-a-kind production, also described as make- or engineer to order, customer order driven production. In this type of manufacturing organisations, decisions are taken with a lot of uncertainty. And these companies face more and more the same demands for short delivery times etc, as make to stock companies.

Tools to support decisions where they have to handle this risk, would be a major achievement for these companies. Simulation and SIMMEK-II, with further development, can be such a tool.

In this type of companies, as in most others, the amount of data available is enormous. Much more than a human can possibly absorb. Neither can a human use all this data to make models, nor interpret results from such large models.

This leads me to the second, connected area of future research area of SIMMEK-II. An intelligent extraction of data from databases to use in modelling, as well as an intelligent extraction of results from an experiment. The intelligent extraction would mean ways of merging product types into families when modelling, etc.

The future could then be an integration of a scheduling system and SIMMEK-II. Such a combined tool could be regarded as an executing tool, where schedules are generated, evaluated and tested, consequences examined, before orders are released to be performed immediately. The schedules will be updated and improved whenever new information is available, but consequences are examined for a longer horizon.