7. OPERATIONAL USE OF SIMULATION IN PRODUCTION MANAGEMENT

7.1 Introduction

For some years now simulation experts have pointed at the potentials of and the need to use simulation at operational level in production management. A number of papers dealing with manufacturing simulation has also tried to address simulation's place in a CIM environment. But I feel that too little concern has been taken in trying to find the effects of using this type of simulation has on the organisations implementing it, and on the humans working in the organisation.

7.1.1 Traditional use of manufacturing simulation

Up to now manufacturing simulation has been used mainly in situations where the decisions to be made, have mainly long term effects. It has been used for decision support in situations that are months and maybe years ahead, as one of many tools in factory planning. A typical example is the use of simulation to decide on the number of machines of a certain type in an extension of an existing plant, i.e., a decision at strategic level, see Section 1.5. In such project-like tasks there are days and weeks available (and certainly needed) for doing all the different jobs that are needed for a complete simulation experiment. Specially the data collection and the verification/validation phases of an experiment should be kept in mind. They are both time consuming, and they need to be performed in co-operation with the personnel responsible for the plant.

7.1.2 Scheduling systems

Computer aided systems for scheduling or detailed planning are a family of systems closely related to simulation systems. In fact many people refer to testing different schedules in a scheduling system as being simulation. And they are fully entitled to do so.

As I see it, scheduling systems and some simulation systems are coming very close in their approach. In fact we will in near future see scheduling systems with true simulation functions and simulation systems with much more advanced scheduling functions.

7.1.3 What is simulation in this context

Again it is necessary to mention two of the criteria for defining what is simulation in this context. To be able to define it a simulation system, the system must use statistics, and have a dynamic behaviour.

Using statistics is required in two stages of an experiment;

*   Modelling by using statistical distributions

*   Result calculations by statistical methods

To be able to create a realistic model, even when modelling the duration of this week's jobs on a certain machine resource, statistical distributions must be used.

And the results from one replication = one occurrence of the event sequence, are not enough to be able to predict whether for instance a schedule is feasible. Repeated replications with the same input, and statistical result collections, must be applied to get reliable results.

A dynamic behaviour means that a "true" simulation system does not know what the next job is going to be until the previous is done. A scheduling system "knows" the schedule for each

resource for a fixed period of time ahead (one day, one week). A simulation system does only know what is currently being done, and is prepared for any influence (delay of material, prolonged jobs, breakdown of machines, etc.).

Section 7.6 will give some ideas about how scheduling and simulation systems may be used to improve the planning function and the evaluation of plans.

7.2 Manufacturing simulation at an operational level

Traditionally, manufacturing simulation has been used at factory planning level, i.e., for design of layout and capacity analysis. For some years now people have been talking about simulation of plans and schedules on a weekly, daily or even hourly basis. Between these levels there are all sorts of combinations.

7.2.1 Differences between simulation used at operational level and strategic level

Table 7.1 shows some of the characteristics of these two levels that simulation may be used at. It must be pointed out that the table shows the values for the majority of experiments/models. There are, of course, many exceptions from these. One example is that models used at strategic level may well be small, but still most of them are large.

Characteristics	Operational level	Strategic level
Model size	small (medium)	large
Simulation period	short	long
Robustness of models	low	high
Input accuracy	high	medium (high)
Output accuracy	high	medium (high)
Detailing	high (extreme)	low
No. of scheduling rules	large	small

Table 7.1 Characteristics of simulation models and experiments

7.2.1.1 Model size

This is just to point out that models used in simulation at operational level are normally smaller than those used at strategic level. By size is meant the size of the real world the models are representing (# of products, # of resources, area, etc.).

7.2.1.2 Simulation period

The values here are obvious, but still interesting. The simulation period in operational simulation varies from a month and down to one day, or even half a day. A strategic simulation period is normally between one week and up to more than a year.

Again there are exceptions. One example is a peak-time simulation experiment in connection with an FMS installation. This is a strategic simulation experiment, but the simulation period may only be a few hours.

The normally short simulating periods in operational use increases the importance of proper use of warm up time, replications, and statistical treatment of the output. Use of these functions should therefore be automated for the user.

