APEM journal
Advances in Production Engineering & Management
Volume 16 | Number 1 | March 2021 | pp 125–135
https://doi.org/10.14743/apem2021.1.389
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

A new management approach based on Additive Manufacturing technologies and Industry 4.0 requirements

Patalas-Maliszewska, J.[a,*], **Topczak, M.**[a]

[a]Institute of Mechanical Engineering, University of Zielona Góra, Poland

ABSTRACT

Nowadays, it is necessary to formulate and implement a development strategy in manufacturing enterprises, in line with the assumptions of the Industry 4.0 concept. In this context, a gap in the research has been observed in effective management methods, in order to gain a competitive advantage through the implementation and use of Additive Manufacturing (AM) technologies. The main purpose of the study is to build a new approach to management, based on the implementation of new AM technologies and good practice. This paper uses the detailed literature studies and results from the empirical research of some 250 Polish manufacturing enterprises; this material contains a sample thereof, processed into a new approach. The major contributions of the work are as follows: (1) identification of current management areas in which manufacturing companies focus their activities, in the context of Industry 4.0, (2) the establishment of the correlation between gaining a competitive advantage and implementing AM technologies in the context of Industry 4.0, (3) Defining the so-called AM4.0CARD as a new management approach, based on AM technologies and the requirements of Industry 4.0. Managers of manufacturing enterprises, thanks to the use of the proposed approach, may take a strategic decision, regarding the implementation of AM technologies, due to the possibility of forecasting the impact of such an investment on the improvement of the company's competitive advantage.

ARTICLE INFO

Keywords:
Smart manufacturing;
Industry 4.0;
Additive Manufacturing (AM);
3D printing;
Strategy;
Management;
Empirical research;
Competitive advantage;
Balanced scorecard

**Corresponding author:*
j.patalas-maliszewska@iim.uz.zgora.pl
(Patalas-Maliszewska, J.)

Article history:
Received 14 June 2020
Revised 4 March 2021
Accepted 6 March 2021

1. Introduction

The fourth industrial revolution, also referred to as Industry 4.0, is based primarily on the close co-operation between systems related to cybernetic and physical components. Industry 4.0 has resulted in the high integration with the Internet of people and digitally controlled machines, information technologies and networking [1]. Elements and materials produced, or used for production, are identifiable at every stage and have been enhanced with the possibility of independently communicating with each other vertically, from individual components to the company's IT department and from the IT department to the components, in systems based on the assumptions of Industry 4.0. The flow of information is implemented horizontally between machines involved in the production process and the company's production system. The assets of the largest and fastest growing companies are innovative; we are talking about the latest and most innovative technologies and machines, apart from software and digital algorithms, permitted to operate on the network [2, 3]. The concept of Industry 4.0 significantly contributes to changes in manufacturing companies and particularly affects the need to constantly adapt to

customer needs. Industry 4.0 introduces leading IT solutions into all aspects of production. Thanks to the use of advanced ICT technologies, it is possible to adapt production to customer expectations more accurately while maintaining low costs, high quality and efficiency and developing automation towards the implementation of cyber-physical systems and testing human-machine interactions [4, 5]. In connection with the digital revolution observed in industry, management theories are emerging, based on new technologies and achieving competitive advantages in the market, in tandem with the requirements of Industry 4.0.

The basis of Industry 4.0 is its advanced production technologies, which include additive, manufacturing (AM) technologies [6]. AM is treated as a combination of materials with the aim of obtaining a real object, based on 3D CAD data [6, 7]. Metals, ceramics, metal alloys, as well as plastics are used in these technologies. Additive manufacturing technologies, due to their specificity, increase flexibility in production and facilitate the speedy and hitch-free launch of a product. AM technologies are widely used in rapid prototyping and production, as well as in the manufacture of products with complex shapes, which would not otherwise be possible with traditional manufacturing methods. Thanks to the production capabilities achieved using AM technology, with special regard to the production of objects of any shape and structure, AM technologies are the perfect solution for an on-demand, customised production system and support more significant designs and manufacturing freedom to create innovation in Industry 4.0. Thus, machines using AM technologies are very versatile; changing the direction of production or of manufactured products does not require retooling of the production line, as is usually the case with traditional technologies. Thanks to this, time is saved and human participation reduced. Additionally, AM technologies usually recycle material [8].

