Short Term Scheduling in Electronics Manufacturing using Discrete-Event Simulation

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ABSTRACT: This paper describes how Discrete-Event simulation can be used in production optimization of electronics assembly lines where a lot of decisions concerning production are currently still taken only based on workers experience. Interview of those workers however often shows a lack of understanding of the parameters affecting production. In some cases, choices that are made can even be justified by untrue beliefs. It is quite common that notions such as bottlenecks and their impact on overall line capacity are ignored.

For this reason, this work focused on how discrete-event simulation could be used to improve production in electronics manufacturing by providing a better understanding of the production environment. It can also be used in a straight forward way to test different scenarios for improvement or it can provide information for designing new production facilities. In the case study presented in this paper, different scheduling policies have been proposed and results have been compared according to predefined optimization targets.

KEYWORDS: production optimization, discrete-event simulation, scheduling, printed circuit board

I. DISCRETE-EVENT SIMULATION

Production and human resources management in electronics manufacturing has taken a new dimension recently. Since a few years electronics industry has become more and more competitive and many companies are now facing productivity problems. New questions have arisen when the activity started slowing down and when the order books diminished. The production tool needs to become more flexible and adapt to the market demand. This was a good opportunity to introduce discrete events simulation as a tool for evaluating the performance of any optimization method before implementing it in the factory.

Nowadays traditional quality and process-time techniques such as flowcharts or spreadsheets are not anymore sufficient to manage production and new tools are therefore needed. Simulation modelling is a problem-solving methodology for analysing complex systems. [Schriber, 1987] defines simulation as “the modelling of a process that mimics the response of the actual system to events that take place over time”. In addition to this, [Pedgen & al., 1995] define simulation as “the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operating system”. The model can be used to:

- Analyse current operations and identify problems area (e.g. bottlenecks …).
- Test various scenarios for improvement.
- Design new manufacturing systems.

Simulation models allow to test the potential changes to an existing system without disturbing it or to evaluate the design of a new system without building it [Law A M & al., 1998] [Schriber T J & al., 1997]. Simulation early in the design cycle is important because the cost to repair mistakes increases dramatically the later in the product life cycle that the error is detected. This methodology also allows comparing new concepts, equipments or scenarios before purchasing.

For some purpose, simulations are better than the analysis of real data. With real data, it is never possible to perfectly know the real-world process that caused a particular measure to occur, because of the too complex interactions inherent in large systems. In a simulation, the analyst controls all the factors making up the data and can manipulate these systematically to see directly how specific problems and assumptions affect the analysis. Because simulation software keeps track of statistics about model elements, performance can be evaluated by analysing the model data.

Now business processes such as supply chain, customer service or new product development are too complex and dynamic to be understood and analysed with spreadsheet or flowcharting techniques. The interactions of resources with processes, products and services result in a very large number of scenarios and outcomes that are impossible to understand and evaluate without the help of a computer simulation model. Old techniques are adequate for answering “what” questions, but not for “how”, “when” and “what if” questions.

Ten or twenty years ago, average costs, quality and process-time techniques were sufficient to do process design and process management. But they are not enough anymore and major errors were made when processes were designed and driven by average techniques. By using process simulation techniques, it is now possible to test pessimistic scenarios (what will happen if 2 machines are down at the same time…), to test all kind of “what-if” scenarios, to visualize and understand the processes’ flows.

This ability to simulate a real system’s behaviour according to some predefined parameters can also be used as an evaluation tool for new control methods. These methods aimed at optimizing can be tested before any possible implementation. In the following part of this paper we will present how discrete-event simulation has been used to optimize production at an electronics manufacturing plant. Experimental framework will be presented to describe and justify modelling choices. Last part will focus on optimization methods that have been considered as possible solutions and results obtained through simulation.

II. PRESENTATION OF THE CONTEXT

A. GENERAL USE OF DISCRETE-EVENT MODELS

Discrete-event simulation has already been used in many ways to get knowledge about the behaviour of a system under certain conditions. [Estremadoyro D N & al., 1997] for example presents with its Electronics Manufacturing Simulator a solution for rapid modelling of assembly lines. Companies wanting to purchase new production systems can check the consistency of their choices before agreeing for the investment. Through TAKT time calculation, companies can avoid the purchase of “bottleneck machines”. Such a tool however is limited to production lines with simple specifications but not in a problem-solving approach.

