AM IN THE AEROSPACE INDUSTRY

THE STATE OF THE INDUSTRY, MAY 2016

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A survey of the Canadian aerospace industry reveals a difference in perception among AM stakeholders.

ABSTRACT

HEC Montréal gathered the opinions of over 70 organizations from every level of the additive manufacturing (AM) value chain in order to measure the differences in stakeholders' perceptions of AM-related opportunities, challenges, cost drivers and advancement initiatives. Results showed a lack of interest from the manufacturers, an underestimate of post-processing operations costs and a divergence in the opinions of stakeholders about the initiatives that should be undertaken to accelerate AM deployment.

Methodology and scope

The scope of research is restricted to the integration of metal AM technologies in Canada's aerospace industry. The data was gathered via a survey of 107 participants from more than 70 organizations and via 15 interviews with representatives from every segment of the supply chain.

Areas of concern and recommendations

There is a <u>lack of interest among manufacturers to invest in AM</u> due to the initial investment, which is too high and too risky given the speed of evolution of AM technologies and the low demand from OEMs. For AM deployment to happen, manufacturers must have an interest in the technology. This objective could be achieved through R&D tax credits, adapted R&D funding programs, collaborative R&D and/or strategic partnerships.

One obstacle faced by early adopters is the <u>underestimate of post-processing operations costs</u>. These costs can be high for multiple reasons, such as inappropriate product design, inappropriate support structure design, overpriced post-printing operations or an inadequate local supply chain.

<u>The absence of AM equipment in the OEM's plants</u> can cause a lack of trust and understanding of the process which leads to a reluctance to place orders of components made via AM.

To improve trust in and demand for AM products, OEMs will have to work closely with academia and research centres on applications of AM in the aerospace industry. Added to that, certifications and standards will need to be developed as soon as possible.

Results show <u>a divergence in the opinions of stakeholders about the initiatives that should be undertaken to accelerate AM deployment</u>. Academia and research centres would like efforts to be made to increase the technology's readiness level (TRL), contract manufacturers want the investment in equipment to be less risky, and OEMs want the focus to be placed on material and process certifications and standards. The needs of the different industry segments vary according to the challenges they face. None is necessarily more important than the next, but rather, since they are all linked together, they must evolve in parallel. Therefore, multiple efforts should be made in research, design techniques & tools, certifications & standards, and the creation of profitable business cases.

The full version of the report includes a more complete analysis of the topics discussed previously as well as recommendations to address these concerns. The appendix contains the main results of the Canada-wide survey and is publicly accessible to enable stakeholders to use the results as they see fit.

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Keywords

3D printing, additive manufacturing, aerospace, technology integration, emerging technology, supply chain, innovation.

THE INTEGRATION OF AM IN THE AEROSPACE SUPPLY CHAIN

1.1 Introduction

Additive manufacturing (AM), more commonly known as 3D printing, is a rapidly-evolving technology that promises a competitive advantage to businesses able to correctly integrate it into their processes. It offers advantages such as faster prototyping, accelerated product development, lighter structures, new innovative and complex design, and even the ability to create parts that were once impossible to manufacture with traditional equipment. The following research project aims to facilitate the integration of metal AM into the Canadian aerospace supply chain. Due to its versatility, AM could provide an interesting niche for Canadian manufacturing SMEs by allowing them to manufacture a large spectrum of metal products without an in-house foundry, forge or press. Canada is ranked among the global elite in the aerospace industry, and the development of AM expertise is essential to ensuring local suppliers remain competitive and keep pace with modern manufacturing.

This study is part of a M.Sc. thesis supported by HEC Montréal, NSERC and CRIAQ. The core of the research is a Canada-wide survey that helped in understanding How to successfully integrate metal additive manufacturing in the Canadian aerospace supply chain. The solution will be presented as recommendations based on observations of the actual state of the industry. The participation of over 70 organizations in this study highlighted concerns about the actual state of the industry, such as misconceptions by multiple stakeholders as to AM's true potential, the lack of demand by OEMs, the underestimating of post-processing operations, and the need to adapt R&D programs to new business cases.

1.2 Methodology

With the collaboration of 15 members of the industry, a survey questionnaire was designed to reliably capture respondents' perceptions of AM. The survey was sent to 307 participants in 182 organizations related to the Canadian aerospace industry in February 2016. From the initial list, 107 participants from more than 70 organizations responded to the survey. Respondents were segmented into the six categories below in order to group organizations with similar behaviors and objectives. The acronyms in parentheses correspond to the 15 anonymous specialists who were interviewed in order to build the survey questionnaire and analyze the results obtained.

- Metal Powder Providers (MPP1, MPP2)
- AM Equipment Manufacturers (EM1, EM2)
- Traditional Contract Manufacturers (CM1, CM2); Contract Manufacturers with In-house AM Equipment (CMAM1)[1]
- Original Equipment Manufacturers and Tier 1: (OEM1, OEM2)[2]
- Academia: (ACAD1, ACAD2, ACAD3)
- Others: (CRD1, CRD2, CRD3)

The distribution of respondents is shown in the two figures below. The survey results reliably illustrate the reality of the market and will help organizations justify their future AM-related investments.

