# Simulation of subassembly production at shipyards

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## Abstract

To survive in the current shipbuilding industry it is of vital importance for shipyards to achieve an optimal utilization of resources, make an achievable planning and ensure that this planning is kept. Possible problems should be eliminated before production starts and if unexpected disturbances occur in the actual production the right measures should be taken. Due to the dynamic nature of the production process, the continuous variation in products and the complexity of both, all this can hardly be achieved with conventional static planning and analysis systems. Simulation provides a solution here, since this enables the modelling and evaluation of the dynamic relations between product and production process. After a global introduction to production simulation in general and the application of simulation at the Flensburger shipyard, this paper presents a tool that has been developed to simulate the various complex assembly processes taking place at shipyards. Subsequently the simulation model for the subassembly production at Flensburger, in which this tool is applied, will be discussed.

**Key Words:** computer simulation, shipbuilding, assembly processes, shipyard processes

## 1. Introduction

Whereas simulation is used for many years already as a tool for planning and control of production in series production, like the automotive industry, it has only recently become of interest to the ship production industry. The apparent slow introduction of simulation within the shipbuilding industry is amongst others due to the complex and changing character of both the product and the production process. But nowadays, shipyards get more and more interested in simulation as a tool for planning, controlling and thus optimizing their production processes.

The Flensburger Shipyard (FSG) is one of the leading European shipyards with respect to the development and application of production simulation. The ultimate goal of the yard is to develop a virtual shipyard in which all the dynamic production processes at the yard can be modelled and evaluated (Steinhauer [1]).

Research and development in the field of production simulation are one of the main research areas at the department of Ship Production at Delft University of Technology: development of Virtual Manufacturing and Virtual Prototyping in the shipbuilding industry, which is seen as an opportunity for

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the Dutch shipyards to maintain or improve their competitiveness (Van Alphen [2]).

Both FSG and DUT are partners within SimCoMar (Simulation Cooperation in the Maritime Industry). This cooperation, currently containing five partners (shipyards, universities and research centres), has the goal to stimulate research and development in the field of production simulation in the shipbuilding industry, see figure 1. SimCoMar is open for new partners that are interested in either development or application of simulation in shipbuilding.

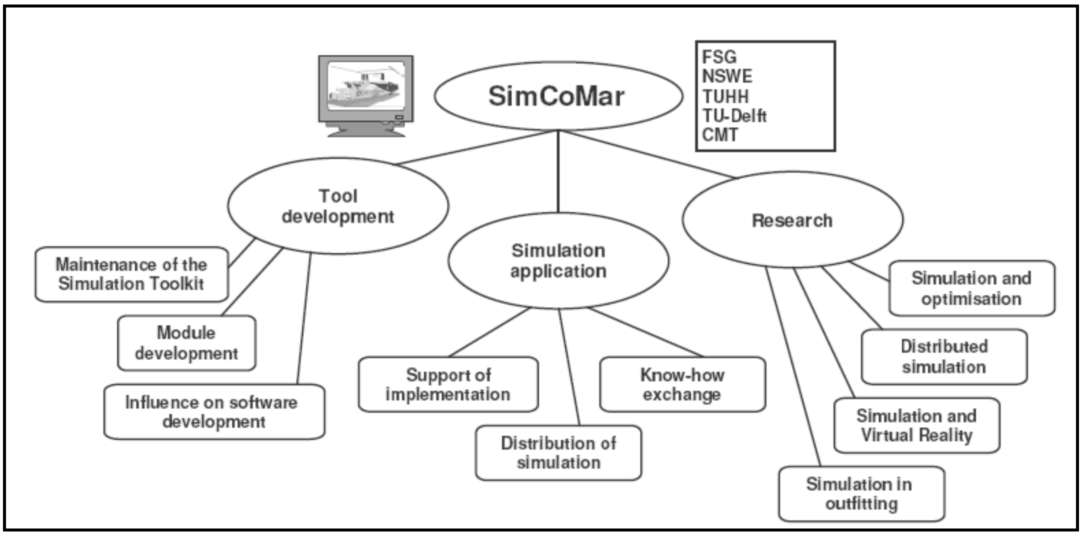

**Fig. 1.** SimCoMar organization and tasks (Steinhauer [3])

## 2. Application fields of simulation at Flensburger

After successful implementation of the simulation in the layout and material flow planning the field of application was extended to production planning.

The layout planning at Flensburger is pushed by a production development project. The concept for the future shipyard is being developed which is to be realised by several investment projects. These investment projects are supported by simulations, i.e. before the decision for the investment is made all functionalities and influences on the rest of the production have been verified.

Simulation supports the production planning in three phases: strategic planning, tactical planning and operational control, see figure 2. In strategic planning a new order is planned in the early design phase, even prior to securing that order. Building methods and sequences have to be optimised, and make-or-buy decisions prepared. The tactical planning aims at the optimisation of the plan for the next weeks in certain production stations, considering the actual production status. In this phase the changeable parameters are the production planning and personnel allocation. In operational planning foremen on the shop floor react on actual changes (e.g. machine breakdowns).

