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Exploring Challenges in the Integration of Additive Manufacturing

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Abstract. The purpose of this paper is to identify the challenges in the integration of additive manufacturing (AM) that management faces in large manufacturing companies. Based on a case study consisting of a focus group, interview, informal meetings, direct and participant observations, company documents, reports, presentations, and field notes, seven dimensions containing 20 challenges were identified. The challenges were mentioned by 10 participants from four functional organizations. Thereafter, the 20 challenges were sorted into the three stages of integration. The results suggest a newly emerging theme that builds upon an existing framework. Organizational change was a unanimous concern by all functional organizations when contemplating integrating AM into the whole organization. Most of the challenges appear in the pre-integration stage and the post-integration stage compared to the integration stage which only highlighted two challenges. Future research should investigate solutions that contain proper actions and capabilities to overcome the identified challenges to enhance facilitating the integration of AM step-by-step.

Keywords: Additive manufacturing · Industrial 3D Printing · Integration · Challenges · Management

1 Introduction

Additive manufacturing (AM) is a key technology in the future of manufacturing [1]. AM is defined as the “...*process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing technologies.*” [2]. With its ability to add materials layer-by-layer it is now possible to produce and manufacture complex products that were never possible through conventional manufacturing (CM). Complex products can utilize and benefit AM with, for example, reduced cost, reduced lead time, reduced weight, reduced carbon footprint, as well as improved performance [3].

To unlock the full potential of AM in the manufacturing industry AM needs to be integrated into the whole organization consisting of functional organizations such as

operations, purchasing, sales, technology, etc. Integration is referred to as interaction processes involving information exchange and co-production to combine different parts into one whole meaning [4]. Information exchange and co-production are crucial to ensure the integration of AM into the whole organization and not solely in the individual functional organizations [5].

There are two main problems in the context of integrating AM. Firstly, the complexity of AM can influence and change how products are developed, for example, new materials, process selection, technology selection, redesign, manufacturing strategy, quality management, build or manufacture, post-processing, and application, compared to CM [6, 7]. Secondly, the issues with the integration are still challenging for many manufacturing companies. Especially those who are much less familiar with AM, those who are being introduced to it for the first time, and those wanting to scale up [8]. There is usually a bottleneck when integrating AM into the whole organization, the level of knowledge in the industry professionals in the different functional organizations, amount of ongoing and finished AM-related development projects, and if someone is working full-time with AM in the company [9].

The management perspective of AM is receiving increased attention from scientific journals but still lacks clear definitions. Previous research has highlighted that “...AM seems to have different impacts for large companies, which need further investigation.” [10, p. 1432]. There is a need to investigate the integration of AM into large companies in the manufacturing industry through case study research since industry professionals in management positions still experience challenges [10, 11].

To this background, the purpose of this paper is to identify the challenges in the integration of AM that management faces in large manufacturing companies. This would then provide an understanding of what large manufacturing companies should consider in terms of challenges when integrating AM.

2 Frame of Reference

Integration could be seen as the next step from introduction, application, adoption, and implementation toward industrialization [6]. Previous research has focused on the challenges of integrating various technologies, for example, AM and metal casting [12], and on integrating AM in a learning factory [13]. An AM implementation framework consists of general factors that are important to consider when categorizing challenges related to the integration of AM [11]. The general factors can be summarized into:

- *External forces* (e.g., competitive pressures, environmental legislation, customer requirements),
- *AM strategy* (e.g., the alignment between business, manufacturing, and research and development strategy),
- *AM supply chain* (e.g., AM system vendors, material suppliers, customers, location of manufacture),
- *System of operations* (e.g., design for AM, AM process planning, quality control, AM cost accounting systems, integration),
- *Organizational change* (e.g., business size, organizational structure, workforce experience, workforce skill, organizational culture), and

- *AM technology* (e.g., AM standards, technology maturity, technology benefits and tradeoffs, rapid prototyping legacy).

Furthermore, challenges faced by Danish and German manufacturers in adopting AM have been identified [14]. Identified barriers to implementing AM in the Indian automotive sector have been analyzed [9]. Factors that are important to consider when implementing AM from a management perspective have been identified [10]. Additional barriers have been identified in the integration of AM technologies into manufacturing systems [5]. In several studies [5, 9–11], it is not recognized that the challenges can be different depending on the point in time. This differentiation has been considered in the adoption of AM in the context of AM service providers [14] and the implementation of AM for mass customization in the dental industry [15] but not for the integration of AM in the commercial vehicle sector. A definition of implementation along with a life-cycle model in terms of a three-stage sequence (in this research *stages of integration*) has been constructed [16].

1. Pre-installation, in this research *pre-integration*, represents the resources that are relevant to the success or failure of integrating AM which are evaluated.
2. Installation and commissioning, in this research *integration*, ensure the successful and consistent realization of a working order after having AM integrated.
3. Post-commissioning, in this research *post-integration*, include continuous improvements of technical and business-related activities with having AM integrated.

