SIM-SERV CASE STUDY: SIMULATION-BASED PRODUCTION SCHEDULING AND CAPACITY OPTIMISATION

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ABSTRACT

The simulation tools developed to support customised solving of a production scheduling and capacity optimisation problem for medium-sized UK based company are presented. The improvements of the simulation-based scheduling approach and its benefits in practice are given. Decorpart case study presented in the paper was developed within Sim-Serv Thematic Network project 'Virtual Institute on Production-Oriented Simulation' under the EU-funded GROWTH research programme.

INTRODUCTION

Modern production scheduling tools are very powerful and offer a vast range of options and parameters for adapting the tool's behaviour to the requirements of the real process. However, the more options exist, the more difficult it becomes in practice to find the best configuration of the tool. Even experts often cannot predict the effects of many possibilities. Testing out even a small number of possible configurations in reality, and studying their effects on the real production process might take months and might severely reduce the overall performance. Hence such tests are not feasible in practice. It is much faster, easier, safer and cheaper to test and optimise a production scheduler using a simulation model than using the real process.

In order to make the best use of an advanced and sophisticated scheduling tool in the piece-part SME manufacturing and to find an optimal configuration of its rules and parameters, modular simulation models of the entire business/production process and production anodising stage were built to test out the effects of various scheduler configurations. Testing and optimisation of the scheduling tool configuration was carried out off-line using the models. The real production process was not disturbed, and the optimal configuration was found very quickly at low cost.

Simulation-based production scheduling and capacity optimisation case study presented in the paper was developed within Sim-Serv Thematic Network project 'Virtual Institute on Production-Oriented Simulation' (www.sim-serv.com).

SIM-SERV: VIRTUAL CENTRE OF SIMULATION SERVICES

Simulation technology may be applied over a vast range of industrial, commercial, infra-structural and general service areas. The above-mentioned Thematic Network project 'Virtual Institute on Production-Oriented Simulation' itself focuses (Krauth 2002) on product- and product-oriented simulation. Among the significant areas of manufacturing the project sector range includes the following areas: Machine Tools, Transports, Power Plants and Mechanical Engineering. The main applications are related to Advanced Control of Manufacturing, Product Simulation, Waste Minimisation, Business Process Models, Environmental Protection, Accident Analysis, Process Redesign and Engineering and Logistics.

It is widely accepted that simulation in spite of obvious power and benefits is not widely used in industry as it could be. The estimated potential for saving and improvement in European Industry, which could be achieved by proper use of simulation, is enormous. The main objective of Sim-Serv is to turn potential into real benefits. The central service of Sim-Serv on its web site presents a database of technical and scientific information about simulation, relevant case studies and success stories, a list of supplies and links to them, different services to support both potential users and suppliers as customised solution and technology providers. Industrial users could also find independent consultation and advice about possibilities of applying simulation technology to their business, the expected costs and benefits. An in-depth analysis of the problem leads to a recommendations of suitable solutions and suppliers who are able to deliver them.

Moreover, the supply side consists of numerous small companies that offer in many cases highly specialised tools and solutions. They tend to have problems getting Europe-wide visibility and finding customers from a broad range of industry sections. Through dissemination and marketing activities, Sim-Serv facilitates access to European market even for small and medium-sized providers. As successful could be mentioned cooperation of two technology suppliers - Department

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of Modelling and Simulation of the Riga Technical University from Latvia and Preactor International from UK, that in a very short period of less than three months provided customised problem solutions to UK-based Decorpart company that are presented in the paper.

DECORPART CASE STUDY

Decorpart that is a medium-sized company produces a wide range of different small, pressed aluminium parts in large quantities to a range of other consumer-focused businesses. Typical applications include spray assemblies for perfumes and dispenser units for asthma sufferers. The business lies in a highly competitive sector and its success depends on achieving high efficiency and low cost of manufacturing in all production steps. Production scheduling becomes therefore very critical. In the past, this company had already installed software tools supporting the scheduling of individual areas of the production process.

To improve the overall company performance, increase its output and reduce the product lead-time, an automatic supply chain server, - an overall scheduling system coordinating all local systems, was planned to be introduced. In order to deliver the best possible solution to the customer, the supplier of the scheduling tool, Preactor International decided to use simulation for finding the optimal configuration of the scheduling tool.