Based on the analysis of the literature on the subject, we have determined that there are management theories applicable in the context of Industry 4.0. On the other hand, the development of AM technology is evident, as has been confirmed on the basis of empirical research on the use of AM technologies in western Poland, to name but one location. However, answers to the following questions are sought: (1) Does the implementation of AM technology increase a company's competitiveness on the market? (2) What factors influence the decision to implement AM technology? (3) What strategic goals can be achieved by implementing AM technologies?

This paper deals with problems related to management theory, as described in the research literature of 2018-2020, namely, the obtainment, in the market, of competitive advantages by manufacturing companies, due to use the modern technologies in the context of Industry 4.0. Our purpose, in this research, is to advance the literature on the relationship between competition within a manufacturing company and the implementation of AM, in the context of meeting a company's requirements *vis-à-vis* the Industry 4.0 concept. Therefore, a new management approach (CARD), based on AM technologies and the requirements of Industry 4.0 (so-called AM4.0CARD) is proposed.

2. Research methodology

The research was carried out in two stages: (1) analysis of the literature and (2) the empirical research to identify current areas of interest and management-oriented activities in the context of the implementation of AM technologies. In the first stage, current professional literature was analysed, highlighting the main management theories on achieving competitive advantage, verification methods, areas of application and limitations. We reviewed 35 articles published between 2018-2020. Articles obtained from databases (mostly Elsevier) were subjected to an analysis of the preliminary content, based on the titles of the articles and their abstracts. The publication period was set from 2018 to 2020. The knowledge contained in the articles was analysed and extracted, with particular attention being paid to management theory with aim of obtaining a competitive advantage, the correlation with Industry 4.0 and the models verifying the theory thereof and the possible applications and limitations to be encountered when applying a given theory. In the final step, we collected the data, analysed it and proceeded to write this paper. In researching the literature, a research gap was identified in the context of management theory, based on AM technologies with particular reference to Industry 4.0.

In the second stage of the research, at the end of 2019, we tested 250 Polish manufacturing companies from western Poland (from the Lubuskie Voivodeship, Lower Silesia, Opole, Greater Poland and West Pomeranian Voivodeship) in the metal (125) and automotive (125) industries. The tests were carried out using the survey method. The survey questionnaire included multi-choice, closed questions. Among the automotive companies, were 92 small enterprises, 29 medium enterprises and 4 large enterprises, while representatives of the metal industry comprised 95 small enterprises, 27 medium enterprises and 3 large enterprises. The respondents in the automotive industry were mostly representatives of the management (69) and company owners (32), specialist employees, including technologists, logisticians, designers, marketing employees (16) and company support employees, including assistants, accountants, administrative staff, etc. (8). In the metal industry, the respondents to the survey were mainly representatives of the management (72), owners and shareholders (36) and specialist employees, in the fields of quality, production, purchasing, design and construction, among others (13) and company support employees, including accountants and sales/sales department staff (4). The research group represents 1 % of manufacturing companies from the automotive industry and the metal industry, in western Poland [6] based on data from Central Statistical Office of Poland, Warsaw. In the second stage, through empirical research, the interest in AM technologies of respondents, who use AM in production was identified, which indicates the development of additive technologies.

In order to find the answer to our research question, correlation analysis was used. Correlation analysis is a statistical study that describes the strength of a linear relationship between two variables. The value characterising the relation is the correlation coefficient of the sample (r). It takes its values from the closed interval $<-1; 1>$. A value of -1 indicates there is a perfect negative correlation and a value of 1 indicates a perfect positive correlation. A value of 0 indicates no linear correlation [9].

