INCREASING PERFORMANCE EFFICIENCY IN MANUFACTURING SYSTEMS WITH PRODUCTION IMPROVEMENT TECHNIQUES AND DISCRETE-EVENT SIMULATION

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Abstract. *DES (Discrete-Event Simulation) is a tool for better understanding of manufacturing systems. When a simulation model is built, the key values shown in the model enable the user to draw adequate conclusions about the system. To achieve best results, production improvement techniques should be implemented in the analysis. TPS (Toyota Production System), TPM (Total Productive Maintenance), SMED (Single-Minute Exchange of Die) are all production improvement techniques. OEE (Overall Equipment Effectiveness) with its components have shown to be a suitable measurement method of a system. The components of OEE are availability, quality rate and performance. Several case studies have investigated a combination of DES and production improvement techniques of a manufacturing system. When combined with adequate production techniques the potential to improve a system is beneficial. Three case studies improved the performance of the manufacturing system by 6, 14 and 18%, respectively, using the combination.*

Keywords. *Discrete-Event Simulation (DES), Production Improvement Techniques, Manufacturing Systems, Productivity Improvement*

1. Introduction

There is a need to establish a procedure to increase performance in manufacturing systems. A company needs to maintain or preferably increase productivity in a system. The continuous improvement process is necessary to stay competitive. Studies from advanced manufacturing systems have shown that the OEE is as low as 50% (Blanchard, 1997; Ericsson, 1997). 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.

It is suggested to combine the two disciplines DES (Discrete-Event Simulation) and production improvement techniques, see Figure 1. The figure indicates there is a tendency to be skilled in only one of the disciplines. The manufacturing system will benefit from more integration. When the DES model is used together with adequate production improvement techniques it may yield in improvement of the manufacturing systems.

Flexibility in the systems has also attracted more and more attention. The systems should be designed with production capability and routing alternatives in mind. The inflexible structure of many manufacturing systems does not work with the rapid technological change and challenging market demand (Wu, 1994). A more multidisciplinary approach of the design and performance improvement is desired. Often there are little or no difference in the products put on the market by competitors and therefore product price and time to market are variables to achieve success for a company. Thus, manufacturing systems that are able to address these issues put a company in a better position than those that do not.

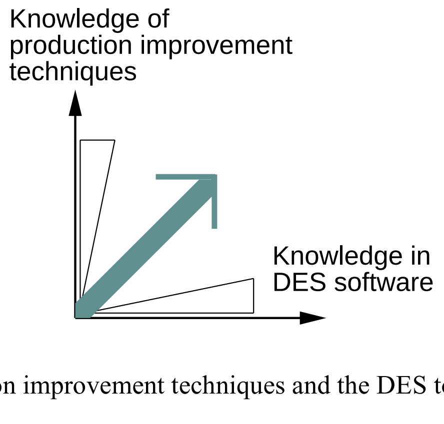

Figure 1. The combination of production improvement techniques and the DES tool is beneficial.

2. Design of Manufacturing Systems

From an operator's point of view, automation of a system often means that the most important work tasks disappear (Kidd, 1995, Bainbridge 1983). The remaining tasks are often characterized as more supportive and could be activities such as filling up material and handling production disturbances. The problems can also be aggravated by a poorly designed HMI (Human-Machine Interface). The introduction of sophisticated computerized systems has in many cases led to tighter connection between human and machine instead of the opposite as was intended. The issue, which needs to be addressed, is why technology is designed in such a way to produce unsatisfactory work conditions. The work task has been given to the robot and the job of the operator has become unskilled, trivial and machine-paced.

The production system is much more than the equipment (Brödner, 1991). The system also includes the work force, its skills, the allocation and the sequences of working tasks. The relations among all these elements determine the performance of the production. The combined resources of technology, work organization, and skill profiles must be well suited to each other. The principle of “organization first, technology second” is also asserted. The development and use of technology is the result of social relations and interests that set the conditions and objectives under which technology develops.