Table 1: Survey participation per supply chain segment

Participation per SC segment		
Segment	Nb. of organizations	Nb. Of participants
Metal Powder provider	2 to 4	4
AM Equipment manufacturer	4 to 5	6
Contract manufacturer	30 to 34	35
OEMs	10 to12	19
Academia (universities and colleges)	11 to 15	25
Others	12 to 16	18
Total	71 to 86	107

The survey questionnaire[3] contained seven questions covering the following subjects:

1 The contract manufacturer segment includes all aerospace suppliers and contract manufacturers from Tier 2 and 3, with and without in-house AM equipment.
2 The OEM segment encompasses all organizations that own their designs, with or without internal manufacturing capabilities. This includes original equipment manufacturers and Tier 1.
3 The integral version of the questionnaire can be found in the Appendix.

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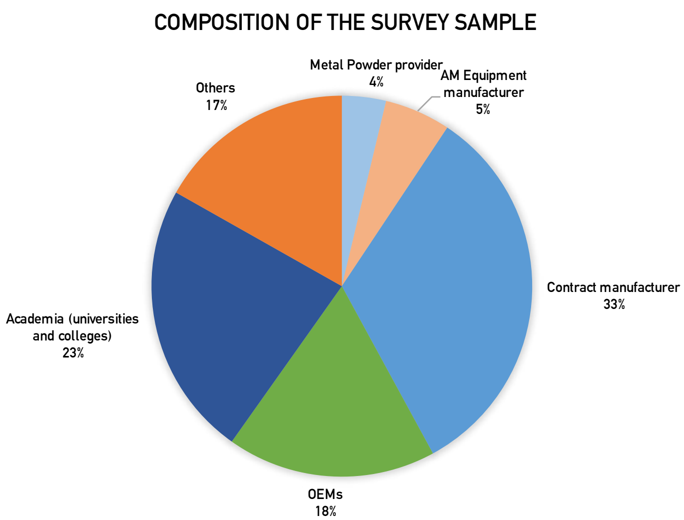

Figure 1: Composition of the survey sample

- The nature of the respondent's manufacturing operations (traditional or AM)
- Perceived opportunities for utilizing AM
- Perceived challenges for utilizing AM
- Perceived most influential cost drivers in AM
- Type of AM-related initiatives that could accelerate AM deployment

1.3 Divergence of preferences for support initiatives

For the last question of the survey, each respondent was asked to select the suggested support initiative that would have the most added value for its organization. The distribution of the results, shown in figure 2, clearly illustrates three initiatives that stand out in the list. It also shows a clear divergence of preferences among OEMs, contract manufacturers, academia and other organizations. The following section will discuss the different points of view based on the interviews with some of the participants.

The three initiatives that stand out are:

- AM-specific government programs to increase the technical readiness level (TRL)
- AM-specific governmental subsidies for equipment acquisition
- Material and process certifications and standards

The results also show that industry priorities are not necessarily qualified labour training, specialized consulting services or shared AM factories.

However, while qualified labour training did not stand out as a priority, this does not mean it is unimportant. It only indicates it is not the top priority for the vast majority of survey respondents. Based on the interviews with CRD1, CRD2, EM2, OEM1 and OEM2, design expertise is considered as the starting point of AM. There will be a growing need for better optimization and simulation software. Even if it is possible to train traditional technicians, engineers and operators in designing for AM it is the next generation of designers that will come up with more innovative business cases based on a different design mindset (interviews with CRD1, CRD2, EM2, OEM1 and OEM2). Engineering-related programs should be adapted to the new technological trends (interview with CRD1).

In order to provide a better overview of the opinions of the various segments, the figures below are a modification of Figure 2 that separates academia others and OEM-contract manufacturers.

Figure 3 isolates academia, research centres and para-governmental organizations to show their preference to invest in programs to increase the TRL of AM technologies.

The limited performance of available AM equipment and the quality of print are obstacles for AM deployment (interview with CRD2). An increase in AM machine performance and print quality will lead to a rise in market demand for products produced through additive manufacturing.

Collaborative research is an effective way to share the knowledge and risks of AM-related R&D projects.

