Production Process Planning in Additive Manufacturing and Conventional Machining Technology Manufacturing System

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Main goal of this study is to describe and design manufacturing system which is using Additive manufacturing technology for production of semi-finished products and conventional machining technology for finishing operations, then demonstrate requirements of such production on simulation model on production planning and then analyze and summarize the outputs of the production model. The model is made with aid of modern Digital Factory tools. The main purpose of the model is to provide a complex tool for this study in order to analyze and optimize the fictive production system in needed range and complexity. The topic of Rapid Prototyping and Additive manufacturing technologies is very recent topic in industry. But still, there are only few examples of production systems, which are really using Rapid Prototyping technologies as a part of the production or production line. The advantage of these technologies is their versatility, but on the other hand, as a part of production system, they can have different demands on for example production planning, area consumption or maintenance, that can affect whole production system.

Keywords: Additive Manufacturing, Metal Printing and Machining, Digital Factory Tools, Production Optimization, Production Capacity Planning

1 Introduction

In this paper the Digital Factory tools are used through Plant Simulation software from Siemens to design and optimize fictive model of production system with Additive manufacturing and conventional machining technologies. Because of the development of the model, it will be possible to assess the impact of using Rapid Prototyping technologies in conventional system.

Digital factory tools can be used during whole lifecycle of the product – from preproduction phases, preparation, up to its production and following expedition to the customer. Some companies used them to make their production more effective or to increase the production capacity. With digital factory tools it is much easier to plan, analyze, simulate and to manage the whole production. These tools can also be used outside of production planning, for example in Ergonomics, data management, etc. [1,2]

2 Key features of the digital factory model

First steps in model design was to establish which products will be manufactured and on which technologies (machines). For some production variability, 4 types of products were established (simply named A, B, C and D). The core of the model is usage of DMLS (Digital Metal Laser Sintering) 3D printers. The products are supposed to be printed on one substrate plate in batch – not only 1 product during one print. The other manufacturing technologies were incorporated into the systems with knowledge of processing of the metal 3D printed parts and with knowledge of conventional manufacturing technologies. Exact types of machines are not specified in this study. Simplified manufacturing process is shown in the Fig. 1 (printing – EDM wire cutting – heat treatment – milling (A, B)/tumbling (C, D) – control). Products are printed on DMLS 3D printers, then separated from the substrate plate on EDM machine (Electrical Discharge Machining), heat treated in ovens, machined on Milling centers and in the end of the production process is quality control on CMM machines (Coordinate-measuring machine) and on 100% of the production. The warehouse management or expedition processes are not parts of the model. [3]

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

Due to maximum usage of DLMS 3D printers it was necessary to adapt the rest of the production throughout all variants of the model. The basic presumption of the model is, that there will be 6 DMLS 3D printers in the production system, which should print roughly 15000 pcs of semi-finished products per year (roughly 7500 pcs per 183 days). This number came from first simple capacity calculations and represents minimum production of the unoptimized production system. The number of machines in other workplaces was modified to achieve highest possible usage of DLMS 3D printers. [4]

3 Design of the digital factory model

During the development of the model 3 different variants were made. Specification and different features of every variant will be described in this chapter.

The variant no. 1 was the first one made and is the least complex of all variants. It was needed mainly for rough setting of the input parameters. It includes capacity and cost calculations, a model of production layout and the first simulation in Plant Simulation. On the basis of the initial simulation, the optimization of the production system is carried out in another variant.

The variant no. 2 is more wide and optimized compared to the previous variant. Main features are presence of the set-up times and presence of the intermediate storage (buffers). The purpose was to find a bottleneck in the production process and to come up with more optimal solution of production system or to optimize count of machines either way, to ensure most productive and effective production system.

The variant no. 3 was about design of a simulation model that would eliminate the drawbacks of the second variant – blocking of some machines, transportation of products through the production hall, optimized set-up times, usage of robots etc. This last variant of the model is the most complex and closest to a real physical production system. [2,7,8]

3.1 Variant no. 1 – Design and results

The first variant of the study served mainly for rough design of the production system. Estimated cost calculations, number of machines and employees were established in this variant. In Tab. 1 are shown capacity calculations on each work place and production times (manufacturing and non-manufacturing times). These production times are same in all variants. Quantity of products (q_i) manufactured was set to 15000 pcs per year (7500 per monitoring period of 183 days). In this stage of study, manipulation times were not specified, set-up times were absent in the simulation and buffers or product distribution through the system wasn't established in the model during the simulation. [5,6]