The problem is to build simulation tools, which will embrace the arrival of orders and sequencing of production to meet these demands. An important aspect is to model the production process itself in order to ensure that its main stages are optimally loaded at all times. The important anodising stage has to be modelled in most detail. The overall impact of simulation is expected to be higher plant throughput with lower unit costs.

The following key objectives are stated in the problem: to model interrelated business and production processes at the company, to determine the overall lead time of orders, to test the sensitivity of the overall lead time of the production process to optimisation, particularly at the anodising production stage.

This simulation tool to be introduced is aimed to use for testing configuration of the finite-capacity scheduling and advanced planning Preactor software tool and for iterative optimising its performance off-line prior to its implementation and integration at the customer's site. The envisaged scheme is aimed to complement and link together, localised advisory systems previously installed on individual areas of the production process.

IMPROVEMENT APPROACH

A custom-built business/manufacturing model was built that simulates the arrival of orders; it shows the queuing of the orders for processing. The individual machines in each process stage were modelled as a group of machines with an overall capacity per day or per week. The model was built in a modular style so that each production stage could be further modelled to a greater level of detail. The anodising stage of the production process was modelled in a greater level of detail following successful validation of the initial model.

The batch anodising process stage sub-model was refined to model the individual anodising tanks, so that colour changeover and set-up times have been be modelled. Queue ranking rules were developed to minimise the colour changes to test whether the overall lead- time of orders is sensitive to optimisation of the anodising process stage. The Production Simulation System Promodel that allows easily to built-in Excel files was used as a basic tool for simulation software development.

The simulation scope then required an amalgamation of the Preactor scheduling tool with: (1) a high-level business/ manufacturing system model, and (2) production process anodising stage sub-model detailed representation.

These two models that developed by the simulation supplier, i.e. Riga Technical University, were used for testing an initial configuration of the Preactor scheduler and iterative optimisation of its parameters and rules off-line prior to its implementation at the customer's site.

BUSINESS/MANUFACTURING SIMULATION MODEL

The high-level business/manufacturing model is aimed to model interrelated business and production processes at the company, to analyse and optimise business processes at the planning department dealing with processing of incoming enquiries and planning production orders already confirmed by customers. Comparison of two alternatives planning scenarios using the simulation model was done to check the benefits of introducing at the company an automatic advanced production planning and capacity optimisation tool with a maximum response time of 0.1 hour per inquiry.

This custom-built entire business/manufacturing model (see, Figure 1) was developed that: (1) simulates the arrivals of enquiries and their processing time, (2) generates orders becoming confirmed by customers and orders planning time, and (3) shows the queuing of the production orders for processing. There are two types of incoming enquiries – PH_Enquiries or Pharmaceutical Enquiries, and PC_Enquiries or Personal Care Enquiries. Production itself consists of the following processing stages: Pressing, Degreasing, Jigging, Anodising, and Packing. In each stage the individual machines were modelled as a group with an overall capacity per day or per week.

Based on analysis of historical data and taking accounts their stochastic nature, the following probability distributions (Table 1) were derived in order to generate in the model the time between arrivals of Enquiries, processing times of the Enquiries, average response time from the customer and actual planning time of Confirmed Orders. About 33 % of all incoming enquiries are PH_Enquiries. Probability of Enquiries becoming an Order decreases as function of planning response time including queuing time and is given in Table 2. The value of confirmed orders received by the company increases as a function of the planning response time and average value per enquiry is defined.

Table 1: Probability Distributions (all values are given in minutes)

Data	Distribution Type	Distribution
Time between arrivals of Enquiries PH_Enquiries PC_Enquiries	 Exponential Exponential	 E(60) E(20)
Processing time of Enquiries	Uniform	U[35,5] U[4,6]
Response time from a customer	Constant	24 * 60
Actual planning time of Confirmed Orders	Uniform	U[55,5]

Table 2: Probability of Enquiries Becoming an Order

(Enquiry becoming Confirmed)	Planning Response Time
50%	<1 Hour
20%	1 – 8 Hours
10%	24 – 48 Hours

Average lead-time for an order in each production stage was defined by the triangular distribution with the following parameters: min=1080, mode=1440 and max=1800. No queues were defined for model locations such as Pressing, Degreasing, Jigging, Anodising, and Packing.

