WORK STANDS MODELING IN ADDITIVE MANUFACTURING

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Abstract: With the development of new technologies, companies are looking for solutions that will support implementation of production tasks and orders. This needs could be fulfilled by set of solutions that allow for their further development. However, as companies develop, they must also pay attention to the problem of work process planning. The development of new technologies, including automation and robotization of the production line, has also contributed to changes in the area of workplace design and analysis. Along with the changes made to the workplaces and production line, there is also the problem of their ergonomics and safety. There are many studies in the literature on job requirements, recommendations and standards for job design. In the article, attention is drawn to virtual research and analysis of ergonomics of the workplace. In order to better plan production processes, right data to support organization and safety is needed. Nowadays, enterprises are increasingly looking for better solutions in this area as well. Because of speed of changes setting up on market and in company environment, requires real time changes in planning and designing work processes. This is important because of the rapid and emergency procedure for printing components, which are temporarily unavailable on the market and the demand is huge. Like in the case of the printing mask endings for hospital staff and other users in the fight against SARS-CoV-2 pandemic.

Key words: additive manufacturing, planning printout, workplace

1. INTRODUCTION

For better plan production processes, there is need to have the right data to support organization and processes inside the organisation. Nowadays, companies are increasingly looking for better solutions in this area [3, 7, 16]. In addition to simulation, companies are starting to use for example Virtual Reality. Due to the speed of on the market and in the company environment, it requires real-time changes in planning and designing work processes to. There is a need for continuous analysis and design of processes and workplaces in order to achieve better parameters [12, 17, 18]. Develop of additive manufacturing technology and materials have made possibility to use component printing also in industry or medicine. With increasing interest of this area and the personalization of products, there is a need, for analyses and implementation of new solutions in the workplace and in the printing area. The problem also increases, when companies implement several stations in one place, but with different parameters, batch materials, and the scheduling of printout is realize on several printers at the same time. Also 3D printing can be an interesting alternative for standard production, because of increasing quality of the filaments. Additionally, using the concept of Industry 4.0 and related elements, the company has a chance to realize a more flexible production, for adapt to the personalized needs of customers. This is possible because, this solution (I4.0) includes the existence for example intelligent systems, that are cross-linked. Vertically linked to other processes inside the company and horizontally linked - value-creating networks, that can be managed in real time, from the beginning of order to the end, when the product is delivered to the customer. This is important in terms of personalised products, changing customer requirements and dynamic market [6, 10, 20]. The technologies, that support Industry 4.0 are shown in Figure 1.

Fig. 1. Technologies of Industry 4.0 [10]

These elements are single technologies, but thru developing them, especially Internet of Things, enterprises can become an advanced, self-sufficient enterprises of the future. However, in the article focused on view elements: 3D printing, and integration, to realise a parallel, continuous and flexible printing process, supported by a networked connection of printers and computers. This enables flexible human-machine and machine-computer cooperation in order to make a personalized product in a short time.
In the area of additive manufacturing, there are many articles concerning on: this technology, materials, development of possibilities in various areas, planning of operations, without analyzing the ergonomics of a workplaces or the possibility of developing them [8, 19, 22].
In the article a short development of additive manufacturing and an analysis of the problem concerning on the selected type of workstation are presented. A diagram of data collection from the workplace and ways of storing them is also presented.

2. MATERIALS AND METHODS

Additive manufacturing has developed rapidly in recent years. This is caused by the availability of new materials, that are more durable and suitable for printers. There are many materials available on the market. Each of them have different properties and applications. Popular materials are: ABS (acrylonitrile butadiene styrene), PLA (polylactide), ASA (acrylonitrile styrene acrylate) and PMMA (poly methyl methacrylate). The printout of mask endings realized in Department of Engineering Processes Automation and Integrated Manufacturing Systems, was made of the polyethylene. On the other hand, the development of technology and engineering has allowed to design of better and bigger printers. Over time, the use of printing has also increased. At the beginning, small simple elements were printed. With time, the printouts became more complicated and bigger. for example, houses, elements that are movable, or specialist elements used in medicine [4, 8, 19]. Regardless of the selected printer types and material, the planning and printing process is a complex process, in which many aspects have to be considered and many problems have to be solved at the same time. Especially, if it is industrial printing, realized continuously print on several printers at the same time.

2.1 Realization of the additive manufacturing process

The possibility of using additive manufacturing has many advantages, but also disadvantages. The advantages are [4, 22]:

– make a quick prototype,
– analysing the prototype before starting production,
– access to various materials,
– access to different types of printers,
–access to libraries from any computer (data storage in the cloud),
– possibility to observe the printing.