Finally exploited is the capability of the Balanced Scorecard (BSC) to identify the relationship between competition within a manufacturing company and the implementation of AM technologies, in the context of meeting a company's requirements by combining the results of the literature review, the empirical research results and the correlation analysis results. The use of BSC can provide a manufacturing company's strategy [10]. Therefore, a new approach to management (CARD), based on the implementation of AM technologies, was built using the Balanced Scorecard and it is for this reason that identification of the main management problems, needs to be concentrated on four strategic areas in production companies, namely, the customers (the sales market), the finances (including production resources), the processes (production processes) and development (research and development projects). The Balanced Scorecard is a tool that enables the identification of problems in given areas, together with the planning of strategic goals, activities and controls through evaluation of the measure. This tool allows the accurate perspective of actions to be analysed at specified time intervals, so that solutions to identifying problems can be planned while measuring the achievement of goals.

3. Results and discussion

3.1 Literature review results

In the literature on manufacturing, the changes refer to Industry 4.0 [11]. Manufacturing companies focus on the implementation of new technologies in order to meet market requirements and also face the challenge of adjusting manufacturing processes, keeping in mind strategies towards sustainable development, the proposal of products manufactured with a low energy input, using reduced levels of resources and low emissions of waste and exhaust gases. By analysing the literature on the subject, it was possible to identify the main areas in which manufacturing enterprises focus their management activities, dictated by the digital revolution of industry. Data obtained on the basis of literature analysis was collected and summarised in Table 1.

Table 1 Management theories aimed at competitive advantage according to the requirements of Industry 4.0

No.	Management theory aimed at competitive advantage	Aspects of Industry 4.0	References
1.	Theory based on technology-oriented alliances (the hiring of R&D scientists from competitors within the industry)	Technology implementation and development	[12]
2.	Theory based on sustainability in the context of a company's mainstream competitive strategy	Sustainability	[13]
3.	Theory based on sustainable development and inter-temporal trade-offs	Sustainability	[14]
4.	The competence-based view of submarket industrial evolution, that is, the convergence toward homogeneous or heterogeneous industry structures, e.g. the positioning of incumbents	Big data	[15]
5.	Theory based on the concept of relational rivalry (Competition between firms)	No direct correlation	[16]
6.	Theory based on the creative integration of several information and communication technologies (ICTs)	Networking, ICTs, Internet of things	[17, 18]
7.	Theory based on corporate social responsibility (CSR)	No direct correlation	[19]
8.	Theory based on effective risk management in technological innovation and the implications thereof	Big data	[20]
9.	Institutional theory and international entrepreneurship (internationalisation)	No direct correlation	[21, 22]
10.	Theory based on the product-service-systems (PSS) strategy	Networking, Internet of things	[23, 24]
11.	Theory based on the use of business models by management	No direct correlation	[25]
12.	Theory based on the accumulation of knowledge strategies and knowledge management	Big data	[26, 27]
13.	Strategy based on effective research and development (R&D)	Technology development and implementation, big data	[28]
14.	Theory based on management of the green supply chain (GSCM)	Sustainability	[29]
15.	Method based on the synergy effect	Networking	[30]
16.	Theory based on the development of a product and the portfolio design method	Networking, big data, technology development and implementation	[31, 32]
17.	Theory based on identifying and implementing the best technology	Additive manufacturing, technology development and implementation	[33]
18.	Theory based on the management of a sustainable supply chain (SSCM)	Sustainability	[34]
19.	Theory based on business analytics in manufacturing:	Big data	[35]
20.	Smart manufacturing (SM)	Smart manufacturing, Internet of things, big data, building blocks, additive manufacturing	[36]
21.	Theory based on improving the systematic learning within a factory based on the level of maturity	Big data, smart manufacturing, technology development and implementation	[37]
22.	Theory based on implementing project management good practices and lean production methodologies	Additive manufacturing, smart manufacturing, big data	[38]
23.	Methodology for the design of agile product development networks	Networking, Internet of things	[39]
24.	Theory based on open innovation (OI)	Technology development and implementation, networking	[40]

An analysis of the management theories, presented in Table 1, indicates that 20 are correlated with Industry 4.0 while the remaining 4 have no direct correlation thereto. In carrying out further analysis of the data in Table 1, the data was divided into those main areas on which management theories focus and into which the theories were divided, according to the examples of Industry 4.0 to which they applied. To this end, theories were analysed and divided into five main groups or areas on which management activities focus: (1) company—environment relations; (2) company relations—other company relations; (3) processes; (4) products; (5) knowledge and competences. The division of theories into main areas of activity is presented in Table 2.