Currently PH_Enquiries are processed by 1 planner, and PC_Enquiries are processed by another 3 planners that spent about 70% of their time on planning operations. Working day duration is equal to 8 hours per day, from 9:00 till 5:00. Employment costs per year for planning staff are fixed.

The entire business/manufacturing model diagram is illustrated in Figure 1. The following controllable variables are defined in the model: 1) a number of planners that process enquires, response to customers and plan confirmed orders for production; 2) the response time for enquiries, and 3) planning time for confirmed orders. The time between arrivals of enquiries, customer response time to confirm or cancel enquiries, the probability an enquiry becoming confirmed or becoming an order, and order processing time for different production stages are regarded as environmental variables in the model.

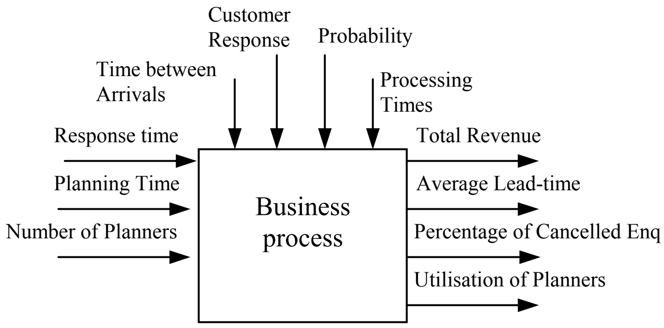

Figure 1: Black-box Diagram

The following simulation output data such as Total Revenue, Average Lead-time, Percentage of Cancelled Enquiries and Utilisation of Planners and are defined as the model performance indicators.

Visualization of the entire business/manufacturing simulation model is presented in Figure 3. On-line and off-line statistics is provided in the model. Outputs reflecting model dynamics could be followed on the model main screen. Simulation results are also automatically saved in a database and formatted in Excel sheets.

ANODISING STAGE SIMULATION MODEL

The anodising stage sub-model (Merkuryeva, et.al.) is aimed to determine whether the implementation of specific production orders queue ranking rules will improve the processes at a batch anodising plant. The model itself simulates the individual anodising tanks so that colour changeover, set-up operations and processing times can be modelled. Based on the historical data about order processing the most probable list of incoming orders to be weekly processed is generated in the model.

Orders scheduling rules are simulated and tested in order to decrease their total processing time of all aluminium parts to be anodised. Production rate that is an average number of flight bars processed per hour and frames utilisation coefficient are used to measure effectiveness of the anodising plant itself. The real system to be simulated is conceptualised in Figure 2.

