6. CASE EXAMPLES 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 within production management. The purpose is then to illustrate some effects of certain topics or phenomena within production management. It has also extensively been used in students' projects and diploma work. Some of these projects are listed below.

6.1 Raufoss AS

One of the major simulation studies performed with SIMMEK is the one that was performed at Raufoss AS. The main results from this experiment is described in this section. Of particular interest from this study, except obviously the conclusions from the experiments, is a set of algorithms that was developed to improve the result analysis. These algorithms have not been generalised and implemented as a part of SIMMEK, but both the concept and the algorithms themselves are guidelines for how to analyse a large set of results from a simulation study of a manufacturing system. The algorithms are described in Section 7, as these types of additional means are necessary to use simulation at an operational level.

Situated at Raufoss, Raufoss AS 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.

6.1.1 The plant and how it is operated

The plant modelled in this case is one producing car bumpers of aluminium and plastic. The bumpers are sold on long term contracts with weekly or fortnightly orders being placed on short delivery times, often only a couple of days. These delivery times are normally shorter than the throughput time, which makes it necessary to make to stock. The production resources are of three main categories; personnel, advanced and costly machinery, and simpler stations like assembly stations. The set-up times of the machinery were at the time the simulation experiment was performed, on the average between three and four hours. This is, of course, dependent on how you calculate the average. One of the goals of the simulation experiments was to see the effects of a major reduction in set-up times.

The set-up times create series effects, leading to large series or batch sizes. On the other hand, the demand for low inventory and Just In Time performance will lead to a reduction of these batch sizes. The SIMMEK simulation tool was used, and the goal was to investigate the improvement effects in inventory turnover by changing batch sizes, tuning the production orders and adjusting capacity. The effects of a possible reduction in set-up times were also evaluated.

6.1.2 The goals of the simulation

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 results of the simulation were to be measured by focusing on a small set of result extracted from simulation result set produced by SIMMEK. This extracted set of results is shown in Table 6.1.

Result factor	*Description*
Inventory turnover	The total income (measured in manufacturing product costs)/average inventory
Delivery performance	The percentage of orders shipped according to schedule (day)
Inventory value	Sum of work in process and finished goods
Costs of inventory	Inventory value x 20 % interest rate
Throughput time	The time from the first operation can start on one batch, until all parts are complete

Table 6.1 Main result factors to be studied at Raufoss

The experiments were performed in two major steps. In the first step, the delivery performance was allowed to vary within a range between 70 % and 100 %. But for the final experiment the conditions were set that the delivery performance should be between 97,5 % and 100 %, and, of course, as high as possible within the range.

It was accepted that the model of the plant could not be a 100 % comparable to the plant itself. It was accepted and agreed that the simulation should focus on *comparing* different scenarios, rather than predict future inventory values, etc.

It was also a goal for Raufoss to investigate through this pilot study whether simulation was an efficient tool for this use or not.

As developers of SIMMEK it was important to test the tool on a real case. The test was to answer at least three questions;

1. Could the tool be used to model all the existing phenomena that occurred at Raufoss ?

2. How many hours and days were needed for modelling, result analysis, etc. ?

3. Was it possible for the Raufoss personnel to model the factory by themselves ?

Underlying all these questions were the basic purpose from an R & D view; to identify how to improve the SIMMEK tool.

6.1.3 The project

The work was performed during approx. one year. It was a split of work between the personnel from Raufoss and me. Together we agreed on the basic goals of the study, what were the main result factors, what to include and what to leave out of the model, etc.

All the data collection was performed at Raufoss by their own people. The data was collected and written down on paper sheets formatted specially for this use. The format was made according to the input format of SIMMEK.

The models were developed on my computer at NTH, Macintosh II, 4 Mb RAM, 40 Mb Disk, and 38020 processor (no math processor).

The input was mailed or faxed to me in Trondheim, as were the results back to Raufoss. The final conclusion were discussed in two meetings, one for each of the two phases.

6.1.4 Models

The car bumper plant consists of a number of production lines, some welding stations, a heating oven, and a number of assembly and packing stations. Each production line is dedicated to one or a family of products.

