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Additive Manufacturing Technology:
Realities and Strategic Perspectives From India

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ABSTRACT

The authors studied strategic aspects pertaining to adoption drivers, challenges and strategic value of Additive Manufacturing Technology (AMT) in the Indian manufacturing landscape. An exploratory qualitative study with semi-structured in-depth personal interviews of experts was completed and the data was content analysed. Indian firms have identified the need for AMT in R&D and prototype generation. AMT implementation helps Indian firms in mass customization and eases the manufacturing of complex geometric shapes. This study insights would help AMT managers in emerging economies to enable adoption drivers, overcome challenges and add strategic value with AMT. This is one of the very first studies on AMT with theoretical perspectives on the Miltenberg framework, adoption drivers, challenges and strategic value in the Indian manufacturing landscape.

KEYWORDS

Additive Manufacturing Technology (AMT), Adoption Drivers, Business Value, Short-Term and Long-Term Technology Strategy

1. INTRODUCTION

Additive Manufacturing Technology (AMT) or 3D Printing is a manufacturing process where the final object is manufactured by addition or deposition of the material layer by layer to build an object from a 3D Computer Aided Design file (Rayna and Struikova, 2015). AMT can be classified into seven types: (1) Stereo Lithography (SLA) (2) Digital Light Processing (DLP) (3) Fused Deposition Modelling (FDM) (4) Selective Laser Sintering (SLS) (5) Selective Laser Melting (SLM) (6) Electronic Beam Melting (EBM) (7) Laminated Object Manufacturing (LOM) (Vasquez, 2015). These typologies differ on the basic principle of functioning that is the method in which the layers are added over each other (Vasquez, 2015).

AMT has extensive benefits in terms of providing a vast range of design opportunities to the manufacturing companies using it (Klahn, Leutenecker and Meuboldt, 2015). One of the main advantages of AMT is that it provides a flexibility towards production of engineered to order parts without incurring heavy wastage of material while manufacturing (Koren, 2006; Dolgui and Proth, 2010; Berman, 2012). With AMT, the limitations of conventional manufacturing do not constrain

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designers. The designers get a better level of flexibility with geometry and shape of the final object (Schumpeter, 2012). AMT can reduce the production life cycle material mass, energy, and water consumption by eliminating scrap (Cozmei and Caloian, 2012). Further, Cozmei and Caloian, (2012) argued that AMT has a positive impact on sustainability and is a step towards green manufacturing. AMT also provides a certain degree of repairing and refabrication of old and worn out parts thus enhancing the cause of sustainability (Kakati, 1997). Further, AMT helps in sustaining higher mechanical and thermal stresses (Klahn, Leutenecker and Meuboldt, 2015).

AMT literature is also rich with nuances of AMT adding business value. AMT adds value in different industries in different manners. AMT adds value in the aerospace industry by increasing the performance efficiency by weight reduction (Cozmei and Caloian, 2012). Similarly, AMT also is beneficial in military applications as more complex and dynamic life-saving tools can be manufactured without high risk (Cozmei and Caloian, 2012). Application of AMT has been successful in the field of space technology as it enabled manufacturing of parts with different composites and alloys (Koren, 2006; Dolgui and Proth, 2010; Berman, 2012).

AMT in the world of manufacturing has been christened as a disruptive technological innovation (Campbell & Olga, 2013). Disruptive Technologies (DT) are such innovations which have the potential to create both new market and new value network (Christensen, 1995). Further, Christensen (1995) argued that DTs eventually over a period will alter the current market scenario favourably (Christensen, 1995). AMT carries the potency to bring revolutionary changes in both business models and ecosystems (Rayna and Struikova, 2015). AMT is one such manufacturing technology which can disrupt the existing manufacturing field and orient it in a different path altogether (Englyst, 2007). In the early 2000s, 3D printing was used only for manufacturing prototypes (Ortt, 2017). Through subsequent advancement in technology, slowly AMT is becoming the mainstream manufacturing in companies (Ortt, 2017). AMT has provided the ease of printing as a ready to use 3-D object for manufacturers. This can disrupt the traditional manufacturing process. Thus, it is argued that AMT would have great impact on the way companies design their long-term and short-term strategy on technology and manufacturing (Kakati, 1997).

The authors in this research aim to explore the strategic value of AMT. Strategic value is defined as the benefit that a firm may receive from the extant consumer because of the strategic initiatives undertaken by the firm over and above the costs incurred by the company in long-term (Mellor, Hao & Zhang, 2013). It is argued that the current political, economic and administrative scenario in India is favouring the manufacturing sector. National level initiatives like 'Make in India' are a boost for manufacturing industries (www.makeinindia.com, 2017) At such juncture where AMT is being adopted by various companies across the globe, Indian manufacturing firms can also utilize the opportunity to include AMT in their manufacturing process.

Indian companies have started to adopt AMT, but AMT application is still in its nascent stage. The authors in this study explore the strategic value, drivers and strategy implementation challenges that firms are confronting with respect to adoption and application of AMT. It has been widely advocated in the developed countries that manufacturing firms should incorporate AMT in their manufacturing process.

This motivates authors' for conducting this research on AMT. There have been very few attempts to study AMT and its impact on business strategy till now. Thus, this paper is one of the first attempt to contribute about strategic imperatives of AMT in the expanding Indian manufacturing landscape.

2. LITERATURE REVIEW AND RESEARCHABLE GAPS

The introduction section mentioned that there is lack of available research material in AMT domain with respect to Indian industries. To study literature on strategic value with respect to additive manufacturing, the authors consulted online journal databases like Emerald Insight, ProQuest, Google scholar articles, Ebsco search host and IEEE. The author used 'and logic' and AMT keywords

composed of 'additive manufacturing, technology, strategic value, 3D printing, manufacturing strategy' for searching papers. A total of 36 papers by various authors were identified post search. The authors for the literature review however found only 23 research papers to be relevant to the topic.