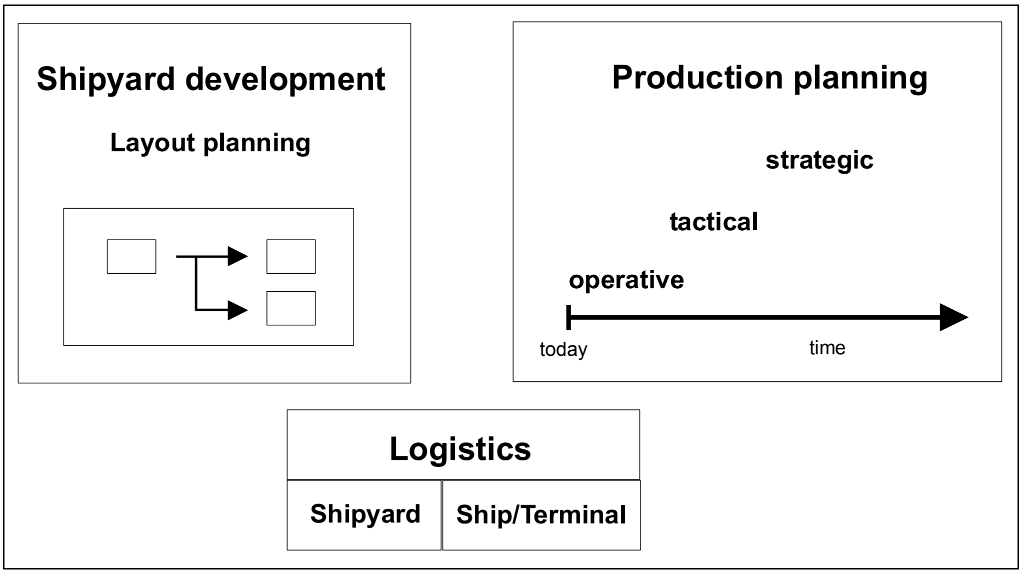

**Fig. 2.** Application fields of simulation at FSG (Steinhauer, [3])

## 3. The Simulation Toolkit for Shipbuilding (STS)

At FSG, simulation models are built following the simulation toolkit concept. In this concept the various functionalities that are available in a (production) system are subdivided in three groups (Kosturiak [4]):

1. Moving units (MUs) are the parts that flow through the simulation model. They represent partly or entirely finished products (structural parts, engine parts, pipes, etc), material, and so on;
2. Stationary elements represent working stations, transporting facilities, transporting aids, buffers, stores, machines, robots, and so on;
3. Organizational elements are used to simulate non-physical aspects like shift calendars, personnel allocation and working strategies.

The organizational and stationary elements are so-called simulation tools. These simulation tools can easily be integrated in a simulation model. A simulation tool can be adjusted to the specific needs of a simulation model by adjustment of the tools parameters. Besides, tools can communicate with each other with the help of small amounts of programming code, thus managing the material flow and processes taking place in the simulation model.

The technology for simulation of production and logistics has been developed according to the requirements of the automotive industry. For this industry several class libraries with ready to use simulation tools, so-called simulation toolkits, are available. An automotive production can easily be modelled by a combination of predefined simulation tools. However, since the available simulation toolkits do not meet the requirements of the shipbuilding industry a specific Simulation Toolkit for Shipbuilding (STS) has been developed at FSG, using the software package eM-Plant by Tecnomatix.

eM-Plant has a class library with basic simulation tools and, more importantly, allows an almost unlimited further development of simulation tools by users. The STS contains the various physical and organizational functionalities that are present at shipyards.

One of the main advantages of the STS is its universal applicability, which is underlined by the fact that it is used by all the members within SimCoMar. Another strength of the STS is the reusability of simulation tools, which is illuminated in figure 3. Single simulation tools can be used in several simulation models, enabling building different simulation models from the same set of tools. Maintaining and changing simulation models is facilitated due to the fact that individual simulation tools can be edited and afterwards reintegrated in the toolkit, updating all the simulation models that are created using the STS.