The number of items of the different entity types in the model of the plant is as follows;

Products and components		72	
Resources			
Machines	64		
Operators	54		
			118
	Total		190

Table 6.2 Number of different types of entities

Most bumpers are made from aluminium and plastic parts which are assembled together. The entire production is controlled from the production lines where aluminium is extruded and bent into the required shape. These production lines are also called First operation machines, and they are named the following;

Name	*Average set-up time*	*Distribution used*
M01	4,5 hours	UNI (3,5 5,5)
M02	3,5 hours	UNI (3,0 4,0)
M03	4,0 hours	CON (4,0)
M04	4,0 hours	UNI (3,0 5,0)
M15	3,0 hours	UNI (2,5 3,5)
M16	6-15 hours	UNI (varying)
M17	2 hours	UNI (1,75 2,25)
M19	8 hours	CON (8)
M20	4 hours	CON (4)

Table 6.3 First operations machines

Of other special interest are the ovens used to harden the bumpers. They had to be modelled in a special way, as the way they were controlled at Raufoss were not according to a strict algorithm. These ovens are named OVN-12, OVN-32 and OVN-X.

Each product and component had from 1 to 9 process steps, including the assembly operations. The machines are operated on 1, 2 or 3 shifts. For some of the machines the first simulations runs showed that the availability that was given as input, for instance 7,7 hours for 1 shift, were not enough to get all the required work done. This made the verification of the models very difficult. For most of these cases the input was wrong, simply that the operation times were inaccurate. Almost 50 hours of verification work were spent on these mistakes. Some machines were also actually overloaded, and had to be operated for 120 % of one shift.

The models all together consisted of more than 5 000 data elements.

6.1.5 Experiments and results in phase 1

In phase one there was created more than 30 different variants of models, out of which these five were considered as those where the results were so promising that they were the basis for further experiments:

K.I	Model of current plant		
K.II	All batch sizes reduced to 80 %		
K.III	All batch sizes reduced to 60 %		
K.IV	Batch sizes as follows;	All products in M-17	100 %
		All products in M-2	80 %
		Orig. batch sizes of < 1 000	100 %
		All other products	60 %

K.VI	Batch sizes as follows;	All products in M-2		80 %
		Orig. batch sizes of < 1 000		100 %
		All other products		60 %
		Set up times;	M-17	1 hour
		Others	2 hours	

Table 6.4 Models in phase 1

The results from the five extracted experiments are shown in the following table;

Model	IT	DP	IV	CIV	TPT
K.I	13,6	73 %	23,8 MNOK	4,8 MNOK	9 days
K.II	13,9	75 %	23,2 MNOK	4,6 MNOK	7 days
K.III	14,1	70 %	21,1 MNOK	4,2 MNOK	7 days
K.IV	15,7	93 %	20,6 MNOK	4,1 MNOK	7 days
K.VI	17,6	89 %	18,3 MNOK	3,7 MNOK	6 days

Table 6.5 Main results from phase 1

Legend; IT = Inventory turnover
DP = Delivery performance
IV = Inventory value
CIV = Costs of inventory
TPT = Throughput time

The preliminary conclusion was obvious. It was possible to reduce the inventory in the model with more than 5 million NOK, from 23,8 MNOK to 18,3 MNOK. This was a result of a combination of reduced batch sizes and reduced set-up times.

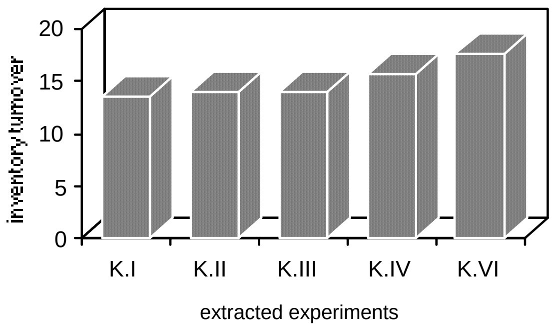

Figure 6.1 Inventory turnover, ref. Table 6.5

A reduction of batch sizes alone gave a reduction of 3 MNOK. As these models were not 100 % similar to the real plant, it was the improvement factor that was most important.

The inventory turnover can be reduced by reduced batch sizes with an improvement factor equal to;

Improvement factor = IT(K.IV) / IT (K.I) = 15,7/13,6 = 1,15

==> *15 % improvement*

Combined with reduced set-up times the inventory turnover can be reduced by;

Improvement factor = IT(K.VI) / IT (K.I) = 17,6/13,6 = 1,29

==> *29 % improvement*

From Raufoss it was commented that the most important effect of this reduction was that in the new situation there would be 29 % less material to control at the same time. This would improve their ability to meet all due dates in the future.

As can be seen from the table, the delivery performance was also improved from K.I to K.VI. But Raufoss had as a strategy never to have less than 97,5 % delivery performance. At this stage they had to “pay” for this by having even greater stock levels of completed bumpers, than modelled in these models.

It was therefore decided to run a second phase of the project, with more tuned models, so that the required delivery performance was achieved.

