Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 30 (2015) 311 – 316

www.elsevier.com/locate/procedia

7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business

# Evaluation of Cost Structures of Additive Manufacturing Processes Using a New Business Model

Malte Schröder[a]*, Björn Falk[a], Robert Schmitt[a]

[a]RWTH Aachen University, Laboratory for Machine Tools and Production Engineering, Steinbachstrasse 19, 52074 Aachen, Germany

* Corresponding author. Tel.: +49-241-80-25785 ; fax: + 49-241-80-25785. *E-mail address:* Malte.Schroeder@wzl.rwth-aachen.de

**Abstract**

The individualization and customization of products is one the most important trends for industrial companies. New technologies like additive manufacturing (e. g. 3D-printing) are enablers for the further development of this trend. Companies offering production systems for those technologies are more and more required to embed Industrial Product Service Systems (IPSS) to assert theirselves on the market.
The aim of this research is to develop a business model which evaluates process costs of additive manufacturing technologies. The relevant technologies are Stereolithography, Selective Laser Melting, Fused Deposition Modeling, Selective Laser Melting, Electron Beam Melting and Laser Cladding. Product costs can be calculated easily and the outcome of the evaluation will serve as a valuable decision base for industrial decision makers on how to invest in a special technology. By embedding this service in the production system/ machines software, a big step for a new industrial service is provided.
The paper is structured in four steps. Firstly, based on a detailed description of the state of the art research, an analysis of the most important process steps in additive manufacturing is presented. A new business model for additive manufacturing technologies is introduced afterwards including the implementation of this business model in a software tool. Furthermore case studies for different product types and product quantities are explained and detailed values for process costs are provided. In the last step, a sensitivity analysis is done to find the most important parameters (cost drivers) for those case studies.
The business model and the evaluation of cost structures for additive manufacturing technologies is unique in the field of IPSS. Using a cost and investment calculation, the companies can significantly increase the effort and quality of price calculations for their products. Furthermore cost drivers are evaluated and recommendations for technology related investments are given.


Peer-review under responsibility of the International Scientific Committee of the 7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business

*Keywords:* additive manufacturing; business model; sensitivity analysis; cost structure

## 1. Introduction

Additive manufacturing technologies are all technologies producing components automatically by setting up or joining volume elements preferably in layers. Additive manufacturing technologies are with a growth of 34,9% in 2013 the most increasing manufacturing technology [1, 2, 3]. The current market volume of machinery and services of additive manufacturing is estimated at 3.7 billion euros, equivalent to an amount of 2% of the total machine tool market [2]. Conservative estimations expect a market volume of 7 billion euros in 2016. In 2020 the estimated volume will reach $11 billion [1]. Overall, there is a total market potential of about 130 billion euros [2].

During additive manufacturing processes, quality issues often occur due to operator or machine failures. The rejection rates are high and industry-standard product quality rates can rarely be achieved. In order to produce products of high quality reproducible, companies need to invest in a range of facilities for quality improvement and assurance. “A detailed analysis of the current manufacturing costs and evaluation of expected improvements reveals a cost reduction potential of


Peer-review under responsibility of the International Scientific Committee of the 7th Industrial Product-Service Systems Conference - PSS, industry transformation for sustainability and business
doi:10.1016/j.procir.2015.02.144

about 60% in the next 5 years and another 30% within the next 10 years” [1]. For that reason there seems to be great potential in those investments. Their usefulness needs to be assessed individually prior to their implementation.

Thus, there is a need to analyze different approaches from a financial perspective and to evaluate the economic efficiency. Especially for small and medium sized companies, it is crucial to be able to assess the possible investments in advance. Therefore this service has to be integrated as a product service system in additive manufacturing.

The focus of this work is the development of a cost model, that is applicable for various generative manufacturing processes. The cost model will be used to identify significant cost optimization potentials. In addition, it will be used for sensitivity analysis to identify main cost drivers.

## 2. Literature review and relevant research work

In recent years, cost models were developed separately for different additive manufacturing processes. In this chapter, the main existing cost models are presented and briefly discussed in order to gain an overview of the current opportunities for cost estimation of additive manufacturing processes.

### *2.1. Model by Hopkins and Dickens*

Hopkins and Dickens developed their model with the intention of a comparison of additive manufacturing processes (in particular Stereolithography (SLA), Fused Deposition Modeling (FDM) and Selective Laser Melting (SLS)) with a classic production process, the injection molding. The model can be used for different components and batch sizes to identify the specific unit costs in order to accurately identify break-even points. The approach of the authors provides a breakdown of costs into three elements. The machine costs, personnel costs and material costs.

It is important to note that the model calculates the material costs of the SLS without a notification of material recycling of the powder. Even post-processing activities as surface treatments or other forms of finishing are not included in the calculations. This also applies to all types of overheads. [4]

### *2.2. Model by Ruffo, Tuck und Hague*

Another cost model was established by Ruffo, Tuck and Hague to estimate the cost of small to medium batch sizes in the SLS production process. As an extension to the model of Hopkins and Dickens, the authors understand their model as a full cost model and observe more influences than the previously recognized material, personnel and machine costs.

The cost model schema follows the principle of the allocation of cost-relevant activities to direct and indirect costs, giving a detailed overview of the structure of the printing costs. The identified cost-related activities are material, software, hardware, personnel expenses, equipment purchase and maintenance, as well as production and management. [5]

### *2.3. Model by Gibson, Rosen and Stucker*

The costs of additive manufacturing are separated in four main categories by Gibson, Rosen and Stucker. They relate to the cost of the machine, production costs, material costs and labor costs. The sum of these cost categories represents the total costs.

The production costs are mainly depending on the time of printing. In this model the print time is calculated more accurately than in any other cost model. As well as the print time, Gibson, Rosen and Stucker designed the calculation of material cost applicable for several additive manufacturing processes. This calculation is based on the mathematical approach that the machine has to measure vectors to build up the product. This means that all kind of processes can be modeled that build products in single layers e. g. by the use of nozzle, laser or welding torch. [6]

### *2.4. Model by Ingole et al.*

The cost model by Ingole et al. was developed within a study trying to improve the rapid tooling – making it faster and cheaper using the FDM process. The cost model was used to evaluate the degree of process changes or investments.

The costs in this model consist of the machine costs, material costs , labor costs as well as pre- and post-processing costs. In the calculations, however, a fundamental difference in comparison to the other models is presented. The calculation of the individual cost items is based on dimensional, homogeneous equations, which already include the benefits of the use of rapid prototyping in the calculation itself. It is exclusively a cost-benefit model. The model and the equations in particular are less suitable to perform solely cost considerations. [7]

### *2.5. Model by Lindemann et al.*

Lindemann et al. choose a time-driven activity-based costing approach for the design of the cost model. To identify the cost-relevant processes, initially all activities are divided into four main process steps. These main process steps are preparatory activities, the printing process, the post-processing and the material treatments to improve the material properties. [8]

### *2.6. Implications of literature review*

In all the presented cost models, there is consensus that some specific cost elements in additive manufacturing exist. However those elements have a great variation in their weighting. In some models, single cost elements were not taken into account at all. Other models strive for the recognition of all costs to reach a full cost model. Most of the existing models try to represent costs completely and realistically.

The process-based approach seems to be more and more important because of the usually small economies of scale and the focus on just one single order. This approach collects the