7.2.1.3 Robustness of models

This has certainly much to do with the size of the models and the simulation time. Large models run for long periods tend to be more robust than small models run for short periods. The stride for robust models also at operational level results in high demands on input and output accuracy, in detailing and in the number of scheduling rules needed. Robust models are essential in this type of simulation. Answers from the simulation are needed almost immediately, and mistakes should not occur. In order to avoid mistakes the manual input from the keyboard should be as small as possible, and the simulator must be totally reliable. It must also be able to spot and correct any obvious mistakes or misunderstandings.

7.2.1.4 Accuracy in input and output

"Nonsense in, nonsense out" is absolutely valid for operational simulation. But quite a lot can be done to prevent nonsense from appearing in the input.

7.2.1.5 Detailing and number of scheduling rules

Again these points are obvious. To be able to analyse a scheduling rule, this scheduling rule must be modelled in detail.

7.3 Technical features

There is a number of technical features that must be available in a simulator if it is going to be implemented as a decision support tool at operational level. These features can all be connected to the characteristics in Table 7.1. Another way of illustrating why operational simulation is different from strategic simulation, is shown below. These are the most important reasons why so many improvements are needed;

*   Increased detailing and robustness needed

*   Shorter time available for experiments

*   Higher accuracy needed

*   Non simulation experts performing the experiments

The rest of this section will try to relate these reasons to the direct effects on the technical appearance and implementation of a manufacturing simulator used at operational level.

In later parts of this section a set of algorithms will be described. These algorithms were developed to improve the speed of performing simulation experiments of a case study at Raufoss AS. This study may be categorised as tactical; deciding on rules and principles of production management and control.

7.3.1 Increased detailing

7.3.1.1 In input

The increased detailing concerns different areas of a simulation model. First there is a need for more detailed input to the system. This can be illustrated by an example. When modelling for a strategic purpose, it is possible to simplify the inter arrival rates of jobs of the same type by

using a distribution. This satisfies the required detailing, and it is possible to make decisions based on the results from this simulation.

If modelling for an operational purpose, there may be only one occurrence of each job type. This fact requires a more accurate input of the arrival time of the jobs. These arrival times may be the planned start-up times or start-up windows.

For a manufacturing simulator to be adequate for both strategic and operational simulation, it must be flexible in the input module. And this is a really big challenge, because flexible often means complex.

7.3.1.2 Model behaviour

The other main effect of the high degree of detail needed concerns the model behaviour. This means that the simulation system must be able to behave the same way the real systems do, and to follow the same planning, scheduling and controlling rules. One example is the rule telling what happens to an order if there is no room for it in the queuing place in front of a machine. Try find a place for it near by, or transport it to another buffer store? And what happens if there are no trucks available for this transport?

The main problem here is that some of these rules are not strictly algorithmic, they may vary from person to person executing them, and also vary with time. The conclusion is that it must be possible to model the use of these rules on an individual basis.

There are at least two alternatives when trying to solve this problem. One is to make a company specific implementation of the simulator. The other is to implement a large number of rules to choose from.

We have been using the last one of these solutions. Although there seems to be an enormous number of situations and rules, they can be generalised and grouped into a reasonable number. With a limited effort we have covered between 80 and 90 % of the situations. This is based on a survey made in three different company installations. But in the remaining 10-20 % there may be situations that are critical to the validity of the model [19].

In the other solution there is a danger that it is impossible to finish; there will always be another rule that is not implemented yet. And 90 % of the time will be used trying to model the remaining 10 % of the situations.

7.3.2 Integration of computer systems

Time and simulation experience are often limited when performing operational simulation experiments. Another crucial factor is the accuracy demands. No human can compete in speed with computers and wires in transferring large amount of data information from one system to another. Thus the potential of integrating the simulation system to other computer based systems is obvious. The key question is how much data is needed. This largely depends on how the different computer systems are going to operate and share data. Figures 7.1 and 7.2 focus on how the data is shared, 7.1, or not, 7.2. Between these extremes there are numbers of other solutions. A good description of an implementation can be found in [20].

In alternative 7.1 there is a common database containing the operative process plans. The planning/scheduling function receives input from Sales forecast/Long term plans/Production orders, and production feedback through the Monitor function. Together with information from the Operative process plan database, and based on a set of scheduling rules, the Short term plans (schedules) are made. The simulator receives the schedules, extracts information from the databases, Operational process plans and Historical data, and sets up a simulation model where uncertainty is introduced by using statistical distributions. The advantages of this solution are that the data is only stored in one place, and no unnecessary information is transferred. The most important disadvantage is that the transformation of the data from the Operational database must be performed every time a simulation model is made.

