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SIMULATION MODELING OF AN AUTOMATED SYSTEM FOR ELECTROSTATIC POWDER COATING

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ABSTRACT

This paper presents results obtained from a simulation of an automated system for the electrostatic powder coating of metal components in the electronics industry, in the United Kingdom. Following a brief overview of the application of simulation to automated manufacturing environments, the simulation modeling of the above mentioned system is described. The simulation model was developed using the software package "WITNESS", and was experimented with in order to discover the possibilities of increasing the throughput of the system. Results obtained are discussed as well as lines of further research.

1 INTRODUCTION

A greater emphasis on developing and using automated manufacturing systems to improve productivity and reduce costs is a result of increased competition in many industries. Because of the complexity and dynamic behaviour of such systems, simulation modeling is becoming one of the most popular methods of evaluating their design and operating strategies (Hlupic and Paul, 1993), (Hollocks, 1992), (Pidd, 1992), (O'Keefe and Haddock, 1991).

This paper describes an application of simulation to an automated manufacturing environment. The paper is structured as follows. After a review of some publications that describe the simulation modeling of automated manufacturing systems, a simulation study of an automated system for the electrostatic powder coating of metal components in the electronics industry is presented.

A brief description of the system under consideration is provided, with an emphasis on its logical behaviour. Subsequently, a simulation model developed using the manufacturing simulator "WITNESS" is described and the appropriateness of this software tool for modeling the system being studied is discussed.

Various production alternatives tested by experiments are reviewed together with the results obtained. Finally, following conclusions that outline the benefits provided by simulation, the possibilities for further use of the developed model are addressed.

2 MANUFACTURING AND SIMULATION

The number of simulation applications in automated manufacturing environments is constantly increasing. Evidence can be found from the literature, which describes individual case studies and surveys of manufacturing simulation studies.

Many examples of when simulation was used during the planning and design of automated manufacturing systems, and particularly flexible manufacturing systems, or when simulation provided help in solving production management problems, can be found. For example, Cheng (1985), Kiran et al (1989), Lenz (1983), and Schroer (1989) examine the use of simulation for FMS design, whilst Fan and Sackett (1989), Ingalls and Shannon (1986), Novels and Wichmann (1989) and Bollino (1988) describe the application of simulation to production scheduling.

In addition to particular case studies, there are many publications that provide surveys of simulation being used to solve problems that arise in automated manufacturing systems. For example, Kochar and Ma (1989) describe the major characteristics of simulation studies carried out in order to facilitate decision making when solving production management problems. Hlupic and Paul (1991) address the problems to be solved, the software tools used, and the main results obtained in a number of FMS simulation studies.

Singhal et al (1987) discuss how models can play a major role in the design and control of complex automated manufacturing systems, and provide a review of several studies where simulation was used to assist in system design, production planning, scheduling and control.

Kiran and Smith (1983) report on numerous simulation studies carried out in the area of production scheduling, and Ramasesh (1990) provides a state-of-the-art survey of simulation based research on the dynamic job shop scheduling problem.

Similarly, Ballakur and Steudel (1984) describe simulation studies carried out to address problems such as scheduling and sequencing, workload balancing, work flow structure analysis and the evaluation of job shop capacity. In the context of current and future issues concerning FMS scheduling, Hutchinson (1991) discusses several simulation studies which were carried out in order to improve the performance of flexible manufacturing systems.

The above mentioned publications are a good illustration of the popularity of simulation for modeling the complexity of automated manufacturing systems. For similar reasons of complexity, simulation was chosen for the modeling of an automated system for the electrostatic powder coating of metal components. Research was carried out in order to discover the possibilities of increasing the throughput of the system.

3 ELECTROSTATIC POWDER COATING

The automated system for the electrostatic powder coating of metal components is installed in the United Kingdom. Although this system is a part of the factory that produces electronics products, it can be considered as a separate unit due to its specific characteristics and function.

The system paints various metal components using the methods of electrostatic powder coating. These components are produced in flexible manufacturing cells installed in the same factory, and after coating are assembled with other components to create final products. The layout of the system is shown in Figure 1. The entire system consists of a large overhead conveyor chain passing through several processing areas. Components to be coated are attached to flight bars, which are mounted on the conveyor. The number of parts per flight bar depends on the product type, of which there is a range of almost two thousand different part types. For example, one large part may need two flight bars, whilst on the other hand five hundred small parts can be jigged together and hung on one flight bar.