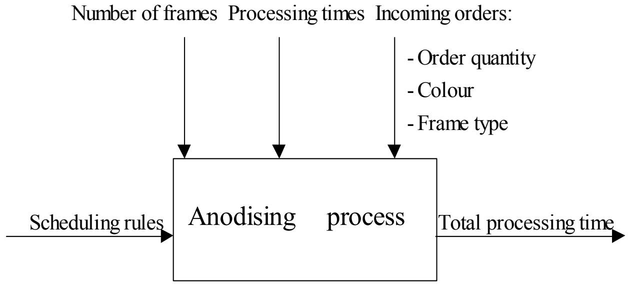

Figure 2: Anodising Model Diagram

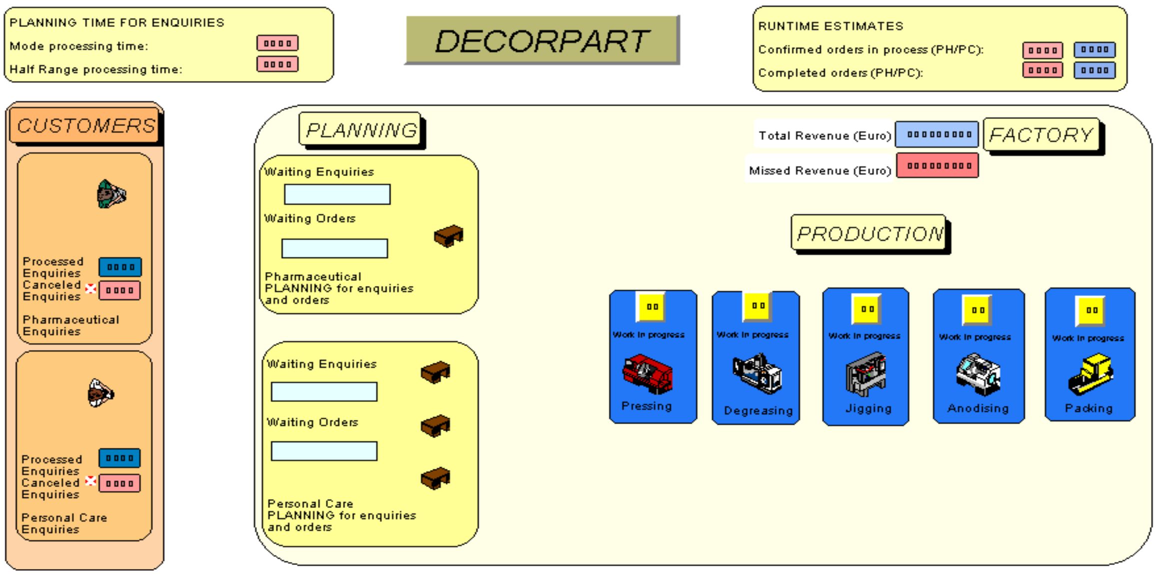

Figure 3: A High-level Business/Manufacturing System Simulation Model Visualisation

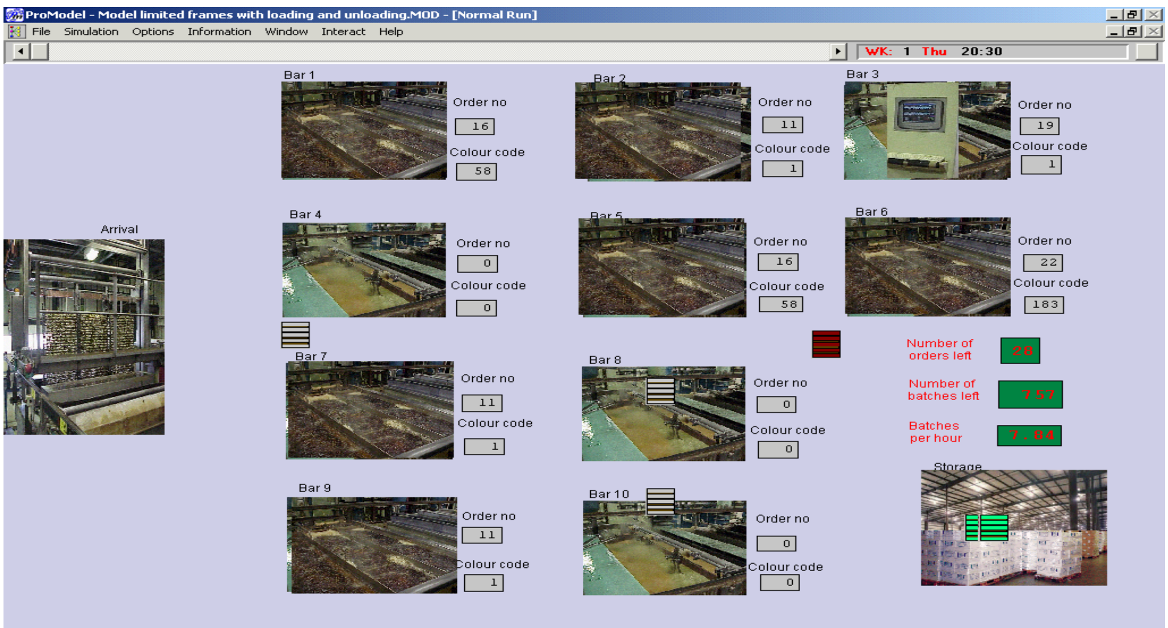

Figure 4: The Anodising Stage Simulation Model Visualisation

The following controllable variables are defined in the model: sequence numbers of orders to be processed in a week and the number of frames of specific types that are available at the plant.