The main difference in alternative 7.2 is that the simulator has "copies" of the databases. These databases must be updated every time the original databases are updated. Or at least and most probably at some fixed time, for example every midnight. This way the simulation model is "always there", it is only the schedules that must be added. The problem here is the continuous updating of these simulation databases.

This slows both the monitoring and planning/scheduling functions. Based on these ideas and specifications, Borgen [12] has implemented these integration facilities with the ZETA-MPS system. The historical database does not exist in this system.
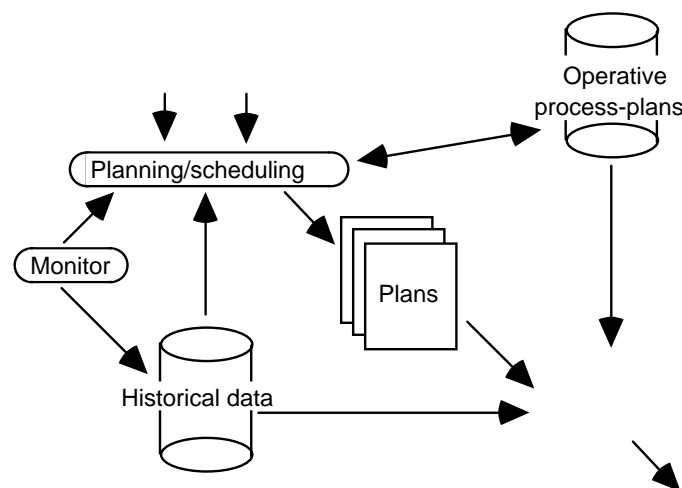

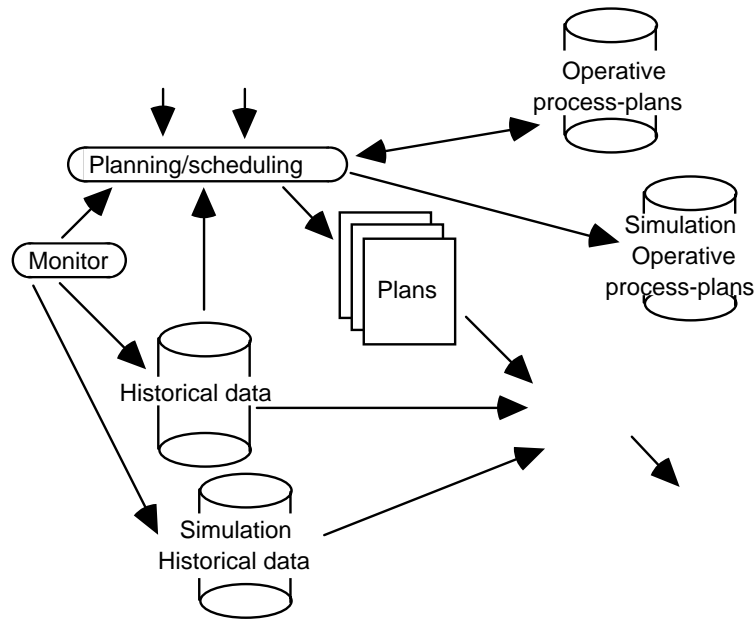*Figure 7.1 Planning and simulation with common databases*

Figure 7.2 Planning and simulation with separate databases

7.3.3 Monitor function/Production data feedback

In Figure 7.1, there is shown a function called Monitor. This is a function providing feedback of real production data. It is needed for two purposes. To be able to make feasible schedules all necessary information of the status of the manufacturing system must be available. Are the jobs on schedule, are any machines broken down, etc.? This must be a more or less on-line function where the operators immediately updates the database.

The information needed to be able to perform a simulation experiment does not require an on-line updating. But it must be updated regularly. The sensitivity of this information is high. One wrong value far away from its correct value will effect the parameters in the simulation model.

7.3.4 Simulation expertise in system

If simulation at operational level is to be successful, it must be performed by those responsible for the planning/scheduling function. And these people are most likely not simulation experts. And when they want to perform a simulation they have no time to hire one either. The conclusion here is that the knowledge and work normally performed by these not available experts, must be available in the system.