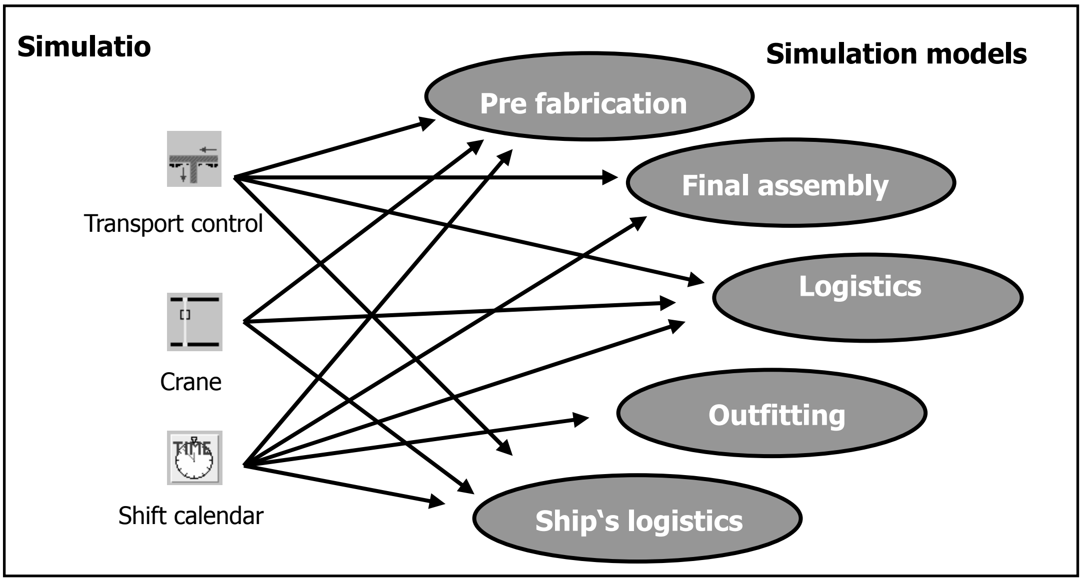

**Fig. 3.** Synergy effects through utilization of simulation tools (Steinhauer [5]).

# 4. Simulation tool assembly control

## Concept of the simulation tool

To enable the simulation of multiple complex assembly processes that take place at shipyards, the simulation tool 'Assembly Control' has been developed (Hertel [7]). As has been explained before, a distinction can be made between so-called organizational and stationary simulation tools. 'Assembly Control' has been developed as an organizational tool, since it does not represent a physical production facility, but can be used to simulate the assembly processes taking place in a specific production facility that is represented by a stationary tool. Therefore 'Assembly Control' can be used in combination with almost every stationary simulation tool representing the specific production facility. The exceptions to this rule are the transporting facilities to which 'Assembly Control' is not applicable.

Assembly processes are simulated on construction level. This means that the assembly of each construction is simulated independently. Thus, several assembly processes can be simulated at the same moment. Just as in reality, the amount of constructions that can be assembled simultaneously in the simulation environment depends on two main aspects: the space that is available in a production station and the available resources. Constructions that are assembled simultaneously in the simulation environment do influence each others assembly process due to the fact that the (limited) available resources have to be shared.

If constructions are considered to consist of a variable but discrete and limited number of parts, the assembly of a construction using ‘Assembly Control’ can be split up in four main steps:

1. selecting the parts that must be assembled in a construction;
2. classification of parts in part classes, which are used to determine the assembly sequence;
3. transporting the parts to the production station where the construction is being assembled;
4. assembling the parts into the construction.

The last step, the physical assembly of parts in a construction is simulated using a so-called assembly strategy. Since the assembly strategy concept is the backbone of ‘Assembly Control’ it is explained in more detail now.

## Assembly strategies

### Process steps

One of the main ideas of the assembly strategy concept is that the complete assembly process of a construction can be subdivided in a discrete number of process steps. The division in process steps is made according to the following rules:

1. the parts that must be assembled in a construction can be categorized in so-called part classes of similar parts;
2. the assembly process of each of the distinguished part classes is subdivided in a discrete number of process steps.

Thus, the complete assembly process of a construction equals the sum product of the distinguished part classes and the process steps for each part class. All the single parts (instances of part classes) that must be assembled in a construction advance through the sequence of process steps. However, only those process steps whose part class corresponds with the part class of the single part are executed.

### Process information

For each of the distinguished process steps the following three process parameters can be adjusted, thus linking product and process information:

- personnel qualification;
- personnel quantity;
- process time.

Both the qualification and the amount of personnel that is required to execute a specific process step can be adjusted for each separate process step within an assembly strategy. The process times reflect both the product and production process. Thus, making more personnel available in the model will not decrease to process time of one single process step. However, when more personnel is available more process steps can be executed parallel up. An upper limit can be set to the maximum amount of parallel processes, reflecting logical and physical constraints of constructions and production facilities. The execution of parallel process steps and the determination of process times will be discussed in more detail below.

## Clustering of process steps in stages

The sequence in which a construction is assembled (i.e. its process steps are carried out) can be arranged by putting the distinguished process steps in a specific order. Moreover, the assembly sequence is determined by the clustering of process steps into so-called ‘stages’. Each stage contains one or more process steps. The stages within an assembly strategy are carried out sequentially. The next stage is only started when the current stage is completely finished. The sequence of process steps within a stage is executed consecutively for each single part (an instance of a part class). After a single part has advanced through all process steps within a stage (skipping those process steps that do not have a part class that corresponds with the part class of the single part), the next single part starts moving through the process steps in the stage.

This process is repeated until all the single parts (of part classes that are represented in the construction) have advanced through the current stage. Then the current stage is finished and the succeeding stage is started.

## Parallel assembly processes

Until now we have described a completely sequential process. This does not reflect the shipbuilding practice. To enable the simulation of parallel assembly processes, the maximum number of processes can be set for each stage. This limits the number of instances (of part classes) that advances through the process steps within a stage simultaneously.

It must be pointed out that the availability of personnel should not influence the amount of maximum parallel processes that is set in an assembly strategy. The value should be based on the physical and logical constraints. These constraints reflect the assembled construction (type). The value that has been set for the maximum parallel processes is an upper limit that often is not reached in a simulation run due to shortage of personnel or production facilities (like cranes), which then is the actual bottleneck in the assembly process.

## Determination of process times

The main concept of process time determination is that a number of different algorithms have been integrated in 'Assembly Control'. For each process step within an assembly strategy, one of these algorithms can be selected to calculate the process time. This algorithm can be tailored for an individual process step through adjustment of the algorithm coefficients, which reflect the situation in a specific production station and the attributes of the used resources.

However, the algorithm coefficients can depend on product parameters. Therefore it should be possible to differentiate these coefficients for one process step, with respect to the dimensions of the parts that are to be assembled.