After the parts have been loaded on the flight bars in the loading area, they are transported through several processing areas, prior to their unloading after the last processing stage. The first stage is pretreatment, where parts are degreased and washed in order to be properly painted. Following pretreatment, parts are transported to the oven, where they are dried. Finally, after drying, the parts are ready for powder coating (painting).

There are two automatic and two manual booths for painting. One manual booth is only used when one or two parts are painted as a sample, whilst the other is used when the batch size is small (less than 20 parts) or when a particular batch has high priority. In all other cases automatic booths are used, where the parts are automatically coated. One automatic booth is dedicated to one special colour, whilst all other colours are painted on the other booth.

Following coating, parts are further transported to the oven, where they are baked in order to preserve the coating. After this last stage of processing, parts go to the unloading area, where they are unloaded from the flight bars, separated and moved out of this system. Only the main characteristics of the system have been described here. It is not possible to succinctly describe its full complexity, because there are many additional details, such as various features of the parts which make the distinction between hundreds of different part types, details of the manpower in the system (although this system is mainly automated, labour is needed for loading and unloading, cleaning the painting booths, manual painting etc.) and details about breakdowns of the conveyor and spraying guns or of complicated shift patterns. However, some relevant additional details are provided in the description of the simulation model.

4 THE SIMULATION MODEL

The simulation model was developed using the "WITNESS" software package for manufacturing simulation, which handles visual interactive simulation. The main reason why this package was chosen is its ability to allow additional programming for modeling specific features of the system. This was necessary because of the complexity of the system being modelled.

Prior to model development, the system was studied and data collected for several weeks. The majority of data was collected on the shop floor, where workers filled in forms especially designed for this purpose. These data were then statistically analyzed and used in the model. Information about the system was also obtained by interviewing managers and production engineers, and studying some previous reports about the system. Finally, the durations of some operations were measured several times during the actual production process, and the values obtained used for the model.

