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Determination Of The Level Of Automation For Additive Manufacturing Process Chains

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Abstract

Industrial manufacturing is confronted with increased cost pressure due to international competition. The use of automation solutions can help to optimally exploit existing potentials and react to market competitors. In particular, increased productivity and shorter cycle times lead to reduced costs and increased capabilities. New manufacturing technologies can also help to achieve an advantage over market competitors. In recent years, additive manufacturing technologies in particular have gained in importance.

Laser Powder Bed Fusion (L-PBF) is an additive manufacturing (AM) technology that enables the production of highly complex and individualized metal components. A significant disadvantage of L-PBF is the required post-processing of additive manufactured parts, which is necessary to remove auxiliary structures, separate the workpieces from the substrate plate and obtain high precision as well as low surface roughness. Automation of these post-processes is a crucial factor for increasing productivity and thus for further industrialization of L-PBF. In order to exploit this potential optimally, the level of automation has to be determined.

In this paper, a methodology is presented that enables the determination of the level of automation for the additive process chain with L-BPF. The focus is on evaluating the level of automation of individual manufacturing technologies due to consideration of technology-specific requirements and characteristics. The scope of the analysis is not limited to technologies; handling processes are also taken into account. A differentiated evaluation of the level of automation is enabled by the definition of technology-specific and cross-technology sub-tasks.

Keywords

Laser Powder Bed Fusion; L-PBF; automation; level of automation; process chain; additive manufacturing; AM; post-processing

1. Introduction

The increasing number of variants requires manufacturing to optimize flexibility. Addressing this demand, additive manufacturing processes are becoming more and more viable. The number of machines and printed parts sold has grown steadily in recent years due to the increased productivity and quality of AM machines and increasing market diffusion of the technology [1, 2]. In addition, manufacturing companies in high-wage countries such as Germany are facing increased competition due to the cost advantages of production in Asia

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and Eastern Europe. The application of automation solutions has the potential to significantly increase productivity and thus ensure competitiveness in the international market environment. The current state of the art in the industry shows that the automation potential in the additive process chain is not fully exploited. Especially in the area of post processing, the majority of process steps are currently conducted manually, which leads to high costs [3]. Since the costs incurred for the additive manufacturing of a component are compared to both conventional manufacturing methods and competing companies, the reduction of costs is an important priority for the economic use of additive manufacturing technologies in industrial manufacturing [3].

Determining the level of automation (LOA) is able to support the assessment of the status quo in terms of productivity. For improving the status quo, it is necessary to identify potentials and define fields of action. For this purpose, specific requirements for automation and special constraints of the additive process chain have to be considered. A methodology for the determination of the LOA enables the assessment of the current state and the identification of potentials for the significant improvement of productivity.

This paper presents a methodology that enables the determination of the LOA for the additive process chain with L-BPF. The focus is on evaluating the LOA of individual manufacturing technologies due to consideration of technology-specific requirements and characteristics. The scope of the analysis is not limited to technologies; handling processes are also taken into account. A differentiated evaluation of the LOA is enabled by the definition of technology-specific and cross-technology sub-tasks. In the second chapter, the initial situation concerning the additive process chain is presented using the example of the AM technology L-PBF and the need for a methodology to determine the current level and potential of automation is derived. The following third chapter describes the methodology that enables the determination of the LOA for the additive process chain. In the fourth chapter, the exemplary application of the methodology is briefly described. The final chapter five concludes the paper and presents possible directions for further research.

2. Initial Situation

With the number of additively built parts and products growing year after year, AM technologies are becoming increasingly important and shape the world of production in the future [4]. Based on the principle that a solid body is formed by joining material layer by layer using a chemical or physical process, additive manufactured components only have few minor design constraints such as the layers' thickness [2, 5, 6]. One of the most important and most used technologies in the group of AM technologies is L-PBF [1]. Here, the AM principle is realized by a layer-wise application of metal powder [1]. Molten powder is fused with the surrounding material by a laser, solidifies and thus forms the component layer wise [2, 5]. There are several advantages of L-PBF: Similar mechanical properties compared to parts conventionally manufactured, density of almost one hundred percent and new design possibilities for metal components and the integration of several functions into one single component allows individualization and topology or material optimization for lightweight constructions [7,8, 9, 10]. But there are also disadvantages of L-PBF that need to be reconsidered: For the additive manufacturing process itself, support structures and a baseplate are necessary to mitigate the warping and to dissipate heat [7]. Furthermore, the removal of unfused excess powder is necessary after the build process due to the risk of powder cross-contamination and associated quality degradation or adverse effects on the workers' health [4, 5]. A rough surface, significant shape deviations and residual stress can lead to warping or anisotropic mechanical properties [8, 11]. Therefore, L-PBF is used in combination with other conventional manufacturing technologies to ensure dimensional and positional accuracy of the manufactured components [5, 10, 11, 12].