The order quantity, part colour and used frame type for incoming orders are regarded as environmental or independent variables. If these properties are given, the other properties of orders in the order list can be determined. Other environmental variables are the number of frames in stock, the time it takes to load and unload flight bars, the time it takes to set-up flight bars between the processing of different colours and the processing time necessary to anodise one batch of components.

The most important performance indicator is defined as the total processing time of all orders in the order list. Among other performance indicators that could be used to control an anodising process in the real system, the following performance measures can be mentioned: an average production rate, frame loading efficiency, flight bars utilization and plant productivity.

The General Order List is created based on analysis of historical data about the orders that were planned and processed at the plant in a certain period. It includes the following input data: Week Number, Order Number, Order Quantity, Colour, Frame Type and Capacity, Frames in Stock, Number of Batches and Sequence Number (Tables 3, 4).

Table 3: Fragment of General Order List (1)

No	Week	Order No			Order Qty (x 1000)	Colour		Frame Type
1	1	1135	1	0001	100	Bright	Silver	C1
2	1	1135	1	0134	100	Bright	Gold	C1

Table 4: Fragment of General Order List (2)

No	Week	Frame Type	Frame Capacity	Frames in stock	Number of batches	Seq No
1	1	C1	1292	15	26	8
2	1	C1	1292	15	26	6

The last four digits of the order number Order No in Table 3 refer to the code of the colour that the components should get. Each frame type had a different number of components that can be placed upon it, which is called the frame capacity. The number of frames of specific type available is called as Frame in stock. Only three frames can be loaded on each flight bar. Processing time of one batch of components in a flight bar depends on the program that is used in the anodising process is defined by a Sequence Number (Seq No) in Table 4.

Based on the General Order List analysis done within Excel environment, processing times are described by the triangular distribution and generated in the simulation model. For example, for sequence 8, which is used by orders with colour code 0001 the triangular distribution with the following parameters min=54, max=72 and mode=58 minutes is used in the model. Frequency of order colour and order quantity in the General Order List as well as of the frame type to be used are defined by empirical distributions. For simplification it is assumed that order quantity and frame type depends on the product colour to be anodised.

Based on fitted probability distributions the Input Order List to be processed in a week is generated using so called transformation tables (Merkuryeva, et. al.). Example of the completed Input Order List is presented in Tables 5, 6. Let note that parameters of the probability distribution that fit processing times (such as minimum, maximum and most likely value), the number of batches that order should be split up in and the number of frames necessary to process all batches are also included in the Input Order List.

Table 5: Fragment of the Input Order List (1)

No	Colour code	Qty (x 1000)	Frame Type	Frame Capacity	Processing time (*min*)
1	0058	28	7	3456	54
2	0003	225	2	1900	64
3	0001	224	6	3456	54

A screenshot of the model visualisation presented in the Figure 4 was created by animation of four pictures from the real company that simulates in the model order arrivals and storage as well as colour change over, set up and order processing operations. The user could follow the flow of batches from the arrival location and analyse the current stage of the anodising process for each order. Different colours are used for incoming and processed entities. Entities that are processed move on to the storage location.

Table 6: Fragment of the Input Order List (2)

No	Processing time *mode*	Processing time *max*	Batch No	Frames No	Frames left
1	58	72	3	9	0
2	87	92	45	135	0
3	58	72	22	65	2

On-line statistics is provided by three counters display the following performance characteristics of the anodising plant: the number of orders that are left to process, the number of batches left to process and the average number of processed batches per hour. Two additional counters along with the flight bars indicate the current number and the colour of the order that is currently being processed. Total processing time of all incoming orders, frames loading efficiency and plant utilisation can be found in the General Simulation Output Report.

OPTIMISATION OF BUSINESS PROCESSES

Based on the sensitivity analysis of the above-described high-level business/manufacturing system model it was concluded that decreasing response time for enquiries by 5 % would lead to increase of the company total revenue by about 10 %.

