Perspectives of Operational Additive Manufacturing – Case Studies from the Czech Aerospace Industry

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Abstract

This paper presents the output of the quantitative and qualitative survey on the additive manufacturing adoption in the Czech Republic, which was conducted at the end of 2016 and in 2017. The discussion concerns the aircraft industry. The results of a quantitative survey provide a general understanding of the current scope of additive manufacturing implementation. The in-depth semi-structured interviews are conducted with two selected aircraft first-tier suppliers. The interviews provide insight into the road map used for the adoption of additive manufacturing. It depicts the main issues that each company must resolve during the transition from traditional to additive manufacturing.

Keywords: Additive manufacturing, Efficiency, Obstacles, Aerospace, Czech Republic

Introduction

Christopher (2016) identifies numerous factors and deterrents such as, rapid product and service customization, short delivery time and competitive prices. There exist contradictory targets that are impossible to achieve within the traditional operational environments that use outmoded efficiency-enhancing techniques that include Lean Six Sigma. As a result, management practitioners and academicians seek alternatives to completely re-engineer supply chains and operations to become sufficiently agile and efficient to deliver customized products that meet customer requirements.
One possible solution to accommodate market changes is to employ additive manufacturing (AM) and replace current subtractive, formative and assembling operational methods. The concept of AM originated in the late 1980s (Bourell, Beaman, Leu, & Rosen, 2009), however, academicians have concentrated their attention on this topic only since 2010 (Jin, Ji, Li, & Yu, 2017). Despite this, the notion that AM is well accepted within Research and Development (R&D) processes, there is hesitation as to how and where to introduce within the production process. AM is indifferent in terms of costs when considering the complexity of product, optimization of the production process and design limitations (Huang, Liu, Mokasdar, & Hou, 2012). Therefore, the objective of this manuscript is to provide a practical insight into the latter.

Methodology

The principal component of this research encompasses findings identified by means of quantitative and qualitative research. The quantitative, qualitative sources, and literature review substantiate the research findings. According to Bryman and Bell (2011), research methods can be a mix of quantitative and qualitative.

The quantitative research maps the current adoption of AM in the Czech Republic in the main sectors of the economy: aircraft and automotive industry (23 %), electronic industry (6 %), energetics (7 %), pharmaceuticals (10 %), chemical manufacturing (4 %), FMCG (6 %), plastics industry (3 %) and producers of machinery (39 %). The values in brackets represent the distribution of companies among the industries in the study. The authors conducted the research in cooperation with the consulting company EY in November and December 2016. The questionnaire contains 11 questions and this discussion presents a sample of the findings due to the limited space. The respond rate was 10 %. The team distributed the web based questionnaire using an email link to 715 companies with seventy responding. Table 1 provides an overview of the corporate profile.

Table 1 – Structure of companies

Number of Employees	Number of Companies
1-49	8
50-249	23
250-999	30
1000-5000	9

Source: Authors' Own

The authors select two companies from the aircraft industry for the semi-structured in-depth interviews to formulate two case studies. This enables the detection of any significant aspects, both real and perceived, of the complexities associated with the adoption of additive manufacturing. Yin (1994) argues that two comparative case studies are sufficient to produce relevant outcomes.

The two companies represent a medium-sized enterprise of Czech origin as well as subsidiaries of larger international firms. In addition, the level to which AM was adopted and was in place served as additional criteria.

The aim of the comparative case study is to identify the road map used to adopt AM in the Czech Republic. Therefore, the authors sought the industry and companies that are the most matured in AM. The selected companies met the formulated requirements. The focal position for the interview was the leading technical or engineering manager responsible for AM. The names of the interviewees are coded to retain anonymity.

Table 2 – Interviewee

Code	Position
EM	Technology manager
GK	Additive project manager

Source: Authors' Own

In order to prepare for the session, interviewee received the questions. This also facilitated the internal approval process with the relevant corporate authority. The questions comprise three areas:

- The early investigations and initial steps to uncover the circumstances leading to commence AM adoption;

- The current situation consequential to the degree of AM maturity within the company, and
- Plans to capture the future orientation and strategy of the company relative to AM as a result of maturity.

The authors formulate a road map based on the above-mentioned three areas. It demonstrates the critical path to additive manufacturing adoption based on the two case studies. The structure follows the traditional guidelines of technological innovation that consists of the following: research, proof of concept, pilot project and finally, product. The authors use only the first three steps as the AM adoption is a work in progress and is neither completed nor standardized in operation. Some companies are quite mature in the areas of the AM technology, processes (R&A, production, spare parts, etc.) and in some products. The last stage of innovation is not present yet.