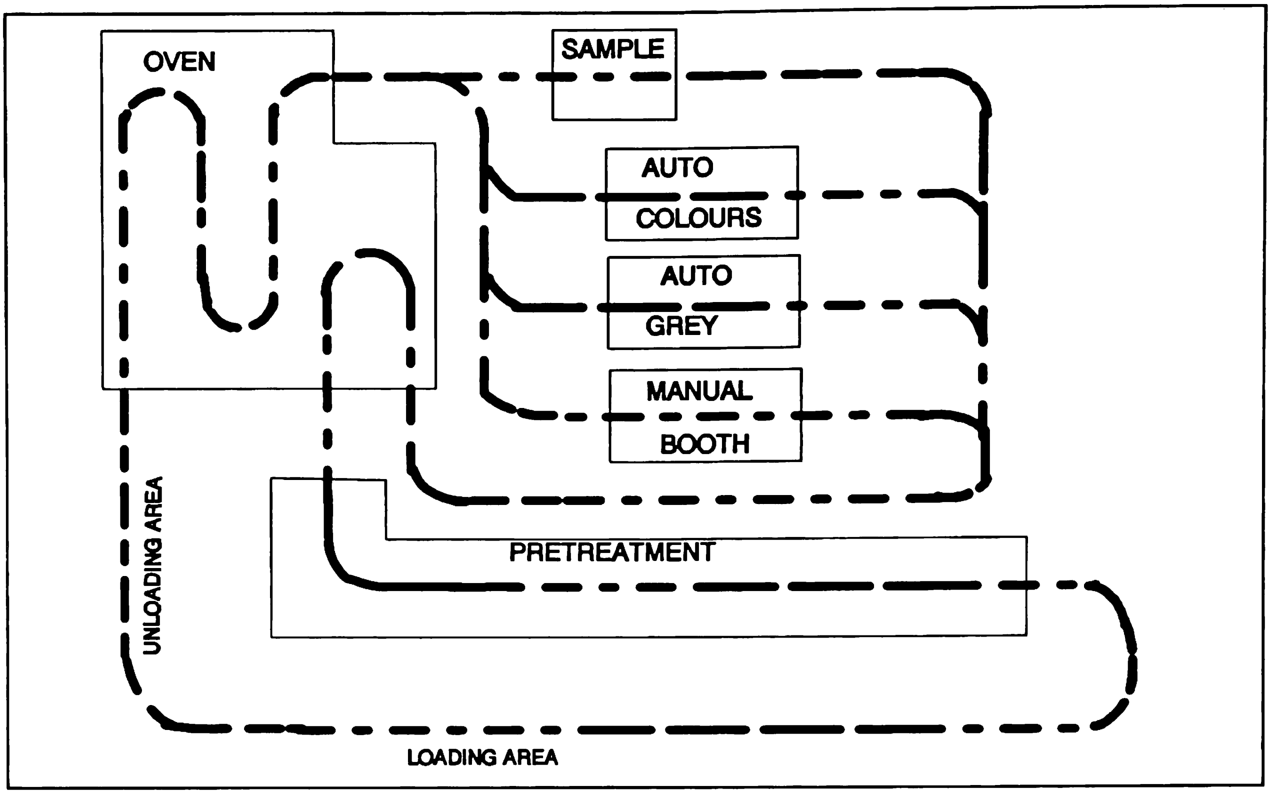

Figure 1: The layout of the system

The simulation model was developed gradually. An increasing number of details were added to the model and tested repeatedly. This iterative process resulted in more than sixty different versions of the model. The final version contains more than 220 model elements.

Whilst physical elements of the system (parts, conveyors, processing stations, labour etc.) were modelled by specifying their parameters in predefined forms, logical elements had to be additionally programmed. Thus, many additional functions were written, conditions for routing programmed, and part attributes defined. For example, the part attributes defined relate to the colour, batch size, batch priority, number of parts per flight bar, batch number, masking requirements, the number of the booth on which the batch will be painted, the total number of flight bars required for a particular batch, and the requirements of the manual finish for painting if the part is complex. Conditions in the form of input and output rules were programmed for many parts of the model. For example, when the batch has to be routed to one booth for painting, attributes such as colour, batch size or priority are tested and, depending on the values of these attributes, the batch is routed in the appropriate direction.

Almost thirty functions were written in order to model special characteristics of the system. Many of these functions invoke built-in functions provided by "WITNESS". Figure 2 shows an example of the function which returns the number of parts unloaded from the particular flight bar, after all phases of the powder coating are finished. This simple function illustrates the syntax and the structure of the code.

After each iterative change, the model was thoroughly tested. In addition to animation, which provided the most significant help for model verification, many other facilities for testing the model are available. For example, the values of functions and variables can be displayed and changed dynamically as the simulation progresses. It is also possible to obtain information about the state of particular elements, and information about the attributes of the parts present in the specific elements.

The final version of the model gave results (throughput) that varied about 1% from the real values, so this model was accepted as a basis for further experimentation. Several experiments were run, and the results obtained were compared to the values obtained in the real system. The experiments are discussed below.

```
AA=np_fbar   (* attribute number of parts per flight bar*)
BB= MOD (b_size,np_fbar) (*function MOD*)
KK=nfb  (*attribute total number of flight bars for particular
                    batch*)
ww=b_size   (* attribute batch size*)
IF ww < AA
 RETURN ww
ELSEIF BB<>0
 IF XX < KK-1
  RETURN AA
 ELSEIF XX=KK-1
  RETURN BB
 ELSE
  RETURN AA
 ENDIF
ELSE
RETURN AA
ENDIF
```

Figure 2: An example of the function that determines the number of parts unloaded from the flight bar

In order to use the software package "WITNESS" for model development, some approximations to the system had to be made. Also, the lack of good experimental facilities become evident. It was not easy to learn the package, and many problems with computer memory occurred due to the complexity of the model. However, this package was flexible enough to model all essential details of the system. As such, "WITNESS" can be considered as a good manufacturing simulator, and probably subsequent versions of the package will eliminate some of the deficiencies evident in the present version.

5 EXPERIMENTS AND RESULTS

The model was used as the basis for testing various production alternatives. Production engineers proposed testing several changes to the system, which resulted in the simulation of five different versions of the model, in addition to simulating the present situation.

Consequently, six different models were simulated. The main aim of experimentation was to see the impact of changes on throughput in the system, but machine and labour utilizations were also considered. Model 1 represents the present situation. In model 2, the number of parts loaded on flight bars was doubled, because it is possible to jig parts together, and paint them only on one side.

Model 3 simulated the use of three automatic spray booths, with a new colour mix. At present, there are 19 different colours, which complicates the operation of the system, because after each colour change booths have to be cleaned for about 45 minutes. In this new version, only 5 colours are used.

Model 4 simulates the automatic spraying of 25% of the parts that are sprayed manually at the moment. Similarly, model 5 simulates the automatic spraying of 50% of the parts that are now sprayed manually, whilst model 6 simulates the automatic spraying of 75% of the parts that are now sprayed manually.

