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Procedia CIRP 81 (2019) 612–617

www.elsevier.com/locate/procedia

52nd CIRP Conference on Manufacturing Systems

A Suitability Analysis Method for Additive Manufacturing Technologies in Small and Medium-Sized Companies

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Abstract

Additive manufacturing is a key technology which applies the ideas of Industry 4.0 in order to enable the production of personalized and highly customized products economically. Especially small and medium sized companies often lack the competence and experience to evaluate objectively and profoundly the potential of additive manufacturing technologies. This paper presents a systematic and user-oriented method for a suitability analysis for the application of additive manufacturing technologies in small and medium sized companies. Furthermore, the method has been validated in a small medical technology company evaluating the additive manufacturing potential of an existing surgery tool.

Keywords: additive manufacturing; suitability analysis method; technology assessment; 3D-printing; rapid manufacturing

1. Introduction

Additive manufacturing enables the tool-free production of individualized products and thus represents a key technology of Industry 4.0 [1]. In contrast to classic processing methods such as milling, turning or forging, it allows the production of complex geometries based on a layered construction and production [2]. In addition, additive processes are highly interesting for a wide range of applications due to the variety of usable materials such as ceramics, metal, plastic etc. [2].

Despite the above-mentioned advantages of this technology, additive manufacturing did not succeed yet to be emplaced correspondingly [3]. This can be attributed to the inhibition threshold created by the companies based on high expectancies with respect to the new technology [4]. Plenty of companies lack competence and experience to allow a detailed assessment of the potentials of additive manufacturing techniques [5]. Thus, there is a need to enable companies to evaluate the potential benefit of this technology on one hand and to determine the limits of this technology on the other hand [4].

1.1. Purpose of this paper

This paper provides an approach to evaluate the potential of additive manufacturing for a particular product or a group of products, respectively. This approach guides interested companies step by step to a suitability assessment of additive manufacturing techniques within the context of the business, offering application specific support and using a systematic procedure. The developed method comprises not only the steps but also the required tools. Particularly for small and medium sized companies with limited human resources and for companies with only little knowledge of additive manufacturing this structured procedure offers advantages by efficiently raising the essential questions.

10.1016/j.procir.2019.03.164

1.2. Research approach

The research approach to develop the method applied consists of the following four phases:

1. A questionnaire-based survey of challenges and fields of action using additive manufacturing by medical technology companies (Status Quo).
2. A literature review of related work with respect to existing suitability analyses for additive manufacturing.
3. The development of a systematic and application-oriented suitability analysis method.
4. The validation of this suitability analysis method by experts of additive manufacturing followed by a field application at a medical technology company.

2. Questionnaire-based survey

An empiric survey among small and midsize medical technology companies was conducted to identify the major action fields when introducing additive manufacturing technology. The authors focused upon the branch medical technology due to its accelerated growth, its high innovational strength and its influence by midsize companies [6]. A questionnaire-based empiric survey of 26 companies with and without existing knowledge of additive manufacturing was conducted. The questionnaire, whose results can be reviewed in detail in [6], is structured into the following four parts:

1. Information on the surveyed company (revenue, number of employees, manufactured products, production type)
2. Current status of additive manufacturing in the surveyed company (general knowledge in additive manufacturing and previous experience)
3. Potentials through additive manufacturing (regarding process, product and company)
4. Challenges and fields of action of additive manufacturing

Thus, the major challenges with respect to the introduction of additive manufacturing have been identified. These challenges provide a starting point for scientific studies to find out solutions for further acceptance and establishment of additive manufacturing technology. One action field highly rated by the interviewed companies is the increase of know-how to implement additive manufacturing (see Figure 1).

On a scale from 0 (very unimportant) to 5 (very important) how important is for you an **increase of know-how to implement additive manufacturing**?

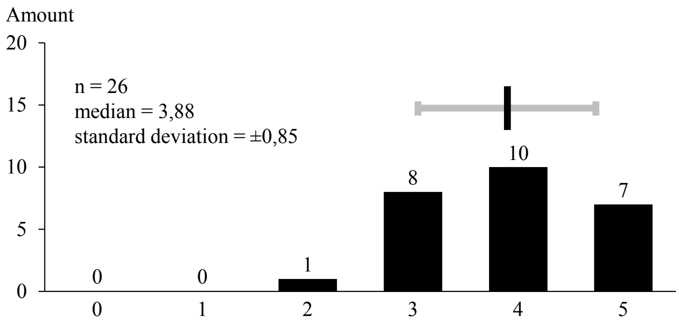

Fig. 1. Histogram of action field increase of know-how for implementation.