Tab. 1 *Capacity Calculation*

Workplace	Manufacturing time	Quantity of products (year)	Set-up time	Shifts	Number of machines	
	t_{ACi} [min]	q_i [pcs/year]	t_{BC} [min/batch]		Teor.	Real
DMLS printing	128.6	15000	40	3	5.82	6
Wire cutting	12.86	15000	20	1	1.99	2
Milling	100	15000	3	2	4.5	5
CMM	6	30000	5	1	2.37	3

In the following Tab. 2 are shown numbers of machines in each work place. Unlike in previous table, in this one are also indicated machines in all work places (heat treatment, wire cutting). Number of machines in HT and WC workplace was determined roughly, without further calculations, because they are not expected to be bottlenecks of the production. During the reporting period (183 days) 10693 pcs of products were made during the simulation (see Fig. 2). It is more than foresight made by simple calculation in Tab. 1. Another part of the variant no. 1 was design of the 3D model of the production's system layout (Fig. 3) according to the calcula1tions presented in this variant.

Tab. 2 *Number of machines – variant no. 1*

Workplace	Number of machines
DMLS printing	6
Wire cutting	2
Heat treatment	2
Tumbling	2
CNC milling	5
CMM	3

Cumulated Statistics of the Parts which the Drain Deleted

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	A	1:00:49:16.9925	2668	1	22.82%	0.00%	77.18%	13.79%	
Drain	B	21:42:34.5084	2671	1	26.17%	0.00%	73.83%	15.69%	
Drain	C	14:48:41.1979	2678	1	25.96%	0.00%	74.04%	13.98%	
Drain	D	13:43:34.5516	2676	1	27.62%	0.00%	72.38%	14.91%	