Table 2 Division of management theory in the area

Management area	The sequence number of the theory (from Table 1)
Company relations—environment	2, 3, 7, 9, 14, 18
Company relations—other company	1, 5, 24
Processes	6, 8, 11, 15, 17, 19, 20, 22
Products	10, 16, 23
Knowledge and competences	1, 4, 6, 12, 13, 19, 21, 24

The literature analysed presents the current management theories that are applied in the context of Industry 4.0. When analysing the data collected in Table 1 and Table 2, there is a visible tendency for manufacturing enterprises to focus on management in two, main areas, namely: processes and knowledge and competences. In addition, there is a clear tendency that most theories are correlated with Industry 4.0 and are applicable in aspects such as: big data, networking, the Internet of things, smart manufacturing, etc. Changes related to Industry 4.0 shape the trend, and force companies to adapt to the expectations of a competitive market. The changing needs of customers mean that, ever more frequently, companies are forced to react quickly and thus to modernise production lines. This is a necessary process but it is time consuming and requires considerable resources. Thanks to the use of AM technology, the use of flexible production, reduces production time, reduces the need to change the production line, allows products to be produced in any shape and reduces human participation in the production process. AM technologies allow products to be produced, based on 3D CAD data, by adding material, layer-by-layer to create a solid object and thus solve various Fourth Revolution issues. However, we have not found an approach to management, based on the implementation of AM technologies in the context of planning strategic action, with the aim of achieving a company's competitive edge. By proposing a new approach, based on the implementation of AM technology, in the context of Industry 4.0, we intend to present the impact of obtaining a competitive advantage by a production company implementing AM technology, using the results of the literature research, the results of the empirical research and the strategic analysis tool.

3.2. Empirical research results

The results obtained were subjected to statistical analysis in the Statistica v.13.3 programme and we examined the correlation between the results obtained. In order to examine the validity of hypothesis 1, we analysed the correlation between the research results related to competitive advantage and the motives for implementing AM technology in the enterprise. The results were collected and are presented in Table 3.

Analysing the results of the statistical surveys obtained, we noticed that the highest correlation occurs between competitive advantage and freedom in product design. Probably, the companies participating in the survey see a real opportunity in gaining a competitive advantage by offering consumers the opportunity to buy any product, personalised according to the customer's expectations. In addition, the motive, indicated for the implementation of AM, suggests that companies want the possibility of quickly transforming production lines in order to be able to produce any product, depending on the needs of the market. The indication for this motive, for the implementation of AM, also suggests that companies want to be able to produce products of any shape, even those with the most complex geometry which could not be produced using traditional, manufacturing methods. In addition, companies see that a competitive advantage can be gained by not having assembly lines, but rather, by having products personalised, using materials efficiently and responding quickly to market needs.

We also examined the correlation between the results of the research, as related to knowledge about AM and competitive advantage. The research covered factors indicating competitive advantage and the factors describing knowledge prerequisite for the implementation of AM technologies, namely: research results related to interest in implementing AM technologies. This factor was chosen because employees' knowledge about AM technology should include knowledge about processes to which AM technologies (and the methods related to AM) can be applied. The data was collected and is presented in Table 4.