The companies expect that more know-how to implement additive manufacturing will be conditioned and provided. The answers to this question did not correlate with the size of the company. Therefore, this field of action appears to be generic, independent of the size of the company. This furthermore is enforced by the fact, that no bias on this answer could be observed comparing medical technology companies, which already use additive manufacturing with those, which have no experience with this technology. Thus, the increase of know-how for implementation clearly is a field of action for the introduction of additive manufacturing. In this particular field the interviewed companies see the necessity of an application-oriented and structured suitability analysis, which on one hand reflects the choice of a suitable product, material and process and on the other hand assesses qualitatively, production-technically and economically the introduction of additive manufacturing (see Figure 2).

Evaluate the necessity of an application-oriented and structured **suitability analysis for additive manufacturing processes** in your company from 0 (not necessary at all) to 5 (highly desired).

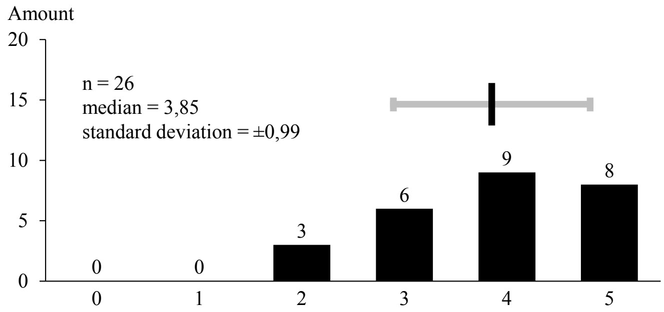

Fig. 2. Histogram of action field necessity of a suitability analysis method for additive manufacturing processes.

Table 1. Related work on existing suitability analyses.

Source	Author (Year)	Description
[5]	Feldmann & Pumpe (2016)	Phased decision-making process that supports both the decision-making process in terms of investment as well as the implementation of additive manufacturing.
[7]	Mellor et al. (2014)	A conceptual framework for the implementation of additive manufacturing that considers external forces as well as internal factors like strategic, technological, organisational, operational and supply chain factors.
[8]	Deradjat & Minshall (2017),	Framework of rapid manufacturing implementation for mass customisation considering strategic, technological, operational, organisational and external factors.

3. Related work

In order to examine the extent to which existing methods address this identified field of action, a literature review has been conducted. In this review, various approaches have been identified that address the implementation of additive manufacturing processes, which are described in Table 1. The procedure model of [5] for the decision and implementation of additive manufacturing processes focuses on this process until a decision for or against additive manufacturing. But there are no application-oriented tools for the interested companies. In addition, the changes in the manufacturing process due to a conversion to additive manufacturing are not considered at all. The models of [7] and [8] are conceptual and mainly focus on the implementation of additive manufacturing technologies after a decision for the use of additive manufacturing technologies. However, the process up to this decision is not considered in the models described.

Thus, there is a research gap here, which is to be closed in the context of this work with the developed suitability analysis and the supporting tools.

4. Suitability Analysis

In order to address the identified needs in the empirical survey and the literature review, this chapter presents a structured and user-friendly model for testing the product suitability for additive manufacturing. This suitability analysis method, which is shown in Fig. 3, includes the selection of suitable materials and technologies as well as qualitative, technical and economic analyses [6].

4.1. Structure of the suitability analysis

The initial point of the developed process model is the company's interest in the use of additive manufacturing. Subsequently, the user of the model first executes the *Selection level*, which represents the left wing of the V-model (Figure 3). Furthermore, based on an additive manufactured prototype various analyses are conducted at the *Analysis level*, which represent the right wing of the V-model. With these analyses a profound decision can be made on the use of additive manufacturing for the selected product or product group.

All findings gained during *Prototyping* and in the *Analysis level* can be reflected as adjustments to the *Selection level*. If, for example, the material is insufficiently break-resistant during the qualitative analysis, this can be reflected in the material selection and a new material can be selected. With this adjustment, the suitability analysis method is repeated from the point of the material selection.