A more common use of discrete-event simulation is to replace static analysis in capacity planning [Andersson M & al., 1998] or scheduling of resources. For [Czarmecki H & al., 1997] “capacity planning is the process of determining the tooling, personnel, and equipment resources that are required to meet customer demand. Scheduling is the time-sequenced allocation of these resources”. Main target for companies using discrete-event simulation is usually to improve the operational control of their manufacturing system and to be able to confirm their production rates [Williams E J & al., 1997]. In [Harmonosky & al., 1999], simulation is used to shorten the ramp-up period when moving from prototype production type towards mass production. But confirming a production rate is not only a necessity when demand is high, but very often it is even more important in case of over-capacity of the production tool. Producing in a cost-efficient way means that resources should not stay idle. Required increase in flexibility towards external demand can also be achieved through discrete-event simulation [Jackson M & al., 1997]. In the same line, [Savsar M, 1997] uses discrete-event simulation to analyze the capability of a pull-push system to achieve just-in-time production on an electronics assembly line.

B. CASE STUDY: PKC GROUP

PKC Group is a company involved in the production of Printed Circuit Boards, mainly control cards for the automotive industry. Earlier work has already been done with this company [Gebus & al., 2002]. The aim of this project was to develop decision helping tools based on intelligent methods adapted to the specific needs of electronics manufacturing. Two problems were addressed: Defect localization on Printed Circuit Boards and production optimization. According to the first results, the system is successful for new products, even in the ramp-up stage.

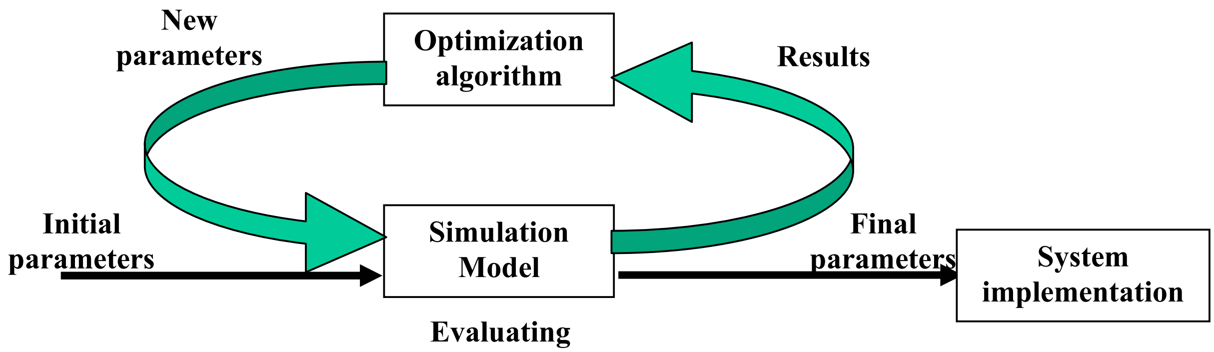

Figure 1: Optimization with a simulation model

Once a system had been developed that can absorb a larger amount of defects, emphasis during the year 2002 was put on production optimization of the assembly lines. Currently, a lot of decisions are still taken only based on workers experience, but those workers often show a lack basic knowledge of the parameters influencing production such as bottlenecks and their impact on overall line capacity. Discrete-event simulation has therefore also been used as a vector for familiarizing operators with production management requirements. But the ability to simulate a real system's behaviour according to some predefined parameters can also be used as an evaluation tool for new control methods. Figure 1 shows how simulation can be used to run iterative optimization algorithms. It is for example possible to simulate production over a certain period of time and check the system's reactivity to changes in workload. This way, optimization methods don't need to rely only on current situation of the production system in order to find an optimum solution that will most probably not be reached in the real process. Instead, different solutions can be compared and the one that offers the best results according to predefined parameters can be chosen.

In case of PKC Group, because of an economical slowdown and a decrease in customer demand, the company wanted to increase the cost efficiency of their production. In normal times, material costs represent nearly 70% of the costs of a product, but this decreases when machines are not used at maximum capacity, replaced by labour cost. One solution to limit the effect of labour cost would be to increase the flexibility of the production tool and to shut down one of the lines, meaning that fewer operators would be needed for an equivalent output. Therefore discrete-event simulation has been used as a tool to analyze the effect of different production parameters on various quality and flexibility indicators. Parameters and indicators are described in details in the experimental framework