But disadventages are:

– possible defects in the printed elements,
– high cost of printers,
– long printing time of complex elements,
– possibility of hacking data from the system.

The problem, that appears during the additive manufacturing is also related to the access of the appropriate printers at a defined time. Especially during printing elements on several printers at the same time. As shown on Figure 2, the printout is realized on three printers. This is a set of printers, where only specific types of mask endings could be printed. Finally, 5 types of mask endings and additional elements were printed. The implementation of the tasks depends on the required parameters of the finished elements, input material, etc. Having several printers, which can fulfill customer requirements, the operator sends the task to the concrete printers. However, the printers are not always free. When a failure or a new job appears, all changes must be considered. And then problems arise, namely: which jobs have priority, which priority rules will be applied, or has the manufacturer suitable printers? If the manufacturer fullfils the criteria of the printed parameters and materials, the operator must properly organize the jobs. For this purpose, appropriate scheduling systems are used. This allow make various simulations, and implement the best solutions with existing limitations.

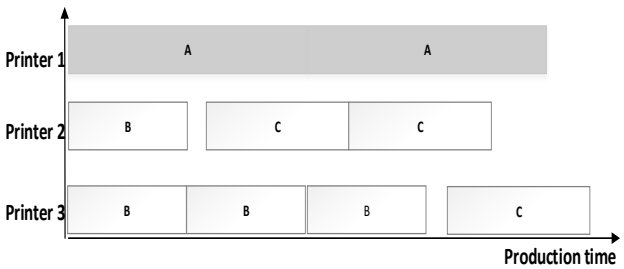

Fig. 2. Example of a printers scheduling

The problem related to the above drawing concerns also, first of all on: the right printing schedule and secondly, to the right number of employees working with printers. Other problems include: the exchange of filaments, complications during printing, incorrect printouts, access to pre-developed models, data generation and storage, appropriate workspace organization. These problems increase, when enterprises use more printers, with different filaments.

Depending on the customer's needs, there are currently several materials from which can be printed elements: metallic, super-alloys, polymeric, composites and ceramics [1, 15].
The increase of interest in the additive manufacturing area by enterprises, makes it necessary to pay attention to several important aspects.

2.2 The problem of workstation placement

The increasingly of better printers and filaments encourage producers, to use this type of manufacturing more widely. Especially, if it can be only a part of the production process from a larger element. The problem arises, when several printers are used at the same time. Of course, the area, where the printers work is a separate area, however, it must be remembered, that during printing, operators must have access to each printer - because of setting up and running of the print, but also because of incorrect prints or printer failures. It is also important to remember, that every printer requires proper access to the filament. This problem must be also considered during planning workplace allocations. In addition to the standard requirements for work space planning, four basic elements must be considered, like on Figure 3 [11].

Fig. 3. Elements of a workspace

Each of elements concern on a different area: information - all data related with printing and planning process, workprocess - description of the printing process, needed materials, components, printing time, etc., development of the workplace - possibility of expanding the workplace, improvement, ergonomics and work safety, environment - all elements, that influence on the employee's work and the printing process.
These elements are the basis of the area work, in particular, but additive manufacturing should be characterised by such features as indicated on Figure 4.

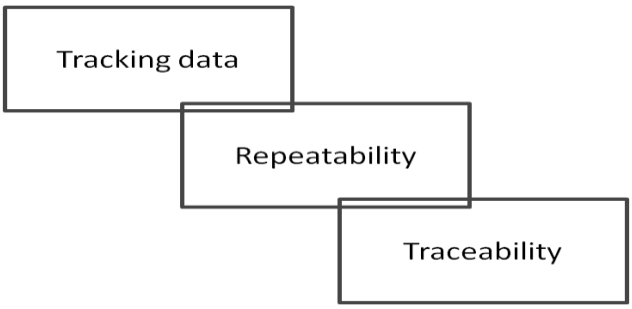

Fig. 4. Most characteristics of a 3-D printing

While analysing the additive manufacturing processes, the above elements should be defined more precisely [4, 8]:

1.Tracking data includes:
–machine-generated data (e.g. technology, machine status, activity, sensor data),
– part data (e.g. part orientation, position, parameters),
– material data (e.g. material type, stock levels),
–post-processing and quality management data (e.g. post-processing steps, compliance requirements),
– data for reporting (e.g. print success vs. failure rate, throughput).