3. Techniques for Improving Manufacturing Systems

There are many production improvement techniques. Some of them are used in the case studies presented. The methods have been established by some of the most profitable companies worldwide.

3.1. Lean production

The trend towards flexible manufacturing, shorter lifetime for the products and a shorter product cycle has shaped new ideas in manufacturing. Lean manufacturing is one of the most significant trends in the last decade that have had a large impact on design of manufacturing systems. Womack, Jones & Roos (1990) have in their study of the automotive industry described the difference between mass and lean production. Mass production consists of interchangeability of parts, simplicity of attaching them to each other, marketing and management techniques. Lean production, on the opposite, focuses on small batches, mistakes to be shown instantly, a continuous and incremental improvement process called “kaizen”, five why's, supply chains and JIT (Just-In-Time) system utilizing for example Kanban. In short, the Kanban system is an information system that controls the production quantity in every process. In many cases, the Kanban system handles the JIT production method.

The truly lean plant transfers the maximum number of tasks and responsibilities to those workers actually adding value to the product on the line. Furthermore, it has in place a system for detecting defects that quickly traces every problem, once discovered, to its ultimate cause. The automotive industry has been in the front line of lean manufacturing and lean product development. The change of a company in the direction of lean thinking is a long, time-consuming process stretching over many years. It can only be achieved if an overall approach is taken to completely transform the company. However, benchmarking and observations around the world have shown the following astonishing results: converting a classic batch- and queue production system to continuous flow by the customer will double labour productivity throughout the system including all involved personnel, direct and indirect (Womack & Jones, 1996). The production times are typically cut by 90% and reduced inventories are also reduced with 90%. At the same time quality improves and time-to-market for new products shrinks. The potential is summarized in Table 1.

Table 1. The potential of lean production, figures are indicative (based on Womack and Jones, 1996).

	Batch-and-queue	Lean
Production time	100%	10%
Inventory	100%	10%
Quality		Superior
Time-to-market		Shorter

3.2. The issue about highly automated systems

Highly automated manufacturing systems are also called monumental ditto (Womack & Jones, 1996). Huge investments in automation and equipment may require production in batch mode. There are various examples when machines have been replaced with more inexpensive and flexible equipment. Because of continuous improvement and change of process requirements require movements or altering of machines, “monumental machining” is another form of waste. Automation of a manufacturing system is often associated with a financial risk. There is a risk especially for smaller companies of financial instability when investing in expensive FMS (Flexible Manufacturing System). It is suggested to develop a manufacturing strategy (Archer, 1984). The shorter life cycles and demand for quicker time-to-market of products may mean that there are other alternatives to new production capacity than investing in highly sophisticated manufacturing systems.

3.3. Supply chain management

Certain trends can be noticed in the area of supply chains and are described as centralization of production units, lead-time reduction, more outsourcing and the content increase in the products. This is normally shown by modularization and augmented functionality. The suppliers' role is widened from only pure manufacturing to other areas, e.g. distribution logistics and design (Mattsson, 1999). There is also an overall change in the market towards shorter and shorter product life cycles. The more different competing companies in the area and the longer backwards from the product market the more difficult for the company to react on the changes and the shorter time is available for any reaction. Production disturbances in manufacturing systems can partly describe the current need for inventories. No facility can fully rely on the production system and products are piled up in advance in different places. Especially in the multinational companies the trend during the last decade has been to produce leaner and leaner with reduced stocks. Combined with globalization and an outsourcing has resulted in more semi-finished products to be shipped to different production sites across the globe.

3.4. Toyota Production Systems

Among the most competitive manufacturing systems in the world is the TPS (Toyota Production System). Many elements in their production systems have been spread around the world as state-of-the-art of manufacturing. The principal consideration is to reduce costs by completely eliminating waste in different dimensions (Monden, 1998). Waste can be found in production operations as excessive production resources, overproduction, excessive inventory and unnecessary capital investments. This has to fit together with the three other sub-goals: quantity control, quality assurance and respect for humanity. All these items together constitute TPS.