Since the algorithm coefficients represent the situation in a specific production station and its resources, it should be possible to adjust the coefficients for a specific simulation model. The model specific algorithm coefficients can be stored in a so-called process time table. One process time table can be made for one production station. This single process time table is used by all the assembly strategies for this production station.

## Flexibility of assembly strategies

One of the strengths of the assembly strategy concept is its flexibility with respect to both the number of strategies as well as the complexity of an individual strategy. Considering the number of strategies that must be developed, there is the flexibility to either use one assembly strategy for a group of constructions or to develop specific assembly strategies for special constructions that contain unusual parts or have an unusual assembly process. In this way generic assembly strategies can be developed for construction classes and, if necessary, individual assembly strategies can be developed for special constructions. For example, in the simulation model that is described later in this paper, one main assembly strategy was developed from which eight assembly strategies could be deduced with only a few changes. Only these eight assembly strategies were needed to simulate the assembly of over 2000 small sections (belonging to one ship). This means that in fact, the difficult task of setting up an assembly strategy has only been executed once, for the development of the one main strategy. As long as the production process and the product structure do not change, these eight assembly strategies can be used over and over again for successive ships.

The flexibility of the assembly strategy concept also leads to the possibility to expand an assembly strategy throughout the model development process. The size of an assembly strategy depends on the number of part classes that has been defined, and the number of process steps that has been distinguished for the various part classes. On the one hand, the simplest assembly strategy would consist of one part class, whose assembly process consists of one process step. On the other hand, the number of part classes and process steps per part class is unlimited, allowing an extremely detailed assembly process simulation.

The flexibility of the assembly strategy concept mentioned above makes 'Assembly Control' extremely suitable for a top-down approach of simulation model development. Initially, a rough model is created, which is expanded and specified in a number of model development loops, until the model fits its requirements.

### Applications of assembly control

The universal applicability and flexibility of 'Assembly Control' are demonstrated by the fact that it has been successfully applied until now in five FSG simulation models, covering the various assembling stations, amongst others the assembly of closed sections, blocks and the hull erection on the slipway.

Other possible applications of 'Assembly Control' that are being investigated are the simulation of the outfitting of ships and 'Engineering for production'. Simulation of outfitting of ships is one of the main challenges for the SimCoMar simulation team. Tests indicate that the subdivision of an assembly process in steps and stages could be suitable for the representation of outfitting processes, which are executed on two levels as well: zone and system oriented outfitting. As such it could in principle also be used for assembly of totally different objects, e.g. components of mechanical systems, such as engines and pumps. This could then be used in conjunction with machining shop simulation, see e.g. Bernaert [8].

Engineering for production focuses on the effects of different design and engineering alternatives on the production process. 'Assembly Control' could be used to optimize a construction from a production point of view, through simulation of the assembly of various alternative designs.

## 5. Simulation model of subassembly production at FSG

One of the simulation models in which 'Assembly Control' has been integrated is the simulation model for the subassembly production at FSG. The main production facility is the construction site. Here steel-parts and pre-outfitting parts are supplied, which are used for the assembly of small panels and sections. The assembled constructions are delivered to the main section assembly line afterwards. Figure 4 gives an impression of the subassembly production.

**Fig. 4.** Subassembly production at FSG

As a starting point for the development of the simulation model a thorough system analysis has been carried out, dealing with the following aspects:

- organization of the subassembly production department;
- classification of the constructions that are assembled and the parts that are supplied;
- available resources: cranes, welding machines, buffers, etc;
- the material flow through the production station and the requirements for the execution of the separate process steps;
- planning of work and the scheduling of personnel.

The next step was to translate the results of the system analysis into a dynamic simulation model using the already available simulation tools in the STS, the standard eM-Plant class library and the newly developed simulation tool 'Assembly Control'. The fact that almost all the required tools were already available in the STS enormously decreased the modelling effort. This model was set-up as a sub model of the complete representation of the entire production department at FSG.

Figure 5 gives an impression of the simulation model that has been created. The dark grey area represents the actual production facilities, containing various stationary simulation tools. The hatched light grey area in the lower right-hand corner contains the organizational simulation tools and control methods that arrange the material flow through the model and control the production processes.