The literature review first starts with the definitional perspectives on AMT. Across literature, the authors observed various definitions of additive manufacturing and 3D printing as stated by other researchers. Khajavi, Partanen, Holmstro (2013) defined AM as a digital technology to manufacture 3-dimensional objects with the help of a CAD file. Pannet (2014) had defined AM as a technology to print a 3D object layer by layer using a CAD file. Nonino (2017) has defined additive manufacturing as a manufacturing process used to join materials by printing it in a layer by layer pattern using a Computer Aided Design file.Many researchers had commented that additive manufacturing as essentially 3D printing as a technology which has the potential to disrupt the existing manufacturing process (Dawson, 2014; Hyman, 2011; Lipson, 2014; Merrill, 2014; Potstada et al., 2016; Soubra, 2013; Sung-Won, 2013).

The authors have also incorporated the Miltenburg's manufacturing strategy framework in the paper (Miltenburg, 2005; 2008). Miltenberg's framework is basically used in a factory within factory setup to determine the production system which can be used for a factory (Miltenburg, 2005; 2008). Miltenburg's frameworks is governed by six manufacturing levers which are- human Resources, organization structure and control, production planning and control, sourcing, process technologies and facilities. In Miltenburg's manufacturing strategy framework apart from the six manufacturing levers, there are six manufacturing outputs namely-cost, quality, performance, innovativeness, flexibility and delivery. Miltenberg's, (2005; 2008) framework could be applied for analysing the current Indian manufacturing scenario with perspectives on AMT. The same has been done in this paper for analysis.

Subsequently, the authors in this paper have classified extant literature in three tables; Table 1 describes the drivers for AMT, while Table 2 enlists the benefits of AMT as per various extant researchers. Table 3 tabulates the challenges faced by companies while implementing AMT.

In the literature review conducted by authors, it was noticed that there is a lack of availability of literature on the drivers, challenges and strategic value of AMT from an Indian perspective. Most of

Table 1. Business drivers of AMT

Sr. No.	Authors	Reasons
1	Edh Mirzaei, Fredriksson & Winroth (2015)	• AMT leads to effective manufacturing operations due to reduced lead time and reduction in non-value adding activities. • AMT creates a right fit between manufacturing and marketing functions because it adds value. • Strategic alignment of manufacturing and design functions can be achieved through AMT.
2	Khajavi, Partanen & Holmstro (2013)	• AMT contributes by increasing value to customers by reducing lead time and producing more prototypes with lesser resources. • AMT provides ease of Maintenance and Repair Operations (MRO) by enabling easy printing of the defective parts for replacement. • AMT leads to decrease in holding of raw material inventory. • AMT improves efficiency due to increased throughput rate.
3	Riis, Johansen, Waehrens & Englyst (2007)	• AMT broadens manufacturing value through increased manufacturing agility by manufacturing the product in lesser time. • Changing demand of customers can be fulfilled with AMT with less efforts as quick customization is possible. • Innovative manufacturing practices can be adopted by implementing AMT.
4	Cozmei & Caloian (2012)	• AMT provides product flexibility (as quick change in design is possible as it can be easily printed). • Decentralized manufacturing is possible because of the presence of 3D printer and material at vendor locations. • AMT facilitates reduction in equipment and material costs.

Table 2. Business benefits due to adoption of AMT

Sr. No.	Authors	Benefits
1	Kakati (1997)	• Low forecasting error can be achieved by adopting AMT as Just In Time principle can be adopted. • Reduced requirement of raw material and work in process inventory due to adoption of AMT. • Increased throughput rate as the lead time decreases due to AMT implementation • Reduced scrap and waste generation rates as 100% utilization of primary material can be achieved using AMT. • Increased flexibility as AMT provides options for customization.
2	Weller, Kleer & Piller (2015)	• With AMT high customization is possible because changes in design can be made at an early stage in the CAD file. • Functional improvement in the part generated using AMT can be achieved. • Structurally robust components can be designed by optimizing geometry with AMT. • Higher manufacturing flexibility can be achieved by implementing AMT with respect to classical techniques. • With AMT there is reduction in assembly process as the part is directly printed as one unit thus minimal assembly is required.
3	Khajavi, Partanen & Holmstro (2013)	• There is minimal need for change in tools as the part is printed as a single unit without change in tools and requirement of joints. • Small batches can be produced economically with AMT • Product optimization is feasible with AMT. • Lower Inventories can be stored as AMT promotes JIT principle.
4	Cozmei & Caloian (2012)	• Complex geometrical shapes can be manufactured with ease with AMT. • AMT decreases lead time. • Materials like titanium which are difficult to machine can be used with relative ease with AMT. • There is increased productivity with AMT as lead time is decreased and throughput is increased.
5	Klahna, Leuteneckerb, Meboldtb (2015)	• Complex shapes can be manufactured using AMT. • Small lot size production is feasible economically with AMT. • AMT provides greater freedom in design as there is no constraint in design regarding the shapes. • AMT enables usage of novel materials for manufacturing. • AMT facilitates decentralized manufacturing.
6	Petrovic, Gonzalez, Ferrando, Gordillo, Ramo, Puchades & Grin (2011)	• AMT facilitates ease of producing complex shapes. • Implementation of AMT helps in decreasing lead time. • Mechanical properties can be improved by using AMT. • Wastage is reduced because of AMT implementation.

the studies that have been conducted are in developed countries. Thus, an Indian perspective was found to be missing. The authors in this paper have attempted to bridge this gap. An explorative study was conducted by using a semi-structured in-depth open-ended questionnaire. Interview of experts from different types of organizations associated with AMT was done. The research was also conducted with a motive to understand the current level of adoption of AMT in India. Further, the study also assessed the strategic value created by AMT for the companies adopting it. The research was also conducted with an intention to understand the nature of government support extended to the companies adopting it. This was important to understand since many countries have prepared policy-level frameworks and included additive manufacturing in the national manufacturing policies of their country. The authors also intended to find out the short- and long-term strategy and goals of the companies who have adopted AMT. The adoption of technology has been studied here from a managerial point of view based upon the benefits of adopting AMT and the challenges of implementing AMT. If one looks from a firm centric point of view, then from an economic perspective the economic feasibility of the technology (AMT in this case) becomes a pivotal decision-making point. Cost-benefit considerations are simplistic yet well entrenched in literature (Quah & Haldane, 2007; Layard, 1994). Cost benefit