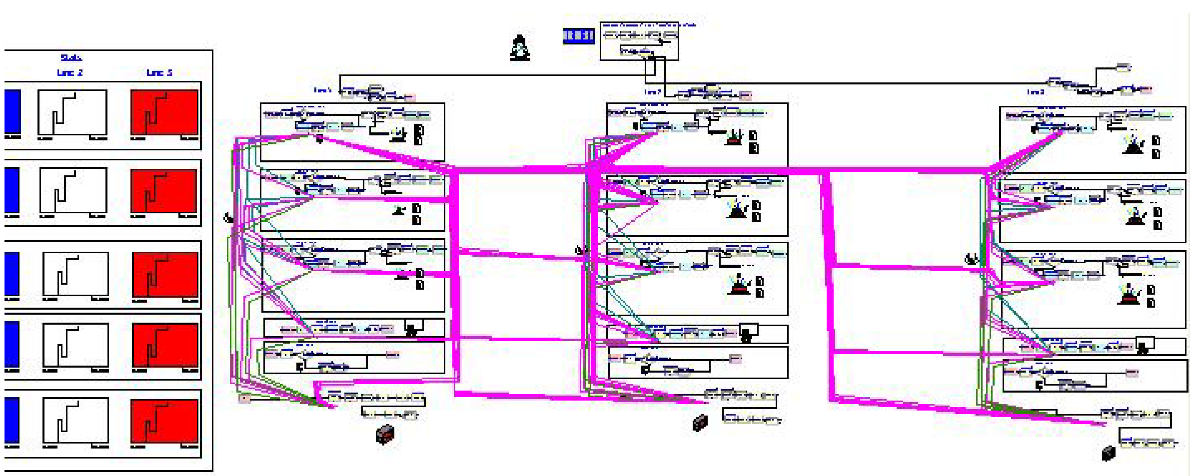

Figure 2: General overview of the simulation model

III. MODELLING CHOICES AND EXPERIMENTAL FRAMEWORK

A. THE SIMULATION MODEL

Production lines in electronics manufacturing have already been described in earlier work [Gebus, 2000]. It is a very linear process composed of a sequence of standard elements linked by conveyors. Machines are mainly used for paste printing, component placement and soldering. The production tool is composed of three assembly lines almost identical in their design. In addition to these material resources, a production line would not be complete without human operators. Even if modern production systems are increasingly automated, human operators still play an important part on the production. They take care of the visual inspection of PCBs before their entry to the soldering oven, but they are also in charge of basic maintenance and setup of the machines. Situation during the time of the project was that two operators on each line were in charge of conducting them and one additional specialized operator was supervising all three lines in case of more severe breakdowns or failures. Therefore, both production and human resources management have been included in the simulation model given on Figure 2.

B. EXPERIMENTAL FRAMEWORK

The experimental framework describes all the circumstances under which the system is observed and tested. Among other things, it gives a description concerning parameters for the model and ways to interpret simulation results.

a) Optimization Functions

The optimization functions have been chosen according to what can be observed through the simulation model and the general targets defined for the company, namely flexibility increase. Not all of those indicators however have been used in our results.

- **Delays:** Probably the biggest production constraint, when the company takes in and accepts an order, the customer assumes that he will get the product at a given time. Delays give information about the ability to respect due dates.
- **Stock levels:** They give a complement of information to the delays. It is not only important to produce before a due date, but from an economical point of view stock levels must be kept as low as possible.
- **Resources workload:** In order to have smooth and maximum production, production lines should be balanced and workload distributed equally between resources. The workload of the entire production line is defined by the bottleneck resource. Therefore a high workload on one of the resources will affect global performance of the line.
- **Buffer levels:** They are a second indicator of bottlenecks. Buffers are also used to obtain smooth production and increase flexibility in case of breakdowns.
- **Simulation time:** It can give a rough overall indication on the performance of a scheduling policy since it is the amount of time needed to process a given set of orders. However, it shouldn't be forgotten that with some scheduling policies, some lines may run empty long before the end of the simulation, affecting simulation statistics.

b) Input Variables

Only two kinds of input variables have been used in this simulation.

- **Scheduling policies:** They are the different strategies used to affect resources to incoming orders.
- **Number of operators:** Depending on the number of operators, production will run more or less smoothly. Finding the right amount of operators needed is a consequence to the main target which is to increase flexibility.

Input variables shouldn't be confused with parameters inherent to the model such as MTBF (Mean Time Between Failures) and MTTR (Mean Time To Repair). These values, however important, are not part of any optimization approach but are considered to be constraint relative to the production tool. The same applies to process and setup times, they are constraint relative to a product.

c) Initialization and Termination procedures

State of the model at the beginning of the simulation has been chosen with all servers, machines and queue lines empty. Reason for this choice is given by the aim of the simulation, which is to compare different scheduling policies. The most important is therefore to have the same initialisation parameters for every simulation run. In order to reduce initial bias, a warm-up period can be used before starting to collect any statistical data.