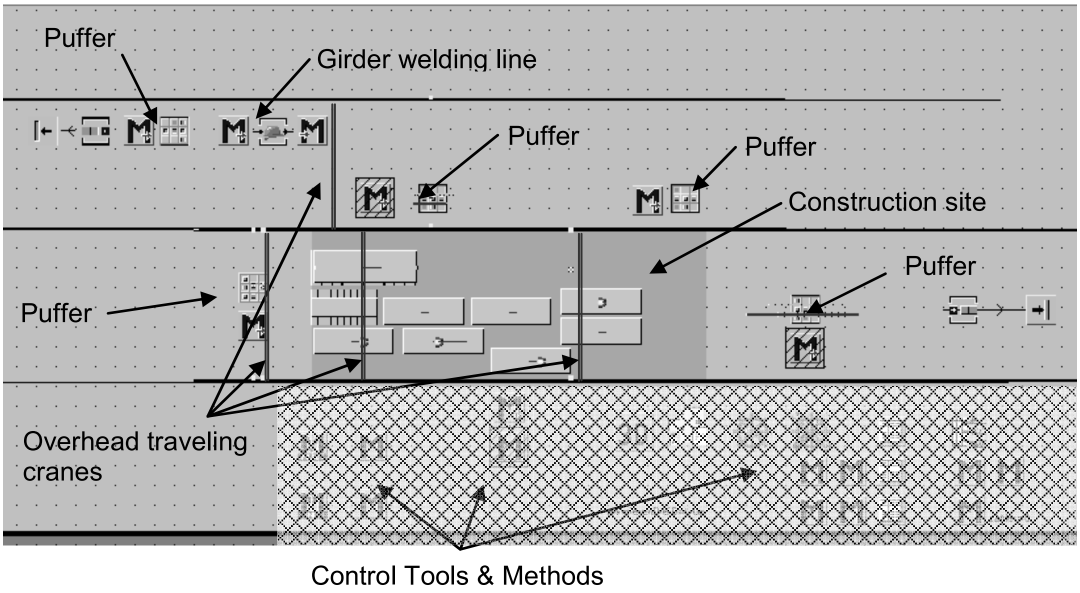

**Fig. 5.** Simulation model of subassembly production at FSG (Puffer = Buffer)

## Input data

The data that are needed by the simulation model are imported in the model from the central simulation database at FSG that stores the required data from the various data sources, see figure 6. Three main data categories can be distinguished: product data, process data and planning data.

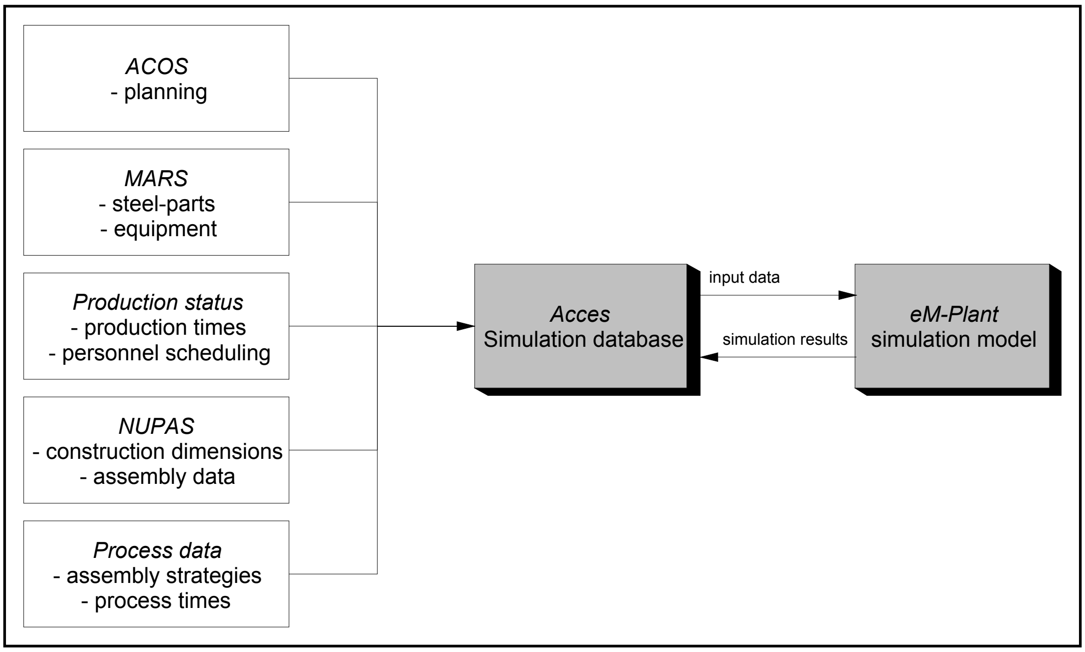

**Fig. 6.** Data supply to the simulation model

### Product data

For both the constructions that are assembled as well as the supplied material the following information is needed: identification nr, main dimensions, weight, successor (i.e. a succeeding job in which the construction or part is used as input to assemble a bigger section, module or block), etc. Furthermore assembly data are needed, which provide the possibility to assign single parts to the construction in which they must be assembled.

### Process data

Two different types of process data are distinguished: assembly strategies and process times. The assembly strategies are used to determine the sequence in which constructions are being assembled in the working station, the process times are needed to calculate the duration of each single process step in the assembly strategies. The assembly strategies and the process times are used as input for the simulation tool 'Assembly Control'.

### Planning data

Two different types of planning data are used in the subassembly production simulation model: job start dates and personnel scheduling.

The planning of the subassembly production is made on job level. All the constructions that need to be assembled in one specific section of the ship to be built are allocated to one job. Job start dates are used to control the inflow of constructions that must be assembled and the supply of material into the simulation model. For various reasons the actual production will not completely follow the provided production planning. Therefore the actual job start dates are administrated to get a correct production status.

The planned job start dates and the actual job start dates are used simultaneously in the simulation model. To synchronize the simulation model with the current production status, the actual job start dates are used to simulate the past. When a simulation run has arrived at the present, actual job start dates are no longer available. From this point in time, the planned job start dates are used as earliest starting times to simulate into the future. Note that planned job start dates are necessitated by the fact that the model of this working station is isolated from the overall process. As soon as a total simulation model for the entire shipbuilding process (including engineering etc) would be available, job start dates could be eliminated and only dates relative to the supply of goods and services by third parties (e.g. suppliers) would be used as input.

The weekly personnel schedule is used to input available personnel into the simulation model with the personnel that is available in reality.

