Simulation of a production system of digital factory model using additive and conventional technologies

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Abstract

Nowadays the great emphasis is placed on making production as efficient as possible while reducing production costs. For this reason, before introducing new technologies into production, companies want to make sure that innovation will pay off and will remain competitive. The aim of the paper was to create a model of a digital factory and then to make several variants of simulations. This production system uses additive technologies (3D printing) along with conventional technologies. The simulations were done in Plant Simulation software from Siemens and they should identify bottlenecks in the production system and verify the correctness of capacity calculations. Subsequently all simulations were evaluated and compared with each other.

Key words: Simulation, Production Planning, Additive Technologies, Analysis of Bottle Necks, Plant Simulation

1. Introduction

The topic described in this paper deals with Digital Factory simulation through usage of Digital Factory tools. The tools of the digital factory are now widely used in industry to further enhance companies capability to flexibly react on either product or production system changes. They are also used for simulation of current or future state of production system. In this article the tools are used to simulate fictive production system which is using the combination of additive and conventional production technologies. This combination is not common in the industry, mainly because of current high production cost of printed parts. But thanks to technological progress in additive technology, this mean of production becomes more usable in serial production.

1.1. Components of production system

All created variants simulate the production of four different types of products (artifacts). These products were marked with letters A, B, C, D. Some of them have to be milled after the heat treatment (products A and B) and some are machined on CNC milling machines (products C and D).

1.1.1. DMLS printing

Nowadays, additive technologies are widely used. It is possible to produce very complicated products, even from different materials (metal, plastic, chocolate, etc.). Their disadvantage is the high purchase costs. In our case, we used machines that operate on the DMLS (Digital Metal Laser Sintering) principle. In our case, DMLS printers print a palette containing 20 artifacts. Each pallet always contains only the same kind of artifacts.

1.1.2. Wire cutting

Supports that are an integral part of 3D printing technology are removed at this workplace as well as separating individual artifacts from the motherboard.

1.1.3. Heat treatment

Each sample must be heat treated. In particular, each product must undergo stress relief annealing. Annealing for 120 minutes with 50 pieces and annealing all kinds of products.

1.1.4. Tumbling

Tumbling is applied only to products A and B. The batch was choosen for 40 pcs and it doesn´t depend on type of product. The granulate used for tumbling can be used multiple times.

1.1.5. CNC milling

Machining takes place on CNC milling machines, where machining of shaped surfaces occurs. Only products C and D are processed.

1.1.6. Quality control

All 100% of the products must pass through dimensional and shape control so that the customer does not get the wrong piece (scrap). The inspection takes place at the end of the manufacturing process and is performed on the CMM due to the speed and accuracy of the measurement as well as the way the measured characteristics are evaluated.

1.2. Material flow

The diagram below (Fig. 1) shows the proposed material flow. The used simulation software - PlantSimulation can show us the material flows using the Sankey diagrams. These diagrams differentiate the product type and the line thickness indicates the number of products.

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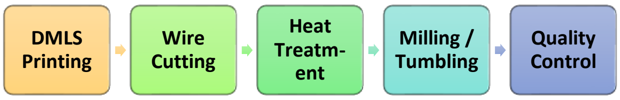

Fig 1*. Established manufacturing process of the production system*

2. Creation of the simulation model

Plant Simulation software from Siemenes was used to create simulations. It is part of Tecnomatix's digital factory tools. Almost anything can be simulated in it - from traffic junction utilization to complex simulation of the entire production system. The PlantSimulation model can be created in 2D and 3D, where CAD models of halls, machines or products in .jt format can be loaded into the simulation model for better representation. Plant Simulation itself includes a fairly large library of machine models, transporters, etc.

2.1. Simulation model set-up

Setting the model needs to be paid more attention because it is crucial to get the right simulation results. The simulation model is made up of many components. The machine is added using the SingleProc. Production times can be set directly or with TableFile. Another important parameter is setting shift via ShiftCalendar. Individual Singleprocs are connected by Connectors. We need to determine the beginning (Source) and the end (Drain). At the end is necessarily to set a EventController where must be set the simulation length.

2.1.1. Bufferu set-up

The buffer, or intermediate storage, had to be placed in front of each workplace or machine. Their size plays a large role during the simulation. If the buffers were too small, the production could be suspended due to depletion in the production hall. It is also necessary to set the buffer type (Queue or Stack). Queue can be understood as FIFO (First In First Out) and Stack as LIFO (Last In First Out)

2.1.2. Shift Calendar set-up

The ShiftCalendar sets individual shifts. It is possible to set their time duration, number and length of individual breaks and it is also possible to include eg public holidays when they are not working. Individual ShiftCalendar can also be used on multiple machines to speed up the creation of a simulation model.