The typical process chain of an additive manufactured component with its post-processes is described in the following. First, the components are built on a baseplate to which they are fused [7]. To form components, various powder layers are locally fused. The additive components are surrounded by unfused powder, which can be recycled also like the substrate plate [6]. The remaining powder must be removed. This is achieved by vacuuming and additional cleaning, but it has to be done within a glove box to safely handle the powder [7]. Recent powder removal-methods also consider ultrasonic cleaning equipment or kinematic powder removal systems [4]. To reduce stress resulting from the AM process, stress relief heat treatment is an option, but there exist also other possible heat treatments according to the requirements of the material [7, 10]. Afterwards, the component is separated from the baseplate by sawing or wire-EDM [11]. Additionally, auxiliary structures need to be removed by manual chiseling and grinding to smooth the surface [11]. Alternatively, milling or other automated subtractive processes can be used [13]. Furthermore, functional features are conducted, e. g. by milling, turning, sink- and wire-EDM [11]. To improve the surface quality, sand blasting or barrel finishing or other subtractive processes according to the component requirements are applied [11]. Apart from the technologies mentioned above, others may also be used [10].

The comparatively low productivity and high costs of such AM process chains are currently a barrier to the economic use of the technology [7]. Industrialization of L-PBF could be achieved by automating the L-PBF manufacturing process chain, as it reduces costs and increases productivity [14, 15]. For the development of automation concepts, an analysis of the status quo of the additive process chain is essential. Therefore, a discourse on scientific approaches to the topic of additive process chain and automation follows:

MÖHRLE considers the L-PBF process chain mainly from an economic and organizational point of view and does not explicitly include automation [11]. BÖCK's approach supports the integration of non-conventional technologies into conventional process chains, but does not address L-PBF and the specific requirements of automation [16]. The approach of PRÜMMER also does not fully consider the automation of the additive process chain. Here, an evaluation system for automated manufacturing systems in toolmaking is presented based on typical technologies in toolmaking. L-PBF and other AM technologies are therefore not considered [18]. In SEIFERMANN's concept, too, automation alternatives are evaluated and selected mainly on the basis of lead time and additional other economic and technological factors. A determination of the degree of automation is not explicitly made here [17]. At WINDMARK, automation alternatives are evaluated and selected based on economic factors. L-PBF and the specific challenges are not addressed [21]. Although KOPF explicitly considers the additive process chain with L-PBF in detail, automation and thus the determination of degrees of automation are only marginally included [20]. Currently, there are two main scientific approaches that explicitly deal with the definition of level of automation. On the one hand FAVRE-BULLE, who considers the level of automation as the quotient of the automated functions of a system in relation to all functions [15]. On the other hand, FROHM defines technological LOA in his approach, but these are general and do not consider the specific requirements of additive manufacturing [24].

The scientific discourse shows that although the approaches are applicable to several technologies, technology-specific characteristics are not taken into account. To achieve improvements in practice, it is necessary to identify technology-specific potentials and to derive requirement-oriented fields of action. For this purpose, the requirements for automation and the special characteristics of the additive process chain must be considered. Ideally, a methodology for determining the LOA can be used to evaluate the current LOA and identify potentials in order to achieve an optimal LOA. The following chapter presents such a methodology.

3. Methodology

Since the methodology should take into account the special characteristics of the additive process chain and the technologies used in it, a technology-specific consideration of the LOA is appropriate. This means that a separate LOA is determined for each technology used in the process chain. This results in a differentiated picture of the process chain. In addition, to consider the technology used in each case, handling functions that are relevant in the respective process step are also considered. The definition of the handling functions is based on the VDI standard 2860 [21]. Since the handling functions often rely on the same peripherals, they can be used in part across technologies to determine the respective LOA.