2.Repeatability
Particularly for serial production, but additive manufacturing must be able to maintain the same standards as traditional manufacturing processes.

3.Traceability
To track every step of additive manufacturing workflows, along with the production steps that need to be taken at any stage. Knowing exactly what action has been performed at what time and gives production data back.

All these elements must complete each other. However, the problem of job distribution and workplace organisation increases even more with complex and advanced printers. There are printers, which are used for example for printing houses. In this field, the problem of the work area and the organisation of the workplace is becoming even more necessary research area.
In addition to this problem, another important aspect of additive manufacturing is the problem of a manage these workplaces.

2.3 The problem of workplace management

As already mentioned, the workplace consists of different types of 3D printers, using different filaments. The problem in this area concerns on the proper support by the employee. In the first step, the functioning of such a workplace was analysed. Figure 5 shows an example of a production hall layout with several printers of various parameters and sizes, as well as a warehouse and a room for print operators. There are two operators responsible

for supporting the printers. The most frequent routes, that operators travel on during their work are also marked. It should be noted that, each worker is also responsible for completing the filaments for the printers and sending the finished printouts for control and then to the warehouse.

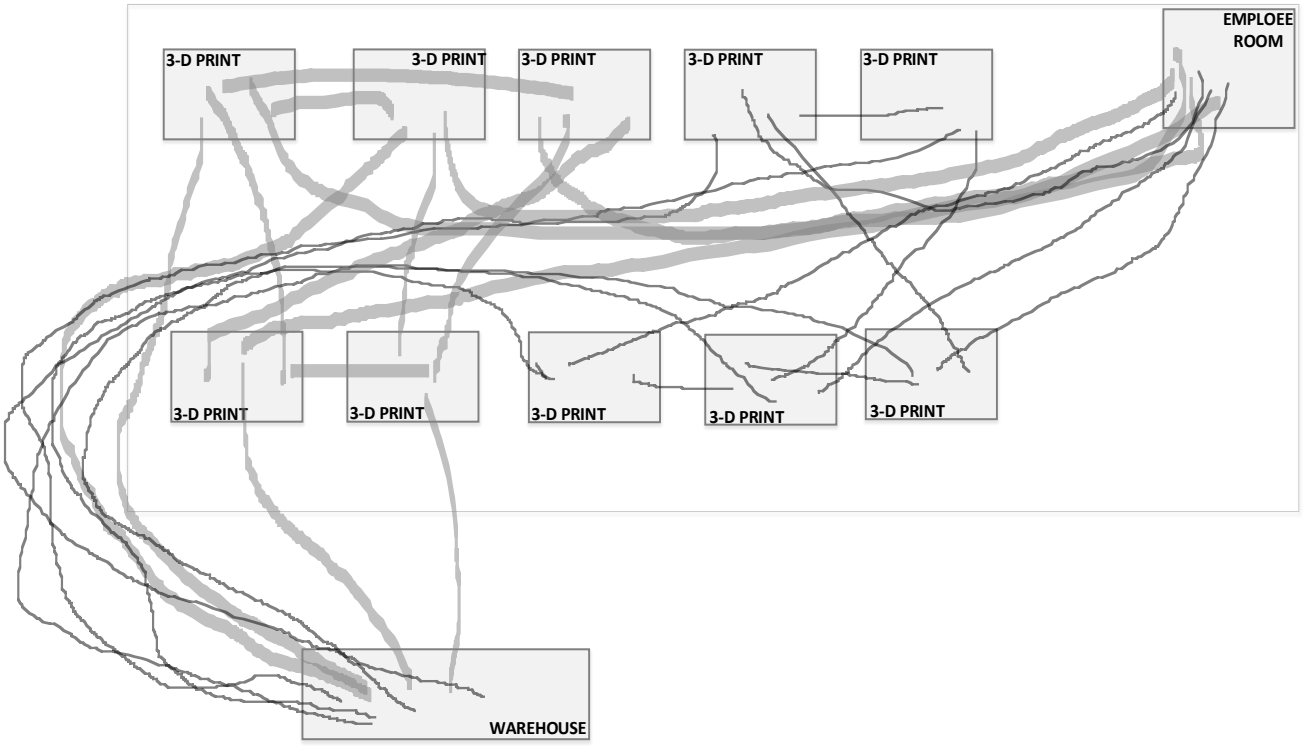

Fig. 5. Diagram Spaghetti for workers on printing place

The problem of the operators working on this workplace, presented by the so-called Spaghetti diagram. This method is used to illustrate the stages of the process by tracking the movement of people, information or materials by drawing lines on a graphical diagram to visualize these movements [2, 21]. Based on the analysis map, it is possible to decide, for example about:

–reduce the paths, by which the material moves (e.g. choose a shorter path),

–relocation of workplaces (if material is moved back and forth),

– the frequency of movement between the different workstations,

–elimination of unnecessary activities (mainly - carrying, packing, unpacking, moving empty containers, etc.),

–unloading the most commonly used crossings and transport paths,

– improve transport.