Table 3 Correlation between motives for implementation AM technologies and competitive advantage

Relations	Correlation	*r*2	*t*	*p*
Cost reduction/competitive advantage	0.261347	0.068303	4.255292	0.000030
Effective use of material/competitive advantage	0.399677	0.159742	6.852541	0.000000
Freedom in product design/competitive advantage	0.476172	0.226740	8.510392	0.000000
No assembly/competitive advantage	0.411996	0.169740	7.106148	0.000000
Product personalisation/competitive advantage	0.411996	0.169740	7.106148	0.000000
Quickly reaction for the needs of market/competitive advantage	0.371527	0.138032	6.289171	0.000000
Optimisation of product function/competitive advantage	0.329615	0.108646	5.486935	0.000000
Development/competitive advantage	0.034717	0.001205	0.545943	0.585598
Product quality/competitive advantage	0.095248	0.009072	1.503779	0.133916
Effectiveness/competitive advantage	-0.062487	0.003905	-0.983990	0.326083
Waste or energy reduction/competitive advantage	-0.035784	0.001280	-0.562747	0.574117
Employee reduction/competitive advantage	-0.050812	0.002582	-0.799608	0.424706

Table 4 Correlation between interest in implementing AM technology and competitive advantage

Relations	Correlation	*r*2	*t*	*p*
FDM/competitive advantage	0.063443	0.004025	1.001124	0.317743
LOM/competitive advantage	0.095360	0.009093	1.508599	0.132674
DLP/competitive advantage	0.193372	0.037393	3.103808	0.002132
PolyJet/competitive advantage	0.159730	0.025514	2.548154	0.011434
DMLS/competitive advantage	0.485181	0.235401	8.738014	0.000000
SLS/competitive advantage	0.063443	0.004025	1.001124	0.317743
SLA/competitive advantage	0.226348	0.051233	3.659508	0.000309
EBM/competitive advantage	0.226348	0.051233	3.659508	0.000309

The results of the statistical analysis indicated that the highest correlation exists between the interest in implementing the DMLS method and competitive advantage. The DMLS method allows the creation of complex shapes by the selective melting of metal powders that would not have been possible using traditional, manufacturing methods. Once again, companies see a competitive advantage in implementing the AM method that allows the design and manufacture of products of any shape, depending on customer expectations and market needs. In addition, a significant correlation was observed for the SLA (Stereolithography) and EBM (Electron Beam Melting) methods. Both methods are used in rapid prototyping. The SLA method involves hardening the resin by laser, allowing the rapid production of plastic prototypes. The EBM method uses an electron beam to melt metal powders, allowing precision parts to be made in a vacuum.

On the basis of the research results, both from analysis of the literature and the empirical research results from 250 Polish manufacturing enterprises, a new management approach was built, based on implementing AM technologies in manufacturing companies, namely the AM4.0 CARD.

3.3. AM4.0CARD – A new approach to management, based on the implementation of a new Additive Manufacturing technologies

The proposed approach is based on a specific, innovative group of AM, the benefits of the implementation of which appear in all production areas. In order to define the strategic action for a manufacturing company, in the context of an increase in competitive advantage, due to the implementation of AM and the adjustment to the requirements of the Industry 4.0 concept, the Balanced Scorecard tool was used. On the basis of data from Table 1, main management areas were identified, which were presented in Table 2. The most frequently discussed area in the literature analysed were processes. By examining process theories, it appears that they are related to Industry 4.0 in the following aspects: Additive manufacturing, big data and networking. The second area is knowledge and competences; it appears that these are related to Industry 4.0 in the aspect of technology development and implementation. The third area is a company's relationship with the environment and then the relationship of companies with one another. In the

case of relationships, a link to Industry 4.0 has been identified in the aspects of sustainability, technology development and implementation. The last area are products, in which association with Industry 4.0 has been identified; this area is in the areas of Networking and the Internet of Things (IoT). Examination of management theories associated with Industry 4.0 has identified four main areas of management: process, product, knowledge and management and lastly, relationships. Based on the results of empirical research, the correlation between the motives for implementing AM technology declared by the manufacturing companies surveyed and a defined competitive advantage was examined. The results of the empirical research indicate a set of factors describing competitive advantages, including new material, adaptation of new manufacturing technologies, investments, personalised products, the management of suppliers and reductions in the waiting time for products. A significant correlation was observed in the case of freedom in product design: the absence of an assembly line, product personalisation, the effective use of material, quick reaction to the needs of the market, improvement in the function of the product and a reduction in costs. Additionally, a significant correlation was observed in the following factors, new material, adaptation of new manufacturing technologies, personalised products and the management of suppliers. Based on the results of an analysis of areas of management and factors correlated with competitive advantage, strategic goals were defined; this process is shown in Table 5.