Table 3. AMT implementation challenges

Sr. No.	Author	Challenges
1	Rylands and Tillmann Böhme, Robert Gorkin III (2015)	• There is initial high cost of equipment and material involved with AMT, as the 3D printer and the auxiliary equipment like atomizer is required with it. • Mass production is difficult to achieve with AMT in the current scenario. • Product launch through AMT is risky as the acceptance level of customers towards 3D printing is still inconsistent.
2	Fan & Birtchnell (2012)	• There is reluctance regarding the acceptance of 3D manufactured product in market. • There is lack of technical standards for 3D printing. • There is scarcity of raw materials for the manufacturers using 3D printer. • Workers need to be trained for acquiring required skillset for AMT.
3	Weller, Kleer & Piller (2015)	• Mass production is challenging to achieve by AMT. • Sometimes required surface finish is difficult to achieve with the current level of AMT. • Quality issues due to lack of technical standards is there with current level of AMT. • There is a physical dimensional limit of the part size that can be printed using AMT with present technology. • Cost associated with AMT are considerably higher than conventional manufacturing techniques presently. • Lack of consumer awareness is also a challenge for AMT adoption.
4	Strong, Sirichakwal, Manogharan, & Wakefield (2017)	• The parts produced using AMT are sometimes not dimensionally accurate. • The surface finish of AM printed parts need to be improved further. • Sometimes the material property of materials used for AMT needs to be improved.

considerations become existential question especially for new technologies like Robotic or AMT (Palmer, Oates & Portney, 1995; Rus & Inglada, 1997). Thus, the authors as a first step on AMT adoption in India considered as research questions benefits and costs of AMT adoption by firms. The research was also conducted to understand the drivers as well as the challenges with AMT.

The research questions are, for Indian manufacturing firms:

1. What are the drivers for adoption of AMT?
2. What are the challenges in implementing AMT?
3. What are the short-term and long-term strategic goals on AMT?
4. What are the business benefits of adopting AMT?
5. What is expected role of government support in AMT adoption?
6. How (Miltenburg, 2005, 2008) manufacturing strategy framework is influenced by AMT?

3. DATA COLLECTION, RESEARCH METHODOLOGY, AND DATA ANALYSIS

The authors undertook an exploratory study to understand the reality regarding AMT in India. AMT is at a very nascent stage and thus the authors at such an early context undertook an exploratory qualitative work as prescribed by Maxwell (1996). Exploratory study was required because AMT is a nascent field of study (Maxwell, 1996) globally and more so in the emerging economies context like in India. As Dubin (1978) and later Gioia and Pitre (1990) had reflected that at the initial stages of a field to establish theories at the beginning of an impending field (here AMT) has to be carried out with empirical investigation. At the inception stage, the scope of empirical work is restricted as the world of practice (in this context the practice of AMT) is limited (Patton, 2005). Thus, the authors could only collect data from a lesser sample size. However past studies in qualitative research

had indeed talked about the notion of theoretical generalization rather than statistical generalization (Corbetta, 2003; Silverman, 2013). Even with the small sample size the authors reached thematic saturation with the current sample size which is a criterion for sample adequacy in qualitative research (Maxwell, 1996). The authors to shortlist the experts list used expertise on AMT as the shortlisting criteria as advocated by qualitative researchers (Corbetta, 2003; Silverman, 2013). Further, the authors also applied non probabilistic snowball sampling in this exploratory study as advocated by Maxwell, (1996). Additionally, there is associated expertise relationship amongst experts as Denzin & Lincoln, (1994) and Bryman, (2006) had prescribed. To understand the what, why and how nature of questions (as mentioned in previous sections) the authors undertook a qualitative study (Dana and Dana, 2005; Dana and Dumez, 2015). The authors conducted In-depth interviews with AMT experts in Indian context (Rubin & Rubin, 2011; Roulston, 2010;2011). The interviews were carried through in-depth personal interviews, skype based interviews and telephonic interviews with experts on AMT. The experts had domain knowledge on AMT as well as contextual knowledge of AMT in India. 9 experts were interviewed for this research. The experts were having expertise in AMT in India as technology users (manufacturers), consultants and researchers. The average experience of the experts on AMT in India was about 4 years. The average interview duration was about 55 minutes. The interviews were conducted first with leading questions and then subsequently with probing questions (Rubin & Rubin, 2011; Roulston, 2010, 2011). Interview protocol was developed. The interviews were conducted such that all the questions were sufficiently answered (Roulston, 2010, 2011). It must be noted that AMT is such a new field in India that with the most experienced manufacturing experts also the average years of experience on AMT was just 4 years. The expert interviews were stopped with 9 interviews as thematic saturation was achieved (Popping, 2000; Weber, 1990; Holsti, 1969). The data collected was transcribed by one of the authors within 72 hours of data collection. The data analysis method was content analysis (Neuendorf, 2016; Weber, 1990; Holsti, 1969). Three types of content analysis were carried out were thematic analysis, relational analysis and intensity analysis (Holsti, 1969; Neuendorf, 2016; Popping, 2000; Weber, 1990;). The codes were developed from extant literature (Popping, 2000; Weber, 1990; Holsti, 1969). The codes were also checked for validity by an external academic expert. Both the authors did the data analysis. The data was categorized and classified to fit into the developed thematic codes. The intra-coder reliability for the authors was 96% and 97%. The intra-coder reliability was checked after a month's gap. The inter-coder reliability was 93% which was carried out by an external expert other than the authors. Both the reliability figures were within acceptable range (Neuendorf, 2016; Holsti, 1969).

4. FINDINGS

The data collected from the experts based on interviews were assessed based upon the codes prepared by the authors from extant literature. The data gathered covered aspects regarding understanding the current reality regarding AMT in India. The data analysis indicated the challenges of AMT, drivers of AMT, government support towards AMT and the strategic value that is created by additive manufacturing. The recorded responses of the experts were analysed based on the key themes. These findings have been tabulated and presented in Tables 4, 5, 6, 7,8, 9, 10, 11, 12 and 13. Table 4 tabulates the various responses of the experts on the motivational factors for adopting AMT in their company. The expert respondents have been denoted in the tables as R1, R2, R3, R4, R5, R6, R7, R8 and R9. Experts from firms that have adopted AMT have foreseen the advantages and benefits that are associated with AMT. The companies that have adopted and implemented AMT desire to establish a strong core competency in additive manufacturing. There is substantial focus on learning being carried out by these companies to understand the process of 3D printing. The focus is to compare the quality of product manufactured with that of traditional manufacturing and to explore the process in more depth.