Considering the layout of the hall and the location of the workstations in the analyzed example, several problems were identified. The first one concerns on the waste of time to move operators from the "print operator's room" to the selected printer, and from the printers to the faraway warehouse for filaments, spare parts, or to put down the finished printouts. The analysis also showed, that the operators, who also are responsible for the CAD models are responsible for: sent the model to the printing, whole printing process, monitor the condition of the input material and the identification of the material in the warehouse. In order to minimize downtime during printing and waste of time, some changes should be made, for example: additional assistance: for monitoring of the printing process; changes in the location of the workstations, including the appropriate print warehouse area; or closer placement of the filament warehouse. A recommended solution is also for example: a system for identifying printing errors and ending batch material, as well as a correction in terms of ergonomics of the workstation and access to the filaments in the warehouse. These improvements can make the preparation and printing process shorter, safer and easier to use.

3. RESULTS AND DISCUSSION

In the era of product personalization, speed in decision-making and changes in planning production are important. The problem becomes more complicated, when the printed elements have to be change at the same time.

3.1 Printing of elements

Execution of production in an emergency situation, where elements are urgently needed, requires the

implementation of complex procedures for preparation and execution of the printout in a short time. In particular, that, the printout is made on several printers at the same time. For this purpose, a system of connected printers and computers may be useful, in order to send print information to a specific printer. On the other hand, the system can be useful, when the selected printer is busy and the printout needs to be moved to the another printer. Figure 6 shows a diagram of required processes needed during realization of the elements printout.

