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TURN LOST PRODUCTION INTO PROFIT – DISCRETE EVENT SIMULATION APPLIED ON RESETTING PERFORMANCE IN MANUFACTURING SYSTEMS

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ABSTRACT

World-class utilization of manufacturing resources is of vital importance to any manufacturing enterprise in the global competition of today. This requirement calls for superior performance of all processes related to the manufacturing of products. One of these processes is the resetting of machinery and equipment between two product runs, which will be the focus area of this text. This paper examines to what extent Discrete Event Simulation (DES) can be applied to the evaluation of resetting performance in manufacturing systems. For this purpose, a DES model of a factory unit in Sweden is used for the research trials, derived from real manufacturing situations. During the case study, DES has shown to be a potential tool for the evaluation of resetting processes. The results from the simulation runs provided valuable information for improvement initiatives. Among other findings a solution is proposed, that turns losses into profit.

1 INTRODUCTION

The improvement of resetting performance in manufacturing systems is, since many decades, a prominent issue for manufacturing development. Recent developments in manufacturing towards increased competition, due to open markets and deregulations, put higher demand on customer responsiveness, shorter lead times, and the ability for short resetting times (Kinnander 2001). Since the advent of Shingo´s SMED system (Shingo 1985) many articles and textbooks on setup time reductions in manufacturing systems have been published and widely recognized and practiced in industry (Sekine and Arai 1992, McIntosh et al 2001, Kaiser et al 2000, Kaiser et al 2002, Brown 2001). The proposed methods from these publications focus on improvement activities involving shop floor personnel, in order to enhance the organizational or technical performance of resetting activities. The optimization of production and inventory holding costs based on set-up time reductions and lot size reductions is another well represented research area in this field of production engineering (Olhager 1989, Trevino et al 1993, Hong and Hayya 1997, Gröndahl 1987, Yang and Deane 1993, Lambert et al 1998). Little attention, however, has been given to the use of modern computer tools, like DES (Discrete Event Simulation), for the improvement of resetting performance. DES is becoming a more and more common technique for enterprise engineering (Johansson and Grünberg 2001, Johansson et al 2002, Ericsson 2002). Simulations are widely used for the determination and evaluation of material flow aspects of manufacturing systems (Johansson and Grünberg 2001, Klingstam and Johansson 2000, Williams et al. 2001, Klingstam and Gullander 1999). This paper investigates to what extent DES can be utilized for the evaluation and improvement of resetting processes in manufacturing systems. For this purpose, a case study, using DES as the tool for finding and quantifying improvement potential for resetting time reductions will be presented.

2 RESETTING OF MANUFACTURING SYSTEMS

The manufacturing of products can be referred to as a logistical system of buffers between value-adding stations. The ideal flow of products would be, if there were no flow interruption at all, like in a straight water pipe, where the velocity of the fluid is only constrained by the density of the fluid and the energy induced. In manufacturing systems, density would compare to the cycle time of the bottleneck process and the energy induced comes from business requirements of delivery lead times and profitability. The flow of products in real manufacturing situations, however, is constrained by many losses. These losses are often referred to as the six big losses of manufacturing, namely idling and minor stoppages, reduced speed, setup and adjustment, defects and rework, breakdown and start-up (Ericsson 1997, Monden 1997). These losses constrain the flow of products in the manufacturing systems in terms of availability, performance rate, and quality rate. Once one of these six losses occurs in the bottleneck operation of a manufacturing system, the flow of products will be interrupted and the time needed to produce a finished product will increase. In non-bottleneck operations the effects of losses can be minimized through the use of buffers of products. Depending on the distribution and magnitude of losses in the manufacturing system the bottleneck of the system can move from the cycle time bottleneck to a bottleneck where the capacity is constrained by frequent losses. DES is commonly used to study and improve this type of manufacturing flow problems.

Machine setups, which are the focus of this paper, are one of the major losses constraining manufacturing flow in the flexible manufacturing of volume products. In this type of manufacturing the conflicting requirements of short cycle times and short resetting times become evident, as the short cycle times ask for rigid machine design with pre-shaped tools and high manufacturing speeds, whereas short resetting times ask for the least amount of machine parts and tooling (Kaiser 1999). The term resetting is here used for all activities needed to change machinery between the stable manufacture of one product to the stable manufacture of another product from a predetermined product range.