## Output data

The results of a simulation run can either be analyzed directly in eM-Plant or they can be exported to the central simulation database, where further analysis is possible. Three main output categories are distinguished: animation, utilization ratio's and production times.

### Animation

One of the advantages of simulation is the possibility to realistically visualize the material flow and production processes taking place in a simulation model. This is an important feature to support communication between the people involved in the work. In a strict sense, this so-called animation is no model output: it does not provide a quantitative output of the model parameters. However, it gives a good impression of the actions taking place during a simulation run, see Figure 7, where a production situation is shown at a particular moment in time, identifying e.g. the location of objects, the room left for other constructions, the employment of cranes and personnel, etc.

**Fig. 7.** Animation of a simulation run

It is also possible to animate the assembly processes in 3D, which helps non simulation experts comprehend the processes that take place, see Figure 8.

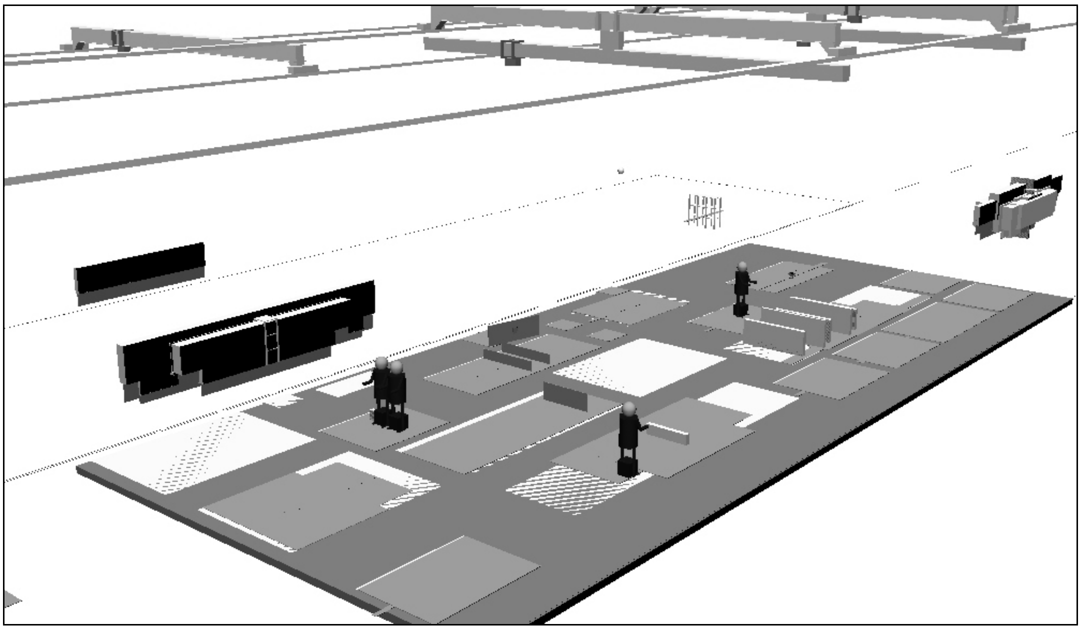

**Fig. 8.** 3D Animation of assembly production

**Resource utilization ratios**

Utilization ratios are particularly useful for bottleneck analysis, i.e. the determination of the resource that is limiting the production capacity at a particular moment in time. The utilization ratios of the personnel, construction site and overhead travelling cranes can be analysed in the subassembly production model, see figure 9 for an example. In this figure the amount of time a worker is actually performing (upper part of bar) and the amount of time a worker is waiting (lower part of the bar) is displayed for each single worker in the concerning simulation run. Each bar represents a single worker here.

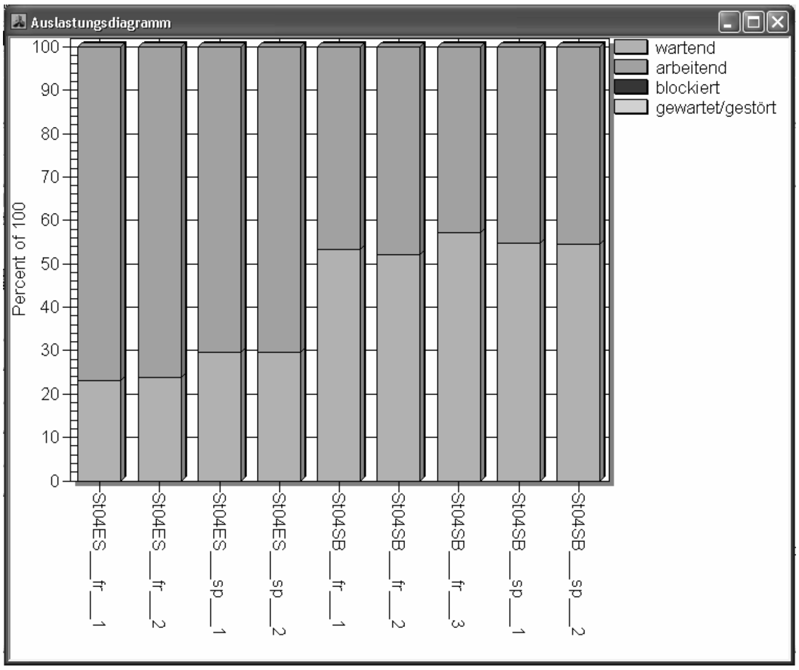

**Fig. 9.** Personnel utilization ratios

**Simulated production times**

To be able to analyze a simulation run in more detail, the simulated production times are exported to the central simulation database of FSG. This database also contains the planned and actual production times and provides the possibility to compare the simulated production times with these planned and actual production times, see figure 10 for an example. In figure 10 the dashed-dot line shows the deviation between actual production start and planned start, the continuous line shows the deviation between simulated production start and actual production start. The dashed line shows the deviation between simulated production end and planned production end.