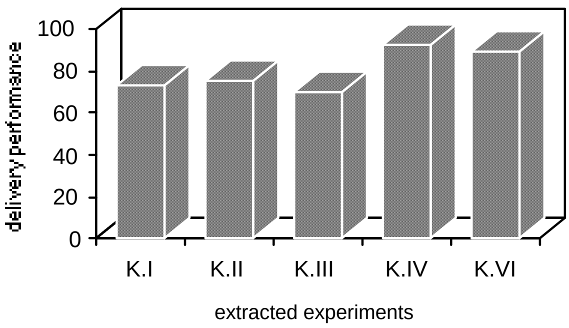

Figure 6.2 Delivery performance, ref. Table 6.5

Although all these models were not 100 % modelling the real plant, the results indicated in the simulation experiment have been achieved to a certain degree at Raufoss. Unfortunately, the demand for these products has decreased over the last few years, following the decreased demand of cars because of the recession. Therefore it has been difficult to compare the results of the models K.II to K.VI with reality, as this reality has changed. More about this in Section 6.1.8.

6.1.6 Experiments and results in phase 2

It was decided to run a second phase of experiments. In this phase 2 the two models K.I and K.VI were examined further. The purpose of this second phase was the same as in the first phase; to see the effects of reduction of set-up times and to find "optimal" lot sizes. What were different were two extra constraints;

* Delivery performance should be better than 97,5 %

* No delays of more than two days

In addition, it was an underlying goal to fulfil these with as little costs, inventory, etc., as possible.

It was very difficult the get the models equal regarding delivery performance. A lot of work was put into this. It was also developed routines to examine the results, tuning the model to produce with as low inventory as possible, still meeting the requirements. A set of algorithms, partly implemented in Excel macro's was developed, see Section 7.

The results achieved in this second phase can be seen from the two following tables.

Model	IT	DP	IV	CIV	TPT
K.I	11,9	97,5 %	27,1 MNOK	5,4 MNOK	8,6 days
K.VI	15,5	98,0 %	20,8 MNOK	4,2 MNOK	6,3 days

Table 6.6 Main results from phase 2

Legend; IT = Inventory turnover
DP = Delivery performance
IV = Inventory value
CIV = Costs of inventory
TPT = Throughput time

Again, the inventory turnover can be reduced by reduced batch sizes with an improvement factor equal to;

Improvement factor = IT(K.VI) / IT (K.I) = 15,5/11,9 = 1,30

==> *30 % improvement*

Although the actual values of inventory turnover are different in the comparable models *between the two phases*, the improvement factor comparing the two models *within the same phase* is fairly constant (29 % versus 30 %).

If we look at the throughput times in the models, Table 6.7, we see the distribution over the product families, where the families are split according to which 1. operation machine they are processed in.

Products in 1. machine	*K.I (days)*	*K.VI (days)*
M-1	7,9	6,6
M-2	5,5	5,0
M-3	12,2	8,9
M-4	13,8	9,8
M-15	5,8	7,4
M-16	16,5	4,4
M-17	7,7	5,7
M-19	4,7	4,6

M-20	5,3	4,1
Total	**8,6**	**6,3**

Table 6.7 Throughput times

All but one product family have decreased their throughput times significantly. For the products in M-15, the reason for the increase was that the reduced batch sizes were not suitable for the operations after the first, resulting in sub batches to wait for very long time in front of some resources.

6.1.7 The work load of the project

This pilot project of using SIMMEK was performed while the tool was still in a major development phase. Hence many hours of the time spent on modelling and validation of the models from Raufoss were actually development work on SIMMEK. In the following table I have put up an estimation of the hours spent on the whole Raufoss project.

Work performed	*Raufoss*	*NTH*	*Total*
Experiment design	20	20	40
Data collection	100	10	110
Modelling	-	100	100
Verification and validation	10	120	130
Result analysis, changes, etc.	5	50	55
Discussions, conclusions etc.	20	20	40
Total	**155**	**320**	**475**

Table 6.8 Total hours spent on the Raufoss case

The work spent on developing the SIMMEK tool, including the detection and correction of bugs, is not included. The same goes for the work of developing the algorithms for tuning the models. The time when the computer was running, and the user was free to perform other duties or tasks, is not included. This would add some 60 - 80 hours to the table.

One run of the model, including human and computer processing time, took approx. 2 hours. The computer processing time was from 1 h. 45 min. to 1 h. 50 min. This was on a Macintosh II, 4 Mb RAM, 40 Mb Disk, and 38020 processor (no math processor).

