Paper I

Reducing bottlenecks in a manufacturing system with automatic data collection and discrete-event simulation

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Abstract

A methodology for working with bottleneck reduction by using a combination of automatic data collection and DES (Discrete-Event Simulation) for a manufacturing system is presented. In the DES model, the bottleneck was identified by studying the simulation runs based on the collected automatic data. A case study showed an improvement of the availability in one machine from 58.5% to 60.2%. This single alteration with a minimum of investment resulted in a 3% increase of the overall output in the manufacturing system consisting of 11 numerically controlled machines and six other stations. A new simulation run was performed one year after the first study in order to see how the improvement work has progressed with the suggested method. The method resulted in an increase of 6% in overall output. It could be assumed that machines in future manufacturing systems will provide automatic data. The data can then be used for DES models when identifying bottlenecks in a manufacturing system.

Keywords

Discrete-Event Simulation (DES), Manufacturing Systems, Bottleneck Reduction, Productivity Improvement, Production Disturbances (PD)

1 Introduction

Elimination of bottlenecks in a manufacturing system is a way to increase efficiency. The method facilitates studies of the most critical part of the manufacturing system. In this regard, it is interesting to work with automatic data collection
in combination with DES (Discrete-Event Simulation). DES models provide the means to change different conditions and see the results in the model. A key issue is to combine production improvement techniques with DES. The potential of a tool like DES for analysis of equipment effectiveness in manufacturing systems is also of interest. Improvements of a manufacturing system are beneficial compared to the simulation costs. The increased production from the manufacturing system may be considerable.

Bottlenecks for one product are not automatically bottlenecks for other products in the same manufacturing line. This is due to process time for the different products in different machines. The reasons are varied from case to case. One study in the electronics industry has shown issues for processes such as suitable dispatching, batching, setup strategies, equipment dedication, hot lot policies etc. (Laure, 1999). According to various investigations, the reasons are often so differentiated that no specific production disturbance can be pointed out without subsequent investigation. Different products in one machine has to be compared with the same product is manufactured in different machines. With more than one machine for the same product there is a greater flexibility to handle production disturbances.

Studies from advanced manufacturing systems in manufacturing industry have shown that the OEE, is about 50% (Blanchard, 1997; Ericsson, 1997). The figure may even be lower during production setup (Ylipää, 2000). Production disturbances affect OEE, as well as the overall production efficiency during the life cycle of a manufacturing system. The disturbances may affect product quality as well as work safety, work environment and satisfaction of workers.

System improvement is important in terms of increased productivity in manufacturing. There are some fundamental performance improving attributes of manufacturing operations. Some previous research has linked the study of effective technological development with organizational learning theory. Existing learning studies relevant to operations improvement may be grouped into five general categories: learning-curve research, function-based learning studies, analytical learning theories, learning microstructure studies and organizational learning theory (Upton & Kim, 1998).

The analytical formalization is that learning in the manufacturing improvement process involves reducing uncertainty in decision-making. Managers gather more information and knowledge about the candidate improvement projects and update their estimates according to Bayesian principles. The improvement work would benefit from a more systematic viewpoint.

The main purpose of the performed case study is to show the improvement of a
manufacturing system when automatic data collection is combined with DES. The findings indicate that the potential is considerable if the automatic data collection system works accurately and the data can be used as input data to the simulation model. The bottleneck analysis is one way to achieve increased performance in a manufacturing system.

2 Automatic Data Collection Systems

Automatic data collection systems are increasingly being used in manufacturing systems. One study used CBS (Corporate Business Systems) according to Robertson & Perera (2001). The input data from CBS and MRP may, however, under many circumstances be far too imprecise to be adequate for input data for the simulation model.

Production disturbances and mistakes are bound to happen under various conditions and it is important to find out what is actually happening. One benefit from a data collection system is that data are continuously logged in all circumstances and time. It is always possible to go back to see what actually went wrong. Another benefit is that measurements of the system are independent from human involvement. The logging will be the same even if the operators are working in different shifts. Thus, the system is able to objectively log all different activities of a manufacturing system. This is important when the same set of circumstances can provoke similar errors and downtimes regardless of the people involved (Reason, 2000). In an automatic system it is easier to categorize this type of problems.