3.1 Determination of sub-tasks

Although the separate consideration of the technologies can already lead to the consideration of certain technology-specific characteristics, such a consideration cannot do adequate justice to the desired level of detail. Therefore, the individual process steps are subdivided into further sub processes. This procedure is based on Hierarchical Task Analysis (HTA), in which individual tasks are subdivided into sub-tasks. New sub-tasks can be identified if they pursue their own (partial) goal. However, it is not specified how detailed the sub-tasks must be subdivided. Thus a focus can be put on sub-tasks, which are to be considered more detailed, while others are subdivided less strongly. [22]

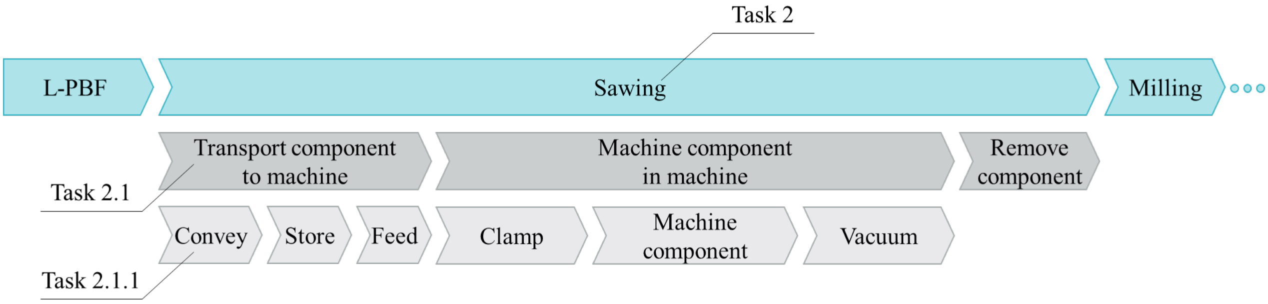


Figure 1: Hierarchical Task Analysis for sawing

Figure 1 shows an overview of how the HTA for sawing can look. The sawing process can be roughly divided into three steps within the process chain: The transport of the component to the machine, the machining of the component in the machine and the removal of the component. A consideration of the LOA at this level cannot yet be carried out in the desired level of detail, as it is not possible to clearly determine the extent to which these steps are automated or carried out manually. Therefore, a further detailing of the tasks is carried out. For the transport of the component to the machine, the sub-tasks conveying, storing and feeding, which are defined as handling functions, are suitable. In the task “Machine the component in machine”, all processes that take place in the immediate vicinity of the machine are taken into account. In order to be able to machine the component on the machine, it must first be clamped. The actual mechanical processing of the component represents a separate sub-task (“Machine component”). During the machining of the component, the extraction of chips can be used. For the removal of the component, only the removal is specified as a sub-task. The further transport of the component is not considered here, as it is considered as an upstream step in a subsequent technology. This ensures that identical processes along the process chain are not considered twice.