4.2. Product suitability

The goal of the first phase is to identify a product or a product group, which are potentially suitable for additive manufacturing. For this product or product group, the further

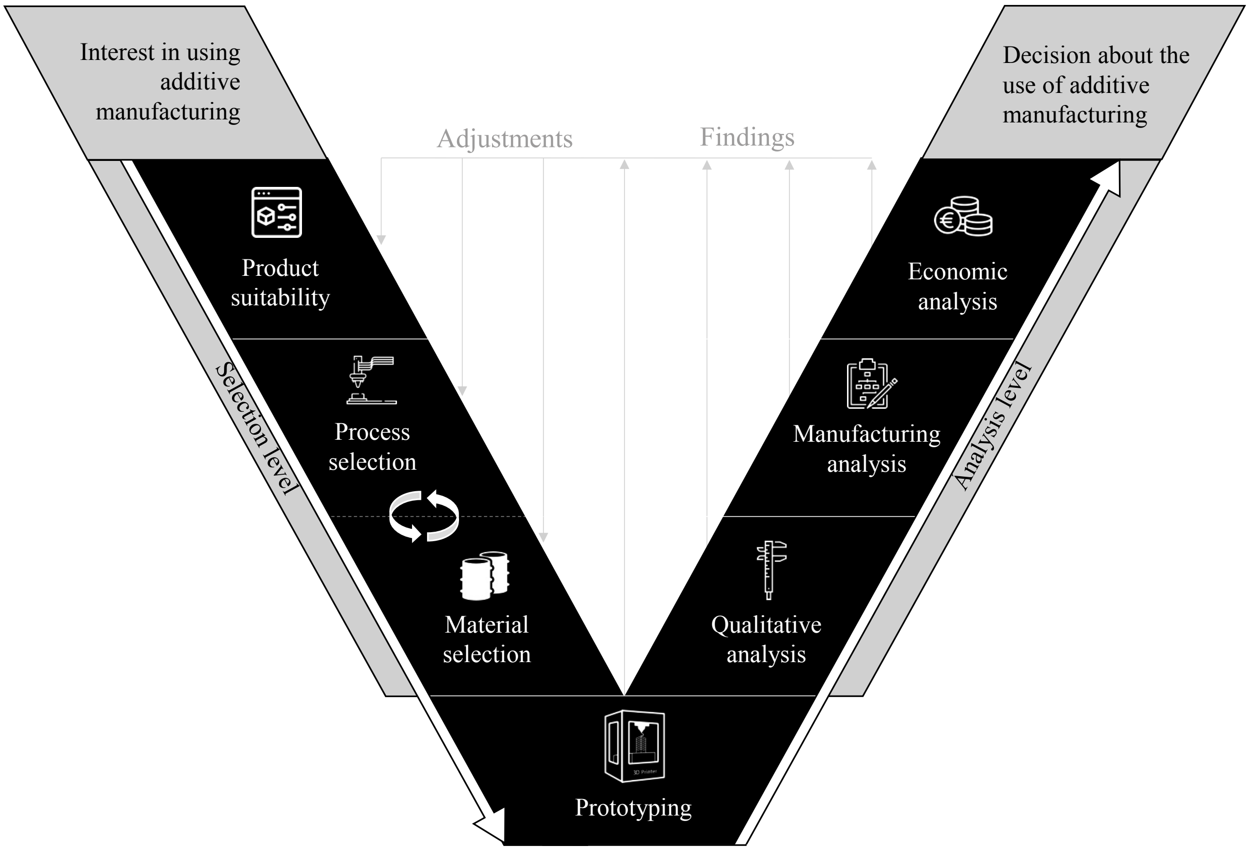

Fig. 3. Suitability analysis for additive manufacturing technologies [6].

phases of the suitability analysis will be processed. Both existing products as well as new developments, can be analysed. In order to preselect the products for which the suitability for additive manufacturing should be determined, a rough economic estimate has to be made at first. If there is a potential for economic improvement, for example, due to high unit costs, the suitability of the product has to be determined. To determine this product suitability the user applies the product suitability matrix, which was developed as part of this research work. In this matrix, various product criteria are queried which must be assessed by the user based on a four-step scale. The result indicates whether additive manufacturing tends to be appropriate for the product to be assessed. Please refer to [6] for a closer look at the tools developed from this research. The result of this phase is thus a selected product or a selected product group which is potentially suitable for additive manufacturing and with which the further process of suitability analysis is conducted.