It is important both from a productivity and safety point of view to get control of production disturbances in a system. Blaming individuals may be considered emotionally more satisfying than targeting the background reasons for improvement of the system. To survive in the long run, however, the improvement projects are among the most important to stay competitive and in business.

For example, aviation has incident reports to avoid possible future accidents. It may be wise to adopt a similar procedure both for incidents and production disturbance issues in manufacturing processes. Documentation may give the opportunity to categorize and find out fundamental reasons why production disturbances occur. It is then easier to tackle and avoid future production disturbances permanently. At the same time many of the production disturbances contain behavioural elements which were not thought to be possible in advance; these can only be solved by human involvement (van der Schaaf, 1995).
Machine developers are increasingly using a common protocol to connect different machines and other equipment to each other. MMS (Manufacturing Message Specification) is an international standard for communication between manufacturing equipment (ISO 9506, 2000). If the format is standardized it will be even easier to obtain data from the machines. However, developments are necessary in the software that handles and presents the information collected from the different machines. Modern control systems make it possible to collect various data from the manufacturing system. New options exist to measure the system’s performance. It is also feasible to measure the efficiency of the different machines with high accuracy. For this purpose time measurements can be in any increment values.

Automatic data collection systems demand some consideration. First, the systems can collect a considerable amount of data and the data have then to be filtered or reduced to be usable. Second, the transfer of the data to input data for the DES model is important. Third, there is a need of categorizing the production disturbance data correctly. The data should be lucid and the amount of data must often be reduced considerably. The different causes of production disturbances that occur are also vital to include. There are two main alternatives; a fully automatic or a semi-automatic system. According to the authors’ experience the semi-automatic system is the best alternative today. In any case the amount of undefined production disturbances must be restricted.

3 Measuring of Key Figures

The difference between tact and cycle time is important to take under consideration (Monden, 1998). From an overall sales perspective the tact time can be described, see equation 1.

\[
\text{Tact time} = \frac{\text{Regular operating hours}}{\text{Saleable quantity of products}} \tag{1}
\]

The tact time indicates the time needed to produce one unit considering the daily saleable quantity. The formula shows the perspective of the entire company. To get an adequate view of the manufacturing line the formula has to be decomposed. A suggested and well used measurement is OEE (Overall Equipment Effectiveness), see equation 2 (Nakajima, 1988; Prickett, 1999).

\[
\text{OEE} = \text{Availability} \cdot \text{Performance rate} \cdot \text{Quality rate} \tag{2}
\]
Performance rate is losses at reduced performance levels. Quality rate is about quality related losses. Based on experience (Nakajima, 1988) an OEE figure of 85% is possible to achieve and also possible to surpass. However, the experience is that many companies are well below the target and according to different studies, for example Ericsson (1997), and case studies performed by Ingemansson & Bolmsjö (2001), the value is more likely to be around 50%. Increased and improved measurement will raise the potential of improvement.

\[
\text{Availability} = \frac{\text{Available time} - \text{Downtime}}{\text{Available time}}
\]

(3)

The key component in the OEE formula is the availability, equation 3. DT refers to the time frame when a production disturbance starts until it ends. Previous studies have shown that WT for any action may in many cases be as long as 90% of total DT (Ingemansson & Bolmsjö, 2001). Accuracy is a key in the measurements. Automatic data collection enables more accurate data to be measured.

The concept of PD (Production Disturbances) may be defined as the time when the manufacturing system is not working properly. One definition describes PD as an unplanned or undesirable state or function of the system (Kuivanen, 1996). PD can also involve prolonged cycle time or product quality deviations. Thus, in many cases it is approximately the same as DT.

Measurements of the different components are important in order to improve the manufacturing system’s OEE and availability. There can always be a discussion of what can be included in the figures. The most common idea is to divide DT in planned and unplanned production disturbances. A survey has been conducted in Sweden of 80 companies showing that the idea of what is regarded as a production disturbance varies considerably (Ingemansson, Bolmsjö & Harlin, 2002).

Cycle time is the total time needed to perform the necessary operations for processes at each machine or station. In real life, cycle time can be longer than tact time since variances in operating time are not considered. In most cases, however, tact time is much longer than cycle time mainly due to various production disturbances. DES may be used as a tool in studying the phenomena.