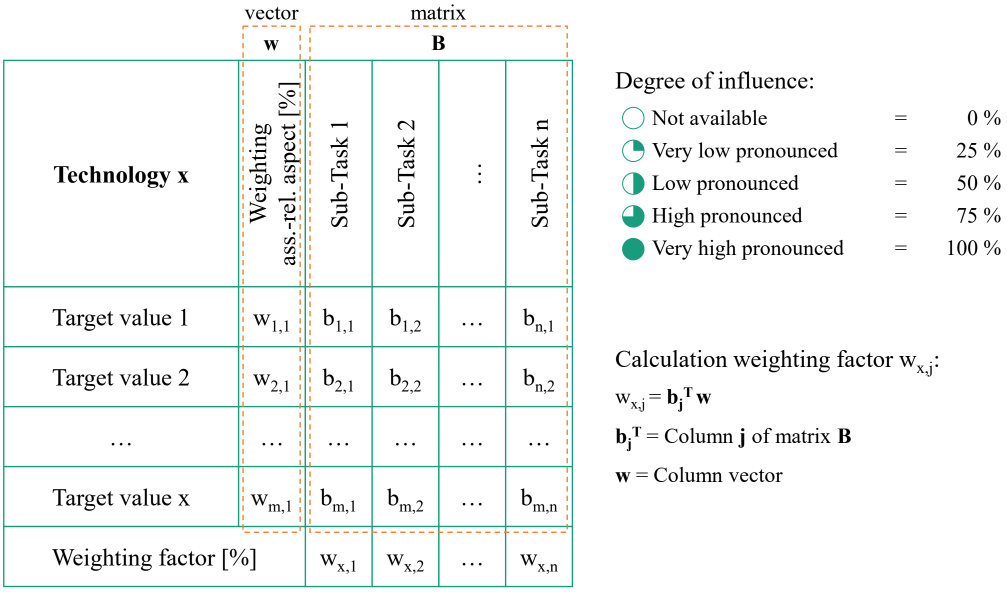
It is noticeable that not every task needs to be subdivided into sub-tasks at the same level of detail. While “Machine component in machine” is divided into four sub-tasks, “Remove component” isn’t further subdivided into sub-tasks. Tasks are only further subdivided if there are processes within a task that differ in terms of automation. It is not decisive whether the LOA of individual sub-tasks actually differs in the end, but merely whether a different LOA can result along the process chain. At this point, it should be noted whether different machines or peripheral systems are used between sub-tasks.

3.2 Weighting of sub-tasks

Since not every sub-task has the same significance for the LOA, the sub-tasks have to be weighted. For this purpose, target values are first defined that are important for automation. These are weighted afterwards with regard to the superordinate goal of the automation, whereby the sum of the goal is 100 %. In addition, the target values take into account the general conditions of the additive process chain. In this way, a weighting succeeds that is strongly adapted to the special characteristics of the additive process chain. Once the target values and the associated weights have been defined, the sub-tasks can be evaluated with regard to their influence on the respective target value. Based on the proficiency levels of the respective sub-tasks, a weighting factor $w_{x,j}$ can be determined. The calculation is shown in following formula:

$$w_{x,i} = \sum_{j=1}^{m} w_{j,y}\, b_{j,i} \tag{1}$$

The sum of the individual weights is normalized to 100 %. Finally, the weighting factors can be used to summarize the automation levels of the sub-tasks (cf. figure 2).



Technology x	Weighting ass.-rel. aspect [%]	Sub-Task 1	Sub-Task 2	…	Sub-Task n
Target value 1	$w_{1,1}$	$b_{1,1}$	$b_{1,2}$	…	$b_{n,1}$
Target value 2	$w_{2,1}$	$b_{2,1}$	$b_{2,2}$	…	$b_{n,2}$
…	…	…	…	…	…
Target value x	$w_{m,1}$	$b_{m,1}$	$b_{m,2}$	…	$b_{m,n}$
Weighting factor [%]		$w_{x,1}$	$w_{x,2}$	…	$w_{x,n}$

Degree of influence:

○	Not available	=	0 %
◔	Very low pronounced	=	25 %
◑	Low pronounced	=	50 %
◕	High pronounced	=	75 %
●	Very high pronounced	=	100 %

Calculation weighting factor $w_{x,j}$:

$w_{x,j} = \mathbf{b}_j^T \mathbf{w}$

$\mathbf{b}_j^T$ = Column **j** of matrix **B**

w = Column vector

Figure 2: Determination of the weighting factors of the sub-tasks [23]

3.3 Definition of the scales for the determination of the automation level

The next step is the linkage of automation level to the individual sub-tasks. Therefore, sub-task-specific scales are developed in the methodology. In this way, it can be ensured that the special characteristics with regard to automation are taken into account for each sub-task. In this respect, the technology-specific approach with the possession of the LOA for each technology differs from approaches that only consider the entire process chain [7].

Following the Dynamo model, the scales for each sub-task are divided into two areas. One scale refers to the mechanical functions as well as the equipment used to conduct the sub-tasks, while the other scale refers to information processing and control [24]. The two scales are independent of each other. Thus, a differentiated view of the task division between employee and automation solution is achieved. To ensure a uniform size of the scales, a seven-level ordinal scale is developed for each sub-task, in which the highest LOA to be achieved is evaluated with the value seven and the lowest with the value one. The levels of each scale are determined based on possible LOAs. It may happen that not every one of the seven levels in the scale is occupied. In these cases, the increase in the LOA is not the same between each proficiency level, but this is taken into account when creating the scales.