2.2. Variant 1

In the first variant was created a digital design of the production system (Fig. 1) and also the capacity calculations that can be seen in Tab. 1. Capacity calculations were made for the expected number of manufactured pieces for the selected period of 183 days to 15,000 pieces.

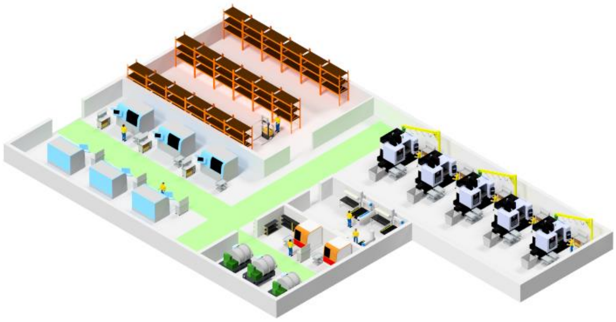

Fig. 1. *3D model of the fictive production system*

The MS Excel spreadsheet editor was used for the calculations. One of the goals of the simulation will be verification of capacity calculations and subsequent optimization of the production system. The shift at each workstation (machines) has been set so that DMLS printers are not blocked by other machines and are used to the maximum. This is mainly due to their large acquisition costs. A simulation model (Fig. 2) was also created to set all parameters (shift, production time, etc.).

Table. 1. *Capacity calculation*

Workplace	**Manufacturing time**	**Set-up time**	**Shifts**	**No. of machines**
	t_{ACi} [min]	t_{BC} [min/batch]		
DMLS printing	128.6	40	3	6
Wire cutting	12,86	20	1	2
Heat treatment	2,4	12,5	1	2
Tumbling	6,67	10	1	2
Milling	100	3	2	5
CMM	6	5	1	2

2.2.1. Evaluation of variant 1

Since the capacity calculations did not include handling times and the size of the buffers was not solved in any way, the number of produced pieces for chosen period was only 10 463 pieces (capacity calculations were made for 15 000 pieces). Therefore, in the next variant, it will be necessary to increase the size of the buffers so that the printers are not blocked

Table. 2. *Results of simulation - Variant 1*

Type of product	**No. of produced products**
A	2 609
B	2 614
C	2 620
D	2 620
TOTAL	**10 463**

2.3. Variant 2

The second variant is different from the previous one in that the buffer capacity had been increased as needed. The figure (Fig. 2) shows the simulation model. Its graphic design is very simple because the individual workstations were created separately and then inserted into the main frame. Fig. 2 also shows Sankey Diagrams, which tells us what kind of product it is. The line thickness indicates the number of pieces (the thicker the line, the more pieces will pass).

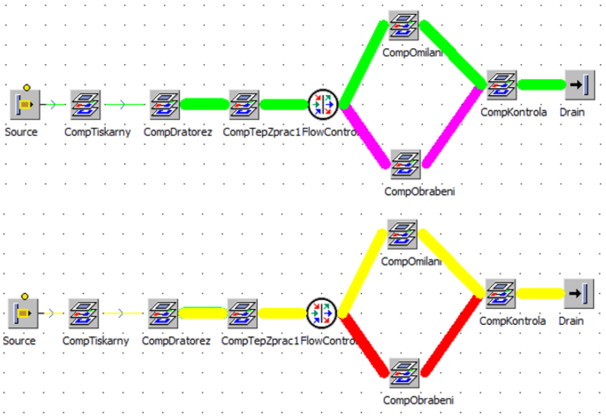

Fig. 2. Sankey diagrams

2.3.1. Evaluation of variant 2

According to assumptions, the increase in buffer capacity has led to an increase in the number of units produced. The cause of blocking DMLS printers was found - CNC milling machines did not manage to produce and a large queue of products was waiting to be machined. A total of 10,693 pieces were produced during the reporting period (Table 3.).

Table 3. *Results of simulation - Variant 2*

Type of product	No. of produced products
A	2 668
B	2 671
C	2 678
D	2 676
TOTAL	**10 693**

2.4. Variant 3

The last variant is the most complex of the made variants. It has been reduced the number of machine tools (5 to 4), tumbling machines and CMM (2 to 1). Also, the buffer capacity has been increased to limit the entire production system. In the previous variant, it was found out that CNC milling machines are not able to work and a there were formed a product queue at their workplace which blocks other machines. For this reason, the number of CNC machines has been reduced from 5 to 4, but at the same time the shiftability of all CNC milling machines has changed (two shift operation has become three shift operation). Among other things, the product logistics of the production hall was solved. Conveyors and transporters were placed in the simulation model. As this variant is the most sophisticated, there is also a 3D view of the simulation model.