4.3. Process and material selection

Once the suitability of the product has been determined, the choice of material and additive manufacturing process follows, which in most cases must be made in mutual dependence. This is illustrated by circulating arrows in the process model. If specific and prescribed materials must be used for the selected product, the material has already been defined and the appropriate additive manufacturing process must be selected accordingly. If, on the other hand, the material plays a subordinate role, a suitable manufacturing process with the desired properties, such as surface quality, can first be selected and then the appropriate material is selected.

4.3.1. Process selection

For the selection of the suitable additive manufacturing method, a further tool is applied, which identifies the most suitable method for the respective application. The developed tool consists of a pairwise comparison in connection with a benefit analysis [6]. The result of this phase is thus the selected additive manufacturing process, which should be used for the previously selected product.

4.3.2. Material selection

If the material of the selected product has a higher importance than the properties of the manufacturing process, the material selection can be made at first with the help of the developed material selection matrix. In this matrix, the most important material properties are listed and can be selected by the user depending on the desired application. Based on this selection, one or more materials are proposed that are most suitable for the respective application based on the required properties. However, the final suitability of the material for the product that should be manufactured additively, must be determined by a service provider, by experts of additive manufacturing or by further research. This cannot be covered by the developed material selection matrix. Nevertheless, it indicates which material type is suitable for the desired product according to the desired properties.

4.4. Prototyping

The goal of this phase is to produce an additive manufactured prototype that can be used for further analyses to evaluate the suitability of the product for additive manufacturing. This can be done, for example, by a service provider who processes the desired material with the desired additive manufacturing process. The result of this phase is an additive prototype of the selected product, which can be used for various analyses in the *Analysis level*.

4.5. Qualitative analysis

The goal of the qualitative analysis is to determine whether the additive prototype meets the quality requirements.

For this purpose, various qualitative tests must be carried out, which may vary from product to product. The selection of suitable quality analyses is to be decided by the user himself. Some examples are measurements of the given dimensions and tolerances, tests of the breaking strength of the product or measurements of the surface roughness. In doing so, the same standards as for the conventionally manufactured product have to be applied. The result of this phase is the decision whether the quality of the additive manufactured product is sufficient. If the quality criteria are met, further analyses can be carried out according to the suitability analysis. If the quality does not meet the requirements, these findings can first be used to make adjustments regarding the material and manufacturing process. However, if this potential change does not indicate an improvement, the selected product should be considered unsuitable for additive manufacturing.

4.6. Manufacturing analysis

The main objective of the manufacturing analysis is to examine the extent to which a changeover from conventional to additive manufacturing processes provides advantages for the selected product. For this purpose, the current conventional manufacturing process has to be recorded first. Each individual manufacturing step must be analysed regarding process time, set-up times, the number of employees involved as well as other important key figures. The same parameters must be determined for the additive manufacturing process. If the additive manufacturing process has advantages compared to the conventional process, the user can proceed to the next phase of the suitability analysis. If, however, the additive manufacturing process is associated with an increased process effort, conventional manufacturing appears to be more appropriate. These findings can also be reflected in the *Selection level* in order to make appropriate adjustments and to go through the suitability analysis again in an adapted form. The result of this phase is the determination whether the changeover to additive manufacturing is worthwhile from a process point of view or whether conventional manufacturing can be considered as the better solution.

4.7. Economic analysis

While the manufacturing analysis focuses on the changes in the manufacturing process, the goal of the final phase of the suitability analysis is the economic evaluation of the changeover to additive manufacturing for the selected product.

The way in which the profitability analysis is conducted depends on the user and how new investments are evaluated in the respective company. For a detailed insight into the classical investment calculation methods, please refer to [9]. If a cost comparison of both alternatives is desired, the classical methods of cost accounting can be used. These can be found in the explanations of [9].