Table 4. Motivation behind adopting AMT in the companies of respective experts

Response	Expert Respondents
The motivation behind adopting AMT in R1's company are: 1. AMT helps in developing and designing fixtures. 2. Prototypes can be manufactured with greater flexibility. 3. The respondent argued that there is increased clarity as the mechanism for fixture can be printed and can be inspected for flaws easily.	R1
The respondent argued that AMT has provided fabrication free status and thus greater flexibility in manufacturing. It has also benefited in reducing scrap generated and lowered the quantity of support material required.	R2
As per the respondent who is a consultant in the field of AMT, companies are motivated to adopt AMT because it leads to reduction in waste generated and helps companies adopt lean practices. The respondent also further stated that the cost of manufacturing and the lead time required also reduced.	R3
As per the respondent, AMT generated business value for the company. The company was motivated to adopt AMT owing to the enormous benefits that were caused by AMT. Complex shapes and designs could be modelled with relative ease using AMT.	R4
AMT promoted innovation in design and created a market value for his company which motivated his firm to further implement AMT in the company.	R5
AMT was adopted in the respondent's company as it was observed that AMT had the potential to reduce manufacturing lead time and create higher flexibility in the manufacturing process.	R6
The respondent suggested that companies that were adopting AMT were definitely creating business value.	R7
Not Applicable	R8
The respondent's company (in the manufacturing of engineered to order products) required high degree of customization. The parts designed have complex geometry. AMT provided the mentioned advantages, the company thus adopted AMT.	R9

In Table 5 the authors have tabulated the responses regarding the challenges faced during implementation of AMT in India. Customer awareness remains to be an area where currently Indian market is lacking knowledge and acceptance regarding AMT. The advantages of AMT are mostly unknown to consumers in Indian FMCG sectors, automobile sector and auto component suppliers. AMT enables a reduction in manufacturing lead time and helps implement Just in Time (JIT) principles more effectively. Material unavailability is a major challenge faced by organizations specifically in the plastic material domain.

Table 6 enumerates the responses of experts regarding value creation by AMT. According to experts, AMT is crucial as it creates value for the company (mostly manufacturing and marketing value). Innovation is the need of the hour and the firms adopting AMT could foster innovation both in the product development as well as at the process stage.

Table 7 tabulates the short-term and long-term strategy adopted by companies with respect to AMT. The short-term strategy is to address any flaws which exists in the current process of AMT. Quality manufacturing is also another parameter which is being addressed at the initial stages by firms. Long-term strategy involves mass production and for achieving scales with economical production capacity.

As observed, the companies are currently focusing on improving the quality of products manufactured using 3D printing. The long-term focus of firms is towards achieving mass production. In Table 8 the changes in a manufacturing process because of AMT adoption are presented. The opinion

Table 5. Challenges faced by experts while implementing AMT

Remarks of Experts	Expert Respondent
1. Mass production is not possible with AMT. 2. Rough surface finish is sometimes obtained through AMT compared to injection moulding. 3. Material availability in Indian market is scarce and most of the material must be imported from abroad for which heavy customs duty needs to be paid. 4. Materials prices are also high.	R1
According to the respondent, the company faced following issues with AMT implementation phase: 1. The market survey conducted by their company found that customers lack awareness about the process of 3D Printing as the technical standards are not mentioned often clearly to customers. 2. Sourcing of raw material for AMT was also a challenge for the company. 3. The cost required to implement a full operational set-up for AMT was high.	R2
Not Applicable	R3
According to the respondent, his company had planned to use 3D Printing for their manufacturing process and thus developed a core competency in this field. The firm could easily shift from conventional manufacturing to additive manufacturing. While implementing additive manufacturing, following challenges were enlisted by the respondent: 1. Transfer of AMT knowledge from the western companies to India possessed a challenge. 2. The set-up cost required to implement AMT was high as well as the material costs.	R4
As per the respondent, AMT implementation phase required changes in terms of the hardware required for the functioning of AMT.	R5
The respondent argued that, AMT implementation required training manpower and developing the skillset specific to this technology.	R6
As per the respondent, material availability has been a challenge for the implementation of AMT.	R7
Not Applicable	R8
1. Rough surface finish compared to injection moulding was observed which has been a challenge. 2. Lower material availability in Indian market is a challenge. Further, most of the material must be imported from abroad for which heavy custom duty is required to be paid. 3. Customer awareness for the product is low.	R9

of experts varied with industry. It can be observed from Table 8, that most of the changes are pertaining to the changes in hardware and the kind of workforce skill base required to be involved with AMT.

Based on the responses provided by the experts, common themes were identified. As mentioned, this was carried out by thematic content analysis. Intensity analysis was performed on the identified themes for the codes. The intensity analysis was based upon the intensity of the words used by the respondent. The more pressing and important themes were analysed. The analysis was then colour coded to stress the importance of that theme with respect to the Indian scenario. Intensity analysis was performed on all the questions from the questionnaire and the more important themes have been presented in decreasing order of importance (from most important to least). Tables 9, 10, 11, 12 and 13 illustrate the intensity analysis with respect to the motivation of experts behind adopting additive manufacturing in their company. The most intense themes are higher up in the Tables 9 to 13 than the less important ones.

Table 10 tabulates the important themes pertaining to challenges for implementing AMT which were identified through the expert interviews conducted.

Table 11 tabulates the nature of government support required for wide spread usage of AMT in Indian manufacturing.

Different types of values can be generated by firms while implementing AMT. This has been tabulated in Table 13.