7.3.4.1 Transformation of data

We have already talked about transformation of real production data into statistical distributions. The time between and length of the breakdowns of each machine must be watched. Any changes caused by, for instance, increased maintenance, improved quality of the raw material or improved skills of the operators should be taken into consideration. In some cases it is possible to "read" such effects from the production data. In other cases such effects can only be evaluated by an operator or a foreman, and a change in the simulation basis done manually.

7.3.4.1 Verification and validation

It is important to notice that the operator will most often not be able to perform these functions. This is normally a difficult and time consuming part of a simulation experiment. The ideal situation will be to have a system that is self-validating. As we have yet a long time (if ever) to see such a system in function, we must settle for systems that do parts of the validation.

7.4 Organisational and human impacts

Using simulation at operational level in a manufacturing organisation will have impacts on the organisation itself. But this statement may well be turned around. It is a change in the organisation that results in a decision to implement a simulation system.

7.4.1 Traditional approach

The traditional approach when a company is considering a manufacturing simulation experiment, is to regard this a project. The project is limited in time, and the results from it is used only once. When deciding on who should perform the experiment, two alternatives are considered and weighed. The one that is most often used is to hire one or more simulation experts for the entire job. The other is to engage one of the companies own potential simulation experts for the job. Such experts inside the company is often hard to find, and they must be trained properly for the job. It is often programmers that are picked for the job.

It is also a question which type(s) of tool(s) that is going to be used. This may vary from general purpose programming languages to special purpose manufacturing simulators. I will here concentrate on the use of general purpose manufacturing simulators.

When hiring someone from the outside (another company or perhaps the programmer group in your own company) for a strategic simulation job, the job is probably properly done. But there is a number of disadvantages and pitfalls as well. I will here mention those that are also important when the possibility of expanding or continue the experiment into use at operational level is considered.

7.4.1.1 Expertise is bought, not accomplished

By this is meant that when the project is finished, the company does not know much more about simulation, they have just got the results.

7.4.1.2 Unwilling to co-operate

Simulation may well be regarded as a sort of test of how well the company is running. If people get the feeling that this is the case in a negative sense, they are not willing to co-operate. And if they are responsible for providing model input, this is crucial for the entire experiment.

7.4.1.3 Validation and verification are difficult

One of the toughest jobs in a simulation experiment is the validation and verification tasks. There are many pitfalls here; things that are obvious to one part (and therefore not mentioned), may be unknown to the other.

7.4.1.4 No faith in results

There is always a danger that since some "outsider" has performed the experiment, the people who are going to use them do not rely on them.

As it probably can be seen these problems and pitfalls affect three main areas; the organisation of the simulation project, the organisation of the company itself when using simulation, and the human aspects.

7.4.2 Organising a manufacturing simulation experiment and installation of a manufacturing simulator

In this section I will mention some ideas and advice to consider when organising a simulation experiment or project. These advice are valid for medium and large companies. Small companies (less than 200 employees) will probably have to approach this problem somewhat different from what we are suggesting. Often they do not have the capacity of allocating own people, and will probably not have the same benefits of doing so.

7.4.2.1 The use of external expertise

There is a number of excellent simulation consultants and experts around. And when you are conducting a "one of a kind" strategic simulation experiment, the best solution will be to hire some of these experts for the job. But if the plan is to use simulation regularly in the future, the only solution is to establish expertise within your own company. The external experts may well be hired in the start-up phase. A large part of their effort should be training of the company's personnel not only in using simulation, but also on how simulation works.

7.4.2.1 Project organisation

The project manager must, of course, be one from the company. And this must be a production manager, production planner or at least someone from this department. He or she should not be a programmer or a computer specialist. Or this should at least not be his/her major occupancy. Remember that the goal of such a project is to improve production management, and not to implement another computer system.

But someone with computer system responsibility must be a part of the project team. The users must, of course, be represented, and also someone from the shop floor, preferably from the workers' union.

The hired simulation experts' role should be more the one of a consultant, and should also be responsible for the training and education within the project.

Another thing I want to point out is how important it is to perform a feasibility study as the first major task in the project. This study will answer the question whether it is possible to implement the expected system within the time and resources available.

Before an installation is complete, a thorough training of the users must take place. This has certainly more to do with the human impacts of using simulation, and will be dealt with in a later

section. But it must be included as a part of the project tasks, and considered carefully when estimating the installation costs and benefits.