Both terminating and non-terminating simulations can be used in order to collect the data necessary for statistical analysis. Simulation is called terminating if the ending criterion of a run is a predefined state of the system. In our case, the predefined state will be the end of production for a given set of orders. This will be sufficient in most of the cases to compare the different optimization functions. In some cases however, depending on the scheduling policy, some lines may run empty long before the end of the simulation run, thus affecting statistical results on resource workload and buffer levels for these lines. In these cases the simulation runs will be stopped after a certain period of time, corresponding to the stationary state of the system. Simulation is then called non-terminating.

IV. SCHEDULING POLICIES

A. FIRST FREE LINE STRATEGY

This is probably the simplest of all scheduling policies but unfortunately in many cases not a very efficient one. It has however been considered in this work as a base for comparison with other, more advanced, strategies. First free line strategy will order the batches by increasing estimated start time. These batches will then be sent to the first production line becoming available. The choice of the production line doesn't depend on any specific criteria. This is the worst case scenario and therefore only poor results are expected.

B. PRIORITY TO OVEN TEMPERATURE STRATEGY

Slightly more advanced than the first free line strategy, priority is here given to the reduction of setup times for the production lines. Longest setup times appear to be for the soldering oven, where temperature changes may take up to an hour. It makes sense therefore to sort batches out according to their required soldering temperature. This strategy categorizes batches according to their soldering temperature and in each category those batches are ordered by increasing start time. Production lines are then affected to a specific oven temperature in order to minimize setups.

C. IMPROVED OVEN TEMPERATURE STRATEGY

Based on the previous strategy, improvement is made on the simulation termination. Strategy B had the disadvantage to let some lines run empty much earlier than other ones, depending on the workload for a specific oven setting. With strategy C, when a production line runs empty, state of the workshop is observed. If another production line has an important remaining workload and several orders in its queue line, then part of this production will be rerouted to the empty production line. This way, oven setup is only done when no other batch is available for a given production line.

D. MIXED STRATEGY

Mixed strategy is a result of observations made on the previous strategy. Changing the oven temperature is a long process but doesn't necessarily penalize production when done in an intelligent fashion. Production lines rarely run completely empty for a specific temperature setting, so strategy C would never apply in a real case. However it is not considered clever for example to run a production line when only few orders are scheduled at a much later date. For this reason it is possible to introduce time windows in which strategy C would apply. Mixed strategy starts therefore production based on an oven temperature priority. However, when workload diminishes and a production line runs empty in a given time window, then orders will be rerouted from the production line with the heaviest workload. After completion, production can go back to normal.

V. FIRST RESULTS

Utilization of the production lines with different scheduling strategies

	Strategy A	Strategy B	Strategy C
Line 1	0.30	0.45	0.26
Line 2	0.29	0.39	0.47
Line 3	0.29	0.63	0.64
Time to complete the batches	163 hours	128 hours	104 hours

Utilization of the production lines with different operator configurations

	2 op. 1 sup.	3 op. 1 sup.	3 op. 2 sup.
Line 1	0.30	0.29	0.29
Line 2	0.29	0.29	0.29
Line 3	0.29	0.29	0.29

Table 1: Simulation Results

Two set of results are given in Table 1. The first one was obtained by simulating three strategies with a given set of orders and comparing the utilization of each production line and the time to complete the given production. The second set of results has been obtained by using the reference strategy and varying the amount of operators. Observations for the second set have been made on the production line utilization

Concerning the choice of a scheduling strategy, as expected strategy A has the poorest performances since no optimization criteria has been chosen. With both strategies B and C we have however a dramatic increase in performance. Utilization becomes much higher as soon as oven temperature is included as a criterion for production line affectation allowing saving up to 60% of production time by lowering maintenance and setup operations. This shows the importance that one single criterion can have on overall performance of a production line. When switching from strategy B to strategy C however, it was not observed the expected smoothening of utilization levels. Reason for this can be the size of the chosen batch but strategy D could not be tested to confirm this idea.

Concerning now the different operator configurations, it has been shown that adding operators or supervisors doesn't have any perceptible effect on overall performance. This would mean that with current failure and breakdown parameters, operator configuration already provides optimum performance.

VI. CONCLUSION

Discrete-event simulation has proven to be a good tool to evaluate performances of different optimization methods. Good results were obtained in the case of various scheduling policies, allowing comparison between different options. The model could now be used to develop intelligent optimization methods. Among others, genetic algorithms have been considered as a possible choice. But any heuristically based methods would benefit greatly of the ability that discrete-event simulation has to mimic real processes.

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