The research phase contains the recognition that the AM technology brings substantial opportunities to business or its business model. Furthermore, the establishment of a team or the dedication of relevant human capacity is the inevitable part of the first phase. The second part represents the identification of the suitable technology and project scope for testing. The latter incorporates the company-specific technology, process, and product. The pilot project examines the technology in a specific process and with a specific customer. The research team validates the viability of the innovation concerned with the fundamental aspects of operation, technology, costs, customer, and legal authority requirements, and the like.

Associated with the described methodology, two research questions (RQ) are formulated pertinent to the Czech Republic:

RQ1: What is the current state of additive manufacturing?

RQ2: What is the road map of successful additive manufacturing adoption?

The quantitative research resolves RQ1 by mapping the scope of AM adoption across industries. The answer to the RQ1 defines the suitable corporate characteristics for the qualitative research to determine RQ2.

Findings

What is the current state of additive manufacturing in the Czech Republic?

The results of the quantitative survey outline that companies in the Czech Republic are aware of the AM (39 %, Figure 1) and use it particularly for rapid prototyping (73 %, Figure 2). Apparently, rapid prototyping is the area wherein companies usually deploy AM as it requires simple technologies, lower investments and fewer process in comparison to AM implementation within production process.

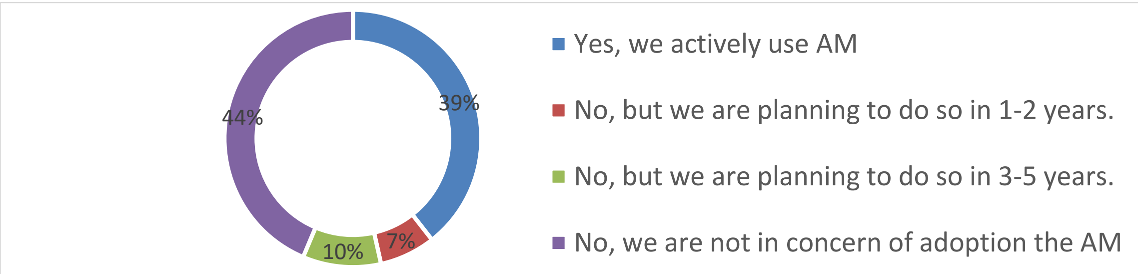

Figure 1 – Adoption of AM in the Czech Republic
Source: Authors' own

The inner circle in Figure 2 represents the engagement of AM in the production process and the outer in the area of R&D. However, the companies expect AM to innovate the production process. This requires an extremely high level of expertness in materials and technologies. This indicates that the adoption within the country is in the first stage as they are mature in rapid prototyping.

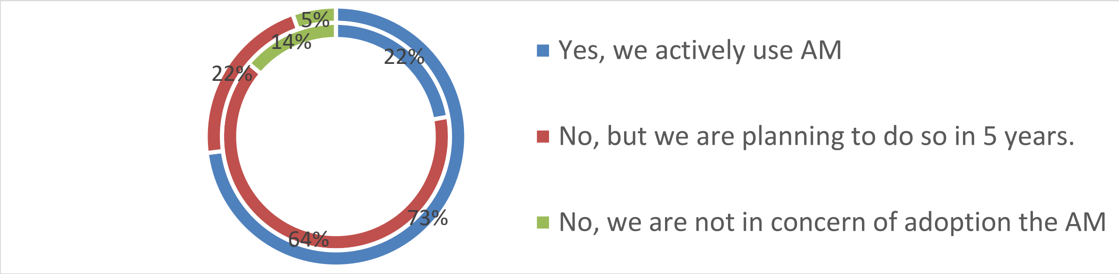

Figure 2 – Adoption in production process and R&D
Source: Authors' own

The major benefits gained from implementation of AM reside in production, logistics of slow movers and in better product customization. These are the traditionally expected benefits. The low logistic cost reduction implies that companies do not extend the AM implementation beyond company boundaries.