Overproduction is a result of continued work when essential operations should be stopped. Excessive inventory allocates resources for more manpower, more equipment and more floor-space both for transport and stock. One of the basic concepts in the Toyota Production Systems is “Kanban”. The main idea is to take control of the material flow and to smooth the production flow by using physical cards. Demand variations of around 10% can be handled by changing only the frequency of Kanban transfers without changing the total number of cards. Kanban should be used to adapt to small fluctuations in demand like fine-tuning of production.

3.5. Total Productive Maintenance

TPM (Total Productive Maintenance) is a concept to get a wider perspective of the maintenance function. The idea is to shift the responsibility for maintenance from a separate department to include all employees. Like TQC (Total Quality Control), TPM is maintenance of equipment performed on a company-wide basis. The main goals are zero breakdowns and zero defects. Maintenance depends heavily on human input and TPM involves total participation of all staff. If maintenance and design engineers cooperated more to close the gap between maintenance and design technology much waste can be avoided (Nakajima, 1988).

The future of competitive manufacturing is probably more oriented towards human-integrated production. The basic requirements for world-class manufacturing are to be outstanding in applied research, production engineering, improvement capability and detailed shop-floor know-how involving good maintenance and to integrate them in a system.

3.6. Single-Minute Exchange of Die

SMED (Single-Minute Exchange of Die) is a technique for setup time reduction (Shingo, 1985). No setup times are under any circumstances allowed to take more than 10 minutes according to the method. The stages for the method can be summarized as: distinguish different types of setup, separating internal and external setup, and converting internal to external setup. It is a continuous process and improvements can be made under all circumstances. There are various examples when setup time has been reduced extensively and made it possible to reduce lot sizes, WIP (Work In Progress) and total production times. The potential to cut setup times is substantial in all manufacturing systems.

4. Overall Equipment Effectiveness - Measuring Performance in Manufacturing Systems

How well a manufacturing system performs can be measured in terms of production rate, quality, time, cost and flexibility. Manufacturing systems have up to today been built much on empirical experiences. In today's complex manufacturing systems, there is a need for a more academic and systematic approach. A systematic model could eliminate problems earlier. Increasing production rates have been the industry focus for many years. OEE (Overall Equipment Effectiveness) is a suitable measurement tool for manufacturing systems and is especially suitable for semi- and automated systems as it describes the efficiency of the flow or equipment. The main components of OEE are availability, performance efficiency and rate of quality products.

A primary goal must be to reduce the time of production disturbances and especially downtime losses as it is the main component of reduced performance in a system. Downtime is a component of the availability formula. This is without doubt the easiest way to increase overall performance for manufacturing systems. Quite surprisingly, the figure of OEE has not improved over the years according to the authors' experience. The question to be answered is why an overall improvement has not taken place in spite of all new powerful tools and management techniques. One explanation may be that at the same time the number of variants have often increased in the same manufacturing line. The ability to measure production disturbances has, however, increased especially among larger and some medium-sized companies. All tools to document production disturbances are there and a more systematic approach will help to increase the overall efficiency.

5. The Use of Discrete-Event Simulation in a Manufacturing System

There are several positive reasons for using DES in improving the performance of a manufacturing system. Advantages compared to other tools are: first, the issue of production disturbance reduction as a subject. The effects of production disturbances can be clearly shown in the model as the visualization is an eminent feature. It is also easy to see the results of different changes in the model. An example is the possibility to change and experiment with known production disturbances, for example preventive maintenance. Second, key figures from the model can easily be obtained, more balanced material flows can for instance be designed with the help of DES. Third, a decision has to be taken regarding key figures such as cycle times and connection of logics. Forth, different production improvement techniques can be tested before they are applied. Finally, the model is useful for educational purpose for all kind of personnel. Disadvantages may be the possibility to miss human aspects, as for example information flow and improvement work. It is not always easy to represent the real world in the model and there are different issues regarding input data as well as validation and verification. To achieve best results, knowledge of production improvement techniques is also necessary to apply.