Table 6. Value creation by AMT

Remarks of Experts	Expert Respondent
Additive manufacturing helped to create business value as well manufacturing value in the respondent's company. Firstly, it helped save millions of dollars annually on tool design and fixture design. Secondly, the requirement of manufacturing drawing had also been reduced.	R1
Manufacturing lead time has been cut to more than half of the original time required. Thus, AMT helped generate manufacturing value in the respondents' company.	R2
According to the respondent, companies adopt AMT because it helped generate business value as well generate a new market for them. It has helped adopting firms win the tag of being an innovative company in the field of manufacturing.	R3
AMT has helped create business value for the respondent's company. The firm could generate more intricate designs with practically no scrap generation.	R4
As per the respondent, AMT helped to reduce manufacturing lead time for generating increased manufacturing value. The firm also secured the right fit between manufacturing and marketing functions to generate business value for the company.	R5
According to the respondent, the full potential of AMT gets generated in a few years' time not immediately. Thus, to access the true value of AMT a longer time horizon needs to be considered	R6
Not Applicable	R7
As per the respondent, AMT had helped generate value not only for the company itself but also for the suppliers of the company. It had generated manufacturing and business value for the entire network.	R8
The respondent's company, provides consultation to the companies implementing AMT. Thus, AMT consulting as a vertical itself has been generated due to this technology.	R9

5. DISCUSSION AND CONCLUSION

Authors have attempted to explore the strategic value of AMT with perspectives from AMT experts from Indian industries. Authors conducted semi-structured in-depth interviews of experts in the field of additive manufacturing from various experts. Experts from 9 different companies were interviewed for this paper. Traditionally in supply chain cost efficiency and delivery time were inversely proportional to each other, because when delivery time decreased, cost incurred for the same, increased (Bhatnagar & Viswanathan, 2000; Agrawal & Nahmias, 1997). With the help of 3D printing, delivery time can be reduced without increasing the cost of the product.

There remains a common consensus amongst Indian experts that 3D printing as a technology has disruption potential. This had been argued by Mellor, Hao, and Zhang (2013). As per Edh Mirzaei, Fredriksson and Winroth (2015), manufacturing operations are simplified by adopting AMT and it leads to reduction in manufacturing lead time. The same was observed by authors from the responses of Indian AMT experts collected through interviews. AMT has the potential to reduce manufacturing lead time which results in quick generation of prototypes, decrease tooling time and decrease in waste generation. Adoption of AMT helped the companies to save their expenses on material in the long run and prevents holding of extra inventory. AMT can lead to decrease in non-value adding activities of the employees which in-turn leads to increase in productivity of Indian firms. One of the major challenges stated as per Weller, Kleer, and Piller (2015), AMT does not produce products with a desirable surface finish. The same was found by the authors during the interviews conducted with various managers from different firms. Lack of well-defined technical standards for AMT affects the dependency on acceptance of the final product. This in turn affected the customer awareness regarding the products manufactured using AMT. This was evident based upon the interview discussions with the experts.

AMT is a value generating technology for companies as argued by Khajavi, Partanen, and Holmstro (2013). The authors also agree with the researchers that AMT is a value adding technology

Table 7. Short-term and long-term AMT strategy adopted by companies

Remarks of Experts	Expert Respondent
As per the respondent, his company planned to acquire a greater number of industrial printers. In the long-term, the company plans to acquire printers that are capable of printing objects with large physical dimensions. This would allow the company to produce parts and prototypes easily.	R1
As per the respondent, long-term strategy of his company would be to develop an environment of 3D Printing friendly market in India. This would involve developing supplier base and ensuring availability of material for AMT.	R2
The respondent argued that, short-term strategy will be to acquire greater market share for 3D printed products. The company will not be focusing on loss incurred in the short run. In the long run future mass production and to smoothen the process of sourcing of material for AMT needs to be ensured.	R3
The respondents company currently has been focussing to develop its core competency in 3D printing. The firm currently had sufficient number of 3D printers to cater to the demand of different Indian companies. The short-term strategy was to acquire as many partners for developing 3D printing market. For a long-term perspective, the respondents company plans to develop his firm as a leading innovator and market leader in 3D printing.	R4
As per the respondent, there will be changes in the firm's business policies regarding manufacturing with increased role of AMT. Also, there will be technological changes made that will be required for adopting AMT in the company.	R5
Short-term strategy of the respondent's company is to focus on improving AMT products quality issues while as per long-term strategy the firms has to incorporate more of AMT along with traditional manufacturing process.	R6
According to the respondent, his company's current strategy is to optimize the processes for AMT. In the longer run, the firm would have large volume production with AMT.	R7
Not applicable	R8
The respondents company provided consultancy to those companies that adopt 3D printing process. For short-term, the company's focus is to develop a strong market. On the long-term, the company plans to launch its own 3D printed products in the market.	R9

Table 8. Operational changes and manufacturing procedural changes on adoption of AMT

Remarks of Experts	Expert Respondent
As per the respondent, no major changes were required to be incorporated in the company's manufacturing process to adopt AMT. The prime motive was to generate prototypes. The respondents argued that AMT is easy to incorporate in manufacturing system.	R1
According to the respondent, there were changes required only in the designing aspect of manufacturing process and it was not difficult to incorporate AMT in the firm.	R2
Not Applicable	R3
The respondents company adopted AMT since its inception. So, they had planned the manufacturing processes as per its need in phases	R4
Not Applicable	R5
Not Applicable	R6
There were changes made on the manpower side as skilled labour with AMT technical knowledge of the process were required by the firm.	R7
Not Applicable	R8
Not Applicable	R9

Table 9. Intensity analysis of themes observed for motivation behind adopting AMT

Sr. No.	Themes	Colour Code	Expert Respondents
1	AMT provides higher degree of flexibility for parts to be manufactured	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
2	Higher degree of customization is possible by implementation of AMT	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
3	AMT promotes ease of manufacturing complex shape	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
4	Manufacturing lead time is significantly reduced due to AMT	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
5	3D printing can manufacture high variety of products	Gray	R1, R2, R3, R4, R6, R7, R8, R9
6	AMT leads to reduction in waste generation	Gray	R1, R2, R4, R5, R6, R7, R8, R9
7	It is possible to reduce holding inventory because of AMT	Gray	R1, R3, R4, R5, R6, R9
8	AMT is becoming the disruptive capable technology in Indian manufacturing	White	R1, R9, R6, R7

Table 10. Intensity analysis of challenges confronted while implementing AMT

Sr. No.	Themes	Colour Code	Expert Respondents
1	Low material availability in Indian market.	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
2	High cost of raw material	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
3	AMT generated parts having rough surface finish.	Black	R1, R2, R9, R4, R5, R8
4	Lack of customer awareness regarding AMT.	Black	R1, R3, R9, R4, R5
5	Lack of clear technical specifications for AMT.	Gray	R1, R3, R9, R6, R5
6	High set-up cost of AMT machines and auxiliary equipment.	Gray	R5, R9, R3, R4
7	Possibility in reducing holding inventory with AMT adoption.	Gray	R1, R3, R4, R5, R6, R9