In accordance with the use of DES for the improvement of manufacturing flow aspects as mentioned above, we would here like to examine the use of DES as a tool for the improvement of resetting processes, throughout this text. As a case study, a manufacturing system for flexible manufacture of volume products has been chosen.

2.1 The Resetting Process – a Flow of Work Steps

For the application of DES to the analysis and improvement of resetting processes, a perspective of flow has to be introduced to resetting of equipment and machinery. A resetting process can be considered as a flow of several discrete work steps following a predefined work sequence. The total work content of the resetting task is the sum of all work steps needed to finalize the total work task. This work content is defined by the design of the equipment and the organization chosen to carry out the work task. Consequently, equipment design and organizational design are the aspects constraining the work flow of a resetting task and thereby the resetting time. Resetting time is here defined as the total elapsed time between the stable manufacture of two product types in a manufacturing system. The workflow for resetting of a manufacturing line is illustrated in Figure 1. The bars in it represent the resetting time of one machine.

Depending on the number of operators, the organization of the resetting will be carried out more or less in parallel. In Figure 1 we can see how e.g., operators A and B perform work tasks in parallel.

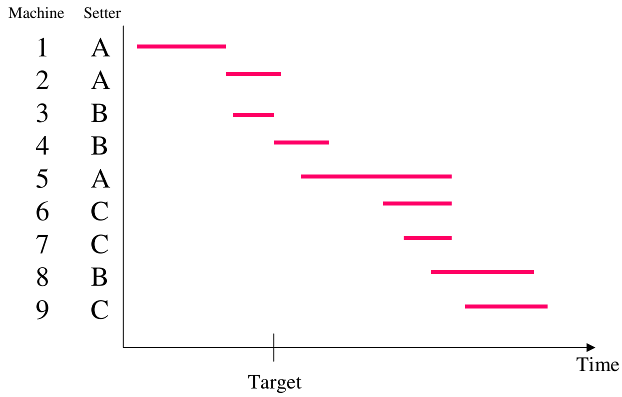

Figure 1: Resetting Organization for Nine Machines Using Three Operators

Improving resetting performance means to improve the workflow of a resetting task by means of changes in equipment design or organizational design. The ultimate goal here would be to unite the manufacturing process and the resetting process into *one* process, where resetting occurs as a part of the cycle time of a product. This means that different products can be produced every cycle. Resetting processes in most manufacturing systems of today, however, are often exposed to different losses, disturbing the workflow of a resetting task. These losses have been identified in a loss model for resetting processes, called the resetting productivity model (Kaiser et al 2000). Keeping these losses to a minimum is a question of optimization of the resetting workflow. It is the intention of the case study, being the framework of this text, to build a flow model of a resetting process and to use the model to investigate different improvement routes for resetting time reduction.

3 CASE STUDY

The idea of utilizing DES for resetting processes is the result of the intersection of two ongoing research projects at the Department of Product and Production Development at Chalmers University of Technology. In order to examine the value of the idea, an industrial partner was involved with a case study on an existing manufacturing system. A flexible manufacturing system for volume production at a manufacturing plant in Sweden was chosen for the case study.

3.1 Description of the Manufacturing System

The studied system is one out of four similar manufacturing systems (line A-D), organized in a factory unit. Line A, which was chosen for the case study, is a flow-oriented line with a continuous one-piece part flow and a minimum of buffers on the conveyors between the value-adding stations. Line A is running with 4 shifts 124 hours a week with a 24-hour stop during weekends. The line is flexible, producing 40 different types of products with 170 final variants. Line A is set up for a new product every second day in average, which means approximately 140 setups per year. With an average resetting time of 4,5 hour per resetting this amounts to a total production loss of 11 % due to resetting. Manufacturing line A is manned with 7 operators during normal operations, but during resetting this manning can be increased to up to 10 operators. The manufacturing line is designed for pull type manufacturing with the bottleneck operation in the beginning of the line for most of the product variants. Manufacturing cycle times are well balanced between the machines and between the different product types manufactured in the line.