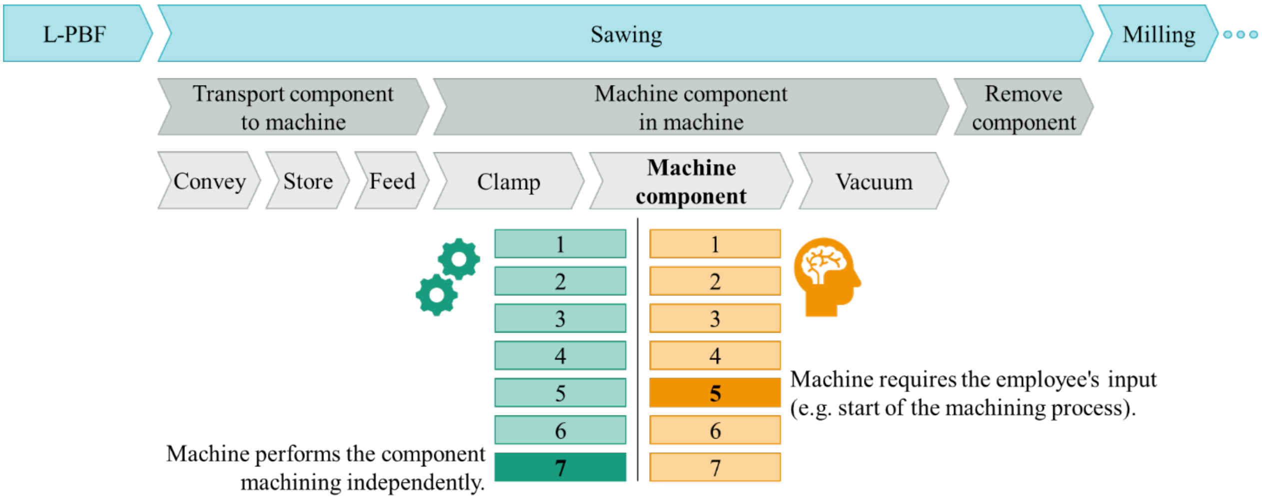


Figure 3: Exemplary representation of the automation scale of a sub-task for sawing

Figure 3 illustrates the automation scale of the sub-task “Machine component” from the process step “Sawing”. The exact definition for assigning a particular value on the scale must be determined in advance for each subtask. Gradations of the scale for mechanics and equipment differ with regard to the tools used and the physical demands on the employees. For the scale for information and control, the decisive factor is what information is available to the employee or whether the work orders are clearly defined so that uniform execution can be ensured independently of the employees. For this, it must also be considered whether the employee makes independent decisions and thus has a strong influence on the execution of the sub-task. In the example, the machine performs the machining of the component independently. Therefore, with regard to the scale for mechanics and equipment, the highest value is assigned. Since the machine requires the employee’s input, e. g. to start the machining process, for the scale of information processing and controls a lower value is chosen.

3.4 Determination of the overall degree of automation

After defining the sub-tasks with the associated weightings and the sub-task-specific scales for determining the LOA, a technology-specific automation level can be calculated. For this purpose, the automation levels of the sub-tasks are added according to their weighting. The designation LOA stands for the calculated LOA. The LOA is calculated for both the mechanical and the cognitive (information processing and control) level.

$$LOA_x = \sum_{j}^{n} w_{x,j} * LOA_{x,j} \tag{2}$$

By determining the LOA of a technology, it is possible to compare the automation in different process chains in relation to the technology under consideration. A comparison between different technologies does only work to a limited extent, since each technology is based on different evaluation scales. However, the cross-technology comparison helps to determine the extent to which automation potentials have been exhausted. In order to identify imbalances in the degree of automation within a process chain, an overview is created that shows the different technologies in terms of their LOA.

In the example shown in Figure 4, all sub-tasks are first evaluated with the two scales. The automation levels of all sub-tasks are then added to form a technology-specific automation level. The overview shows how the LOA of individual technologies can differ from one another. The technologies do not necessarily have to be equipped with different automation technologies. The minima and maxima of a technology realizable in each case can also be decisive for the differences. The overview therefore serves rather to identify the extent to which the automation potentials have been exhausted.