Table 11. Nature of government support that is expected and that has been received for encouraging AMT

Sr. No.	Themes	Colour Code	Expert Respondents
1	Requirement of subsidies from government.	Black	R1, R2, R3, R4, R5, R6, R7, R8, R9
2	No direct support required from government for adopting AMT.	Black	R1, R2, R3, R4, R5, R6, R7, R8, R10
3	Various national level policies like Start-Up India, Digital India as well as development of business corridor may urge companies to start focussing on 3D printing as a shared manufacturing facility in a cluster.	White	R4, R6, R9

Table 12. Short-term and long-term strategy adopted by companies to implement AMT

Sr. No.	Themes	Colour Code	Expert Respondents
1	Short-term strategy is to focus on quality aspects of the products manufactured using AMT.	Black	R1, R2, R3, R4, R5, R6, R7, R9
2	Companies implementing AMT should presently focus on producing higher variety and not large volumes of product.	Black	R1, R2, R3, R4, R6, R8, R9
3	Generate customer awareness and promote advantages of 3D printing to supplier as well as customers in the long run.	Gray	R1, R2, R3, R5, R7, R8
4	Establish a sustainable market for 3D printing on a long-term.	White	R1, R2, R6, R7, R9
5	Focus on producing large quantities of 3D printed products in the long run.	White	R1, R3, R5, R8

Table 13. Types of value generated by implementing AMT in company

Sr. No.	Themes	Colour Code	Expert Respondents
1	Implementing AMT generates business value for company.	Gray	R1, R2, R3, R4, R6, R7, R9
2	Implementing AMT generates manufacturing value for company.	Gray	R1, R2, R3, R4, R6, R8, R9
3	Implementing AMT technology generates marketing value for company.	White	R1, R2, R4, R6, R7, R9

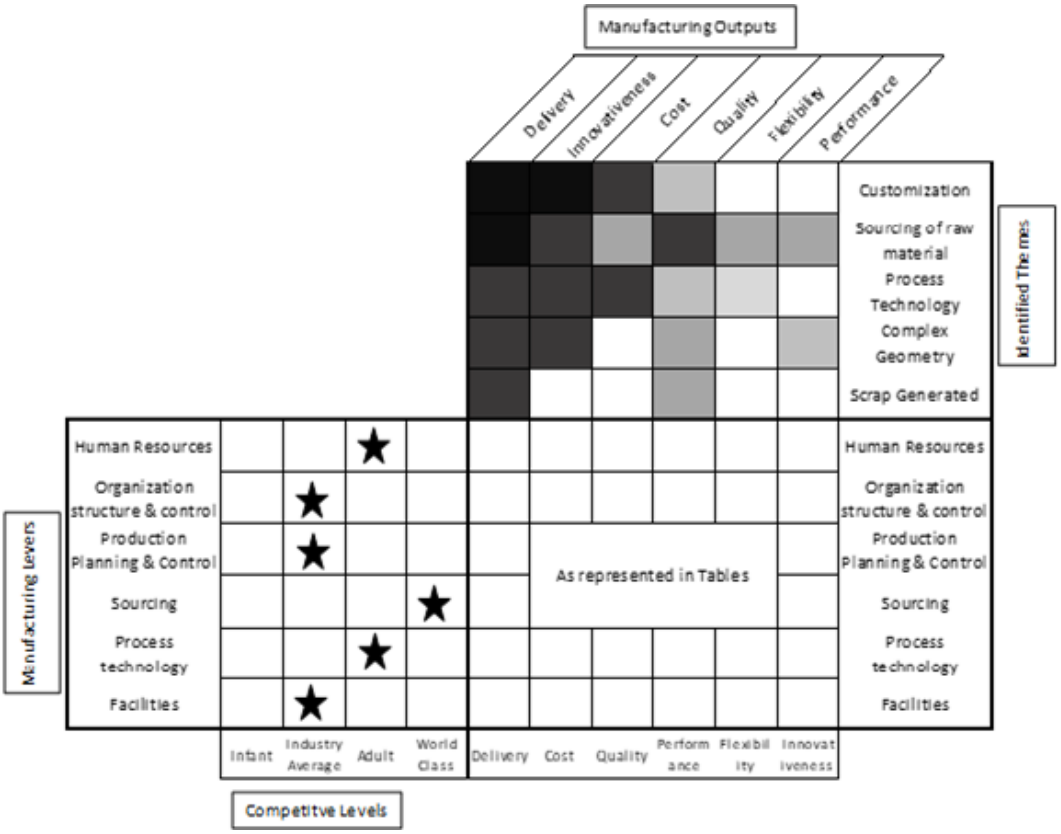
and has successfully created business value for Indian firms that have adopted AMT. Further, it can also be concluded from the interviews conducted with experts that AMT has been able to generate manufacturing as well as marketing value for the Indian companies that have adopted AMT in manufacturing processes. Decrease in manufacturing lead time, provide greater manufacturing flexibility, promote use of new materials, compounds and alloys for manufacturing and thus generate value for firms that had adopted AMT. The authors also witnessed that; Indian companies are currently focussing on improving the quality of product manufactured through AMT. The experts from various companies also argued that AMT has got disruption capability in India which would be realized only in future as there will be more focus on AMT. The authors have structured the discussion section around the Miltenberg's framework (2005, 2008).

The following section dwells with the application of Miltenberg's framework and its modification by the authors for AMT as a technological tool in Indian manufacturing firms. The competitive advantages have been selected through the interviews conducted and the impact of these themes on the manufacturing output has been represented in the paper. Further to this, intensity analysis of the matrix formed by establishing relation between manufacturing output and identified themes, was performed which has been represented in Figure 1.

The effect of manufacturing levers on the manufacturing output in the context of AMT in India have been presented in the Table 14. This inter-dependency of manufacturing outputs has been decided based on the interviews conducted with AMT experts by the authors. The responses of experts were examined and compared to understand the relationships between the manufacturing levers with AMT on manufacturing output.