Response surface based simulation metamodelling analysis performed with MiniTab software showed that for both types of Enguiries the simulation model outputs are more sensitive to Enquiries processing time rather than to orders planning time. For example, for PC_Enquiries the following business/manufacturing regression-type simulation metamodel was received:
Lead-time (PC) = $9277.03 - 21.05 * Enq + 4.83 * Ordr + 0.62 * Enq^2 + 0.41 * Enq * Ordr$.

Optimisation of the model parameters within available system recourses that was performed using Promodel Simrunner Optimiser showed that total revenue maximal value could be received if inquiry response time would not exceed 6 minutes (Table 7). Actually this response time could be only achieved by introducing an automatic PREACTOR Supply Chain Planning Server at the company. Note, that the second optimal design defines optimal combination of enquiries and orders planning time minimising lead-time model indicator.

Table 7:Comparison of Two Optimal Designs

	Enquiry planning time	Order planning time	Revenue €	Lead-time PH (min)	Lead-time PC (min)
Maximised revenue	U(4,6)	U(2,8)	49,900,000	9218.2	9261.1
Minimised lead-time	U(1,11)	U(3,7)	48,210,000	9244.4	9134.7

Finally the following two planning scenarios were compared in the case study using the entire business/manufacturing simulation model: (1) Scenario 1 that corresponded to the current situation with maximum response time equal to 1 Hour per enquiry, not including queuing time; (2) Scenario 2 that uses automatic Preactor Supply Chain Server to respond, this time does not exceed. 0.1 Hour.

Results of simulation experiments while comparing above planning scenarios showed increasing of the Total Revenue, as well as decreasing the Average Lead Time, percentage of cancelled enquiries and essential decreasing utilisation of planners (Table 8). Shorter enquiry processing time provides faster response to the customer leading to higher probability for enquiries to become an order.

Table 8: Comparison of Alternative Planning Scenarios

	Lead Time (min)		Total Revenue (€)	Cancelled enquiries (%)	
	PH	*PC*		*PH*	*PC*
Scenario 1	10805	10414	17.170.588,24	57%	57%
Scenario 2	9793	9617	41.758.823,53	44%	39%

	Utilization			
	PH Planner	PC Planner 1	PC Planner 2	PC Planner 3
Scenario 1	93%	99%	98%	97%
Scenario 2	52%	73%	61%	52%

The total revenue was calculated only for replication at the process stable stage. The counters for completed orders were stated for the replications including the model warm-up period. The last one was estimated almost by three weeks. The replication length was defined as twice as warm-up period. While planning department works only on weekdays, production process is carried on 24 hours a day, seven days a week. After ten replications the variance in the output variable such as average lead-time was small enough to get a half range of five percent average.

TESTING PRODUCTION ORDERS PROCESSING SEQUENCING RULES

The scheduling of orders processing at a batch anodising plant could be interpreted as a finite capacity scheduling problem. The last one is defined as "the process of creating an operation schedule for a set of jobs that are to be produced on a limited set of resources". There is a limited set of resources in the case study, i.e. the number of frames in a stock and the number of flight bars that the frames are loaded on. Generally, in a batch anodising plant the following two problems can occur.

The first one is caused by multiple performing of set-up operations between the processing of orders with different colours. So, decreasing the number of necessary set-up operations will result in reducing the total lead-time at the plant. The second problem relates to a limited number of frames that are available for a specific frame type. Let assume that the last production orders in the list make use of the same frame type. Since this frame type is limited, it will cause queues of orders waiting for free frames, while the flight bars could be empty. The same problem could occur in case when the last order in the list that request a limited frame type is quite large.

As a result, the following order processing sequencing rules that provided simulation scenarios in the case study were analysed. Scenario A0 represents the initial situation, in which no specific sequencing rules are applied and the incoming orders are processed according to their arrival mode. In the other three scenarios, different sequencing rules are introduced. In scenario A1, the orders with the largest quantity of components are processed first. In A2, one handles the orders of one colour first, followed by the next colour. It is expected that this will reduce the total set-up time and hence will solve the first problem mentioned above. In scenario A3 the colours that appear less frequent in the list are processed first while within the group of the same colour, the orders with the largest number of components are processed first. Because the orders are grouped per colour, this could partly solve the first problem and processing of the largest order within one colour could solve the second one.