Fig. 1 *Simulation summary – variant no. 1*

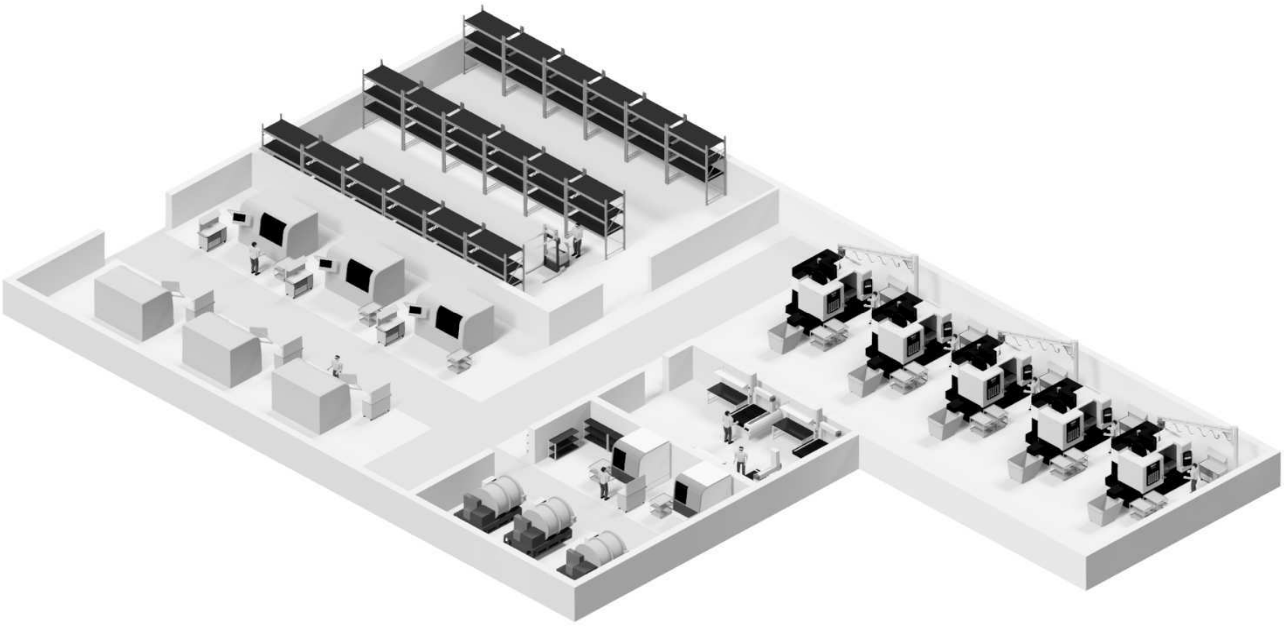

Fig. 3 *3D model of the fictive production system – variant no. 1*

3.2 Variant no. 2 – Design and results

This variant consists of same machines, as the variant no. 1, and their quantity. Big problem of previous variant were waiting times on printers. As a very expensive machine, metal printers should be running continuously to maximize the outcome. Next figure (see Fig. 4) shows layout from the Plant Simulation and also Sankey diagrams. They show material flows (each type of product has its own color). Thickness of lines depicts the intensity of material flow (more products mean wider line).

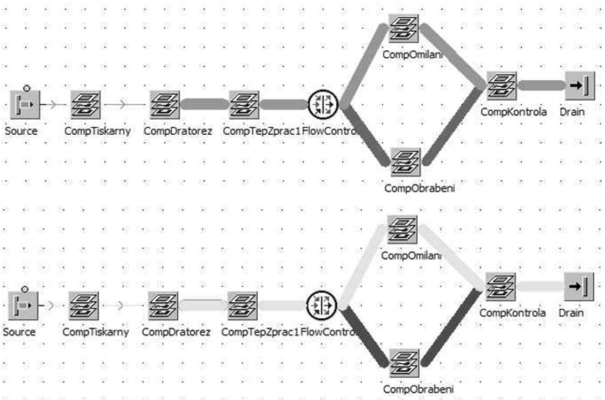

Fig. 4 *Sankey diagrams*

From the Fig. 4 it may appear, that there are only a few machines at each workstation. Each workplace was created separately and then inserted into the basic frame. In this variant, there was no solution for the transport of products between individual workplaces, which affected the number of produced pieces during the monitored period. The total number of machines is the same as in previous variant (see Tab. 2).

According to the results of the simulations of variant no. 1, few features had to be modified, such as incorporating buffers of defined size, incorporating set-up time (this will decrease the productivity but push the model closer to real production system) and the exchange rate on the individual workplace. To maximize the productions of the printers was the main goal. The number of machines and shift calendar stood the same. All milling machines run for three-shift operation – it is same for the variant no. 3.

During the reporting period (the number of pieces produced during the monitored period as well as the time are shown in Fig. 5) 10463 pcs of products were manufactured, which is even slightly less in comparison with variant no. 1. Better material flows lead to increase of production in this variant, but at the same time, the usage of set-up times negated this fact. From Fig. 5 it is also clear that each product waits for manufacturing on average from 76.47% up to 88.35% of the lead time – this is caused mainly by variation of production, long production times and difference between occupied shifts on each technology. Due to this fact, optimized buffers are essential for production systems using Additive technology.

Cumulated Statistics of the Parts which the Drain Deleted

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	A	1:01:13:24.2681	2609	1	22.28%	0.00%	77.71%	13.47%	
Drain	B	22:13:45.7701	2614	1	24.70%	0.00%	75.29%	15.38%	
Drain	C	14:56:18.8511	2620	1	26.21%	0.01%	73.78%	13.86%	
Drain	D	14:00:24.3233	2620	1	30.41%	0.01%	69.59%	14.78%	

Fig. 5 *Simulation summary – variant no. 2*

3.3 Variant no. 3 – Design and results

The last variant is the most complex of all presented variants. Against the second variant, in this one were optimized set-up times and there were added logistics features, such as conveyors, automatic transporters and robots for a basic manipulation operations. The 2D visualization of the layout of variant no. 3 is in the Fig. 6. In this variant a rough 3D model in the Plant Simulation software was made (see Fig. 7) from the 2D layout. [6,7]