The cycle time deviation between machines within the manufacturing of the same product is 20% or 2 seconds from the mean value, whereas the cycle-time deviation between different products is 25 % or 4 seconds per product cycle. Some product variants have to be assembled manually. For these products the bottleneck operations move to the pairing part of the manufacturing line. In this case the cycle time deviation is 49 % or 11,5 seconds per product cycle. The flow layout of line A can be split in four different sections as indicated in Figure 2.

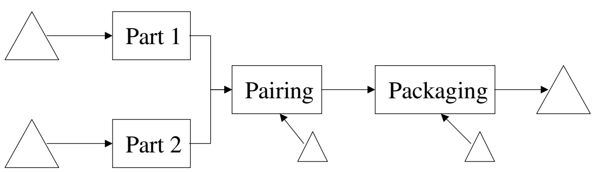

Figure 2: Flow Layout Line A

The flow for the manufacture of *part 1* consists of five consecutive manufacturing operations: measuring, grinding, polishing, and cleaning of part 1 components. The manufacturing flow for *part 2* consists of eight consecutive manufacturing operations: orientation, grinding, polishing, and cleaning of part 2 components. Parts 1 and 2 are then conveyed to the pairing station.

In the pairing station, parts 1 and 2 are assembled with two additional components. The choice of components is depending on size criteria. The flow of operations is pairing of parts 1 and 2, assembly of component A followed by assembly of component B, and weighing of the assembled product. The packaging flow consists of ten consecutive operations for control, etching, and wrapping of the final product. Through the entire manufacturing flow, the different machines are linked by a conveyor system. These conveyors are divided in different sections for the purpose of the manufacturing flow model, which will be described in section 3.2.

3.2 The DES Model

The manufacturing line was modeled in the DES software Automod (Rohrer 1999). The model represents the entire manufacturing flow from hard machining and finishing to the ready and packed product. A snapshot of the model is shown in Figure 3.

3.2.1 Methodology Used

During the case study, the methodology described in Banks et al (1996) was used. The model-building phase at first only included the manufacturing of products. Later on the details, such as scheduled maintenance, resetting flow, and an interface in Excel were added in consecutive order.

3.2.2 Model Usability

The model is very extensive and consists of over 5000 code lines. In order to enhance the usability of the model, a model interface designed and programmed using Visual Basic was made. The model communicates with Excel-files consisting of six sheets connected to both input and output data. The main purpose using this kind of interface is to allow for the personnel at the factory unit to use the model for experiments in the future. The model can also be used for the simulation of the upcoming production schedule, in order to allocate the appropriate amount of resources.

3.2.3 Data Collection

The data collection phase was time consuming, as in many other case studies (Johansson and Grünberg 2001, Johansson et al 2002, Klingstam and Johansson 2000 and Banks et al 1996). Data available from manufacturing management was not sufficient for the DES model. The data had to be complemented with data from observations at the manufacturing line, using interviews and cycle-time studies.

3.2.4 Level of Detail

The model incorporates basically all production-related events within the manufacturing line: cycle times, buffer sizes, conveyor length and speed, batching, fine-tuning of machines, maintenance of the machines, competence matrix of the operators, and tolerance requirements in the pairing station. The most specific part of the model, however, is the modeling of the resetting process of the manufacturing system. For the simulation of resetting processes in manufacturing systems a unique algorithm has been programmed, using the operators and machines to perform resetting activities, which enables the model to enter into the state of resetting. One specific worksheet has been assigned to input parameters related to the resetting processes, and two further worksheets to the output and results of the resetting processes. The input excel-sheet controls the number of operators, and the different resetting activities. The activities during a resetting cycle of a machine in the model are:

1. Dismount

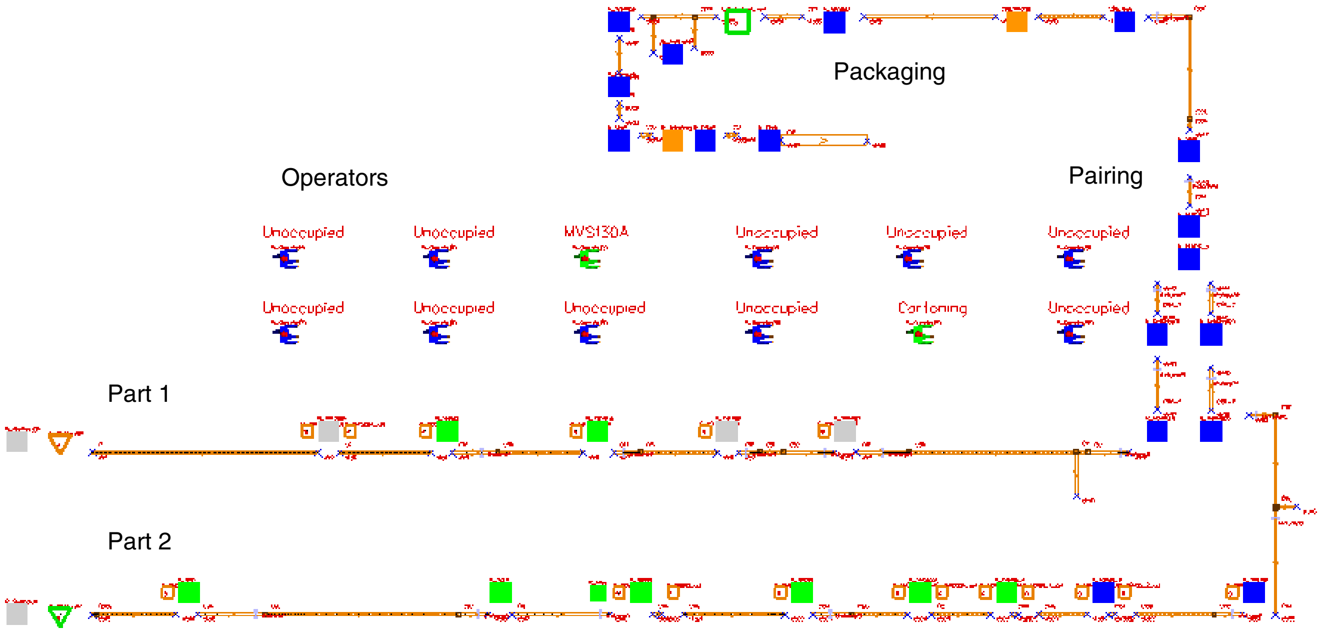

Figure 3: A Snapshot From the DES Model of the Factory Unit Made in Automod.

2. Mount
3. Adjust
4. Start up

Each activity demands a certain competence level and takes a certain time. Using the input sheet, the resetting process can be simulated for different conditions. After the simulation run, the results will be presented in a diagram.

Random breakdowns (MTBF — Mean Time Between Failures) and repairs (MTTR — Mean Time To Repair) of the machines are not considered in the model, as the impact of changes in the experiments would be more difficult to analyze. To add MTBF and MTTR distributions will increase the model-building time as well as the time spent on experiments without adding any value to the results.

3.2.5 Main Model

All the experiments conducted in the case study are based on the same main model, shown in Figure 3. The main model was built up with the input data from the real manufacturing line, with which the model also was verified and validated according to the steps described in Law and McComas (2001). For the different experiments, described in section 3.3, the desired parameters to be analyzed were modified. The following data was used to specify the main simulation model, which also is a model of the real manufacturing line:

- Nine operators available
- Buffer capacities: 1-10 loads
- Three months production
- Thirty resetting occasions
- Tolerance requirements in the pairing station
- Conveyor lengths and photocells
- Cycle-time bottleneck and resetting bottleneck are located in the same machine

3.3 Experimental Design and Simulation

The main objective with the DES model was to simulate different scenarios related to the resetting process of the production system. For this purpose the following questions were formulated regarding the experiments:

1. What effect does the machine cycle time have on the resetting time?
2. How does the number of operators available affect the resetting time?
3. Can buffers be used to achieve parallel resetting of the machines?
4. Can buffers be used to convert lost production time to productive time?

3.3.1 Relation of Resetting Bottleneck to Cycle-Time Bottleneck

The first experiment was simulated in three different scenarios:

1A. The cycle time bottleneck and resetting bottleneck was located at the same machine.

1B. The cycle time bottleneck was located prior to the resetting bottleneck.

1C. The resetting bottleneck was located prior to the cycle time bottleneck.