6. Case Studies

Three case studies are described together with their production improvement techniques. DES was used together with the mentioned methods. This gave the opportunity to evaluate and check the changes before they were implemented in the real world. The manufacturing systems and its logics and measurements were considered. A great effort was made to achieve relevant input data. The new changes in the simulation models were implemented by step by step alteration. Some of the production improvement techniques were used implicitly; lean production, buffers and batch production were avoided whenever possible, TPM, TPS and supply chain management methods were also applied.

6.1. Case study no. 1: Setup reduction with parallel changing

In case study no. 1 the company produces equipment and machines to the window blind industry. A DES model was designed with the objective to increase production and reduce the long waiting times among the 72 braiding machines, see Figure 2. SMED (Single-Minute Exchange of Die) was suggested as working method for production improvement. The method indicated that there where time to save by setup reduction, or more exactly, to reduce the time of changing between the same types of products. However, the SMED method can still be used as the principles are the same.

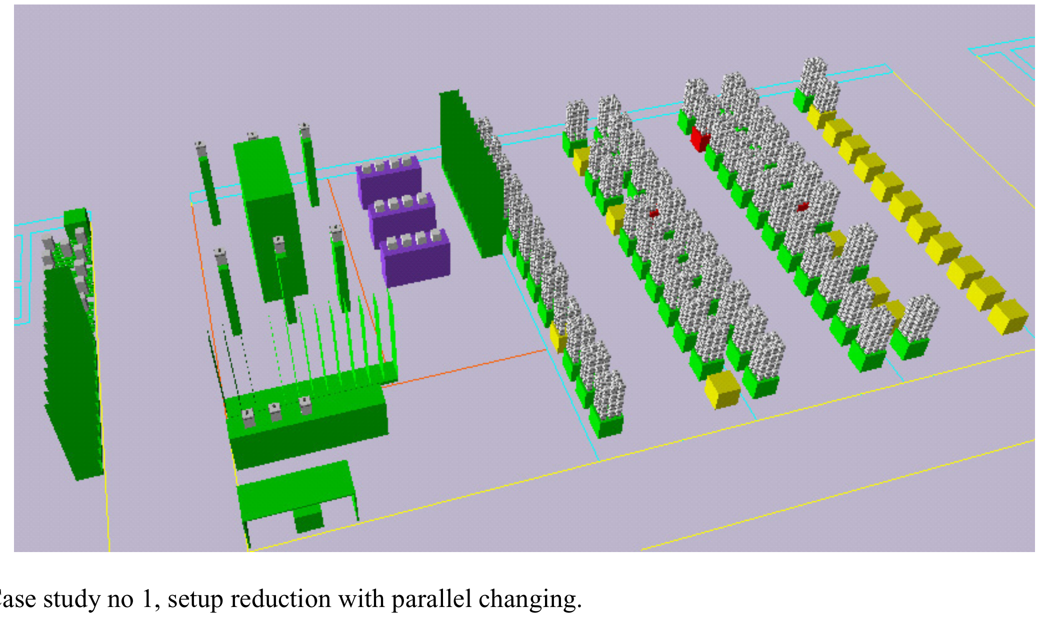

Figure 2. Case study no 1, setup reduction with parallel changing.

It was observed that the machines were often waiting for some action to be taken, especially when the machine was full and new materials have to be loaded. One way of time reduction for setup was to change two or more stations at the same time. Parallel changing of two stations was suggested as an improvement method. The DES model experiments were carried out and the results showed a performance improvement of 18%. The simulation results were then verified by real tests. To go further, experiments were suggested by the authors to investigate the effects if three or more stations were changed at the same time.