The measures in Table 5 were defined on the basis of strategic goals. When designing strategic goals and measures, we took into account the results of the correlation analysis of the motives for implementing AM technology and the factors defining competitive advantage, as well as the results of the literature research. The measures have been designed to allow verification of progress and achievement of strategic goals. Above all, significant interest in laser technologies (e.g. DMLS) and the factors affecting decisions on implementing AM were taken into account: cost reduction, reduction in production times, reduction in barriers to design and in barriers to manufacturing a wide variety of shapes, etc. The perspectives of those actions taken, for implementing strategic goals, based on adopted measures, in accordance with Balanced Scorecard methodology, are formulated in Table 5.

The proposed approach based on the use of AM technology in combination with the theories contained in Table 1, is a new approach, because it directs the enterprise concerned to focus its management activities on specific, innovative manufacturing technology. The approach thus proposes to focus on the new AM technology, enabling the production of finished products and structures of virtually any shape, thereby reducing the assembly stage and human participation. The company's focus on manufacturing with AM technology can help it gain a competitive advantage by being able to respond quickly to market needs without having to switch production lines to a new product, allowing experimentation and prototyping before making large-scale production decisions, which contributes to effective knowledge management and competence in products and processes, as well as to the effective management of resources. The research results may prove useful for manufacturing companies from the metal and automotive industries which are focussed on development and achieving competitive advantage, primarily in the area of manufactured products, product portfolio and quick response to market needs. The main limitations may be differences in the level of development of Polish industry, in relation to other countries in the world. It should be emphasised that the proposed approach was created on the basis of an analysis and empirical research of the literature conducted in metal and automotive manufacturing companies in western Poland (Europe). The proposed approach is the first step to creating an individual, long-term strategy, based on the use of the new AM technology. Creating a long-term strategy should take into account the profile and individual capabilities of the company.

Table 5 AM4.0CARD – A management approach based on the implementation of AM technologies for manufacturing companies in the context of industry 4.0

Perspective	Problem	Strategic goal	Measure	Value	Actions
AM4.0 Customers	Inability to produce a product that meets customer expectations	Adopt and implement AM technology	The number of AM technologies selected, *via* analysis, resulting in the implementation of strategic goals	≥ 3	1. Analysis of new and potentially adaptable production technologies and the selection of a minimum of 3 AM technologies 2. Testing the technology in an external enterprise (research and development unit) before deciding on implementation 3. Comparative analysis of implementation assumptions and the results of empirical research 4. Analysis of the quality of products obtained, using current and envisaged technology
	Limitations in obtaining a product with complex geometry	Product personalisation and freedom in product design			
AM4.0 Finances	Costs of employing production workers	Reduction of employee participation in the production process	Adaptation of AM technology using a laser, e.g. DMLS – a method reducing the assembly stage, allowing the serial production of products of any geometry without the need to retool the machinery Learning and training in the use of new AM technologies	1	1. Selecting a technology that meets the objectives of achieving strategic goals 2. Analysis of the adaptability of new, manufacturing technology 3. Decision to implement the new AM technology 4. Implementation
	Costs associated with the need to change machinery	Quick response to changes and market needs and reduction of conversion costs			
	The relatively large amount of waste material that cannot be recycled	Effective use of material	Indicator of waste material	< 10 %	1. Measurement and analysis of the amount of waste material 2. Control in the management of materials 3. Analysis of emerging, innovative materials in terms of their adaptability to the production process
AM4.0 Processes	Long waiting times for the product	Reduction in production times by reducing the assembly stage	Time of production	-15 %	1. New technology in the production process 2. Adaptation of technology to the requirements of the process and of the product 3. Testing the possibility of obtaining any shape, using AM technology 4. CAD design 5. Production
	Technological limitations in the production of products	Producing products of any shape	The possibility to obtain any shape throughout the production process	100 %	
AM4.0 Development	No access to models	-	-	-	1. New, production process technology 2. Learning and training in the use of new AM technologies 3. Acquiring knowledge and competences through experience in the use of AM technologies
	No R&D activities	Increased level of knowledge and competence in the use of AM technologies	The possibility of acquiring new knowledge and competence	-	