In order to determine if the implementation of one of these sequencing rules improves the anodising process, the orders in the input files are rescheduled in the way the scenarios describe. Then difference in the total processing time of all incoming orders is calculated for scenarios with sequencing rules and the scenario in which no specific rule is applied. In this case, for each replication, common random numbers are used to simulate both scenarios that lead to a lower variance in the estimation of the difference in total processing time between different sequencing rules.

While treatment simulation experiments, the length of the anodising model run is accepted equal to the time between the start of the week that represents the initial situation in the real system and the time that all week orders were processed. As probability distributions are used both in the generation of input data and in the simulation model itself to define the time it takes to anodise the parts at flight bars, the number of necessary replications was determined while generating the input data as well as running simulation experiments. The number of random seeds initially set to twenty was reconsidered while comparing alternatives.

In the case study, mean difference between each specific sequencing rule and the initial scenario was estimated with 0.95% confidence interval. While comparing scenarios A0, A1, 20 replications were performed and the resulting mean difference was estimated by 11,51 hours with 95 % confidence interval equal to (3.82, 19.9) hours. As a result, it was concluded that a significant improvement could be provided at the plant if the rules of scenario A1 are used in for order planning.

Performing What-if analysis allowed testing whether the implementation of the A1 scheduling rule would still be an improvement if the number of frames in stock could be increased. In this case frames are not considered as limited resource in the real system. The results of comparison of specific sequencing rules with unlimited frames showed that in the last case A1 scenario will not make a significant improvement compared to scenario A0 (Table 9). Actually, sorting the orders by colour according to scenario A2 will decrease the total processing time at least by 5.65 hours. At the same time, there will be no significant difference between scenario A2 and A3.

Table 9: Comparison of Alternative Sequencing Rules

Scenarios		Mean difference (hours)	95% confidence interval	Signi ficant
A0	A1	0.01	(-0.55,0.58)	No
A0	A2	6.27	(5.85,6.89)	Yes
A0	A3	6.23	(5.59,6.86)	Yes

CASE STUDY BENEFITS

The modular simulation models provide an inexpensive tool for an overall guidance of piece-part SME manufacturing and testing advanced scheduling middle-scale software packages prior to their implementation at the customer's site. To test and optimise a production scheduler using the simulation software is much faster and easier than using the real process.

System performance output such as overall lead time and process stage lead time by order, average overall lead time of production and average lead time at each stage, received from the simulation models provides system set-up advice on: 1) production activities in order to maximise equipment utilisation decreasing unit manufacturing cost; 2) forward projections for delivery times for new orders, and 3) schedules for product change over at each stage.
Comparing two alternative planning scenarios using the entire business/manufacturing model proved the benefits of introducing automatic PREACTOR Supply Chain Server with maximum respond time 0.1 hour per inquiry. In this case percentage of cancelled enquiries could be decreased by 14-18 % providing increase of the total value of confirmed orders at least twice. Another benefit is expected in utilisation of planning staff as instead 4 planners only one could be needed. Amount of employment costs to be saved is evaluated by 150 000 Euro per year.

The results of simulation experiments with the anodising stage sub-model demonstrated that introducing new specific sequencing rules for incoming orders could provide significant improvements. The total lead time of anodising all aluminium parts from a week order list could be decreased at least by 4 hours up to 19 hours. As a result, production rate at the anodising stage could be increased by 10%, and a significant increase in equipment utilisation and reduction in a unit manufacturing cost could be received.

CONCLUSIONS

The simulation tool presented in the paper could be proposed for piece-part SME manufacturing in order to test advanced planning and capacity optimisation middle scale software packages. Iterative optimisation of initially configured scheduler parameters and rules could be performed by testing them using business/ manufacturing simulation models built in a modular style. It should be noted here that the approach used – to test and optimise planning and control tools off-line by using simulation models rather than using the real process – can be applied to many other software tools, to higher level (MRP; ERP tools) as well as to lower level control tools (MES, warehouse control systems). On other side, development of such simple simulation tool in different industrial sectors could provide also an inexpensive approach to an overall guidance of SME manufacturing towards the optimal conditions without resource to high cost integration of expensive ERP systems and downstream control systems.

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