4 DES and Efficiency Improvement in Manufacturing Systems

Manufacturing systems often have difficulties to reach theoretical output in actually manufactured products. The calculations made at the planning stage before the lines are actually built are seldom in accordance with the actual output. In
many cases the actual results are significantly lower than the estimated figures. There are examples of manufacturing systems, according to the authors’ experience, that have allocated some 50% more working hours in real use than planned from the beginning.

The DES model depends on accurate data for its input. A sophisticated control program gives the opportunity to collect data in a more comprehensive manner. In the end the data will also yield a better and reliable simulation model. Input data issues are critical in making a usable model.

If a potential bottleneck can be eliminated the cost for the DES model is paid many times compared to the investment in equipment and design costs. Still, it may be difficult to allocate funds in a project plan, according to the authors’ experience. There is a need for a new approach that includes DES in the initial planning of manufacturing systems.

Measuring of key figures is an important issue for continuous improvement of the manufacturing system. There can always be a discussion of how the data are measured. The authors’ recommendation is easy understandable key figures such as OEE. The key elements in OEE are availability, performance rate and quality rate. To illustrate the importance of the key figures the link between OEE and financial statements are of great importance (Hansen, 2002). If it is possible to show increased profitability of the company it will be the greatest incentive of them all.

However, the issue is to obtain figures that can be compared to each other. The figures can rapidly indicate production disturbances that have to be reduced. The figures can also initiate a more comprehensive DES study. Shorter production disturbances can unfortunately be hidden in key figures. Those short production disturbances can be very annoying for the operators.

The combination of automatic data collection, measurements of key figures and DES modelling have shown to be beneficial. The industrial case study will describe the method and the potential to improve the system. The method combines the knowledge of the personnel around the manufacturing station together with acquired knowledge from the DES model. The potential to improve production efficiency in a manufacturing system together with DES has been shown to be considerable (Ingemansson & Bolmsjö, 2004). The automatic data enable better quality of input data and in the end better results of the overall study.
5 Industrial Case Study

A manufacturer of engine blocks at a multinational company has been equipped with an automatic data collection system. Different sets of data, DT (DownTime) and TBDT (Time Between DownTime) are logged at each machine. The reason behind each DT is also included whenever it could be extracted automatically from the status of each machine.

The line consists of 11 NC machines and six other stations including assembling, washing and cleaning, and quality control, see Figure 1 for a schematic layout. A casted block is inserted at the beginning of the line. After insertion there are machines for different process stages. The NC machines are used for machining such as milling, drilling, lathe tooling and quality control. At the end of the line the engine block is immediately ready for the assembly line; see “Output” in the same figure.

The current automatic data system made it possible to collect data in a very accurate way. All stops were logged from the shortest DT in seconds to the longest in hours. This means that the actual system performance is easy to measure at each machine and also overall performance of the whole system.

There are no major setups in the system. Other types of engine blocks with, for example, different number of cylinders are produced at other manufacturing lines. The study was carried out in Sweden in 2001 and 2002.
5.1 Case Study Methodology

Input data to the simulation model were extracted directly from the data files of the collection system. Relevant data to the simulation model were then selected from the extensive amount of data stored in the different sets of files. The physical layout of the manufacturing area was used as a basis for the layout of the DES model to enable an accurate and realistic simulation model.

Interviews with personnel at the company were also carried out, mainly among operators, maintenance personnel and industrial engineers. The main reason behind the interviews was to understand the manufacturing process and the possible problems that can occur to achieve information about production disturbances. The operators and maintainers working with the actual system are often the most valuable resource. In this particular case, a study was performed to understand the work tasks of operators and maintainers. A questionnaire and semi-structured interviews were carried out; these are further described in Harlin, Ylipää & Fjällström (2002).

Case studies are used when the investigator has little control over events and when focus is on a contemporary phenomenon with some real-life context (Yin, 1994). Case studies could be used for exploratory, descriptive or explanatory purposes. Strengths of case studies are the ability to deal with a full variety of evidence, such as documents, interviews and observations. The complexity of the performed case study has limited the article to only one study.

