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SIMULATION BASED PERFORMANCE ANALYSIS OF THE MULTI-PRODUCT MANUFACTURING SYSTEM

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Annotation: The paper presents a case study on simulation modelling and analysis of the power supply production line in the factory Power-One Ltd. in Dubnica nad Váhom. Simulation technique is applied to evaluate the performance of the existing manufacturing system and to find the factors with significant impact on the overall performance of the system. The average total processing time for the given set of production orders is used as criterion for comparison of possible variants. Then, a new system design is proposed to enhance the overall performance and is verified using a simulation model. The simulation system WITNESS is used for this study.

Keywords: make-to-order manufacturing, worker allocation, simulation, WITNESS

1 INTRODUCTION

Perhaps the greatest benefit of using simulation as a tool for improving existing manufacturing systems consists in that it allows evaluating the effect of local changes on the overall system performance. Especially in multi-product manufacturing systems which process a wide variety of products in a batch production environment, simulation can significantly help analyse and optimize the capacity utilization by identifying the problems of existing manufacturing facilities (e.g. occurrence of bottlenecks, low utilisation of machines or workers etc.).

The analysis in this paper aims to improve the allocation of available production resources to reduce the total processing time for the given set of production orders.

2 DESCRIPTION OF THE PRODUCTION SYSTEM

EP division (Division for Embedded Products) of the company Power-One, Ltd. in Dubnica nad Váhom produces industrial power supply units, AC/DC and DC/DC of lower power.These products represent the main part of the production program of the company (app. 75% of the total output).

EP division provides a make-to-order manufacturing, where a product can be produced only after receiving the customer’s order only and is based on the combination of standard items and custom-designed items to meet special customer’s needs.

Products are grouped into product families, i.e. groups of products with a defined relationship because of physical and production similarities. Each product family includes products integrated on an identical main board (PCB) and represents several hundreds or thousands of types which differ in input-output parameters, connectors or design according to customer requirements.

The required number of products of one type represents so-called production order for the production line. Not all product families and not all production orders pass through the same procedures in a production line, but there is a lot of procedures that every single product of each product family and each production order have to pass through. These procedures and workplaces are especially difficult to co-ordinate, and therefore this part of production line has been chosen for the simulation analysis.

Operations common for all products:

- Pre-assembly: Connector riveting, Pinning, Assembly of chokes and transformers, Assembly of heat sinks and shunts. The result of pre-assembly operations is a fixed, so far non-electrical connection with PCB.
- Assembly: THT components assembly (through-hole technology – assembly of conventional components to specified places on PCB, without connection). The next manipulation of such fitted PCB is possible only in horizontal position until the PCB is located onto the belt conveyor connected with mass soldering device.
- Mass wave soldering is a large-scale soldering process by which all THT components are soldered to a PCB at one pass. The result is a fixed electrical connection with PCB surface together.
- Visual inspection and correction (quality inspection of soldering process, possible shorts, components positions and polarity). Identified defects are removed directly at this workplace.
- Functional test of the unit, also called a pre-test, where functionality of the components and the whole unit is tested. If the unit fails, it is moved to the repair place No1. After repairing, it is sent again to the functional test place.
- Cleaning and varnishing of unit.
- Final assembly (covering of unit – assembly of top cover, bottom cover and insulation foil).
- Ground test and Hi-Pot (High Potential) test.
- Final test where the complete functionality of the unit is tested. If the unit doesn't work properly, i.e. at least one of the measured parameters is out of range, the unit is moved to the repair place No2. After repairing, it is sent again to the final test place.
- Final inspection of the finished unit, of the label's data and possible connector damaging.

The described part of the production line is depicted in colour in the block diagram in Figure 1.

This production system can be considered as a push system using buffers between each couple of workplaces, excepting THT assembly, after which the assembled boards are directly placed on conveyor belt of wave soldering place.

At this production line, 200 to 400 production types can be processed at once. Each production order has a specified number of pieces released into the production line and moving separated in pallets. The number of pieces in each pallet depends on the PCB size. Pallets are picked out of the buffers randomly by the operator, after he had finished his work on previous production order and put it into the buffer.