The results from the first experiment are shown in Table 1.

Table 1: Experiment Number one. Resetting-Time Compared to Cycle-time Bottleneck and Resetting Bottleneck

Experiment No.	Lost production during resetting [min]
1A	107,1
1B	65,1
1C	103,4

3.3.2 Relation of Resetting Time to the Number of Operators Available

The second experiment was conducted with all parameters set as in the main model, except for the number of operators available at the manufacturing line. The number was altered from one to nine, and the runs were made 2 times with each parameter, 2*9=18 runs. The results from the second experiment are shown in Table 2.

Table 2: Second Experiment. Resetting Time Compared to Number of Operators Available

No. Operators	Lost production during resetting [min]	
	Run 1	Run 2
1	862	887
2	411	412
3	255	258
4	174	173
5	130	129
6	110	108,7
7	107,3	107,2
8	107,2	107,2
9	107,2	107,3

3.3.3 Relation of Resetting Time to the Size of Buffers

The third experiment was based on the main model, with variation of the buffer sizes between the machines. This was altered from the normal capacity (1-10) to a high buffer capacity (100-200). Further, the number of operators available in the manufacturing line also was altered as shown in the second experiment. The results from the second experiment are shown in Table 3.

3.3.4 Converting Downtimes to Productive Time

The fourth experiment is an enhanced version of main question number three. This experiment was made with most parameters set according to the main model. The cycle time bottleneck was moved downstream from the resetting bottleneck, see Figure 4 and Table 4. Another addition was a buffer with the capacity of 200, 30, and one part, which was located directly after the resetting bottleneck. During the run, some time before the resetting process, one machine downstream from the resetting bottleneck was brought down for 10 minutes, i.e., a failure was simulated.

Table 3: Third Experiment. Resetting Time Compared to Buffer Sizes and Number of Operators Available

No. Operators	Lost production during resetting [min]		
	Present buffer capacity (1-10)	Larger buffer capacity (100-200)	Change [%]
2	423,7	369,5	-12,8
3	266,5	207,9	-22,0
4	188,3	128,9	-31,5
5	143,3	108,6	-24,2
6	116,8	103,9	-11,0

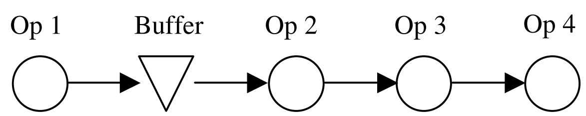

Figure 4: Flow Model Used in Experiment Four.

Table 4: Parameter Values Used in Experiment Four

Operation	1	2	3	4
Cycle time (sec)	8	10	8	20
Resetting time (min)	130	30	30	45

Results from the second experiment are shown in Table 5.

Table 5: Fourth Experiment. Lost Production Depending on Buffer Size Located After the Resetting Bottleneck

Lost production during resetting [min]		
Buffer size 1	Buffer size 30	Buffer size 200
116	100	50
110	101	51
119	104	50
113	104	50
117	99	50

3.4 Conclusions from Case Study

The presented case study includes four experiments considering different aspects of resetting processes in manufacturing systems. From the first experiment can be concluded that the location of the resetting bottleneck to the cycle time bottleneck has an impact on the resetting time of the manufacturing system. Case 1B, with the cycle time bottleneck prior to the resetting bottleneck, shows the most appropriate solution as the cycle time bottleneck will not be constrained by the resetting bottleneck. The lost production due to resetting could be reduced by 42 minutes (107,1

- 65,1=42). The same effect can be expected in manufacturing systems for products with big cycle time deviations, which was not the case in the case-study being framework of this text. Buffers caused by cycle time differences can partly, or even fully, conceal resetting times. In a real manufacturing environment this effect can cause confusion in the follow-up of resetting times and information might be misinterpreted.

Experiment 2 shows the relation of resetting time and the number of operators available for the resetting task. From the second experiment we can see the effect of an increasing amount of available resources for the resetting process. A maximum of parallel work can be achieved with a minimum of 7 operators involved. This rather obvious fact in the DES model was not considered as obvious in the real manufacturing environment. Here, the DES model helped to explain the effect of parallel work activities to the operators, which enhanced learning and decision-making in the improvement team.