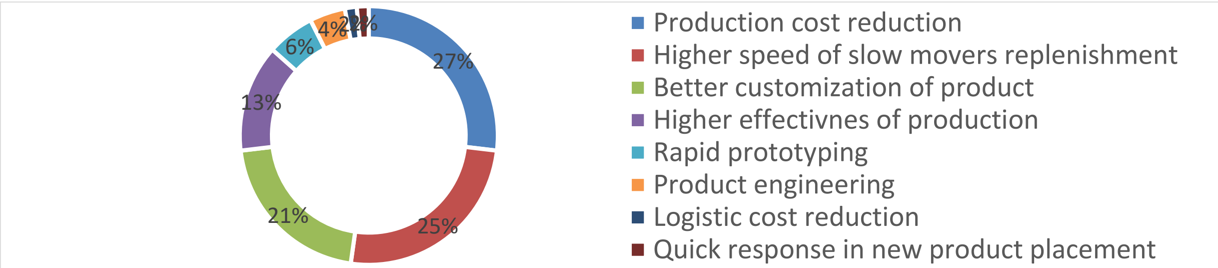

Figure 3 – benefits gained from AM
Source: Authors' own

The barriers include two main categories, the expertness and the financial aspect, which are both closely interrelated. Deep expertness enables the deployment of the technology and material in a suitable process and on the appropriate components, thus creating reasonable savings. It results in lowering the Returned on Investment (ROI) and provides a better acceptance of the technology.

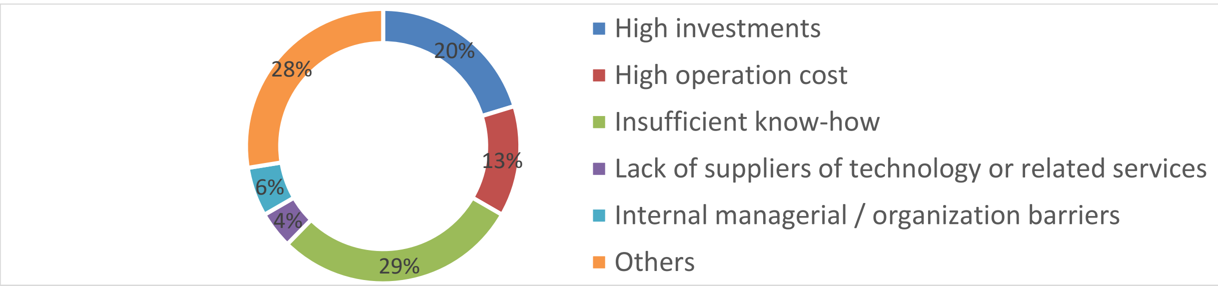

Figure 4 – Perceived barriers of AM adoption
Source: Authors' own

RQ2: What is the road map for additive manufacturing adoption?

Findings relevant to this question are obtained from the in-depth semi-structured interviews with the representatives of the Czech aircraft industry. The structure of the findings follows the innovation cycle guidelines described in the methodological section: research, proof of concept and pilot project.

Research and motivation

The companies experience different circumstances to start additive manufacturing.

Company A

Company A is the only site in the Czech Republic. It lacks incentives from other, especially foreign subsidiaries, to start the innovation. Therefore, the initial motivation is associated with the technology manager in 2007. As a pioneer, he recognized the opportunities that the technology could bring in the future. He initiated discussions with the company C-level. The consideration was very complex and lengthy. "*There was a broad discussion in the company and it took almost 4 years to make the decision to make the step. I appreciated great support from my boss even without having similar support from the owners of the company. There was an invaluable contribution from our long-term supplier of the technologies as it updated us with the offer and relevant AM on the market. We were able to test printing in their facilities and then to borrow one small device at the initial stage of the project. Nonetheless, the supplier wasn´t able to provide us reasonable case studies from the similar business at that time as they weren´t any available.*" (EM)

The major motives to implement additive manufacturing stemmed from:

- Strong belief that this was the technology that disrupts our business
- General proactive attitude to new technologies as they dedicate adequate concern to each upcoming innovation significant to their business. "*We are not a research laboratory but our approach to the upcoming new technologies with the aspect of practicality and economic. We test that and try to push it further*." (EM)
- Company A estimated that AM would become more attractive for customers
- There was the need from internal customers but also potential business from external customer indicated in their feedback. Gained revenue from external customers should cover the operational cost for both internal and external customers.
- Technically skilled and motivated staff.

The technology manager gathered all the relevant data, visited sites and discussed the opportunities with the supplier. The technology manager is the instigator of innovation in the company. This corresponds with his personality, to be ahead of others and to push things further.