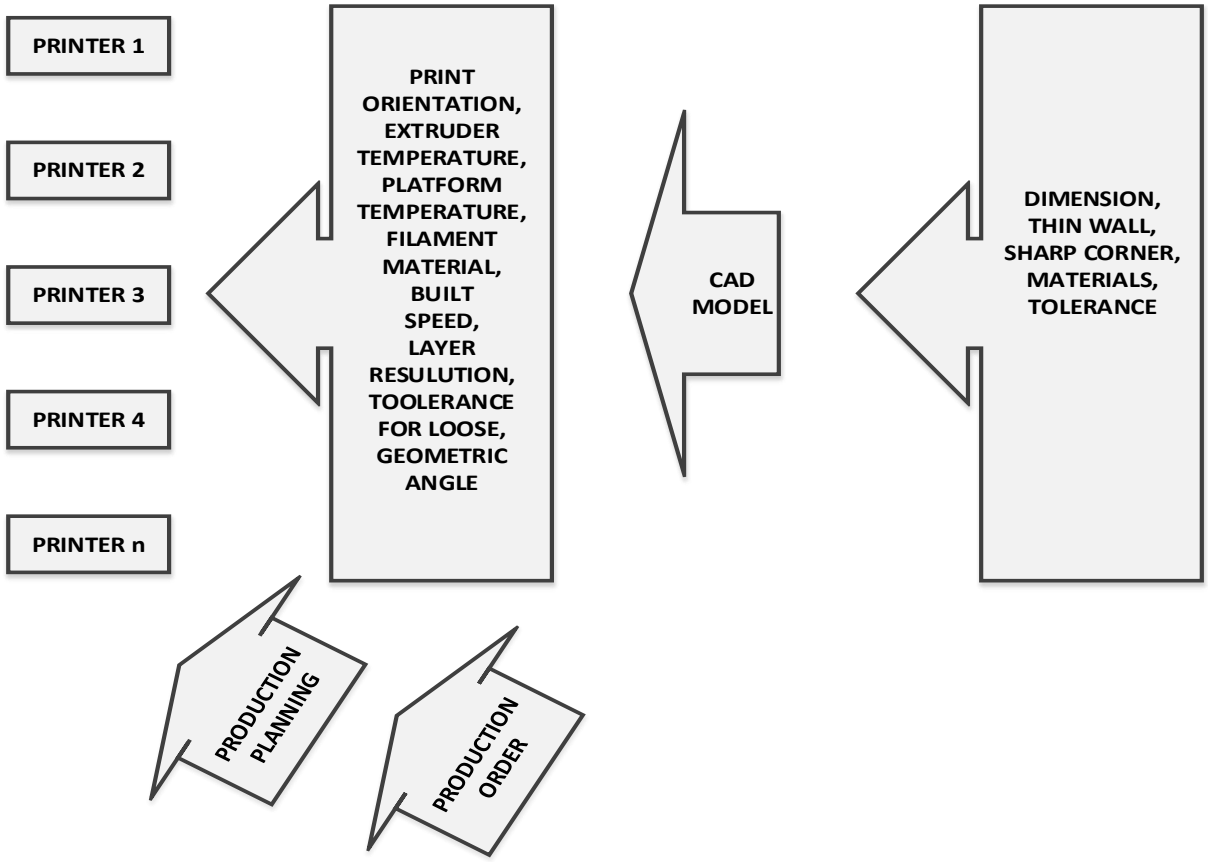

Fig. 6. Schema of processes needed for a 3D printing

In the first phase, the operator must have CAD models, on which the printouts are made. CAD models are created eathier by the operators themselves or are delivered by the customer. Both options before further production are modified properly. It depends of customer requirements and the production capacity of the enterprise. In the next step, if the model fulfills all customer requirements, is sent for printing. The developed models are stored in an appropriate database. Access to the model database, allows operators to make many types of printouts faster, without any additional model analysis. It also gives the opportunity to cooperate with other companies. However, in order to carry out subsequent orders, needed are data about the order, but also information about the current tasks realized in the enterprise. A new order requires new schedules and appropriate production planning, but also access to the newest data. This data are the basis for realize orders, according to the customer's needs, but with higher access to the data, it is necessary to protect it better to prevent data loss.

3.2 Data generation

Because production is being realized, input data such as: amount of printed pieces, dimensions, models, material, etc., are needed. In the next step, data about the work of individual printers are generated: print time, input material, print color, temperature, etc. The collection of this data and information may help realize of future orders. However, the problem is the appropriate storage and analysis of such data. Nowadays, independent databases in the cloud becoming more popular, especially that the accessed is available from any place [5, 14]. Figure 7 shows a diagram of collection and storage of data related to the printout. The diagram shows in general, how complicated in terms of data the printing processes are.