Based on the research results obtained, it can be assumed that the introduction of AM technology into Polish manufacturing companies may contribute to increased interest in Polish products by other EU countries as also to contributing to an increase in the level of exports and competi-

tive advantage. In this matter, a key role is played by the costs associated with production, which shape the price of a given product. The additive manufacturing technology facilitates the production of ready-made structures, the assembly of which would be impossible or at least very difficult using conventional manufacturing methods. In addition to a significant reduction in waste and the maximum use of materials, the production of structures, with complex geometry but without an assembly stage, is the most obvious of the competitive advantages.

4. Conclusion

The proposed approach, namely, the AM 4.0CARD, based on the adaptation of AM technology to manufacturing companies, can be introduced in companies that are focussed on development and continuous improvement. This approach is different from that analysed (Table 1) because it focusses on one specific, innovative group of additive manufacturing (AM) technologies. The AM technology-based approach allows the production company to adapt processes and organisations to the changes dictated by Industry 4.0. Thus, the company, using the proposed approach, can gain a competitive advantage, in a relatively short time, by reducing waste, reducing human participation in the process and producing products of any shape which require no further processing or assembly. AM technologies allow products with a complex geometry to be produced, which would not otherwise be possible, using traditional technologies. This is a huge opportunity for manufacturing companies, because it allows quick responses to the changing needs of the market, without having to re-invest in the machine park and retool. Thus, the time and the amount of the resources, involved in production, are saved. The proposed approach indicates the goals and how they are achieved, which is the scenario for the next step in the implementation of AM technology.

The main limitation to the approach, based on the adaptation of AM technology, is its limited potential for usability in resource-limited enterprises. Unfortunately, the costs of purchasing machines using AM technologies and the costs associated with adapting infrastructure and training personnel are still high. In this case, companies considering implementing AM technology should make an accurate estimate of the costs and the return on investment, taking into account the actual cost of the investment and all the benefits of using AM technology, the efficient use of materials, the reduction of waste, the reduction of the number of employees involved in the production process, freedom to design and produce products without having to change the machine park and to produce products with a complex geometry that could not be produced by traditional manufacturing methods – all of which can really contribute to increasing the company's financial result over a relatively short period, by introducing new products onto the market. In addition, it should be emphasised that the theory was built based on an analysis of the scientific literature and solely on the basis of research carried out in a representative group of 1 % of Polish manufacturing companies in two industries, in western Poland (Europe), the automotive and metal industries. The research was conducted at the end of 2019, which also suggests that it is worth conducting research in the next period, in order to examine changes and evaluations. Another limitation to the application of the proposed theory is the material used in production. Not every material can be used in AM technologies. Sometimes, the inability to change the material used for production can completely waste the chance and purpose of adapting to AM technology. Therefore, an in-depth analysis of the adaptation or replacement of AM technology in a production company is needed, based on the parameters of current production methods and the parameters of the AM technology selected. This is the research direction proposed by the authors of the article.

Further research should be aimed at analysing the possibilities of implementing AM technologies and directing further actions to designing a universal solution to decision making. It is worth emphasising that a new approach will be built in order to take decisions about the implementation of AM technology in a production company, taking into account all relevant, production parameters.

Acknowledgement

This work is supported by the Polish Minister of Science and Higher Education Programme *Regional Initiative of Excellence 2019–2022*, Project no. 003/RID/2018/19, Funding amount: 11936596.10 PLN.

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