COMPANY B

COMPANY B represents the global company with subsidiaries located in and outside Europe. The additive manufacturing is one of the pillars of their corporate digital strategy. COMPANY B calls to establish an AM team in the Czech Republic. "*The COMPANY B called me from Russia to form a team consisting of people from Turkey, Portugal, France and other countries to build knowledgebase of AM. We started completely from scratch here but there was the motivation to do something with that. The beginning of AM in Czech was the consequence of the successful certification of the component for the engine in Boeing in 2015. That provoked more concern about AM on global scale.*" (GK). The GK had gained experience about AM in Russia and helped develop both know-how and motivation in local subsidiary for AM. "*There is great advantage that our company has high level of knowledge about AM globally, so the local team has sufficient information support even when they start with that. We receive case studies from different subsidiaries on weekly bases which helps for motivate of my colleagues.*" (GK)

Proof of concept

Company A

Company A did not analyze the ROI at the beginning but identified major opportunities for the engineering process. In addition, there was the strong belief in the applicability of AM in the production of plastics for external customers. The preliminary analysis demonstrated that AM shortened the engineering process significantly. There is always a problem with quantification of the overall impact. *"When AM shortens only lead-time of the engineering and is not extended to other subsequent processes including logistics then the benefits are limited. We still challenge to suspicion from some internal staff that it is costlier than the traditional approach. However, we benefit from shorter engineering lead-time as the engineer can provide more tasks weekly. Thus, we can provide higher complexity to our customers."* (EM). Company A decided to buy and test Fused Deposition Modeling (FDM) technology based on the expertness achieved in the initial phase. They especially appreciated that the supplier of AM technology made available to them a small device for preliminary testing. "*We purchased small FDM device and washing machine needed for post processing and that was how we started with AM. Firstly, I was the only one responsible for AM but then the programmer joined me at my request. Later on, I extended the team by additional 3 people. We didn´t hire external consultants. I just cooperated with the supplier of the technology. However, sooner did I keep more knowledge about AM in our internal processes than the supplier had. AM is not an easy technology as you make the 3D model and then send it to the printing device. We had to figure out and sort out many issues ourselves, but it pushed us always further. The key was the engineering team keened on the AM. We tested AM in our internal R&D and production processes as well as each product ordered from our customers relevant to AM. When there was a possibility to test it, we did it. That was how we built expertness in AM technology based on our own experience.* (EM)

The outcome of the proof of concept is as follows:

Understanding the lead-time structure of the AM process. *The preparatory phase takes from 15 minutes to one hour depending on the complexity of the product and readiness of the received data from the customers. The planning software overestimates a bit the operation lead-time, which gives us space for the urgent customer orders. What surprised us is the length of post process finalization. We automated it by the AM washing machine, but some material requires manual operation in removing the supporting material.* (EM). *Limitation was on the size of the FDM envelope and so was the size of the product. We can produce even high size parts, but we usually build it up by fixing two smaller parts together."* (EM)

Technology and material. Company A started with FMD than it extended technology to Poly-jet. "*We have 2 FMD devices with the envelope of 90x60x90 cm that we use for the major operation of printing medium and large parts and one smaller device which helps us meeting peaks. In addition, we have Poly-jet AM device that hasn´t met our expectations yet. It can produce multicolor products but there is low demand on it. Furthermore, the Poly-jet can print multi material objects with very smooth covers because of very thin layer (0,013 cm). Poly-jet is faster than FMD but there is limited demand on it in the meanwhile. Nonetheless, the customers stick to the traditional* *production process and don´t apply there AM yet. Hence, we produce smooth covers by consequent manual processing."* (EM). Company A uses different materials regarding their attributes. "*We use ABS M30 in FDM technology because it provides required hardness. For jigs we use Polycarbonates to reach the solidity. Another material that we use is the ULTEM 9085 that is certified for aircraft industry for non-flammability and non-self-flammability. Company A tests the materials against temperature, as it is highly important attribute in the aircraft industry. The material should preserve characteristics till -50 ^{o}C. Polycarbonates and ULTEM 9085 meet this requirement but the ABS M30 preserves the characteristics only to -30 ^{o}C. We also tested and use Polyvinildulfon and we also sometimes combine ABS and Polycarbonate. Furthermore, we use Nylon as it enables making products with very smooth surface"*. (EM). The company has to reflect the method of post processing as each material has different features. Each method separates product and the supporting structure differently either by water, chemical liquids or by manual or automated extraction. "*Customers usually don't know which particular material they need. They have the idea about characteristics of the product but it´s up to us to have the expertness in materials and to choose the right one for the customer. Our competitive advantage is the expertness in AM and individual approach to each customer*." (EM).