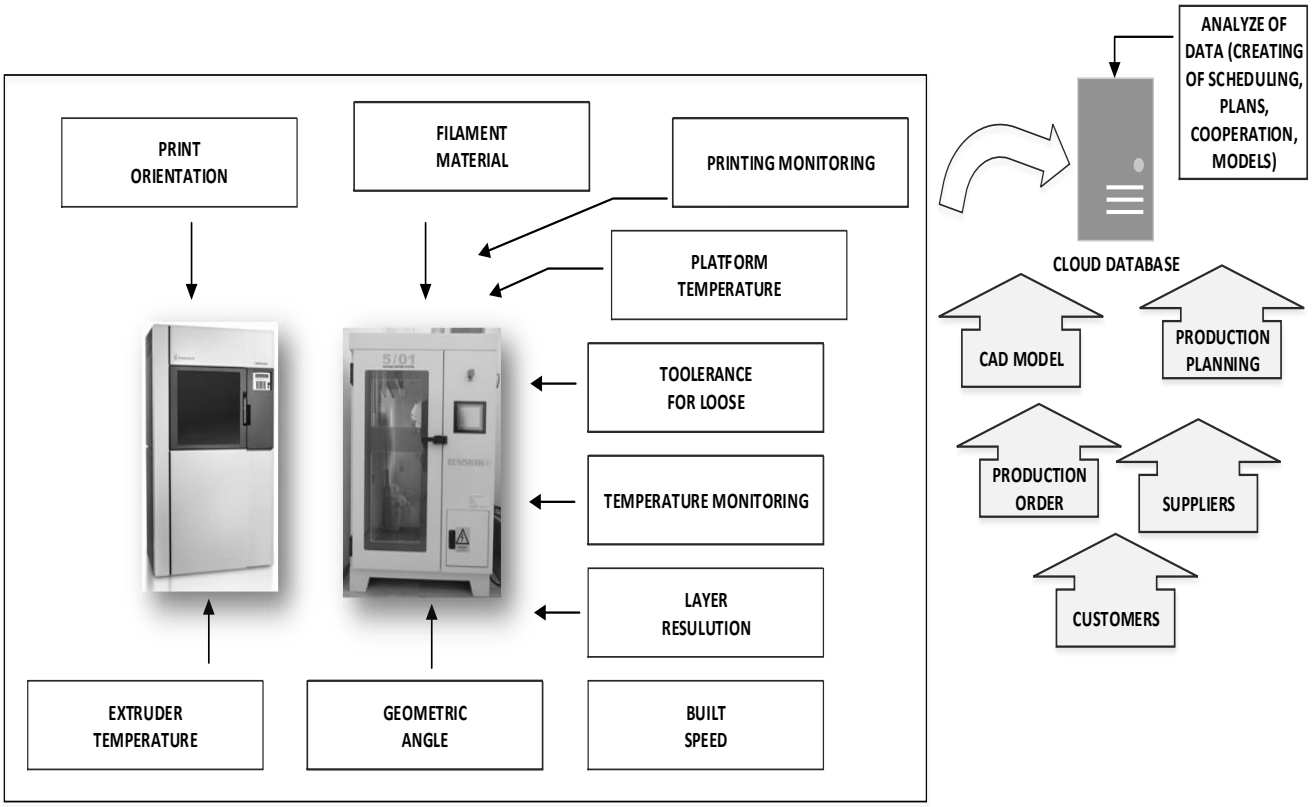

Fig. 7. Schema of a generating and collecting data from printing

Not only the parameters of printers and input materials are important, but also the data and information, influence on the printing process are important to. In this field an appropriate database is nedeed, in which all data related to the printing process, as well as production order and planning will be collected. Thanks to advanced of Big Data solutions, extensive cloud databases are created, which include data about printed models, materials, printer parameters, print times, but also information about customers, suppliers, production plans or schedules. The need of proper protection of such databases to prevent data loss also becomes very important element of this issue. The possibilities offered by today's market and technologies, make possible to change printing process into a smart process using IoT (Internet of Things). IoT is a kind of functioning system of machines, equipment, that can automatically communicate and exchange data over the network without human intervention. This is a very wide concept, which includes a growing amount of intelligent equipment. Connecting all smart equipments to the Internet, created a lot of new opportunities, but also risks. This type of systems must be even better protected against hacking attacks and data loss. [9, 13]. While of using smart systems, it is still necessary to define the scope of required tasks, realized in production and also to develop schedules. Without this, it will not be possible to start production in the right time.

3.3 The scheduling problem

Due to the personalisation of products and dynamic changes in the market, it is necessary to plan the production of printed elements accordingly. According to the Just in Time rule in terms of needed materials and components, it is also required to properly plan the production tasks and schedule. With the input data (amount of printed parts, product models, color, dimensions, material), it is possible to determine, which printer will be suitable to the job. However, without information about the production plan and busy printers, it is not possible to determine the start time of the next job. As the number of production orders increase, the problem of appropriate production planning and scheduling also increases. The situation becomes more complicated, when the number of orders have to be added to an already developed plan. In this field, appropriate data is required as well as programs to support scheduling. An example of a schedule, taken from an order showed in Figure 8.