It is typical that most hours are spent on data collection and verification & validation. The split between data collection and modelling is also not very clear. If more time had been spent on data collection (verifying values as they were collected), this would have reduced significantly the time spent on modelling. A similar effect would, of course, be seen if the data available in the company was correct in the first place.

6.1.8 Conclusion and discussion from the Raufoss case

6.1.8.1 The results

The conclusions from this experiment are very clear; there is something like a 30% of inventory reduction if the batch sizes and the set-up times are reduced. The statement from the plant manager at Raufoss was clear. “This means 30 % less material to control, giving us a better overview and hence an easier task. The throughput times are also heavily reduced, making it easier to change our production plan on short notice. All this gives us a better chance to meet our overall goal; a delivery performance of at least 97,5%”.

It was also stated that the simulation results were going to be used as an argument for working with a reduction of set-up times.

Unfortunately, the demand for car bumpers has both decreased and changed in mix since the experiment was performed. Therefore it has not been possible to compare the results of the models with any reality, simply because the alternatives modelled do not exist. But from what has been done with reducing batch sizes and set-up times at Raufoss, the results of this implementation support the results obtained with SIMMEK.

There are also some other significant results that were achieved in this project.

Firstly, the project made it necessary to go through all operation times, set-up times, etc., of the whole plant and all the products. This data collection, modelling and verification & validation spotted a number of severe incorrect data. These data were used in the daily planning, and it was very useful to have them checked and corrected.

Secondly, being forced to give input to the model, three persons at Raufoss had to examine their plant very carefully. This gave them a new insight in how things work and are influencing each other in a plant in general, and with their specific plant.

6.1.8.2 On the work load and the usefulness of SIMMEK

The work load of performing this experiment was far more than expected. In a rough estimate, 200 hours were believed to be enough. In the end, more than twice this number were needed. The reasons for this can be summarised in the following points.

The inaccuracy and wrong data that were collected, led to many hours lost searching for any mistakes done in modelling, or even bugs in the system. Mistakes and bugs that were not there.

The modelling environment in SIMMEK is made for giving a lot of varying input data. If the input is equal for one or two, but not all parameter of an object, there is no function for setting these one or two values for all objects. A lot of clicking and pointing had to be done.

When changing the model, it was not possible to give commands like; reduce all batch sizes with 20 %. Each single batch size had to be changed one by one. Again this was very time consuming.

The simulation running speed was not good enough. If a mistake was done in the input phase, and not spotted in the model check, the model would run for almost two hours before the results were there, and the results of the mistake were (hopefully) spotted. If this was experiments run over lunch time or over night, even more valuable time was lost, as “there was nothing to analyse in the morning”.

Some phenomena were not possible to model directly, and were modelled by certain “tricks”. This was also time consuming.

All this led to change proposals for SIMMEK, of which quite a few are already implemented. A major improvement was achieved when the Excel format could be used for giving input and changing models.

The algorithms mentioned earlier are explained in detail in Section 7. Some conclusions on them are relevant here.

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.

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 6.9 Conclusions from the Raufoss case study

6.2 Other case studies with SIMMEK

A number of other studies has been made with SIMMEK. This list gives the most interesting ones, showing the diversity in types of industrial companies and types of problems they have been used to model.

Company	*Type of industry*	*Type of production*	*Problem focused*	*Performed by*
Raufoss	Car parts manufacturer	Make to stock	Batch sizes, set-up times	NTH, Dr.ing work
Håg a.s	Office chair manufacturer	Make to order	Assembly layout	NTH Diploma-work
Glamox	Electric lightening equipment	Make to stock	Assembly lines	Company
Lom	Furniture	Make to stock	Production control	NTH Diploma-work
Nobø Electro	Electric heating	Make to stock	Assembly line control	SINTEF
Raufoss	Chassis car parts	Make to stock/make to order	Batch sizes, set-up times	NTH Diploma-work
Tandberg Data	Data storage equipment	Make to stock	Control principles	NTH Diploma-work
General purpose	Fish farming	Make to stock	Logistics	SINTEF
Nidar	Food	Make to stock	Production capacity	NTH Diploma-work
Figgjo	China ware	Make to stock	Production capacity	NTH Diploma-work
Hagen	Furniture	Make to stock	Production control	SINTEF
Norwesco	Electric devices	Make to stock	Production control	Company

Table 6.10 Case studies with SIMMEK

For all these cases it has been possible to model a plant, or part of it, and to achieve results that can not be obtained by another method. As a conclusion SIMMEK is suitable for a large set of types of industrial plants, as well as for problems varying from strategic, via tactical to operational use.