The result of this last phase is the economic comparison of the conventional manufacturing process with the additive manufacturing process for the selected product. If the additive manufacturing is economically more attractive, the suitability of the selected product for additive manufacturing is determined. In the event that conventional manufacturing is economically more lucrative, these findings can be reflected in the *Selection level* and appropriate adjustments can be made.

The final economic analysis enables a profound decision to be made for or against the use of additive manufacturing processes to produce the selected product.

5. Validation

For the validation of the developed suitability analysis method, experts from additive manufacturing have been interviewed. Furthermore, the method has been tested within a medical technology company.

5.1. Expert Validation

The first version of the method has been presented to four experts during the Rapid.Tech + FabCon 3.D fair 2018 in Erfurt, Germany. The interviewed experts agree that the developed model covers all important aspects to determine the suitability of a product for additive manufacturing. Also, they remarked positively that the sequence of the process and material selection is not rigidly modelled in the method and that this can be adapted on a case-by-case basis. In addition, the holistic view of the method is decisive for the successful application of additive manufacturing processes according to the expert's opinion. A critical remark of the interviewed experts was that the interaction with the additive manufacturing service provider is not sufficiently represented in the method. Here, the additive manufacturing service provider can use his knowledge to propose adjustments to the process and material. In the first version of the method, this was nor clearly modelled and has been improved in the presented second version.

In addition, one expert emphasized to the first version of the method to consider more the profitability aspect already during the product suitability phase. Based on this suggestion, the presented second version of the method has been extended in the product suitability phase by the initial rough economic consideration of the product. Overall, the four interviewed experts of additive manufacturing evaluated the developed method as valid and helpful.

5.2. Use Case

For further validation the developed model was applied in cooperation with a medical technology company. The small sized company, in which the suitability analysis was tested, has 20 employees, a turnover of 2,2 million euros in 2017 and a balance sheet total of almost 1 million euros. For more than 50 years, the company has specialized in manufacturing surgical instruments. The portfolio of manufactured medical products ranges from instruments for the ENT sector (e.g. suction tubes, tonsillotomes and nasal polyp lacers), to bone surgery (e.g. bone holding forceps and wire holding forceps) and spinal surgery (e.g. compressors, distractors and implant holding forceps). The company is interested in producing an implant holding forceps by using additive manufacturing and therefore wants to assess the suitability of this product. The product is used to correct a laterally curved spinal column by shaping a wire that connects the individual spines.

One result of this validation case of the suitability analysis showed that the clear and systematic procedure simplifies the application of the method by users with low or no experience in additive manufacturing. Thus, a well-founded decision on the use of additive manufacturing processes can be made in consecutive steps.

The practical application of the method also identified more potential for improvement and further development. The product suitability matrix can be improved by weighting the individual criteria, as during the validation process it has been shown that not all criteria have not the same significance. This increases the accuracy of the matrix and thus improves its informative value. In addition, users suggested to include also tools for the production and economic phases. This further accelerates the process and helps inexperienced companies in the application of the suitability analysis.

5.3. Feedback-based adjustments

Based on the feedback from the described use case, the suitability analysis is evolved.

For the manufacturing analysis the authors created a tool for a structured value stream analysis which, on the one hand focuses on quantitative criteria like lot size, process time per lot, setup time per lot, number of employees and transport time per lot. On the other hand, qualitative criteria like flexibility of the production, scalability, the environmental impact and the required safety level are considered. The qualitative criteria are weighted, so that they can be adapted to the individual goals of the company.

Moreover, the authors created a tool to calculate the total manufacturing costs to support a fast economic evaluation of the suitability analysis. Based on the input for direct material costs, direct labour costs as well as manufacturing overhead, the manufacturing costs of the products are calculated.

These further tools support the user-friendly approach and enable a simple processing throughout the whole suitability analysis.

6. Conclusion and Outlook

This paper presents a systematic and user-oriented method for a suitability analysis for the application of additive manufacturing technologies in small and medium-sized companies. It covers the whole process from the initial interest to manufacture a product with additive manufacturing technology up to the implementation. Through the structured phases enriched with best practice tools it is suitable for the application in companies with little or no additive manufacturing competencies. The developed method has been validated in a small medical technology company evaluating the additive manufacturing potential of an existing surgery tool. For further improvement, the developed suitability analysis has to be further applied in companies and industries.

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