3 Research Methodology

This research was conducted following the case study guidelines [17] as it allows for in-depth exploration of the challenges in the integration of AM. This research was conducted in collaboration with one large-sized heavy equipment manufacturing company with more than 10 000 employees in the commercial vehicle sector that has factories located in Sweden and globally. They develop and produce heavy equipment machines and tools that are used globally by their customers. The company was chosen based on opportunistic sampling [18] since the company 1) develops and manufactures complex products, 2) utilizes AM in different development projects of varying complexity, and 3) has previous experience in AM.

Qualitative data was collected in the case study as it provides descriptions of the studied phenomenon [19]. Data were collected from one focus group [20] held online with nine participants (Participants A–I) and one separate interview held online with one respondent (Participant J) which covers four functional organizations (Table 1). The participants and the respondent were asked two questions in consecutive order related to 1) the challenges of integrating AM into the company and 2) why AM has not progressed more or not matured enough in the company.

Additional data were collected during one year from informal meetings with six of the participants (Participants B–F & J), direct and participant observations (both internal at the company and external, for example, tours in some of the company's factories, online seminars, and workshops), company documents, reports, presentations, and field notes

to add potentially new findings and complement currently collected data. Reviewing the literature served as a base for building up the frame of reference.

The gathering of the focus group and the interview were recorded (video and audio) and transcribed manually. Through the Gioia method, thematic analysis was used to analyze the collected data [21]. All transcribed data were labeled and listed in spreadsheets for each participant. Thereafter, the labeled data were color-coded, grouped into themes, and categorized into aggregated dimensions. Lastly, the challenges highlighted by the functional organizations were presented and sorted into the three stages of integration based on the life-cycle model [16]. An additional gathering with the focus group was completed to report back on the initial results of the research.

Table 1. Summary of the participants from the focus group and the interview

Designation	Job role	Functional organization	Work experience (years)
Participant A	Head of parts & uptime	Sales	1
Participant B	Project leader aftermarket purchasing	Purchasing	5
Participant C	Manufacturing technology development & governance manager	Operations	3
Participant D	Global head of research engineers	Technology	4
Participant E	Research strategy manager	Technology	3
Participant F	Head of advanced manufacturing engineering & research	Operations	2
Participant G	Global commodity director uptime	Purchasing	9
Participant H	Head of virtual product development	Technology	17
Participant I	Head of purchasing controls	Purchasing	11
Participant J	Strategy & future solutions manager	Technology	4

4 Results

It was observed that the company had many ongoing and finished development projects related to AM. Most of the finished development projects were small-scale, focused on polymer materials, and focused on small-sized parts and components with low complexity, small batch sizes, and relatively low cost. Additionally, there were a few ongoing large-scale development projects concerning metallic materials and focused on small- and medium-sized parts and components with varying complexity, small batch sizes, and varied costs. Further, the company had no one working full-time with AM. The company's business strategy was not oriented toward AM. The consistency in the realization of AM-related development projects was missing.

The results of the thematic analysis highlighted several challenges from a management perspective consisting of 20 themes that have been categorized into seven aggregated dimensions (Table 2). Next, the challenges were sorted into the three stages of integration to enhance the understanding of when in time such challenges appear and from which functional organization such challenge was addressed (Table 3). Most of the challenges appear in the pre-integration stage and the post-integration stage and only two challenges are in the integration stage.

Table 2. Thematic analysis of empirical findings

Examples of 1 st order concepts	2 nd order themes*	Aggregated dimensions
“For example, if we reduce the weight of a [product] by 10 kg on a 20 ton machine we would potentially generate a very low reward.” (Participant D)	Identifying and generating value with AM	Added value
	Impact of AM on the value chain	
“How do we control the intellectual property [with AM parts]?” (Participant B)	Intellectual property	External factors
	Benchmarking and competition with AM	
“One challenge is about how we can make it easier to scale up. How do we go from a pilot to a broader application and scale this for different parts of the organizations and so on?” (Participant F)	Industrialization of AM	AM strategy
	Identifying and defining business cases	
	Limited resources for AM	
“I can say from a technology [perspective], the benefits [of AM in the commercial vehicle sector] are not clearly understood.” (Participant D)	Benefits, abilities, and suitability of AM	AM technology

(continued)

Table 2. (continued)