As it can be comprehended from Table 14 that AMT impacts the various manufacturing outputs in a progressive manner. Table 15 tabulates the impact of AMT on the various manufacturing outputs

Figure 1. Miltenburg's framework (2005, 2008) for AMT in India



in Miltenburg's framework (2005;2008). The responses of different experts were analysed by authors to understand the complete effect on manufacturing outputs.

Table 16 explains the existing capability level of various manufacturing levers with respect to current Indian scenario. This capability level has been represented in the Miltenburg framework (2005;2008) and the capabilities have been portrayed through the interviews conducted with experts.

Indian business landscape is becoming competitive Bhattacharyya (2011). Indian manufacturing firms have to respond to this state. AMT have potency to generate competitive advantage (Porter, 1980, 1985). This research addresses the growing technological changes in the manufacturing sector in India because of the advent of AMT. Through this study, the authors aimed to explore the strategic value of AMT in Indian industries. Semi-structured open-ended in-depth interviews were conducted. It became evident that AMT has made a tremendous impact on the manufacturing outputs as proposed by Miltenberg (2005, 2008). Themes which were identified based upon the interviews of various experts has been proposed. The authors also did an intensity analysis to identify the impact of individual themes which were identified through interviews conducted. External benchmarking of manufacturing levers was carried out by comparing it with the expert responses which was found through the interviews conducted. This benchmarking was then classified into four rankings namely infant, adult, industry average and world class. It can be concluded from this benchmarking that Indian industry is yet to achieve its full potential in AMT and its applications. The various conclusions have been represented through the Miltenburg (2005, 2008) framework.

Table 14. Inter-dependence of manufacturing outputs and the themes identified by the authors through interviews because of AMT Miltenberg (2005, 2008) framework

Manufacturing Lever	Delivery	Cost	Quality	Performance	Flexibility	Innovativeness
Human Resources (HR)	Skilled HR engaged in AMT helps reduce lead time.	The company which has adopted AMT may incur higher cost to recruit trained and skilled workforce to work on AMT. This might however benefit the company in reducing training as well as wage costs for workforce on a long-term.	AMT marginalises the effect of HR skill base. Thus, HR involved with the manufacturing operations of AMT would not relate to quality. However, HR involved in designing would impact the quality of final product.	The performance of skilled and trained workforce on AMT could be better than unskilled workforce	The authors argue that skilled HR involved with the manufacturing operations might not impact the flexibility of the product and AMT process. The authors further argued that the HR deployed with the design of product using AMT can impact the flexibility of the product.	The authors argue that skilled HR might not impact the innovativeness of the system in production. The authors further argue that the HR deployed with the design of product using AMT could have an impact on the innovativeness of the product.
Organization structure and control	The part of organization structure which involves people deployed with the R&D, design, marketing and operations in AMT in a company, helps to reduce delivery time.	Cost incurred is higher for a skilled workforce, but a systematic and well-defined organizational structure involved with AMT might reduce costs incurred eventually.	The quality of the process can be expected to improve by having a proper organization structure deploying AMT.	The performance of the AMT process can be improved by having a well-defined organization structure and control on the R&D, design, marketing & operations department required for AMT.	A structured organizational control promotes a quick transfer of customer feedback received through sales and marketing department. These requirements can then be implemented in a swift and effective manner by design and operations workforce involved with AMT.	The firms which use AMT and can capture customer needs faster and thus could benefit from the early changes adopted in design, materials and processes used to manufacture the final product by AMT.
Production, planning and Control (PPC)	With a well-defined PPC department, delivery time can be reduced deployment with AMT.	It is argued by the authors that PPC might not impact the cost incurred as the need for PPC would be eliminated in AMT process.	A strong PPC will improve the quality of process but might have no effect on the final product manufactured.	PPC could improve the performance of AMT process by having a well-planned schedule for producing final part. Thus, it would help in proper scheduling of raw material required for manufacturing part.	A competent PPC will be able to include changes in the product unless it is already in manufacturing.	The authors argue that PPC might not affect the innovativeness of product as it does not interfere with the design operations of company.
Sourcing	The impact of sourcing on raw material for AMT is directly proportional to delivery time. Lower the time required for sourcing raw material, quicker will be its delivery time.	Sourcing of raw material impacts cost directly in AMT. To procure superior quality of raw material, companies from India often purchase raw material from foreign countries which leads to increase in cost.	The quality of raw material sourced, impacts the quality and functionality of the final product manufactured using additive manufacturing	Sourcing of raw material might not impact the performance of final product as performance depends on the design of product. However, a superior quality of raw material used in AMT can make the product structurally strong thus impacting its performance.	For Indian firms, sourcing of raw material from foreign countries, makes the procurement process of AMT challenging. This is because the ingredients also Indian firms are heavily dependent on foreign players.	Sourcing could not affect innovativeness of product manufactured using AMT as innovativeness is imparted through design.

continued on following page

Table 14. Continued

Manufacturing Lever	Delivery	Cost	Quality	Performance	Flexibility	Innovativeness
Process Technology	AMT process technology affects factors like speed of process, accuracy of process, etc and would affect the delivery time favourably if these factors are optimized for the production process.	Process technology used for AMT process impacts the cost incurred. A process with superior surface finish and densely packed structure would increase the cost. Overall, process technology may help reduce cost as AMT can be widely used for customization of complex parts.	Superior process technology affects the quality of product by producing defect free product. Thus, AMT process technology can affect the product favourably.	Process technology used for AMT will impact the performance of final product as it will improve the repeatability and accuracy of the process.	Advanced process technology may provide more flexibility in manufacturing final product using AMT given that the planners of process technology are proactive in adopting the changes.	AMT process technology elevates the innovativeness of manufacturing processes.
Facilities	The location of manufacturing facility will have an impact on the delivery time. Decentralized manufacturing, which is the case with AMT, might reduce delivery time.	The location of facility has a direct relation with the cost incurred on the product manufactured using AMT. The facility cost parameters need to be optimized.	Facilities do not impact the quality of product manufactured using AMT because of independent operations.	The facilities will not impact the performance of product as it is independent of the operations with AMT.	The facilities do not provide flexibility to the process of AMT manufacturing because of independent operations.	Facilities do not affect innovativeness of AMT product or AMT process because of independent operations.