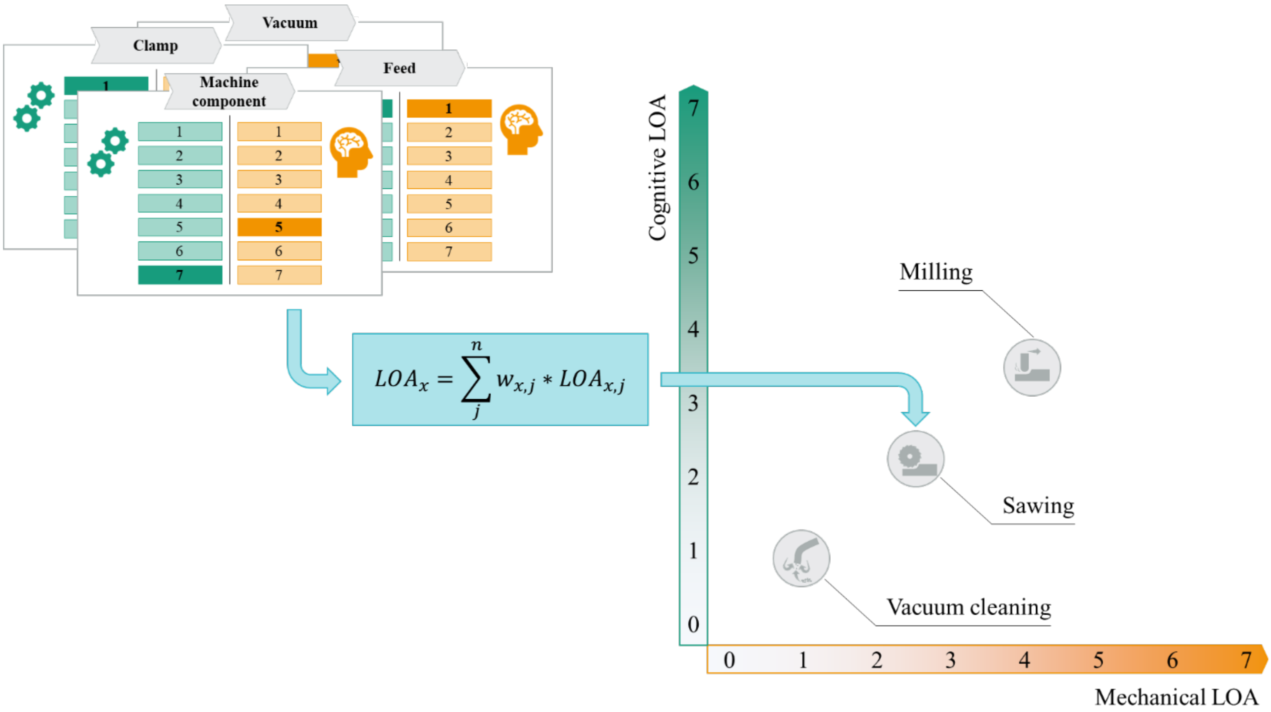


Figure 4: Overview of technology-specific automation levels

4. Application

The developed methodology was applied to an exemplary additive process chain. Each process step was divided into sub-tasks and the corresponding automation level was determined based on the respective scale (maximum of 7 points possible for the mechanical and cognitive classification). With the help of the determined weighting factor, a calculation was possible to determine the total LOA of a process step or technology. Figure 5 provides an overview of the LOA of all the technologies considered.