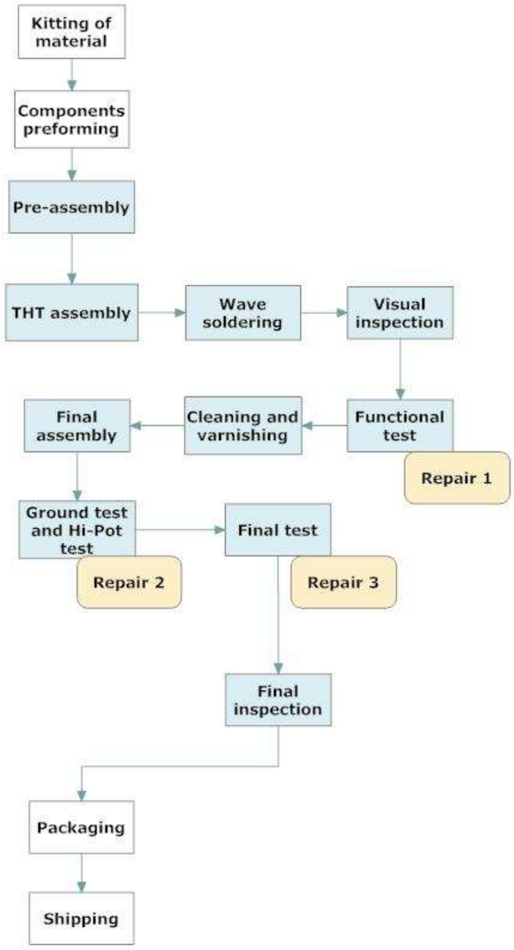


Fig. 1 Block diagram of the production line

3 WITNESS SIMULATION SOFTWARE

WITNESS is a comprehensive discrete event and continuous process simulator. It is designed to model the dynamics of complex systems. It is an established simulation tool used by thousands of organisations worldwide for analysis and validation of business process, to achieve a desired process performance or to support continuous process improvement activities.

WITNESS provides a graphical environment to build simulation models. It enables to represent a real world process in a dynamic animated computer model and allows automating simulation experiments, optimizing material flow across the facility, and generating animated models. A simulation model can incorporate all the variability of real life experience (variable reliability, process times, resource efficiency etc.).

The WITNESS simulation package is capable of modelling a variety of discrete (e.g., part-based) and continuous (e.g., fluids and high-volume fastmoving goods) elements. Depending on the type of element, each can be in any of a number of “states”. These states can be idle (waiting), busy (processing), blocked, in-setup, broken down, waiting labour (cycle/setup/repair) etc.

Complex routing and control logic is achieved with numerous input and output rules as well as special actions using functions. The format for using actions is similar to that of a simple programming language.

Results of simulation can be viewed on the screen either in tabular or graphic format. In addition, several graphical elements are available for summarizing statistics from a model. Pie charts, time-series and histograms provide a meaningful, easily-read format for data from a simulation model run. Reports allow user to examine the performance of elements in the model and provide him with relevant information about their interaction, details and status. Reports can help to identify areas where the model’s operation can be improved.

WITNESS Optimizer provides a plug-in module which can intelligently test different combinations of changes within a model, and carry out the desired experimentation

4 SIMULATION MODEL DESCRIPTION

The aim of this study is to create a model usable for comparing different variants of workers allocation to workplaces, and different ways of choosing the order of processing the production orders at each workplace. The average total processing time for the given set of production orders has been used as a criterion for comparison of possible variants.

To fulfil this aim, the model has to meet the following requirements:

- real number and behaviour of workplaces, machines and workers
- suitable representation of the real number of production orders
- possibility to easy set the number of production orders, cycle times, changeover times and batch sizes for each production order
- real interpretation of cycle time values as stochastic variables
- each machine in model has to recognize the particular type of production order and set the cycle time, setup time and batch size accordingly
- setting the planned and occasional downtimes of the wave soldering machine

The simulation model created in WITNESS meets the above requirements, limiting the number of work order released into the production to maximum 10 which represent all product families. A demonstration of the WITNESS simulation environment is in Figure 2.

Size of the production order and its other parameters for the model – batch size, cycle time, setup time, as well as the number of failed units and workers at each workplace are set in MS Excel, using RAND function for modelling product order fluctuations. This helps change all model parameters easily and flexibly (Figure 3).