6.2. Case study no. 2: Improvement of material flow

The company in case study no. 2 manufactures forklift trucks for warehouses. A manufacturing station that welded frames was studied, see Figure 3. The material flow of products tended to be irregular to some extent. Parts of the ingredients of TPS, (Toyota Production Systems) were implemented. TPS main components are quantity control, quality assurance, and respect for humanity. TPS is also adjusted to lean production which was a method that already was utilized in the company.

Improvement activities were concentrated on achieving better material flow in the robotic welding station. There should always be a queue of frames in front of the robots ready for welding as it was considered the main component of performance improvement. Different proposals for decreasing production disturbances were also suggested. The implementation of decreased waiting times, eliminated on-line programming and more stable process showed an increase in the model of 14%. Some of the measures were implemented instantly and gave a reliable correspondence with the simulated DES model. New methods of seam track welding were also suggested as a way to decrease shorter production disturbances in the welding process.

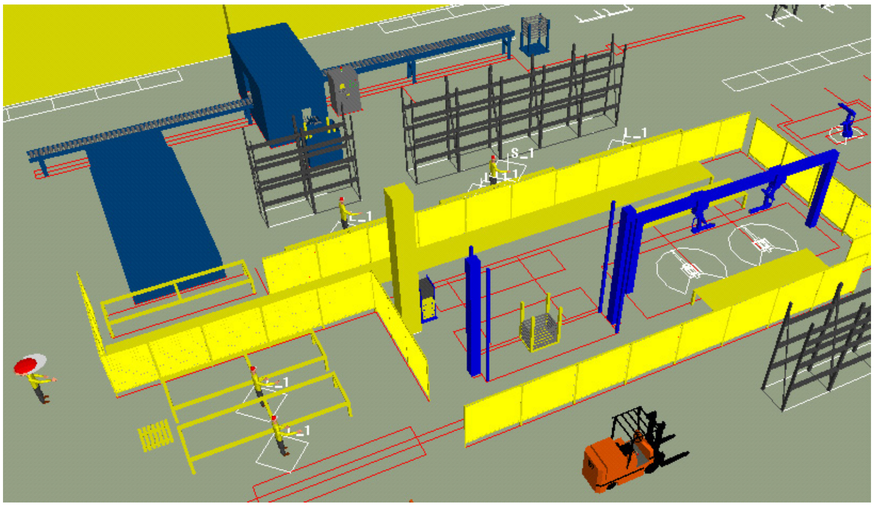

Figure 3. Case study no 2, improvement of material flow in a DES model.

6.3. Case study no. 3: Bottleneck analysis

The company in case study 3 manufactures engine blocks to the automotive industry. The manufacturing line consists of 11 numerically controlled machines and six other types of stations. Automatic data collection from the machines was used as input data to the simulation model. Bottleneck analysis was utilized as the production improvement method. The DES model helped to identify the bottleneck in the system. A manual study was carried out to further investigate the background reasons to why the bottleneck occurred. Then different proposals were suggested for improvement, for example improved tools.

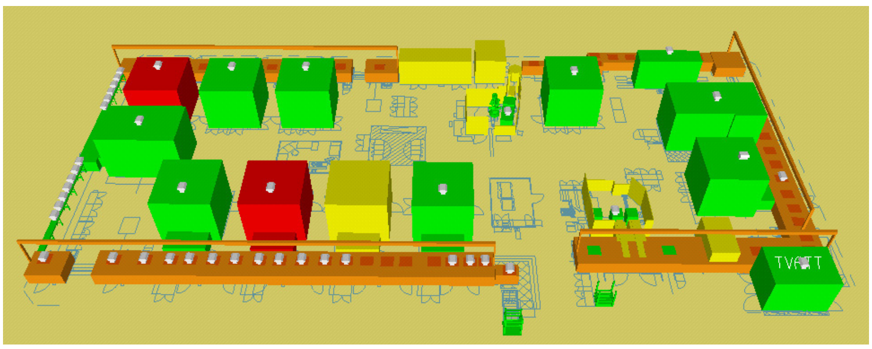

Figure 4. Case study no 3, bottleneck analysis and DES.