All models were simulated under the same conditions. There are 22 random variables in the model, and for each model three experiments with different random number seeds were run. The average values from these three experiments were considered. The model simulated the performance of the system over 40 days, with a warm up period of 7 days.

Table 1 shows the point estimates for the average total and daily throughput obtained for the six models. The magnitude of relative interval lengths ie. the interval which covers all values of throughput, divided by the mean value of throughput (Ceric and Hlupic, 1993), was smaller than 3% for all models except for model 2. For this model, the magnitude of relative interval length was 6.4%, which was mainly caused by variations in the stochastic variable representing the number of parts per flight bar (doubled in this model).

The last row of the table shows the increase in throughput obtained in models 2-6 in comparison with the throughput obtained by model 1 which simulated the present situation. The best results were achieved by model 2 (an increase in throughput of 56%), where the number of parts per flight bar was doubled. The reason why an increase is not even higher is because of the time needed for loading and unloading the flight bars, during which the conveyor is stopped. This can be eliminated by changing the logic of the model, which should include modifications for the workers' tasks and off-line jigging of parts.

The other four models also provided an increase in throughput, but less significantly. Model 3, with three automatic booths and the new colour mix provided an increase in throughput of almost 6%. Models 4,5 and 6, where a part of the components were sprayed automatically on manual booths, gave an increase in throughput of about 4%.

The results presented show that different changes in the way of running the system have different impacts on the measures of performance. Since the main goal of the study was to investigate the ways of increasing the throughput, results regarding this measure of performance are presented and discussed.

The results demonstrate that the greatest improvement will be achieved by jigging the parts together on flight bars, as was simulated in model 2. Although this can probably be accomplished easily for the majority of part types, production engineers will have to find a way to jig the large components which currently require two flight bars.

Table 1: Total and the average daily throughput obtained for 6 models

	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6
TOTAL THR.	39753	62358	42057	41352	41252	41204
DAILY THR.	1419	2227	1450	1476	1473	1470
INCREASE	-	56%	5.7%	4%	3.7%	3.6%

However, even if only some components can be doubled on flight bars, a significant improvement in throughput will be gained. Further experimentation can perhaps provide more precise estimates of those improvements.

Introducing the third booth for automatic spraying requires some additional investment in production equipment, whilst reducing the range of colours may be opposed by customers. Nevertheless, an improvement of 6% can have a significant impact on system efficiency, especially on a long term basis.

The last three models gave an increase in throughput of about 4%. Such a level of production can be achieved without any additional investment, by transferring some batches to one of the automatic booths.

These are some of the changes that can improve the performance of the system being modelled. Other alternatives have to be tested, as well as combinations of several modifications to the present way of running the system. However, the results already obtained have given a good insight to production managers as to which directions they might follow in order to improve the performance of the system.

6 CONCLUSIONS

This paper presents the results of a simulation study of an automated system for the electrostatic powder coating of metal components. Following a brief review of simulation research in automated manufacturing systems, the system being studied in this research is described, as well as the simulation model developed using the simulation package "WITNESS". The simulation of several production alternatives is described together with the results obtained. The possibilities for further use of the developed model, and the prospects for extending simulation research in the factory being analyzed are specified below.

The software package used in this study, "WITNESS", showed very good performance in terms of modeling flexibility, facilities for model verification, transparency of the modeling process, graphical facilities, the variety of physical and logical elements that could be modelled, and several other aspects. The main deficiencies of this package are its poor statistical facilities for experimentation, the hardware requirements, and also that it is difficult to learn.

However, this software can be regarded as adequate for the purposes of such an extensive study, and the efforts needed to learn this package were worthwhile. Results obtained from the simulation of several production alternatives showed which changes should be made in the system in order to improve the effectiveness of the system. In addition, simulation provided a better understanding of system behaviour. This study is a good illustration of the suitability of using simulation for modeling automated manufacturing systems.

7 FUTURE WORK

The results presented in this paper represent an initial phase of the experimentation. Several other alternatives will be tested, including changes to the system configuration, changes in shift pattern and manpower etc.

Since there are plans to transfer a significant amount of production from another factory, the current system for powder coating will not be able to cope with the increased amount of components to be painted. Simulation will undoubtedly have a significant role to play in the assessment of how the efficiency of the system can be significantly improved, or in determining whether a completely new system for powder coating will have to be installed.

In addition, there is the possibility of extending the simulation study to other parts of the factory. There are several flexible manufacturing cells, which will be extended with new CNC machines, so simulation can help to assess the capacity needed to meet any extended demand for products.

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