Table 15. Impact of AMT on the various manufacturing outputs in Miltenburg's framework (2005, 2008)

Sr No.	Manufacturing Output	Impact of AMT on Manufacturing Output
1	Delivery	Application of AMT decreases delivery time as it takes less time to manufacture parts
2	Cost	AMT can produce a part at similar cost or with an increase in the cost as mass production capability cannot be achieved with this technology
3	Quality	The effect of AMT on quality cannot be stated accurately as quality depends on various factors like quality of raw material used, process technology, skill of manpower, etc
4	Performance	The performance of a part produced using AMT is also independent of its manufacturing process. Certain applications like aerospace sector where reduction in weight is required can be achieved using AMT. Thus, performance of part produced using AMT will depend on its application
5	Flexibility	AMT provides a greater flexibility in the manufacturing of product because of free form fabrication and complexity in AMT
6	Innovativeness	AMT provides innovative methods of producing objects with complex geometry

6. SCOPE, FUTURE DIRECTION, AND IMPLICATIONS

The study of Indian AMT manufacturing landscape was a qualitative study. The study was based upon responses received from Indian AMT experts. The expert's responses were analysed based on a qualitative open-ended semi structured questionnaire. These expert responses were then content analysed and categorised in the forms of themes. Thus, the scope of this research has limitations both in methodology as well as in context. In method, the scope is that this research is qualitative research. In context, this study scope is restricted to India. The themes were on drives, challenges, short and long-term strategic imperatives and business gains of AMT in India. Further, the authors had

Table 16. AMT capability level of manufacturing levers in Miltenburg's framework (2005; 2008) with perspective of Indian companies

Sr. No.	Manufacturing Lever	Remarks on Capability Level
1	Human Resource	Through the various interviews conducted with experts, it was understood that human resources engaged with additive manufacturing in India stands at an adult or matured level. The Indian experts have a great knowledge regarding AMT as they are trained in premier centres around the world. Lack of experience and the exposure to advanced AMT is a concern which could be overcome in coming time
2	Organization Structure and Control	The organization structure and control in India related to AMT has been ranked as industry average by the authors (as concluded based on the interviews conducted with experts). As business for 3D printing in India is growing, the potential has not yet been fully realized. Due to this, most of the companies deploy AMT presently only for R&D and prototyping techniques. Thus, a robust organization control on AMT lacks in Indian perspective. The authors argue that with the expansion in business and more innovations would be pursued by Indian companies in future in this field. This would help to have a better organization structure and control regarding AMT
3	Production planning & Control	Indian companies currently deploy AMT mostly for prototyping purposes. In some Indian companies, AMT is used for batch production. Thus, the PPC department is not matured as compared to the global firms (as understood from the expert interviews).
4	Sourcing	The sourcing of raw material in Indian companies often takes place through the foreign companies as foreign Original Equipment Manufacturers (OEM's) supplying a 3D printer have a monopoly on the material provided. 3D printers are designed in a way to accept the raw material as per the specifications mentioned by the OEM's. This makes sourcing of raw material (at similar quality level to the rest of the world) a challenge.
5	Process Technology	The process technology used by Indian companies on AMT is at par with the rest of the world. There are few advanced AMT technological features available only to the top players in world because of the heavy investment in additive manufacturing and R&D made by those companies. Thus, the authors have ranked the process technology at an adult level.
6	Facilities	The AMT facilities under which the Indian companies are operating 3D printing technology presently can be improved in order to compete with the global leaders in the field of AMT.

attempted to implement the Miltenberg framework (2005, 2008) with respect to additive manufacturing perspective in Indian context from the interviews conducted. Theoretically this study thus furthers AMT adoption literature from a cost benefit perspective plus drivers and challenges perspective. This article also contributes to Miltenberg's frameworks in the context of AMT.As this research was carried out in India and thus the themes identified are perfectly suited for the Indian industry in particular. Certain aspects of this study can be extended to international contexts of other emerging economies. Theoretically this research work, advanced Miltenberg framework in the context of AMT in the emerging economy of India. This research theoretically does so by exploring aspects of AMT adoption, drivers, challenges, business gains, short and long-term strategy and expected government support on AMT in India.

In future research work can be carried forward by conducting a quantitative survey method-based model development. This can be done in future when the adoption of AMT in Indian manufacturing firms has matured. Furthermore, the authors propose that a case study can be undertaken by investigating 2-3 firms which have adopted AMT in its manufacturing process for a relatively longer period of time. Such an in-depth detailed analysis can be carried out to understand regarding the strategic value, strategic implications while planning and implementing AMT at the firm level with

longitudinal data. This study was conducted in India where additive manufacturing is currently in its nascent stage. In future, similar studies can also be conducted in emerging economies like Brazil, Russia, China, South Africa to have a comparative understanding in emerging economies with growing economic footprints in the manufacturing sector.

The authors believe that managers in different companies which have adopted AMT or are adopting AMT can benefit from the study. For managers this study would aid them in decision making on AMT adoption. Managers can comprehend and explore what kind of challenges they would confront while implementing AMT. This would help them to address such difficulties beforehand. The understanding on drivers would help them focus on such factors that would enable adoption of AMT. The managers working in different companies on AMT can collaborate to form a common knowledge base. Also, a shared technical aspect regarding AMT processes documentation on AMT can be carried out in India. Miltenberg framework was applied by the authors in this study for including AMT. The insights could be used by managers. This might help them to focus on the relevant and important aspects of AMT process. The thematic and intensity analysis carried out by the authors can provide a platform for managers to identify the important parameters while formulating strategic and tactical decisions regarding AMT as a process. As concluded by the authors and in cognizance of various researchers from around the world, 3D printing has disruption potential by altering the existing supply chain methods of holding inventory. Managers can, therefore, utilize this potential of AMT to reduce costs and increase manufacturing efficiency in their companies as well as supplier network by preparing a stepwise plan for its adoption. The inputs from this study can be used by the managers to identify the challenges that are looming regarding the adoption and usage of AMT in Indian manufacturing. Also, the findings of the study on drivers of AMT can be used to promote the application of AMT by the various managers responsible towards AMT planning and decisions.

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