5.2 Model Building

When the DES model was built, verification and validation were carried out to check the accuracy of the model. Actual yearly data were compared to simulation data and showed acceptable accuracy, less than 5% deviation from real values. The main idea of model verification is to ensure that the conceptual model is reflected accurately. For example, are assumptions on system components and system structure, parameter values, abstractions and simplifications accurately represented? A whole range of questions can be asked in order to achieve a necessary accuracy of the model. What happens if analysts change parameters, input variables, or modules of a simulation model? Is the simulation model an adequate representation of the real world system (Kleijnen, 1998)? Those issues were raised during the model building phase.

The following simplifications have been included in the DES model: The transfers of the engine blocks in a gantry system between the machines were not included.
The time to transport the different engine blocks was much less than the production time of the system and can not by any means be seen as a bottleneck in the system. A normal cycle of the transfer took approximately 20 to 30 seconds compared to 9 to 23 minutes of the NC machines. Materials handling within the machine were not included. The machine time is set to a specific time when the detail was inserted in the machine and ends when the part is removed from the machine again. Internal movements of part and tools were included in the machine time. The simplifications saved time to be used on the main bottleneck studies.

The input in the manufacturing system was always supplied with engine blocks and caused no idle times in the studied DES model. Output was conveyed to the next station without delay and caused no blocking in the studied system. The DES software used in the case study was QUEST.

5.3 Experiments and Results

Many different experiments in the case study were carried out. To show the potential of combining DES with performance improvements a bottleneck study in the manufacturing system is described. Experiments in the DES environment indicated that Operation no. 130 was considered the current bottleneck in the system. The bottleneck was identified by studying the simulation runs and was verified by the statistics from the model. Improvements of this single NC machine were
shown to improve the whole system.

The operation assumed to be the manufacturing bottleneck was further checked in a comprehensive real world study. The study logged different types of production disturbances. Manual logging was carried out in parallel with the automatic system in order to check the behaviour of the machine. A drawback with the current automatic system is that there are too many unclassified events. As a result, the reasons for the different production disturbances are not known. Therefore, supplementary manual logging was necessary to obtain the real causes of the disturbances. Another advantage with the manual logging was that the experience of the operators was included in the study.

The DES model was used for reduction of production disturbances when the model was verified and validated. The results are described in the following example and the figures are also presented in Table 1. The DT was reduced by one third from 22.5 to 15 hours a week. This was accomplished by reducing the tool exchange time by 50%, which is a feasible task. Availability increased in the operation no. 130 from 58.5% to 60.2%. The overall output of the manufacturing system increased by 3% annually with the proposed changes implemented. The decreased amount of DT will also enable smoother production and better working conditions as well.

In addition to the DT reduction at operation 130, other improvement areas were identified in the bottleneck study at the same operation. Today’s cutting tools have longer useful life and the intervals of exchange can be extended. This decreased the need for planned production disturbances. The cutting data have also improved and consequently the cycle time of the different machines can be reduced. The alterations were later implemented on all operations in the manufacturing system with similar machining.

A new simulation was carried out one year later with data from the automatic data collection system. On year to year basis the model indicated an improvement of 6% of overall output in the manufacturing system. The figure was again verified to real production data. At this time two different bottleneck analyses have been concluded and one is ongoing. The results from the bottleneck analysis on one machine were implemented on other machines as well. The investments in equipment to improve the system have been approximately €2000 to 3000. In addition, engineering time has been invested in simulation, analysis and implementation of the improvements.

It was clearly shown as a result in the DES model that the downtimes are causing both blocking and idle times in the system. Four to six machines were observed in the model to be affected when one single machine was down. At rare occasions,
Table 1: Bottleneck reduction with DES.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>One year later</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation 130</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DT per week</td>
<td>22.5 h</td>
<td>15.0 h</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
<td>58.5%</td>
<td>60.2%</td>
<td></td>
</tr>
<tr>
<td><strong>The system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall output increase</td>
<td>-</td>
<td>3%</td>
<td>6%</td>
</tr>
</tbody>
</table>

even more machines were influenced which showed a clear decrease in overall output.

Normally, the machines have one buffer before and another after the same machine. The few extra buffers added in the system are unequally placed. The main extra buffers were six places before and seven buffers after Operation 60, see Figure 2. The buffers help to smooth production flow and it would have been an advantage if the buffers were scattered in different places throughout the system. It can clearly be seen in the system that although the machine time is above average for the first four NC machines there are no bottleneck at this part of the line. The buffers following the first four machines smooth out any production disturbances in the first part of the manufacturing line. If the buffers were more equally distributed throughout the system, the performance of the system would increase even more.