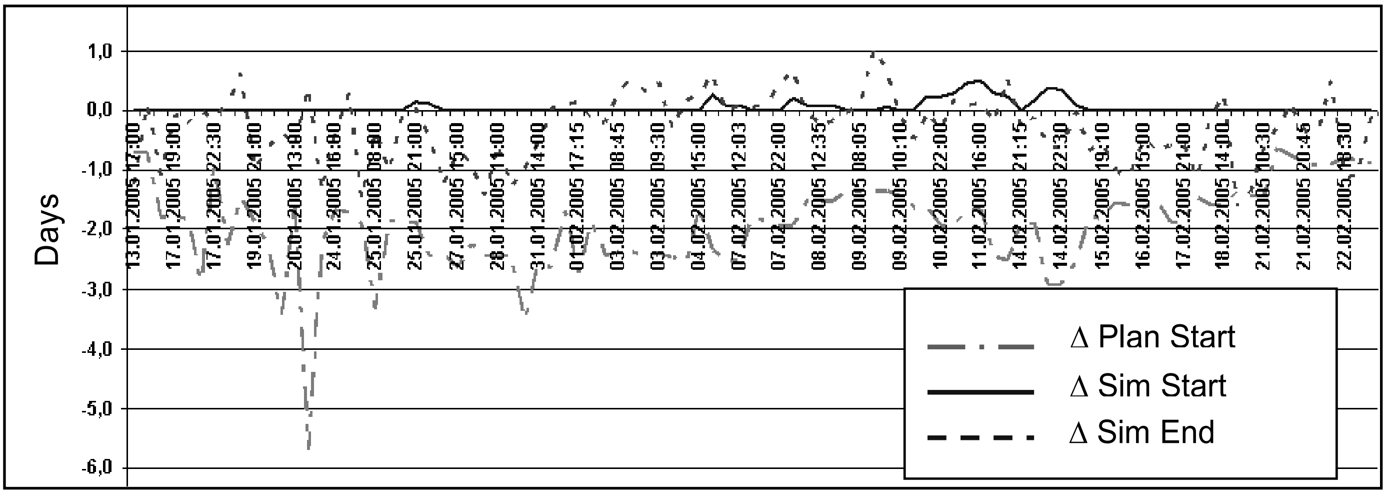

**Fig. 10.** Deviations between planned, simulated and actual production times

## 6. Model applications

As has been mentioned in this paper before, two major applications of production simulation models are support of production planning and production layout development. The developed model of the subassembly production at FSG can be used for both purposes, in this section an example of one of these application will be given showing how the model can be used for short term production control.

### Short term production control

The first application of the simulation model concerns the short term production control. In reality, the foremen leading the subassembly production can control the production in two ways: through the amount of scheduled personnel and through the sequence in which scheduled jobs are executed. The simulation model is used to determine the minimum required amount of personnel that is needed to keep the subassembly production running on schedule, i.e. to supply succeeding production stations in time with fabricated subassemblies.

As an example, three simulation runs have been executed with various amounts of scheduled personnel, two with a standard worker pool (working with and without overtime) and one with a reduced worker pool. After a one month warm up period, during which the simulation model is synchronized with the actual production status using gathered production data, the model runs over a 3 week period in the future.

Two criteria are used to compare the results of the simulation run: the personnel utilization ratios and the time buffer to the succeeding production station. The personnel utilization rate is preferably as high as possible, whereas the buffer to the succeeding production station should be kept low to avoid logistic problems due to the necessity to store finished subassemblies. The buffer should however never become negative, since the succeeding production station would then be held up by the subassembly production.

Figures 11 and 12 show the result of the second simulation run in which the standard worker pool is scheduled without working in overtime. In Figure 11 each dot represents the time buffer between a subassembly production job and its succeeding job; in Figure 12 each bar represents one specific worker.