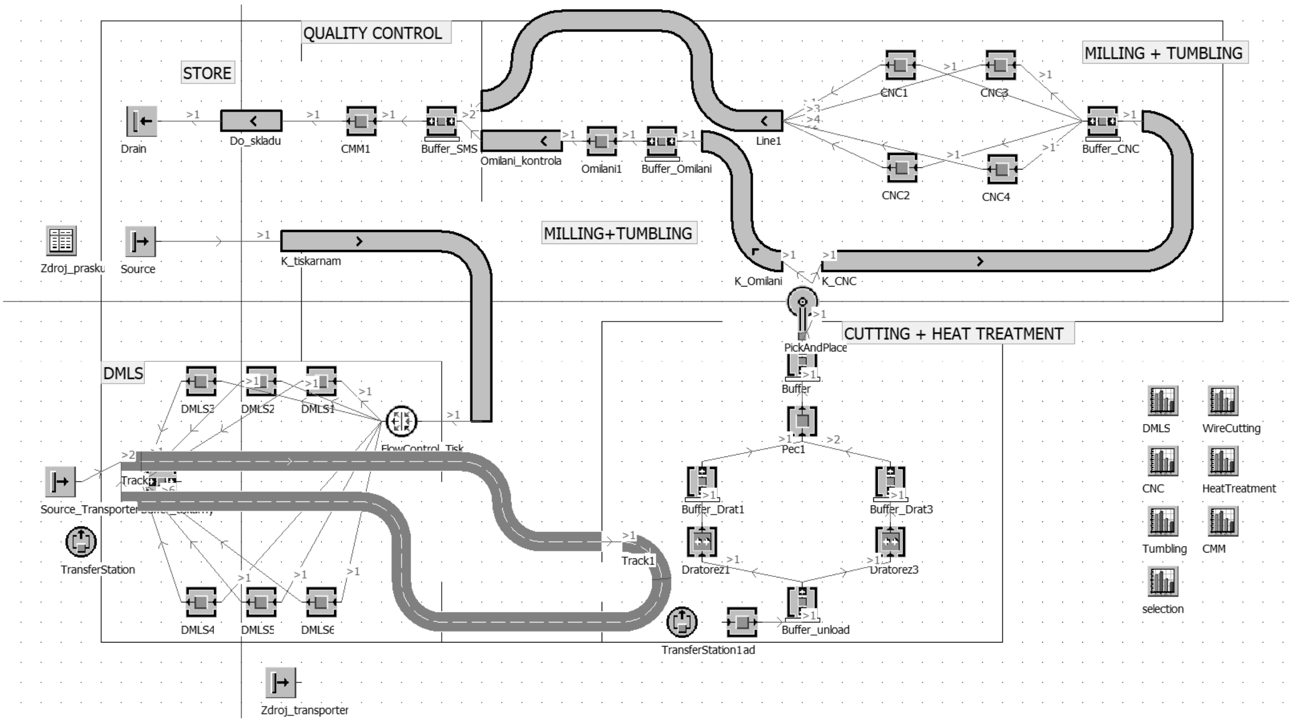

Fig. 6 *Model and layout of variant no. 3*

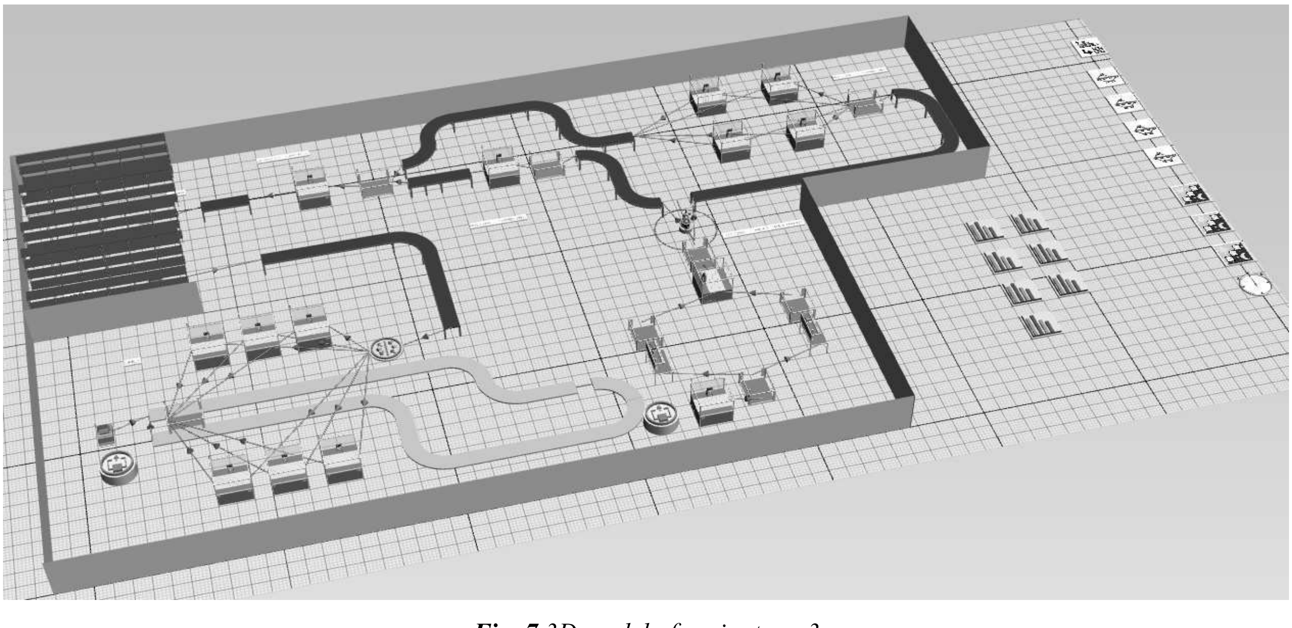

Fig. 7 *3D model of variant no. 3*

In following figure (Fig. 8) are shown usages of some workplaces. Dark blue color represents necessary pause (corresponding with Labor Code), light blue color shows shifts during which machines are not supposed to work. Light brown indicates set-up times of machines. Finally, the green color indicates total working (in this case machining) time of the devices – the main aim of all production systems should to be maximize machining time.

Biggest change in comparison with previous variant is the optimization of machines, mainly in milling (from 5 to 4) tumbling (from 2 to 1) and of CMM machine (from 3 to 1) in quality control department. These changes were made to maximize the effectivity without sacrificing productivity of the whole production system. Lowering the numbers of machines, due to other optimization changes, didn't negatively influence effectivity of printers. The average time distribution through monitored period (183 days) is apparent from Fig. 8.

The unplanned period is caused by decision, that there will be no work on weekends. If the weekends will not be taken into consideration, printers are working 88,8% of the given time in working shifts (no waiting times), milling machines only on 70% and CMM machines only 55% (caused mainly by longer set-up times common when you using this technology). When all other important production features were part of the model at this point, it was possible to definitely optimize counts of machines without further need to leave space in capacity calculation. Due to these facts 2 CMM and 1 milling, 1 tumbling and 1 heat treatment (oven) machine were deleted from the model. The total number of machines used in this variant is shown in Tab. 3. As can be seen in Fig. 9, the number of produced pieces increased thanks to properly sizing buffers, adding logistics and optimizing the model up to 11562 pieces per monitored period. Compared to the variant no. 2, this is an increase in production volume of 9%.