An example of the potential of possible improvement is described: The DT was reduced by one third from 22.5 to 15 hours a week in one single machine. This was accomplished by reducing the tool exchange time by 50%, which was a feasible task. Availability increased in the same machine from 58.5% to 60.2%. The first initial test of bottleneck analysis resulted in a performance improvement of 3%. The decreased amount of DT will also enable smoother production and better working conditions as well. Two concluded together with one ongoing bottleneck analyses have resulted in an overall performance improvement of 6% one year later. The model is illustrated in Figure 4.

7. Discussion

In a case study it is an idea to combine DES with the adequate production techniques to achieve best possible improvement. The model is needed to be according to all rules with necessary input data and logics. A method of reduction of production disturbances by using DES has been described (Ingemansson, Bolmsjö, 2004). Three different steps are suggested. First, the data for production disturbances have to be collected. Second, tests of different alternatives have to be carried out in the DES model. Third, those improvements have to be applied in the real world. Among other benefits is increased knowledge of production disturbance reduction in the organization.

However, a case study also includes different production improvement techniques. By using appropriate techniques the potential increased significantly to improve performance efficiency in the studied manufacturing system. It can always be a discussed whether the most appropriate production improvement method was chosen in each case study. To the author's knowledge, there are some rules but it is more important that any technique is chosen. The company often has some production philosophy guidelines and it is suggested to apply them accordingly.

The different production improvement techniques are overlapping. The specific method used in each case study is combined with the more general methods. An attempt to relate the used techniques to the more general ones is shown in Table 2. In each case study there are various other methods utilized, some of them more implicitly. For example a technique as TPM is involved in all case studies but to a lesser extent.

Table 2. The techniques utilized in the case studies are subsets of more comprehensive techniques.

Case study	Improvement method used in case study	Production philosophy
No. 1	Setup reduction	SMED, TPS, OEE
No. 2	Improvement of material flow	Lean Production, OEE
No. 3	Bottleneck analysis	Lean Production, OEE

Systematic design of manufacturing systems in all parts is rarely seen. Systems are often built in different steps without any extensive strategic planning. In general, only near-time planning is considered for new future products in the same product family and for production capacity increase, e.g. new parallel stations. Many manufacturing systems tend to be considered as “patchworks” built in different sections at different times. There is a need to find more systematic approaches and techniques for overall design of manufacturing systems.

One proven way is to decompose the manufacturing system into subsystems of more manageable sizes. It is of vital importance to dedicate resource requirements for layout design, material handling and production planning subsystems. An overall framework at system level with particular emphasis on system analysis, design and methodology is suggested (Wu & Ellis, 2000). Manufacturing system design specifies physical, human, organizational and finally information and control architecture as principal areas of manufacturing systems design.

In either case study there were any major investments involved. All the studies have shown by non-expensive means that there is a potential to increase overall performance output. However, in all case studies the main cost has been engineering time. This time has been used for data collection, simulation, analysis and implementation of the improvements.

The performance of a manufacturing system is to some extent settled when the actual system is built. More effort should be added before the actual building of the system. Many systems today are highly sophisticated. Actually they have been so complex that some are too automated. 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. With the suggested method, efficiency improvement can be achieved both before and after the system is designed and built.

8. Conclusions

The combination of production improvement tools and DES is beneficial. Three case studies have shown the potential for improvement. Improvement in performance has been 6%, 14% and 18% in the studied case studies. The methods of lean production, supply chain management, TPS (Toyota Production Systems), TPM (Total Productive Maintenance) and SMED (Single-Minute Exchange of Die) were used together with methods of measurement like OEE (Overall Equipment Effectiveness). For a company to stay competitive it is suggested that a combination of the described techniques is applied.

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