"We realized that the lack of knowledge base is why customers don´t want to insource that. It would take them ages to meet the same level with an unbelievable effort." (EM)

What is critical for effectiveness of AM operation is the maintenance. Reliable suppliers of the technology respond quickly but there must be expertness in-house for maintenance. The technicians perform continuous surveillance and small repairs that result in an effective operation and minimal loss in capacities. The AM cannot effectively operate without a strict adherence of the internal standard operation procedures.

In addition to maintenance, the scheduling of production contributes to the effectiveness as each material has different temperature of printing for instance ABS 90^{o}C, Polycarbonates 130^{o}C and the mix of ABS and Polycarbonates 120^{o}C. The transition from one material to the other can be smooth without any stoppages when the program is properly build. Only ULTEM requires some pause for the stabilization.

Like other production processes, organization of supplying material is a highly relevant aspect of effectiveness. The company picks up reputable suppliers that replenishes top-level material. Therefore, there are no serious shortcomings in the supply chain. "*The delivery time is sufficiently short and is from 3 days to one week. We don´t have the problem with stocks as the desired demand coverage is 5 days. We have different segments of customers, for some the delivery time is equal to one day to others it is 2 weeks. Therefore, some volumes are forecasted, and some are planned based on the actual received customer orders. The production schedule is not strictly followed as in other production technologies in our site."* (EM). That creates peaks and downs that can lead to extension of turnover of stocks or hasten stock consumption against the plan.

"We set the system of AM so that it is profitable business and the ROI is below 5 years." (EM).

AM proves to be competitive advantage as customers recognize that even in tenders for non-AM goods. They consider this to be an attribute of innovativeness.

Understandably, the proof of concept phase provides a clear definition of technology, material, and application for specific projects and segment of customers. However, it also outlines that AM is a new progressive technology that companies continuously monitors assets and deploys.

COMPANY B

As the central product of COMPANY B is aircraft engines, their interest if of course, associated with metals given the composition of the inner engine components. *"I started exploring our focal engine component by component respective to AM employment."* (GK) The criteria are as follows: part size (composition), complexity of the composition and certification. "*I pick up composition of which size is close to 40 cm to fully utilize the envelope. Then composition that contains tens of parts and the AM would highly stream line production process thanks to leaving out screwing, welding or soldering. I rejected the compositions with the existing mold as the cost of that would outweighed the savings of AM. Furthermore, I pick up compositions of noncritical parts or without necessary certification from authorities."* (GK).

COMPANY B decides to test the AM on compositions and parts that they engineered for the traditional production process. Therefore, the engineering must develop a digital model of the selected compositions. This complicates the process. AM permits varied component shapes whereas, the shape of traditionally produced components has to be adjusted to the production process. Therefore, COMPANY B identifies the necessity to incorporate decision-making as part of AM deployment within the AM design engineering process. This contributes to the effectiveness not only of the production process but especially to the operational effectiveness due to lower fuel consumption, etc. *"We are not the research laboratory; therefore, we employ only technologies that bring us money which means for us less than 5-year ROI."* (GK)

During the proof of concept, the company calculates the ROI and itis below the limit.

COMPANY B decided to employ Selective laser melting (SLM) because of the material they use in AM.

One of the significant limitation of the current AM operation is the printing speed. Nonetheless, there is the constant increase printing speed in new devices. However, what is relevant to the overall effectiveness is not just the time of printing but overall lead time of the production process. "*We are just analyzing that for the high size components. However, we have already results from analysis of small parts. The traditional production process needed 76 days to produce composition needed 52 activities to accomplish that. AM can produce the same composition only with 10 activities and in 14 days."* (GK) The reduction of the total lead time has enormous impact on the supply chain. "*The AM reduces cost (production and logistic) by 20-25% in small compositions and in large composition consisting of 200 parts is up to 60%."* (GK)

There are other hidden benefits for instance, lower operational cost of the final product.

One of the critical aspects of AM is the post processing operation that ties labor, time and cost. "*We pick up components in which there is now easy post processing. However, it is the issues that did surprise me. Another aspects associated with AM which surprised me was the attitude of people to the surface of products. People still prefer traditional smooth appearance of the components, which is the consequence of the traditional production processes welding, pressing, screwing etc. However, the AM is completely different approach and offers different component inner structure but also the surface. AM can provide nice looking surfaces like the traditional technologies but for higher costs. Does it make sense when the component is inside the product and has constructional function?* (GK) Effectiveness is also in the compromise.