Tab. 3 *Number of machines – variant no. 3*

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

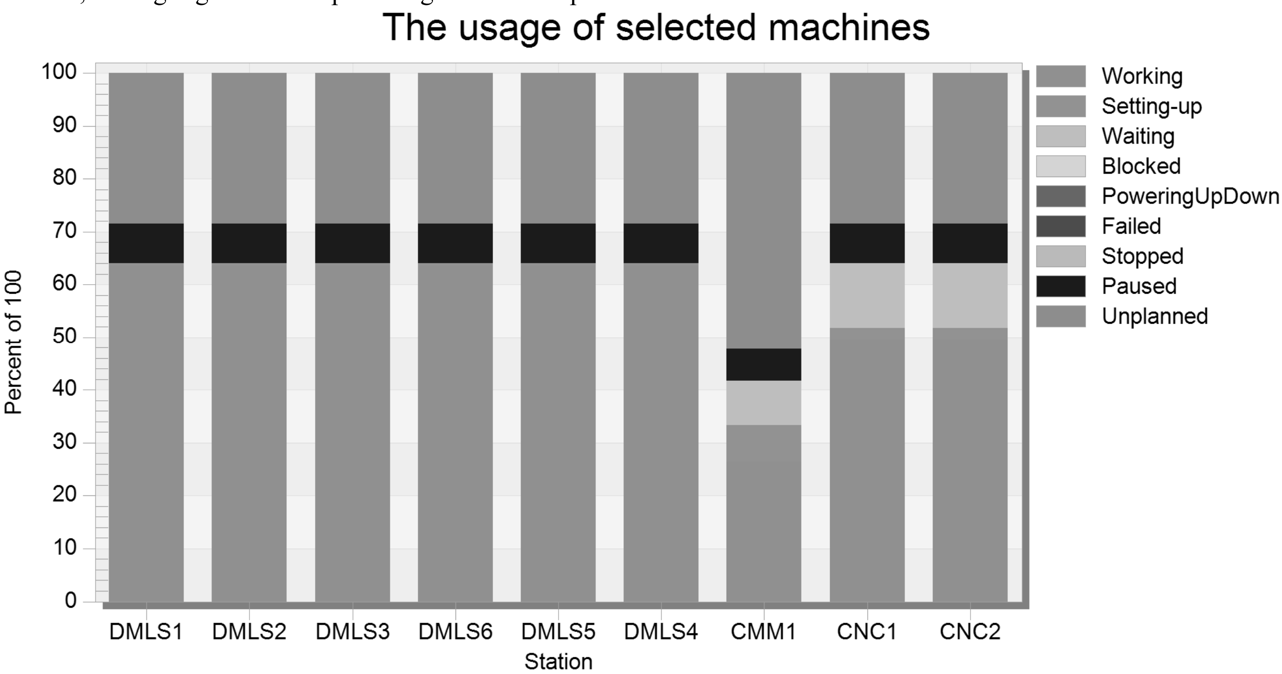

Fig. 8 *The average usage of selected machines – variant no. 3*

Cumulated Statistics of the Parts which the Drain Deleted

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	A	1:12:55:14.9259	2878	1	13.78%	29.38%	56.85%	8.90%	
Drain	B	1:07:54:47.0872	2888	1	17.19%	34.23%	48.58%	10.28%	
Drain	C	23:16:49.2827	2898	1	15.07%	47.45%	37.48%	8.34%	
Drain	D	20:06:04.9103	2898	1	18.23%	55.64%	26.13%	9.66%	

Fig. 9 *Simulation summary – variant no. 3*

4 Summarization and comparison between variants

Each of the three variants contained development of some crucial part of the finite model – variant no. 3. Variant no. 1 served as the foundation in development of variant no. 2 and no. 3. Basic form of the model was described in this variant, containing different used technologies, production times, etc.

The results of the simulation of variant no. 1 aren't that relevant, because there was no transport time between each work places or no set-up times. Also the workplaces weren't balanced.

Second variant built up on variant no. 1, taking in consideration the risen fact, which workplaces had to be balanced differently, that set-up times and shift optimization are crucial for proper model function and results. The number of produced parts almost didn't change. There definitely was room for another optimization of the model and further balancing of the capacities.

Variant no. 3 is the last variant, which represents the final model of the production system. Again, the count of the 3D printers stood the same, but thanks to balanced capacities it was possible to lower the count of other machines (see Tab. 3) without negative effect on effectivity of the production. Because of lower count of machines, the real production system would be more economical effective, and also it would be possible to lower the cost of the product. This measures were only possible because of series of optimization iterations during development of the digital factory model, optimized size of buffers and embedded logistics accompanied with optimized manufacturing process and material flows. Result of production simulation in this final variant is 11562 pieces of products per period (calendar 183 days), which is more than in less optimized variant no. 2. by 9%. It may appear as rather small number, but in consideration, that 3 expensive machines were not used, it is still good result.

This numbers and progression of the model variants depict, that in production systems with Additive and machining technologies is essential to focus on the balancing of the production behind printing, to have stable and short set-up times, and optimized volume of buffers. Adding conveyors rather than manipulation devices proved a better approach, because the conveyors can serve as buffers themselves and further support balancing of the production.

5 Conclusion

This paper presents results of a study, whose aim was to design simulation model within Digital Factory concept of production system with Additive manufacturing and conventional machining technologies and based on this model to present differences against standard production system and to highlight parameters of production, that are vital for such production system to function properly. Recently, common practice is to use Additive technologies for piece production or for design and manufacture of prototypes. Due to its limitations, such as relatively long production times, high cost and product quality, there still are not many examples of these technologies being used in serial production. Because of this fact, there are not many experiences with production and process planning of such production system. Within this paper, approach to design and programming of combined production system was described on developed variant of the digital factory model.

In comparison with standard production system based on conventional machining, system with combination of Additive and machining technologies is much more sensitive, based on the results of production model simulations, to certain parameters, mainly increased size of buffers, set-up times or number of shifts on every technology. This sensitivity is caused by long manufacturing times of Additive technologies accompanied by heat treatment, considerable cost of this technologies and also complicated and heterogeneous volumes and shapes of the products themselves. It is debatable, when there will be common practice to use Additive manufacturing in mass serial production, but due to its benefits and with consideration of the technology and industry development, it is possible, that this combined type of production system will appear more frequently with further progresses in this part of industry.

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