Performance of the existing manufacturing system was evaluated using simulation. As a result two bottlenecks were identified, in particular the workplaces *Cleaning and varnishing*, and *Functional test.* Workplaces *Visual inspection*, *Final inspection*, *Final assembly* and *THT assembly* were marked as having surplus workers.

The simulation experiments detected two critical factors: the sequence of the line order entry and the workers allocation along the line. As the setups at this production line are sequence-dependent, one series of experiments was focused on setup time reduction. The second series was aimed to improve the workers allocation based on their average utilization. Improvements suggestion was based on the analysis of WITNESS simulation results (*Statistics*) using average indicators like *Busy*, *Idle*, *Blocked*, *In-Setup*, *Waiting for Labour*, etc., and subsequent performance evaluation. Nowadays, optimization is carried out using WITNESS module Optimizer.

After comparing and analyzing the simulation results using various combinations of the cycle times, batch sizes, number of workers and other parameters, a new system design has been proposed to enhance the overall performance and verified using the model.

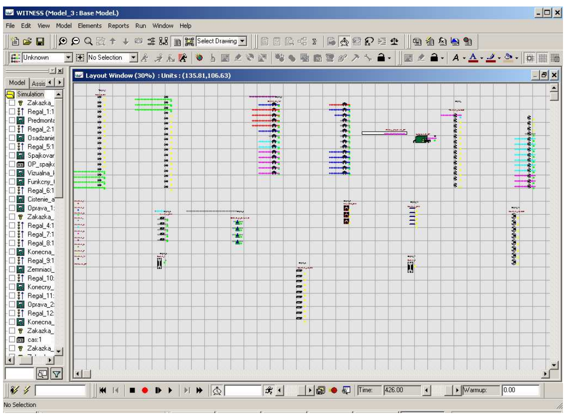


Fig. 2. Demonstration of the simulation model in WITNESS environment

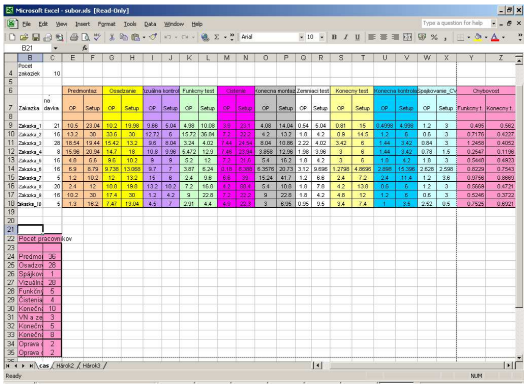


Fig. 3. Illustration of Input data sheet in MS Excel

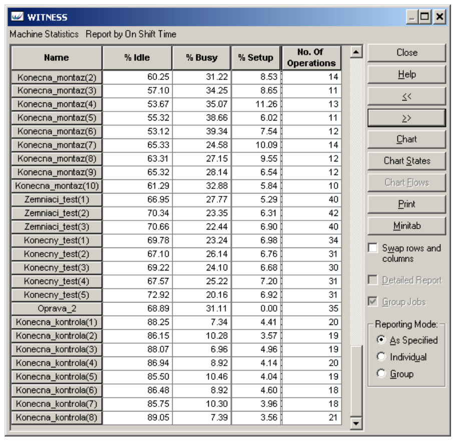
5 PARAMETER OPTIMIZATION AND SIMULATION RESULTS

From experiments with the basic model optimizing actions were suggested, able to reduce the total average orders processing time. Suggestions were focused particularly on the elimination of bottlenecks – moving workers between workplaces, changing number of workers and also changing the way of choosing work order from buffers to reduce the setup times.

Even very small changes of the number of workers or moving workers between workplaces, have a significant impact on the total processing time. Better results were achieved using more combinations. As proved by experiments, the best labour allocation seems to be the *Variant 5: Cleaning and varnishing* 4 => 7, *Visual inspection* 28 => 27, *THT assembly* 28 => 27, *Functional test* 5 => 7, *Final assembly* 10 => 9, *Final inspection* 8=>7.

The model with labour allocation using *Variant 5 (Model 1)* has been used for testing different ways of choosing work orders from the buffers. The impact of changing the sequence of the line order entry has been analyzed, from which two new variants arose.