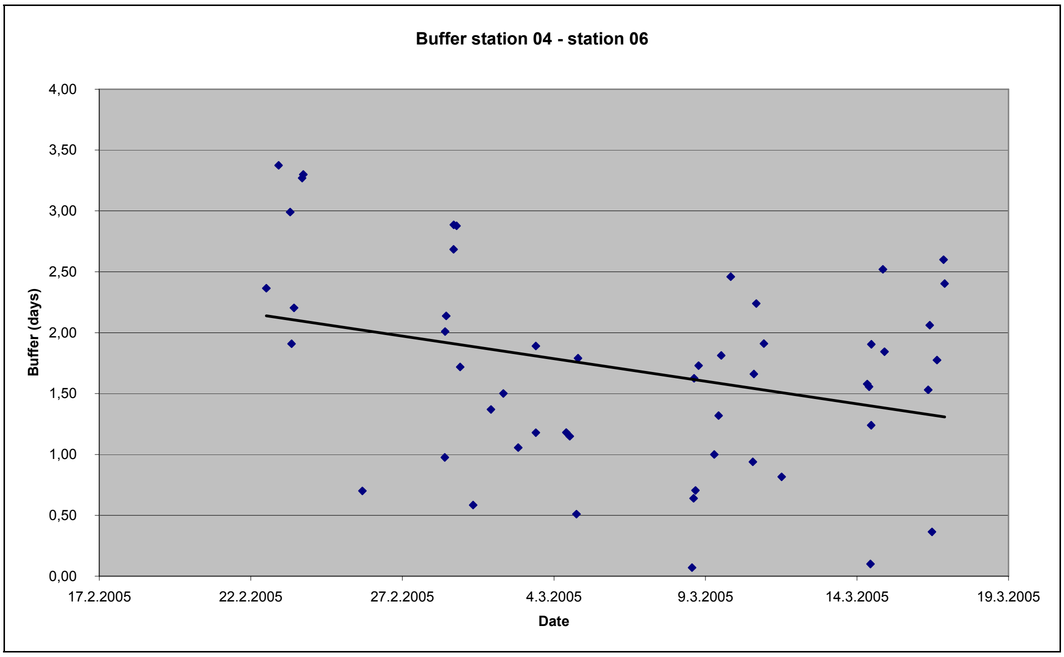

**Fig. 11.** Time buffer between two succeeding production stations

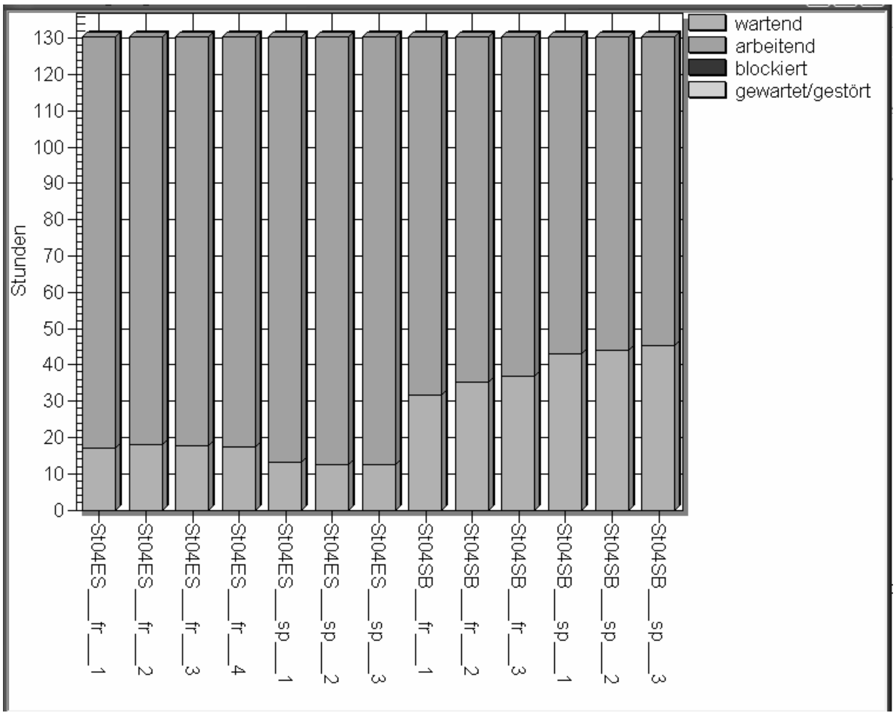

**Fig. 12.** Personnel utilization ratios

In this way, the simulation model can be used to determine the minimal amount of personnel that is required without causing a delay in the production. Tests with the model indicated that considerable savings per week could be achieved for a small production station (with a worker pool of only 10 to 15 people) compared to the average allocation by skilled foremen. By introducing a penalty on late deliveries, one could go one step further and determine the optimal amount of personnel if slight delays would be acceptable (but penalized).

Another aspect that can be investigated with the presented tools, is the possibility to reschedule jobs with a small buffer in favour of jobs with a large buffer, thus reducing the spread in buffer and thereby reducing the required production capacity. Here the utilization of optimization tools could be useful.

# 7. Conclusions

The STS and the standard eM-Plant class library allow a very efficient simulation model development, geared to the typical shipbuilding situation. A model developer can focus on functional and modelling issues, instead of being occupied with programming. The re-use of already available simulation tools decreases the model development time enormously and it increases the reliability of the resultant models

The newly developed simulation tool 'Assembly Control' is a powerful medium for the simulation of the assembly processes taking place at shipyards. The main strength of the tool is its flexibility, with respect to both the number of applied assembly strategies as well as the complexity of the individual assembly strategies. This makes the tool very suitable for a top-down development of simulation models. Another powerful feature of the tool is its universal applicability. Since the tool was developed following the simulation toolkit philosophy it is to a large extent independent of production area and shipyard. This is underlined by the successfully application of the tool in several FSG simulation models. Further application of 'Assembly Control' could focus on simulation of outfitting process and design for production, evaluating the effects of design and engineering on production.

The simulation model of the subassembly production at FSG can be used for two purposes: short term production control by the foremen and planners and the investigation and improvement of the production lay-out by simulation experts. Further development of the model will focus on the integration of optimization tools into the model and on developing strategies for other production situations and applications.

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