7.4.3 The manufacturing organisation

The decision of implementing a simulation system for operational use has an effect on the organisation itself. And this is true even if the decision of implementing the system is a consequence of a reorganisation.

I will not go into a detailed description of distributed production management. I will just point out some facts about this trend within production management theory. The main idea is to distribute the responsibility of production management. Groups of people, departments, production lines, etc. are given long term production tasks, and they control the department themselves. They are allowed to do this as long as they are able to fulfil the long term production tasks.

To be able to control the department they need among other things, computer tools that are reliable. They need a tool to verify that the production requirements that come from production management really are feasible. And they need a tool to verify that the detailed plans and schedules that they put up also satisfy these long term plans. Installation of a simulator as a decision support tool can be the answer to both these two needs.

7.4.4 Human impacts

The organisational impacts are significant, and so are the impacts this type of use of simulation has on the humans in the organisation.

It is already pointed out that representatives from the different groups of employees must take part in the specification and implementation project.

This goes all the way from designing the different strategies and rules that the simulation system is to be controlled by, till the everyday use of the simulation tool. To be able to design and implement the strategies and rules, the planners, schedulers, and foremen have to reveal how they really run the machines, cells and workshops. And this is often not done by using the well defined principles that the manager believes is being used.

Another sensitive area is trying to estimate the uncertainty in operation times and machine availability. When someone is asked how things are going in a cell, it is simply human to give values that at least are not worse than expected. It is only natural to forget some of the breakdowns from last year.

But the real problem is convincing the people that a computer program can predict anything better that they can. Remember that these people may have been working in the cell for years. A similar problem is the fear of comparing the real production figures with those that the computer simulation came up with. It is always difficult to put enough "noise" into a model, and this is the main reason why the simulation results are better than the real ones.

Again the question of distributed responsibility is important. If also the payment strategies are made dependent of the ability to fulfil plans in separate departments, the local manager and his crew will be more interested in using simulation. A good simulation study may be used to verify that the long term plans are simply unrealistic.

7.5 Algorithms for improving result analysis

The algorithms described are developed in a project with the purpose of improving the production management function by simulation of batch production manufacturing systems [21,22]. The purpose of this type of simulation experiments is to support decision of three basic categories; strategic, tactical or operative [23,24], referring to the time horizon the decision is valid for. The algorithms described are to improve the production management decision of these systems, and may be classified as tactical decisions. A typical decision making process being assisted from this type of simulation experiments is what batch sizes should be used for the different products.

7.5.1 Result analysis of large scale models

One of the major dilemmas of simulation is the one between the completeness and detailing of the results, and how easy and quick it is possible to find both the key results, and the key parameters to change.

On one hand it is important to calculate in detail the throughput times, the turnover, the delivery performance and the waiting times for each and every product. And also the average number of items on stock, in production, queuing, etc. This leads to an enormous amount of data from one single experiment. And when performing a series of realistic simulation experiments with a large number of products and components, the number explodes.

On the other hand it is possible to calculate averages over all the products and components. But such average calculations tend to hide a lot of information. And it is simply not good enough for this purpose.

The challenge is then to find a way to consider all the detailed results in a quick way, still being sure that every single result is considered. And still giving the user insight in what is the difference between this experiment and the previous one.

This dilemma became obvious when using SIMMEK to perform analysis of the operation of a car bumper manufacturing company, Raufoss AS. This task needed long sequences of experiments, see Section 6. The time needed to manually examine all the results from a simulation model became critical. And this problem was greatly increased by the "human error" factor; a lot of experiments was simply of little or no meaning since important results were ignored.

The approach was to replace parts of the manual search by a set of searching algorithms.

7.5.2 The algorithms

The algorithms were developed in a very much prototype way. The format of the result files of the SIMMEK tool is that of the Excel spreadsheet. So all the facilities of Excel were available. The very first "versions" were simply using the standard utilities of establishing mathematics relations between the different positions, and also the sorting facilities. In this way it was possible to "range the products" in a particular experiment according to one performance indicator like inventory turnover. This was already helpful, but gave ideas to further extensions.

The next step was then to create macros to search through the results considering more than one factor. These macros were based on and developed for this particular case.