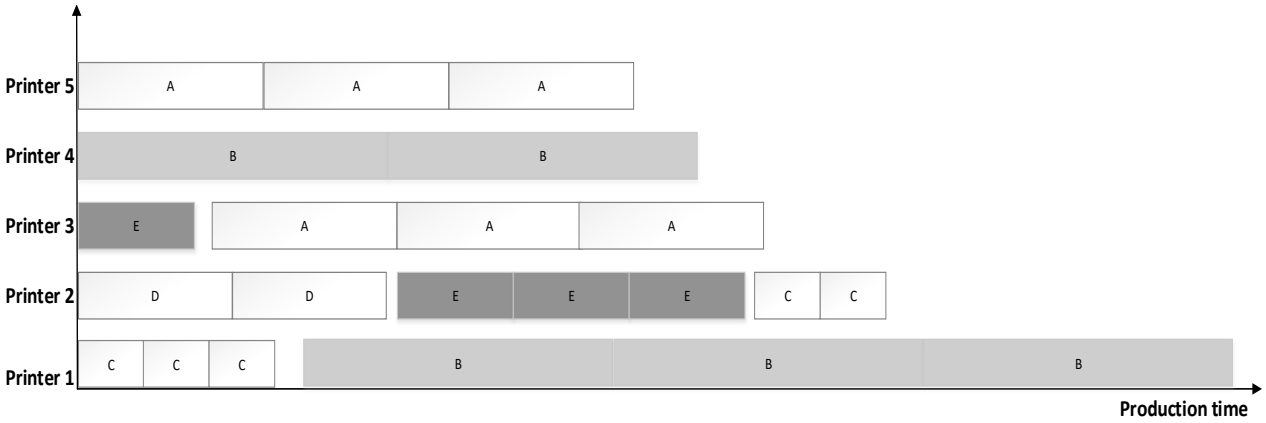

Fig. 8. Schedule of a printing

The above schedule is related to multi-machine tasks. There is a set of free printers M= {1, 2, 3,...n}, realizing tasks from the order in a certain period of time. The symbols of A, B...E, from Figure 8, indicate a printout of an elements (types of mask endings and additional elements type of A, B..E,), printing at the indicated workstation in Department of Engineering Processes Automation and Integrated Manufacturing Systems. Additionally, during the realization of the tasks, few conditions must be fulfilled:

– each job is completed on a dedicated printer,
–each of printers cannot carry out more than one job at any time,
– the task cannot be interrupted.

Based on the data and conditions to fulfill, manager has to organize tasks in order, to complete them in the shortest possible time. So, it is important, to ask the question about: under which criteria, the schedules will be created? - time, cost, failures, amount of used printers, rules of order priority - which is more important, it is possible to realize the next order, etc.? Considering the dynamics of the market and the needs, the problem is to plan the tasks properly, especially in the case of a conflict with resources. This is why, systems supporting production planning and scheduling are so important. However, without appropriate data, it becomes impossible to realize the tasks in the right time and under constraints.

The issues discussed in article include specific problems:

- the layout of workplaces - for this purpose, the workspace must be properly planned. In this situation can be helpfull an appropriate CAD programs, in which workspace can be planned, or simulation systems, connected with Virtual Reality, which allow to planning and testing the workspace.
- the maintenance of workplace - this is a problem linked to the placement of the workplaces. However, one of possibility to testing the appropriate placement and maintenance of the workplaces is Virtual Reality.
- printing of elements - depending of the assumptions of the companies, each of them can adjust the form of print realization, e.g. the customer comes with creating model by themself in CAD or the model is creating by companiess staff.
- data generation - some data from companies are confidential data. Every company with a cloud technology must properly protect data against potential leakage. This is a very serious problem today. However, today, there are better software tracking, which can help with these problems.
- task planning and scheduling under conditions of sudden and emergency production, i.e. in a Covid-19 pandemic situation. Schedule systems are helpful here. In the article used the KbRS system – created in Department of Engineering Processes Automation and Integrated Manufacturing Systems. But can be used other software, which support scheduling problems.

4. CONCLUSIONS

Manufacturing methods have changed over the years. In addition to standard methods, manufacturers are increasingly looking for a new possibility in a production, like an additive manufacturing area. This is important from the point of view of unexpected problems with access to components, e.g. mask endings for hospital staff and other users during the SARS-CoV-2 pandemic. However, as well as the new solutions, that are available, there are also some problems. These problems are related to the implementation of such solutions due to production planning, the characteristic type of production, workstation ergonomics and scheduling.

The article presents a short development of additive manufacturing and an analysis of the problem concerning on this type of workplace. In article a diagram of data collection from the workplace and the ways of its storage is also presented. These are areas that have an impact on the organisation and planning of printing processes. In the process of planning and scheduling, data is fundamental. In the era of personalized products, the amount of data to be analyzed is increasing. With new technologies, which are also included in Industry 4.0, manufacturers have an opportunity to handle with the challenges of variable

production and to adapt to the current trends. These technologies have an impact on realization of tasks, e.g. 3D printing, but also help in collect and analyze data, e.g. Big Data, Cloud, Internet of Things. This influences on a faster and more flexible production process especially that, these systems are connected in a network, which integrate all these fields. Based on these technologies, it is also important, that all data and databases should be properly protected against potential loss, which is also an important part of Industry 4.0. However, in addition to these technologies, attention should be focused also on appropriate scheduling systems, which support planning of such dynamically changing tasks, and also including the constraints, which are imposed by the enterprises.