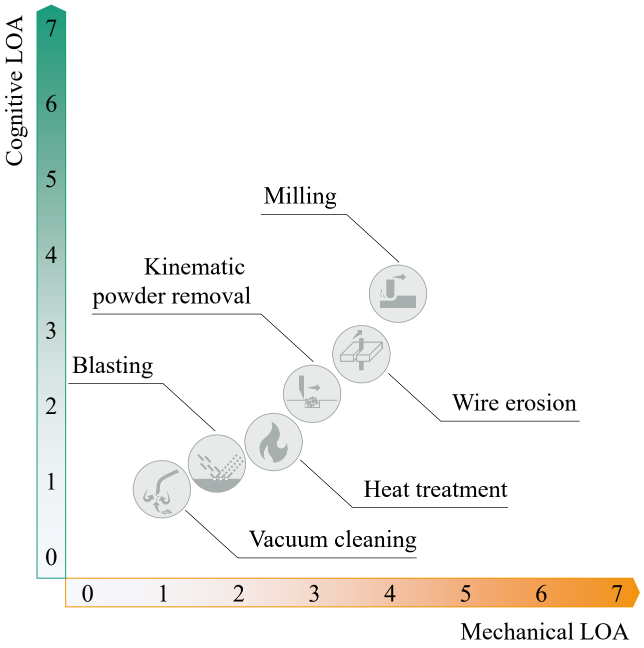


Figure 4: Overview of LOA of technologies considered in the application

Measured by the spectrum of the scale, it is noticeable that the LOA of the technologies considered is relatively low. A higher degree of automation can be seen in some technologies that rely on a static machine (wire erosion, milling). This can be attributed to the equipment of the machines used and leads to a partial automation of some sub-tasks. It is also noticeable that the mechanical LOA is higher than the cognitive degree for all the technologies considered. A stronger focus on the automation of mechanical functions may be one reason for this observation. When considering the LOA, however, it should be noted that the highest LOA cannot be achieved for every technology, since optional sub-tasks are not considered in some cases. Too great a difference in the automation levels of successive sub-tasks would not make sense from an economic point of view, since in this case unmanned production would not be possible despite the automation of individual sub-tasks. A detailed examination of the sub-tasks can also provide information about which higher levels of automation exist and thus serve as a basis to increase the LOA.

5. Conclusion and Outlook

At present, however, components produced using L-PBF cannot be manufactured to a satisfactory quality for immediate use. Therefore, further processing of the components in the additive process chain cannot be dispensed with. A challenge to the use of L-PBF is the high proportion of manual work steps in the further processing of the components, as this makes the entire process chain less economical in many cases. As a result, companies in high-wage countries such as Germany have difficulty withstanding the cost pressure from international competition. Automating the post processing of additively manufactured components can help to reduce the costs of the process chain.

In order to provide a basis for further decisions regarding automation, a methodology has been developed to determine the LOA of the additive process chain. This can be seen as an analysis of the current state and can be used in practice to enable further development of automation solutions. By using different models and methods, it was possible to develop a methodology for determining the degree of automation of an additive process chain. The four essential steps of the methodology for determining the degree of automation were presented in the paper. A distinction was also made between the development and the application of the methodology. Within the scales, the special characteristics of additive manufacturing are considered. In addition, the weightings are designed to match the objectives of automated additive process chain. Since the identification of sub-tasks considers not only the technologies , but also the associated handling functions, a comprehensive view of the value-adding and non-value-adding processes within the process chain can be ensured. Another advantage of the methodology is that it can be easily extended to include other technologies. Due to the large variety of technologies in the additive process chain, any extension may become relevant.

In this paper, the first approach for determining the LOA has been developed, which is explicitly designed for application in the additive process chain. The developed methodology represents a first step to develop an holistic automation strategy. Although measures for improving the LOA can be derived from the methodology, there is no monetary consideration of the automation solutions or no systematic approach. In order to increase the economic efficiency of the additive process chain, it may be useful to consider economic parameters. Moreover, the consideration of other technological parameters can also be beneficial, since maximizing the LOA is not the same as the optimum LOA.

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References

[1] Wohlers, T., 2019. Wohlers Report 2019: 3D Printing and Additive Manufacturing State of the Industry. Wohlers Associates, Inc, Fort Collins, Colorado.

[2] Dzemko, M., Engelmann, B., Hartmann, J., Schmitt, J., 2019. Toward Shifted Production Strategies Through Additive Manufacturing: A Technology and Market Review for Changing Value Chains. Procedia CIRP 86, p. 228.

[3] Zeyn, H., 2017. Industrialisierung der Additiven Fertigung. Digitalisierte Prozesskette - von der Entwicklung bis zum einsetzbaren Artikel. VDE-Verlag GmbH, Berlin.