The algorithms are a first attempt to use knowledge about the relations between parameters in a simulation model of a batch production system, and how the results are influenced and related. This could be seen as an attempt on trying to apply an expert system like approach to production management [25]. It must although be pointed out that these algorithms are not general and far from complete. Further development is needed before they can be considered a knowledge based system assistant in decision making of production management.

7.5.2.1 Assumptions and conditions

Some basic assumptions and conditions were set-up before developing the algorithms. It turned out that not all of them were necessary, but in the original points they were;

1	A basic model of today's situation was already made and was validated
2	The set-up times for all product types on all machines were considered independent of the previous product type being processed on the same machine
3	The time between the start-up of two batches of the same product type was constant during the simulation period (one year)
4	Delivery performance was calculated as the number of orders being placed that could be effectuated without delay, compared to the total number of orders being placed
5	All simulation runs would start with an initial value representing the number of finished parts of each product type at the beginning of the year (initial stock level of finished goods)
6	The calculated interest on Work In Progress and Finished Goods was set to 20 % per year, and was included in the total costs

Table 7.2 Assumptions and conditions

During the work on these experiments, SIMMEK was developed further to allow set-up times to be dependent of the previous product type being processed on the same machine. But the algorithms were still tried out using these assumptions, since this type of dependency was not very important in this case.

In condition 6, the value may be changed, and if it is set to zero, it is not included at all.

7.5.2.2 The overall approach - The outer algorithm

The overall purpose of this experiment was to perform the following steps, keeping the costs within a 1 % increase. This increase was allowed if a significant improvement in inventory turnover and throughput times were achieved. The basic assumption is that such an improvement will over time lead to reduced costs and improved delivery performance.

1	Find the batch sizes, as a percentage of today's batch sizes, giving the highest Inventory Turnover, IT, and shortest throughput Time, TPT, requiring a Delivery Performance, DP better than 97,5 %
2	If the set-up times were reduced by X %, (X=5,10,15,.....50), and 1 was performed, what improvement would this make?

Table 7.3 The outer algorithm

Step 1 was performed trying out batch sizes in percent of today's batch sizes, starting with 100 %, then 95 %, 90 %, according to the algorithm in the next section.

This outer sequence was performed manually, changing the values from the terminal.

7.5.2.3 The inner algorithm

The algorithms were applied on a set of simulation results, where the batch sizes have been reduced to Y % (by the outer algorithm), Initial Values of Finished Stock Level have been set, and the batches re-scheduled.

The legend for this algorithm is the following;

DP = Delivery Performance

IT = Inventory Turnover

IT-previous = IT from previous simulation run

"First operation machines" refer to the machine where the first operation on a product takes place. All machines with set-up times of any significance were this kind of first operation machines.

Initial values refers to assumption 5 of Table 7.2.

```
START

1: IF      DP < 97,5 %   AND   IT < IT-previous
           THEN Previous solution is best. STOP SIMULATION

2: IF      DP > 97,5 % for all products  AND IT>IT-prev
           THEN reduce lot sizes to (Y-5) %

3: IF      DP > 97,5 %  AND  IT < IT-previous
           THEN reduce Initial Stock Values for all products whose
           average stock level is greater than one week's demand

4: IF      DP < 97,5 %  AND  IT > IT-previous
           THEN
                    IF (Resource utilisation of the "First-operation-machines"
           for the products with DP < 97,5 % ) is 100 %
                    THEN increase use of over-time for these machines within
           an increase of 1 % of the Total Costs

                    ELSE  (i.e., not 100 % utilisation of these machines)
                            increase initial stock value of the up to five products
           with lowest DP (all less than 97,5 %)

RUN SIMULATION AGAIN
```

Table 7.4 The inner algorithm

7.5.3 Discussions and conclusions on the algorithms

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 are 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.

7.5.4 Possible further work

There is a lot of possibilities of improving these algorithms. This development may take numerous different directions like;

```
  *      Allow each type of component and product to be treated individually
```

*   Allow each set-up time to be treated individually
*   Allowing more combinations of "demands"
*   Manipulate with the sequencing of the batches
*   Automatic feedback of model data

Table 7.5 Further developments of algorithms

7.6 Scheduling and simulation

As mentioned in Section 7.1.2, computer aided scheduling systems are a family of systems closely related to simulation systems. In many cases these systems are implemented by use of knowledge engineering; using AI based technology, see Section 8.