5. REFERENCES

1. Alghamdy, M., Ahmad, R., Alsayyed, B., (2019). *Material selection methodology for additive manufacturing applications*, Procedia CIRP 84, 486–490.
2. Brunt, D., (2020). *Spaghetti charts and physical distancing*. Available from: https://lean.org.pl/diagram-spaghetti-i-zachowanie-fizycznej-odleglosci/, Accessed: 11/06/2020.
3. Coroiu, A. M., (2015). *Emotional intelligent agent in decision-making process with implications in manufacturing*, International Journal of Modern Manufacturing Technologies, **VII**(2), 43-47.
4. De Jong, J.P.J., de Bruijn, E., (2013). *Innovation lessons from 3-D printing*, Mit Sloan Management Review, **54**(2), 42-53.
5. Gandomi, A., Haider, M., (2015). *Beyond the hype: Big dataconcepts, methods, and analytics*, International Journal of Information Management, **35**(2), 137—144.
6. Götz, M., Gracel, J., (2017). *Przemysł czwartej generacji (Industry 4.0) – wyzwania dla badań w kontekście międzynarodowym*, Kwartalnik Naukowy Uczelni Vistula, **1**(51), 217-235.
7. Gwiazda, A., Sękala, A., Banaś, W., (2017). *Modeling of a production system using the multi-agent approach*, Proceedings of IOP Conf. Ser.: Mater. Sci. Eng, **227**, 012052, 1-6.
8. Huang, Y., et al., (2015). *Additive manufacturing: current state, future potential, gaps and needs, and recommendations*, Journal of Manufacturing Science and Engineering **137**(1), 1-10.
9. Jaskólski, M., (2020). *Co to jest Internet Rzeczy (IoT)?*. Available from: https://www.benchmark.pl/aktualnosci/co-to-jest-internet-rzeczy-iot.html, Accessed: 11/06/2020.
10. Kaliczyńska, M., (2018). *Kluczowe technologie Przemysłu 4.0*. Available from: https://automatykaonline.pl/Artykuly/Przemysl-4.0/Kluczowe-technologie-Przemyslu-4.0, Accessed: 11/06/2020.
11. Kolny, D., Kurczyk, D., Matuszek, J., (2019). *Computer support of ergonomic analysis of working conditions at workstations*, Applied Computer Science, **15**(1), 49–61.
12. Krenczyk, D., Olender, M., (2014). *Production planning and control using advanced simulation systems*, International Journal of Modern Manufacturing., **6**(2), 38-43.
13. Lee, I., Lee, K., (2015). *The Internet of Things (IoT): Applica-tions, investments, and challenges for enterprises*, Business Horizons, **58**(4), 431—440.
14. Lee, I., (2017). *Big data: Dimensions, evolution, impacts, andchallenges*, Business Horizons, **60**, 293-303.
15. Ngo, T. D., et al., (2018). *Additive manufacturing (3D printing): A review of materials, methods, applications and challenges*, Composites Part B: Engineering, **143**, 172-196.
16. Olender, M., Krenczyk, D., (2018). *Manage and control information flow in virtual manufacturing enterprises*, Proceedings of IOP Conference Series, Materials Science and Engineering, **400**, 1-6, 1757-8981.
17. Olender, M., Kalinowski, K., Grabowik, C., (2019). *Practical approach of flexible job shop scheduling using costs and finishing times of operations*, Intelligent Systems in Production Engineering and Maintenance, Advances in Intelligent Systems and Computing, Burduk A., Chlebus E., Nowakowski T., Tubis A. (eds), **835**, 391-400, Springer Nature Switzerland AG.
18. Paszek, A., Wittbrodt, P., (2015). *The method of building a knowledge management system in a manufacturing company*, International Journal of Modern Manufacturing Technologies, **VII**(1), 47-52.
19. Pereira, G.R., Gasi, F., Lourenço, S.R., (2019). *Review, Analysis, and Classification of 3D Printing Literature: Types of Research and Technology Benefits*, International Journal of Advanced Engineering Research and Science (IJAERS), **6**(6), 167-187.
20. Piątek, Z., (2017). *Czym jest Przemysł 4.0? – część 1*. Available from https://przemysl-40.pl/index.php/2017/03/22/czym-jest-przemysl-4-0/, Accessed: 13/06/2020.
21. Senderská, K., Mareš, A., Václav, S., (2017). *Spaghetti diagram application for workers' movement analysis*, U.P.B. Sci. Bull., Series D, **79**(1), 139-150.
22. Witkowska, A., (2019). *Wytwarzanie przyrostowe*. Available from: https://www.utrzymanieruchu.pl/wytwarzanie-przyrostowe/, Accessed: 13/06/2020 .

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