Examples of 1 st order concepts	2 nd order themes*	Aggregated dimensions
	Maturity of AM	
“...are we prepared to invest in certain AM technologies and how far in our supply chain? Do we keep that on our suppliers, or do we take it to the service vans to print it?” (Participant G)	Location of manufacture	AM supply chain
	AM suppliers	
	Financial vulnerability	
“That was a big challenge that we didn’t even have the software and skills in our engineering teams.” (Participant I)	Material, quality, and process perspectives	System of operations
	Testing, experimentation, and evaluation	
	Design for AM	
	Operational planning and organization	
“I hear from Operations [functional organization] sometimes why are we not printing stuff or different parts. We want Technology [functional organization] to tell us what to print and things like that. It seems that we are kind of waiting for each other in different functional organizations to take the first step to ... ‘ok let’s go for this now and try it.’ Perhaps that makes us sometimes get stuck.” (Participant C)	Competence, know-how, and skills in AM	Organizational change
	Prioritization, engagement, and taking initiatives with AM	
	Decision-making	
	Resilience, communication, and coordination	

5 Discussion

The results showed several identified challenges in the integration of AM that different functional organizations face in a large manufacturing company and when those challenges occur in the three stages of integration. The results suggested that a new theme emerged in added value which builds upon previous research [11]. The added value perspective seemed to be an important area for the company in its daily work and overall business strategy. However, it is not clear how added value is defined and used in the context of integrating AM [5, 9–14]. It is suggested that added value could consider the sustainability and product-service-related perspectives [10, 15].

Organizational change was a unanimous concern by all functional organizations. It is suggested that the company should address the concern by answering the following

question: “*What has to change in my business in order for it to be successful?*” [10, p. 1427]. Especially if the company wants to have continued consistency in the realization of development projects related to AM even though AM is not yet integrated into their organization. On the other hand, there was a varied consensus regarding challenges related to AM strategy and AM technology. According to previous research [10, 11, 14, 15], one issue could be the limited knowledge of AM strategy- and AM technology-related challenges.

Table 3. Challenges are sorted into the functional organizations and stages of integration: pre-integration stage (I), integration stage (II), and post-integration stage (III)

Aggregated dimensions	Themed challenges	Functional organizations			
		Operations	Purchasing	Sales	Technology
Added value	Identifying and generating value with AM		I		I
	Impact of AM on the value chain				I
External forces	Intellectual property		III		
	Benchmarking and competition with AM				III
AM strategy	Industrialization of AM		I		I
	Identifying and defining business cases	I	I		I
	Limited resources for AM				I
AM technology	Benefits, abilities, and suitability of AM		I		I
	Maturity of AM		I	I	
AM supply chain	Location of manufacture		I		
	AM suppliers		II		
	Financial vulnerability				III

(continued)

Table 3. (continued)

Aggregated dimensions	Themed challenges	Functional organizations			
		Operations	Purchasing	Sales	Technology
System of operations	Material, quality, and process perspectives		III		III
	Testing, experimentation, and evaluation		III		III
	Design for AM		III		III
	Operational planning and organization		II		II
Organizational change	Competence, know-how, and skills in AM	I	I		I
	Prioritization, engagement, and taking initiatives with AM	III	III		III
	Decision-making		I	I	
	Resilience, communication, and coordination		III		III

It is not surprising that few challenges are present in the integration stage since previous research [14, 15] also highlighted a few challenges with similar distribution over all three stages during the adoption and implementation. However, there might be challenges affecting all three stages simultaneously [15]. Some examples of actions to overcome the challenges are suggested for one challenge in each of the stages of integration. When identifying and defining business cases it is suggested to seek help from AM service providers or AM research institutes [14]. Next, to overcome operational planning and organization challenges it is important to make sure that industry professionals have access to necessary resources (e.g., available workforce, software, money). To prioritize, get engagement, and increase the number of initiatives with AM it is suggested that industry professionals get the opportunity to prioritize such initiatives in their daily work.

6 Conclusions

This paper has identified challenges in the integration of AM that management faces in large manufacturing companies. This research has provided an understanding of what large manufacturing companies should consider in terms of challenges when integrating AM. A new dimension has been added to previous research [11]. Organizational change

is seemingly unavoidable and was unanimously highlighted by several functional organizations of the company. The identified challenges were similarly distributed over all three stages of integration.

Identified challenges may be similar across the commercial vehicle sector in the manufacturing industry and generalization of results in other sectors and industries may be limited. The results might be useful for managers and other decision-makers when planning to integrate AM, planning suitable mitigation strategies, and making more informed decisions related to the integration of AM.

Future research should include insights from engineers, operators, and technicians. Additionally, similar research should be replicated at other large manufacturing companies to further enhance generalizability. This research mainly used qualitative data; hence, future research should include quantitative data or a mix of both. Furthermore, future research should investigate 1) if there are additional challenges affecting all stages of integration simultaneously [15], 2) the relationships between the identified challenges and their influence on the integration of AM [9], and 3) solutions that highlight actions (e.g., mitigation mechanisms) [14] and capabilities, to overcome the identified challenges to enhance facilitating the integration of AM step-by-step.

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