Pilot project

Company A

Company A considers purchasing a jet fusion device to extend the product scope and to increase capacity and the effectiveness of the operation in terms of speed, which is 15

times higher. The jet fusion enables to retain the same mechanic characteristics along with the product unlike FMD. This technology is more suitable for series production rather than customized production. "*Nonetheless, the extension of scope of AM is only in polymers.*" (EM)
Company A monitors also other materials especially glass but stepping into that is not a matter of today. "*I see many opportunities in the new technology and potential business*." (EM). Nonetheless, we have to conduct more analyses and prepare samples for some customer in cooperation with the supplier. We are still not certain that there is sufficient demand on the proposed outputs.
Besides that, the company wants to extend the capacity of FMD by purchasing new device with the envelope of 90x60x90 cm which would mean that the company has the majority of the capacity in the Czech Republic. Extension of the post processing washing machines has to follow that as well otherwise that would become the bottleneck. The AM is still cheaper in the Czech Republic in comparison to the Germany, France and other western European countries because of the labor cost. Material and devices are almost of the same level of price. Especially some technologies of AM are intensive on manual post processing which then make the difference between prices in the Czech Republic and the western neighbors.
There is also ongoing cooperation with our supplier of the AM technology with great mutual benefit.

COMPANY B

The company expands the AM projects and applies for the certification of the critical parts produced by AM. When it succeeds, the extension of AM deployment progresses further in the Czech Republic. This is the next step in the AM road map.
Besides that, the company analyses the possibility to adopt the newer AM technology. "*We are under consideration of Electron Beam Melting (EBM) employment but we are in early stage of it because of the required surface and specific materials that are needed.*" (GK)
"We are working on increasing the share of AM components in our engines." (GK) The current share of AM components on overall engine weight is 35 % and 10% of all compositions are of AM technology.
"What can significantly help us is the higher size of the AM envelope." (GK) The company has the producer and supplier of AM technology in the group achieved by past acquisition. That provides know-how and opportunity to develop AM devices meeting COMPANY B needs without dependency on external suppliers. In addition to that, company is very protective against sharing the knowledge. "*We are launching new AM devices with larger envelope (100x100cm) with 4 lasers which has great impact on speed of the production. That increases our capability to use AM in series production.*" (GK)
Limitation in post processing is currently in the company attention. It develops the idea with an external company that the post processing becomes automated and embedded in AM machine. Fulfilment of this goal is inevitable to employ AM in the series production. One of the major obstacle is a process of certification of aircraft components which is still time consuming regarding MS part. Nonetheless, there is a strong belief in the company about AM prospects. The company designs all engines respecting AM from the start of R&D process.
The testing and acquisitions of technological companies associated with AM leads to the acquisition of knowledge and capabilities. The company aims not to be the user but the provider and the initiator of standards in that area.

Conclusion

The authors conclude that the companies in the Czech Republic are experienced in AM with major applications in R&D. This is an apparent step as AM for R&D requires simpler and cheaper technologies, materials and organization changes unlike an implementation in production. This is the first step to maturity, which enables company to gather information whether to go further and extend the application, or rather maintain the traditional approach or to outsource AM. AM suppliers assist with the initial insight into the technology but further development is completely by the user. It certainly requires enthusiastic technical staff that are sufficiently dedicated to the project and can push AM internally in terms of budget, extension of technology and searching for new possible application in the company. When that is not fulfilled, the company can hardly develop the AM and hits the obstacles of high investments, operational costs and lack of know-how. The accepted ROI and competitive operational cost in comparison to the traditional production technologies are achieved when the dedicated team is capable of analyzing and testing the available AM technologies, materials and proposed products from their portfolio. These tasks cannot be outsourced. The provided case studies demonstrate the effort and issues that each team has to solve to well parametrize AM inside the company. Only then, can the AM provide overall effectiveness and become a competitive advantage built on provision of customization without additional cost. Customization in combination with effectiveness contradicts many traditional production methods. In the company, there is the breaking point that strictly determines the transition point between proof of concept and the pilot project. In company B it was the receipt of certification by AM. Additional milestone in adoption is the change of the engineering process. Company A has not completed this step yet but Company B has started engineering new components for upcoming products respective to AM opportunities. In conclusion, companies in the Czech Republic are still in the proof of concept stage and are exploring the opportunities and possible employment in their processes.

Acknowledgments

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