- ***Model 1 –*** Pallets are chosen from the buffers randomly, after operator finished his work on previous production order and put it into the next buffer.
- ***Model 2 –*** If the operator has not worked on any production order yet, the order is chosen from the buffer randomly. If he already worked on any order he looks for the same order type in the buffer and chooses it. If not, the next order is chosen randomly.



WITNESS
Machine Statistics Report by On Shift Time

Name	% Idle	% Busy	% Setup	No. Of Operations
Konecna_montaz(2)	60.25	31.22	8.53	14
Konecna_montaz(3)	57.10	34.25	8.65	11
Konecna_montaz(4)	53.67	35.07	11.26	13
Konecna_montaz(5)	55.32	38.66	6.02	11
Konecna_montaz(6)	53.12	39.34	7.54	12
Konecna_montaz(7)	65.33	24.58	10.09	14
Konecna_montaz(8)	63.31	27.15	9.55	12
Konecna_montaz(9)	65.32	28.14	6.54	12
Konecna_montaz(10)	61.29	32.88	5.84	10
Zemniaci_test(1)	66.95	27.77	5.29	40
Zemniaci_test(2)	70.34	23.35	6.31	42
Zemniaci_test(3)	70.66	22.44	6.90	40
Konecny_test(1)	69.78	23.24	6.98	34
Konecny_test(2)	67.10	26.14	6.76	31
Konecny_test(3)	69.22	24.10	6.68	30
Konecny_test(4)	67.57	25.22	7.20	31
Konecny_test(5)	72.92	20.16	6.92	31
Oprava_2	68.89	31.11	0.00	35
Konecna_kontrola(1)	88.25	7.34	4.41	20
Konecna_kontrola(2)	86.15	10.28	3.57	19
Konecna_kontrola(3)	88.07	6.96	4.96	19
Konecna_kontrola(4)	86.94	8.92	4.14	20
Konecna_kontrola(5)	85.50	10.46	4.04	19
Konecna_kontrola(6)	86.48	8.92	4.60	18
Konecna_kontrola(7)	85.75	10.30	3.96	18
Konecna_kontrola(8)	89.05	7.39	3.56	21

Fig. 4. Example of results from WITNESS simulation

- ***Model 3 –*** Work orders are chosen in the order from number 1 to number 10.

Comparison of the simulation results from all three models has shown that the assumption about the possibility to shorten the total processing time by decreasing the setup times was right. Further, using Model 2 always led to the best simulation results.

The results achieved with Model 3 were mostly the same as the ones achieved with Model 1, but only with worker allocation from the *Variant 5.* Using the original worker allocation the results were better with *Model 3*.

The possibility of using *Model 3* in practice depends on specific conditions, because connecting the orders to bigger units does not necessarily have to be a good solution for the production (e.g. if a defected part is found on the board, the whole order has to be repaired).

The best solution for this part of production line seems to be a combination of worker allocation from the *Variant 5* and the way of choosing orders used in *Model 2.* Time savings were from 10 to 20% (depending on order sizes).

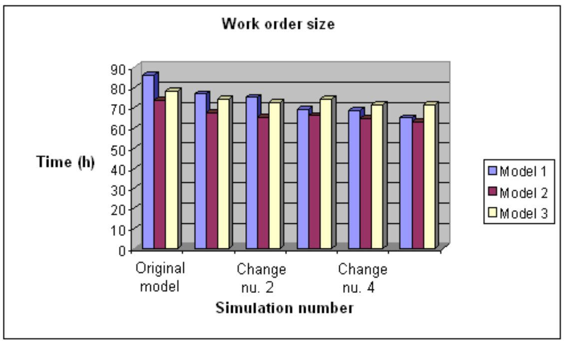


Fig. 5. Comparison of results for Models 1-3
- total average processing time for one of the order sets in original model and Variants 1-5

6 CONCLUSION

The presented case study shows the significance of simulation modelling for the production systems improvement. A multi-product manufacturing system that provides a make-to-order manufacturing was analyzed. In such a system with a very complex dynamics, predicting the local parameter changes influence on the system performance is very difficult. Simulation modelling and analysis using the sophisticated simulation software helps understand the bottlenecks and reserves of the system and to suggest and verify the impact of changes on the system performance. The simulation model proposed is applicable also for solving other complex operational problems.

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