[4] Wohlers, T., Campbell, R.I., 2017. Wohlers report 2017: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates, Inc, Fort Collins, Colo.

[5] Wollbrink, M., Prümmer, M., Kristian, A., Bergs, T., 2019. Methodology for Integration of Additive Manufacturing in Tool Manufacturing Process Chains. Proceedings of the 18th International Manufacturing Conference in China.

[6] Gibson, I., Rosen, D.W., Stucker, B., 2010. Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing. Springer Science+Business Media LLC, Boston, MA.

[7] Horstkotte, R., Heinrich, F., Prümmer, M., Arntz, K., Bergs, T., 2021. Generation and evaluation of automation concepts of additive process chains with Laser Powder Bed Fusion (L-PBF). Procedia CIRP 96, p. 97-102.

[8] Gebhardt, A., 2016. Additive Fertigungsverfahren: Additive Manufacturing und 3D-Drucken für Prototyping - Tooling - Produktion, 5th edn. Hanser, München.

[9] Klahn, C., Leutenecker, B., Meboldt, M., 2014. Design for Additive Manufacturing – Supporting the Substitution of Components in Series Products. Procedia CIRP 21, p. 138.

[10] Verein Deutscher Ingenieure. 3405-2 Additive Fertigungsverfahren. Strahlschmelzen metallischer Bauteile: Qualifizierung, Qualitätssicherung und Nachbearbeitung, Berlin. Beuth Verlag GmbH, 2013.

[11] Möhrle, M., 2018. Gestaltung von Fabrikstrukturen für die additive Fertigung. Springer Vieweg, Berlin.

[12] Wollbrink, M., Maslo, S., Zimmer, D., Abbas, K., Arntz, K., Bergs, T., 2020. Clamping and substrate plate system for continuous additive build-up and post-processing of metal parts. Procedia CIRP 93, p. 108–113.

[13] Denkena, B., Dittrich, M.-A., Henning, S., Lindecke, P., 2018. Investigations on a standardized process chain and support structure related rework procedures of SLM manufactured components. Procedia Manufacturing 18, p. 50

[14] Möhrle, M., Müller, J., Emmelmann, C., 2017. Industrialisierungsstudie Additive Fertigung: Herausforderungen und Ansätze. RTeJournal - Fachforum für Rapid Technologie.

[15] Favre-Bulle, B., 2004. Automatisierung komplexer Industrieprozesse: Systeme, Verfahren und Informationsmanagement. Springer Vienna, Vienna, s.l

[16] Böck, J., 2013. Methode zur Integration nicht-konventioneller Verfahren in flexible Fertigungs- und Montagelinien. Fraunhofer Verlag, Stuttgart

[17] Seifermann, S., 2018. Methode zur angepassten Erhöhung des Automatisierungsgrades hybrider, schlanker Fertigungszellen, 1st edn. Shaker, Herzogenrath.

[18] Prümmer, M., 2020. Kennzahlenbasiertes Bewertungssystem der Leistungsfähigkeit verketteter Fertigungssysteme: In der mechanischen Fertigung des Werkzeugbaus. Apprimus Wissenschaftsverlag, Aachen.

[19] Windmark, C., 2018. Performance-based costing as decision support for development of discrete part production: Linking performance, production costs, and sustainability, Lund.

[20] Kopf, R., 2018. Kostenorientierte Planung von Fertigungsfolgen additiver Technologien, 1st edn.

[21] Richtlinie VDI 2860, 1990. Montage- und Handhabungstechnik.

[22] Kirwan, B.; Ainsworth, L. K., 1992. Guide To Task Analysis. The Task Analysis Working Group. CRC Press, London.

[23] Bilsing, A., 2006. Kennzahlengestützte Bewertung der technologischen Leistungsfähigkeit der Fertigung im Werkzeug- und Formenbau. Diss. RWTH Aachen, Aachen.

[24] Frohm, J.: Levels of automation in production systems. Zugl.: Göteborg, Univ., Diss., 2008. Göteborg: Chalmers Univ. of Technology, 2008

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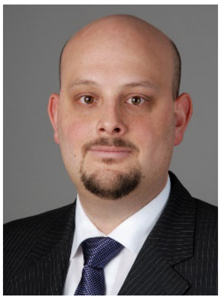

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