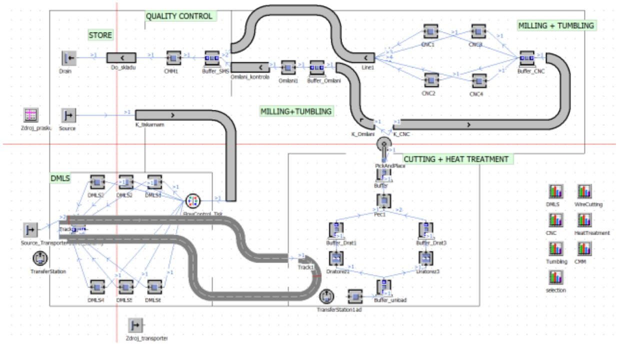

Fig. 3*. 2D model of variant 3*

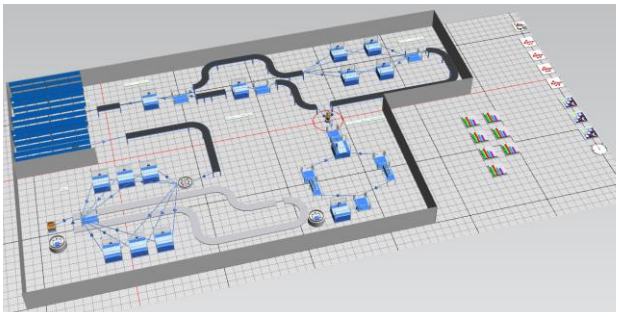

Fig. 4. *3D model of variant 3*

2.4.1. Evaluation of variant 3

A total of 11 562 pieces were produced during the reporting period. The number of individual products is shown in Table 4. This value has increased over previous variants. This was done by eliminating the buffer size issue. A graphical representation is used to illustrate the usage of individual machines (Fig. 5).

Table 4. *Results of simulation - Variant 3*

Type of product	No. of produced products
A	2 878
B	2 888
C	2 898
D	2 898
TOTAL	**11 562**

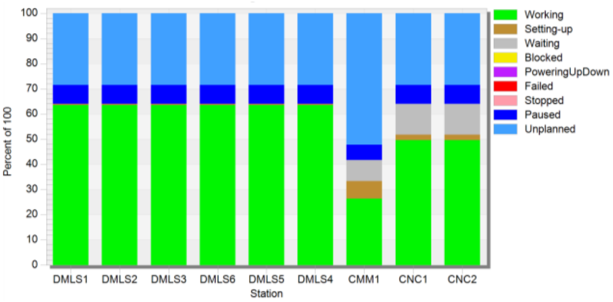

Fig. 5. *Graph of the usage of selected machines - variant 3*

3. Evaluation

The table below (Table 5.) shows the number of machines in each variant. The number of machines had been changed only in the last variant (Variant 3). The entire production system was subordinated to the maximum utilization of DMLS printers, due to their high purchase price.

Table 5. *Number of machines in all variants*

Workplace	No of machines - var. no. 1 and no. 2	No. of machines – var. no. 3
DLMS printing	6	6
Wire cutting	2	2
Heat treatment	2	1
Tumbling	2	1
CNC milling	5	4
CMM	3	1

In table below (Table 6.) you can see the number of produced products in each variant. Thanks to the bigger capacity of buffers in the variant 2 the number of produced products has been increased by 230pcs. In the last variant (Variant 3) the number of some machines were changed. It was also necessarily to change number of shifts at CNC milling machines (from 2 to 3 shifts per day). These changes meant an increase the number of produced product of another 869 pcs during the monitored period.

Table 6. *The comparasion of all variants*

Variant	No. of produced products
1	10 463
2	10 693
3	11 562

4. Conclusion

In this paper a digital model of a fictive factory that uses additive technology along with conventional technologies was made. First step was the design the concept design of production system. Based on the created capacity calculations, three variants of simulations were created, which gradually optimized the proposed model of the production system and found bottlenecks in the production system (DMLS printer and CNC machining). Capacity calculations had been made for 15 000 pcs produced in the reference period (183 days), but the simulations found that these capacity calculations were inaccurate. The result of the simulation in the last variant says that a total of 11 562 pieces could be produced during the monitored period. The main reason are not ideal workplace ques, which are causing latency in production flow and not precisely optimized sizes of buffer and logistic. Those are the main reason for differences between simple capacity calculations and simulation of the digital factory model.

In the case of further optimization, it would be necessary not only to consider fully automated production, but also to involve workers, scrap production, precise machine placement in the simulation and mainly production planning and forecast of production, that would produce even closer resemblance to real production system.

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