It is a delicate problem to decide the suitable number of buffers in a manufacturing system. Too many buffers will lead to a high cost if something in the manufacturing process goes wrong and the manufactured parts have to be altered or discarded. There is also the question about how much capital should be tied in the products. Moreover, it will hide the real problems from being discovered in due course. Several production improvement techniques such as TPS try to minimize the amount of buffers in order to highlight the actual problems at an early stage.

5.4 Conclusions from the Case Study

There are many advantages with the automatic data collection system. One is the exactness. The time accuracy is not possible to measure to the same extent in a manual or semi-manual system. Another advantage is that the measurement is unaffected by subjective judgments. The experiments showed that an improvement in availability of one single machine can improve the whole system’s performance significantly.
The classification of production disturbances chosen by the system is important, as this will be the basis for improvement measures. There are several alternatives to choose from automatic collection systems. If the system is fully automatic and indicates both time and real cause of production disturbances it is important to select the appropriate causes of disturbances. This requires analytical work to be done with the data. In a data collection system intended for disturbance reduction it is important to classify the different background causes in relevant classes. Unclassified data must be less than approximately 10% according to the authors' experience.

The combination of an automatic data collection tool and DES is a suitable way of analyzing production disturbance reduction. The main advantages with the combination seen in the case study are:

- objectiveness of data,
- accuracy of time measurement, and
- the opportunity to classify production disturbances in relevant categories.

6 A Method for Improvement of a Manufacturing System

The connection between DES and the automatic data collection system is illustrated in Figure 3. The automatic data collection system is continuously extracting data from the different machines in the system. Data can be converted with great accuracy to input data for the DES model. Various experiments can then be carried out off-line and do not interact with the actual manufacturing. DES can also be used for prediction of the system. If for example a longer production disturbance occurs, the operator and maintenance team can be given expected downtime to carry out maintenance tasks. The results from the experiments can be used as feedback for different evaluations in the manufacturing system.

A method for improvement in a manufacturing system is presented in Figure 4. The first step is to identify the current bottleneck in the system. The automatic collection system provides adequate data for this issue. The observed bottleneck may be further studied, and although the automatic data collection system gathers various data, even more may be needed. A good way, used in the described case study, is to combine the automatic data with manual logging. A positive aspect is that it includes involvement from the personnel. The operators have valuable expertise that is beneficial to the improvement process. In many projects valuable ideas of improvements are from the operators themselves.
The next step in the study is the DES model work. A model is designed and input data can be more easily accessible compared to a study made without automatic collection system. If correctly handled, this will also enable the model to be more accurate. Different experiments can be carried out to visualize the real background reasons why a certain machine is a bottleneck in the system. The DES model enables many alternative tests to be carried out to find one of the best possible solutions.

Measurements and actions are then implemented to increase productivity where the bottleneck has been discovered. Changes are done gradually and the results are checked to verify improvements. If everything works according to the plan, the cause of the current bottleneck in the system is eliminated and the production flow has increased.

The process can then be re-started which the arrow to the left in Figure 4 indicates. The improvement process is an everlasting issue. Again, the work has to start all over with a study of the system’s new existing bottleneck. A system is seldom so good that it could not be improved a little more. The potential for improvement in terms of equipment efficiency is so sizeable that the process has to be repeated a number of times. In some cases the bottleneck has not changed and more measures have to be taken at the same station until the problem changes to another machine. The work can be repeated until the cost of DES modelling exceeds the savings in performance improvement in the manufacturing system.

6.1 The General Methodology

Improvements of a manufacturing system are needed to stay competitive. Automatic data collection makes it possible to perform bottleneck analysis with the
help of DES, see Figure 5 for the interaction. When all production disturbances are logged down to parts of seconds there are solid input data for the DES model. The DES model will behave accurately compared to the real world and time for validation and verification can be reduced too. A main advantage with the DES model is that bottlenecks are clearly shown. Time can be compressed and the visualization feature is beneficial to decide where the actual bottlenecks are in the system.