More detailed and "better" planning of production is by many seen as the future of production management. The OPT philosophy is based on this; better and more accurate planning and hence control of the bottlenecks is the solution. The ST-Point planning and scheduling system is an example of this type of system.

Others claim strongly that plans have no meaning. Because of uncertainty and changes plans are obsolete before they can be executed, and have little or no use. What we need is flexible systems able to adopt to any changes occurring.

Is it possible to see future scheduling and simulation systems working together, or even the two functions implemented in one system ? In theory it is of course possible, but will such a system be reliable, robust and fast enough ? And what are the requirements for such a system to be operative ? Section 7.3 gave some ideas of integration with computer systems, specially MRPII systems. I will give some more comments on this topic.

Figure 7.3 is a blow up of parts of Figures 7.1, and 7.2, of a scheduling system and a simulation system working together. The scheduling system produces, by alternative algorithms, a set of plans. These are simulated by a simulation system. To be able to simulate historical data is needed, as well as estimates of uncertainty and not scheduled events like machine breakdown. A data collection system, added to the reporting functions of an MRP II system is certainly needed for rapid update of status. Another crucial question is the update of orders, change orders, product specification changes, etc. In one of a kind production (engineer to order), next week's products may not be designed yet.

What will then be the planning time horizon of such a combination of systems working together ? It can be in principle two approaches. It may be used every time there is a "need" for a new schedule. This would mean every time something is executed that differs from the plan. In real life this would mean several times a day, maybe several times an hour. We are in fact talking about a semi-continuous planning and execution, close to what we find, for instance, in process industry.
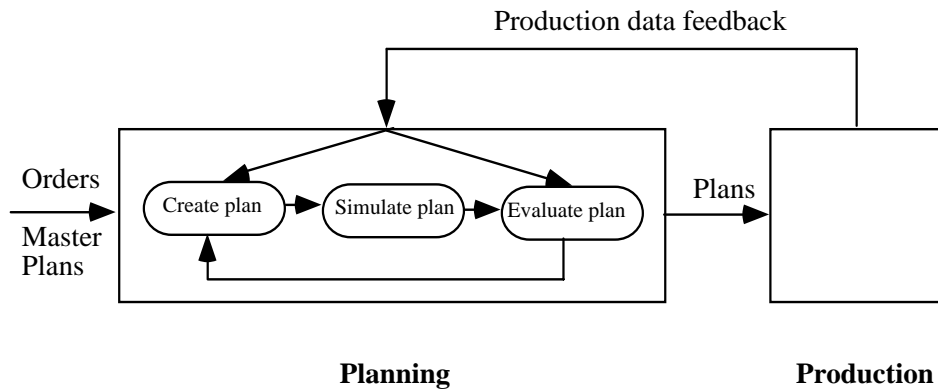
Figure 7.3 Scheduling and simulation

The other approach would be to make schedules and simulate them at fixed hours; once a day, once a week, etc. The crucial question would then be; will a simulated and evaluated plan have a longer life than any other plan? Probably not. Remember that a simulated plan gives one, or at least a very limited number of possible realisations. There is no guarantee what so ever that the simulated plan will come true. In fact the statistics say that this probability is limiting zero as time goes !

Maybe the conclusion to this is that such integrated use of scheduling and simulation will lead to shorter planning horizons, because simulation will show that the plans should not live for long. Or even that plans should be rougher and not so detailed, because the details are changed before they are executed. Only future research and implementation will give more answers and new questions in this area.

7.7 Summary remarks on operational use of manufacturing simulation

It is a common opinion within the manufacturing simulation world that simulation will in the future be used also at operational level. The technical challenges to overcome in order to succeed in this area are not to be underestimated. But the rapid development in computer hardware, user interfaces like windowing and graphics, knowledge based programming techniques, and hardware and software integration are making the way in this area.

The biggest challenge is in convincing management that using simulation in this way, together with other improvements in computerised tools for production management, has large impacts on the organisation itself.

The people in these organisations must be encouraged to take an active part in the development of such tools. They must be given training in using them. And they must be presented with tools they can identify with and approve.

A simulation tool will never be effective if the organisation is not ready for it, and if the people supposed to use it, don't believe in it.

In the future we will see computer tools which are a combination of today's scheduling and simulation tools.