Experiment 3 explains the use of buffers to minimize resetting times. By using increased buffers the number of operators for the resetting task could be reduced, retaining resetting times on the same low level. In other words, buffers can be used to achieve parallel resetting activities.

Finally experiment 4 demonstrates that machine downtime can be converted into productive time, as mentioned in the title of this paper. The lost production due to resetting in the cycle-time bottleneck machine could be reduced from 116 minutes to 50 minutes by the use of buffers in this arrangement. This compares to a 57 % reduction in resetting time, as the resetting-time bottleneck machine will have less impact on the lost production in the cycle-time bottleneck machine.

4 RESULTS AND CONCLUSIONS

With the DES model of a manufacturing system including the resetting process of the manufacturing system and the related simulation runs, it has been proven that DES can be used for the evaluation of resetting processes in manufacturing systems. The results of the simulation experiments provided an enhanced understanding of the relation between the flow of products and the flow of work steps necessary for the resetting of a manufacturing system. The simulations provided valuable information for the ongoing improvement work in the manufacturing system, in terms of facts and figures, as well as a means of visualization for the improvement team. The 3-D simulation model could be used to visualize the different scenarios of a parallel resetting organization. The results also indicate that there is a large potential to increase the productivity in the manufacturing unit by implementing the findings from the DES model into the manufacturing system.

In conclusion, this case study generated a lot of interesting and useful insights on how to reduce the resetting time in a factory unit. Even tough it might be possible to gain similar results by the use of other methods, the use of DES, with its related methodologies (Banks et al 1996) to map and access the problem area, has proved very useful. The general conclusions from this case study can be summarized as follows:

1. Production cycle-time location in comparison to the resetting cycle-time location has a vital impact on the resetting time of the manufacturing line.
2. Increasing the number of operators will make the resetting process more robust.
3. Increased buffer capacity will decrease the impact of the resetting process on lost production.
4. A buffer located directly after the resetting bottleneck can convert downtimes to productive time.

5 DISCUSSION

The findings and conclusion presented in this text are the result of one single case study, using data from one single manufacturing unit. The DES model of the high-volume automated manufacturing unit used here, gives certain constraints that ought to be met in order to use these findings on other systems. But, on the other hand, the theory behind the findings from the case study can be generally applied and used in other cases. The main item that has to be included in the system is the resetting process.

As in many other case studies (Johansson and Grünberg 2001, Johansson et al 2002, Klingstam and Johansson 2000, Banks et al 1996), some of the results can be found without DES. Even if the results and conclusions seem obvious as they are stated, all of them are not likely to be achieved without DES. To avail one-self of all these findings, a lot of other tasks have to be performed during the DES case study (Johansson and Grünberg 2001, Banks et al 1996), such as an extensive data collection, model building, verification, and validation. To succeed in these steps, several employees from the studied manufacturing unit have to be involved.

The importance of reducing the resetting time in a manufacturing unit might not seem to be of highest priority, at a glance. But when there are over 140 resetting occasions in one year, in numerous manufacturing units, decreasing the resetting time with one single minute will result in many hours available for profitable production.

Monden (1997), in his book on the Toyota production system, presented similar findings as in experiment four. The system presented by Monden called “one shot setup”, is based, however, on a logistical concept with unified cycle times in a manufacturing system without buffers, which is not the case in the manufacturing system of this text. In manufacturing systems for flexible manufacture of volume products, with buffers between the value adding stations, the findings from experiment four can be utilized.

6 FUTURE WORK

The results presented in this paper open for further research work on the use of DES techniques to decrease manufacturing losses. Similar models, like the one presented in this paper, could be used on the simulation of maintenance activities in manufacturing systems. The perspective of flow of work steps as applied here, will be equally applicable for manufacturing losses such as, breakdowns and repairs, minor stoppages, and planned maintenance.

For DES of resetting processes in particular further research will be needed to study the issue of the resetting organization in much greater detail than presented here. The use of DES models as an everyday tool for production management and improvement teams also needs further examination

The logistic concepts, discovered during the model-building and experimental phase of the case study, also deserver further consideration. This finding will result in an analysis on how to arrange the factory unit to be able to use these concepts.

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