A disadvantage of many manufacturing systems of today is that all reasons and causes to production disturbances are not accurately logged. The recommendation is that the case study must be combined with real world review. Thus, involvement of the personnel at the manufacturing system is also beneficial. The operators working with the system have proposals to improve performance of the actual system. The method finds this interaction vital and proof of this was made in the case study.

The main advantage with the methodology is the possibility to test changes in the DES model before it is applied in the real world. When a specific type of production disturbance is identified, it can be removed from the DES model and the new results from output can be observed. If the results are satisfactory, the alteration may be implemented in the real world. There is a risk for the system in every change that anything could go wrong in a manufacturing system. An implementation of an improvement may in worst cases jeopardize the whole system. One of
Figure 5: The DES model can identify bottlenecks in the manufacturing system when automatic data are used. Features such as time compression highlights the bottlenecks over a period of time.

The strengths is that all tests can be made beforehand in the DES model before the actual implementation. An even better DES model can be achieved in the future when more of the reasons behind the production disturbances are logged in the automatic system. The improvement process can then be repeated according to Figure 5.

7 Discussion

Improvements in a manufacturing system combined with DES modelling have in the case study shown the bottleneck can be identified and analyzed. Proposals to improve the system can then be given. The method indicated that savings could be achieved. Increase in the performance of the manufacturing system was possible by eliminating the current bottleneck and consequently a reduction of the production disturbances.

However, our findings indicated that if an automatic data collection system is in place some matters should be considered for the best results if it is combined with
A relevant table of failure codes and what actual times are logged are necessary for the simulation model. There is a problem of translating the modes of the machines to acceptable codes. It is not acceptable to have a miscellaneous code that cannot be identified as a specific reason of production disturbance. The production disturbances should be split up in different categories clearly distinguished from each other. To emphasize, a real effort should be taken to find an accurate division of disturbances. If this cannot be solved by data from the machines, a semi-automatic system may be the solution. In that case the operators have to add the causes (or more exactly what they believe are the causes) to the production disturbances according to a predefined list.

The issue about accurate production disturbance registration is vital. Classification of production disturbances is important as it forms the basis for the efficiency measurements and for the key values that are aimed to promote the improvement work. A clear and logical description of production disturbances is needed and key values should support the chosen description. There is a development in the area and the machine manufacturers are increasingly including the option to obtain data directly from the machines. Other important aspects are how to exchange, utilize and document knowledge and experiences from different participants in the production line and other parts of the company.

Bottleneck reduction may be one way to improve performance in a manufacturing system. Production disturbances in manufacturing lines are a common industrial problem (Smet, Gelders & Pintelon, 1997). This study includes a variety of companies. A more systematic approach is needed to prevent and eliminate production disturbances. Another conclusion is that the same methodological approach can be used independently of products manufactured. TPS (Toyota Production System) main components are quantity control, quality assurance, and respect for humanity (Monden, 1998). Improvement activities are one of the fundamental elements of the TPS and many things can be learnt from here. Shorter tact time, shorter cycle time and increased availability will all lead to increased productivity. This will be beneficial to the company and result in higher income, lower cost, less use of tied-up capital and less work hazards.

The performance of a manufacturing system is to some extent settled when the actual system is built. More effort should be taken before the actual building of the system. Many systems in use today are highly sophisticated. Actually they have been so complex that some are talking about too much automation (Womack & Jones, 1996). A system that functions well will serve as the basis for manufacturing of quality products. System reliability, maintainability and dependability are key factors in influencing customer satisfaction (Madu, 1999). With the suggested method, efficiency improvement can be achieved both before and after the
system is designed and built.

8 Conclusions

Working with DES and automatic data collection is a beneficial way of increasing equipment efficiency of a manufacturing system. A case study at a larger manufacturing system has shown the method of bottleneck reduction. An increase of availability from 58.5% to 60.2% in a single machine showed an overall increase in the system of 3% after the improvements were implemented in a system with 21 different operations. One year later the overall output in the system has risen 6% compared to the beginning of the project. The main advantage of the DES model is that all experiments can be carried out off-line and do not disturb the actual manufacturing. The results from the experiments can be used as feedback for evaluations of the manufacturing system. In future manufacturing systems more automatic data will be provided. The data can be used to bottleneck analyses in a manufacturing system with the help of DES according to the described methodology.

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