Research centres and academia can provide high-tech equipment and knowledge to industrial players while working on aligning the TRL of a project with industry needs (interview with CRD1). However, collaborative research is not flawless; it can be improved through the simplification of funding

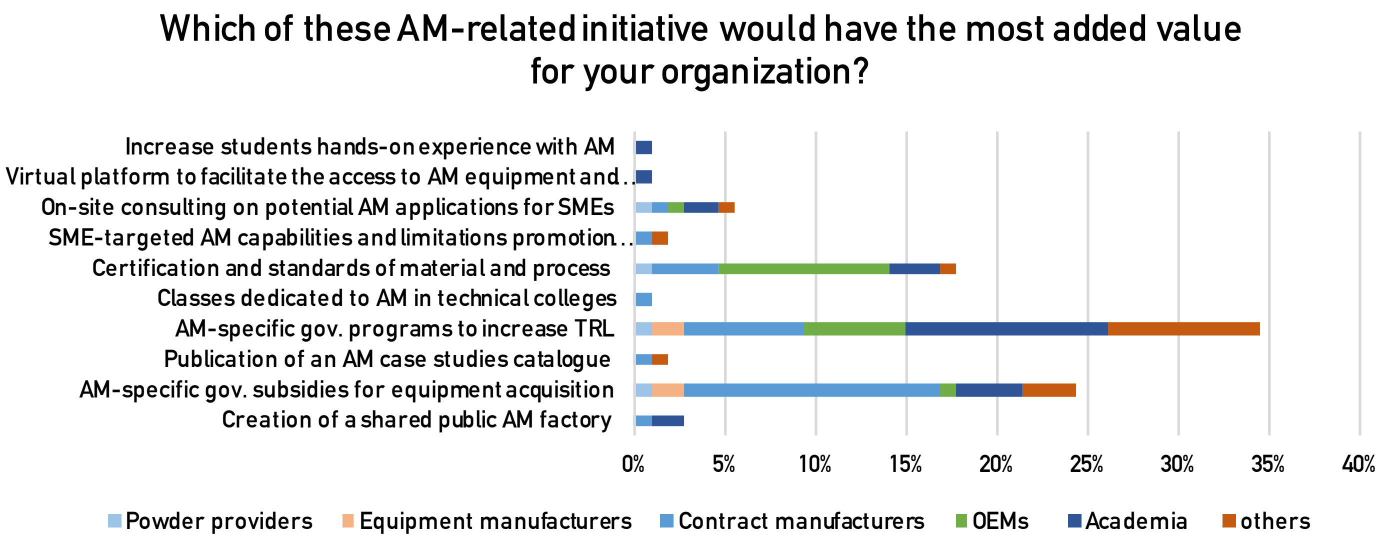

Figure 2: Importance given to multiple AM-related initiatives

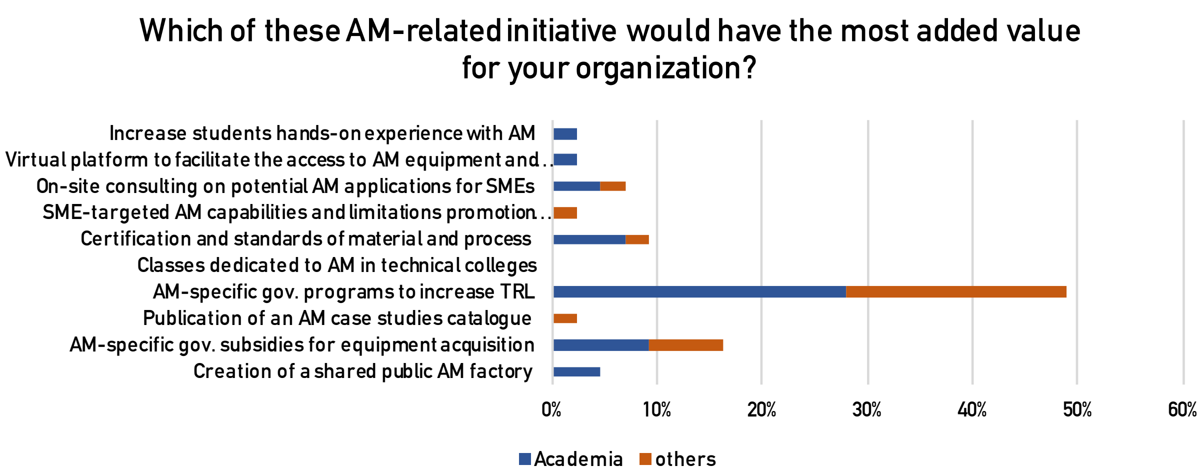

Figure 3: Importance given to multiple AM-related initiatives by Academia, research centres, paragovernmental organizations and others.

mechanisms and government support programs. This would help reduce the administrative burden that sometimes slows projects down (interview with CRD1). Another characteristic of collaborative research made with universities and industrial partners in Canada is the pressure for academic researchers to publish their research. This does not pose a threat for businesses working on low TRL projects (fundamental research and lab experiments), but when it comes to high TRL projects, confidentiality is a priority for industrials (interview with OEM1). The lack of confidentiality in collaborative research with universities discourages industrial partners from joining in for fear of losing their competitive edge.

N.B. The choice of initiatives by academia and R&D centres may be biased by the two following factors: 1) given the fact that these groups work mostly on low TRL projects, their perception of the whole AM industry is biased; 2) AM-specific programs to increase TRL will lead to more R&D projects and therefore increased work and budgets for research centres, colleges and universities.

When isolating the preferences of only OEMs and contract manufacturers (see figure 4), aside from their common interest in increasing the TRL of AM technologies, contract manufacturers show a clear preference in receiving AM-specific subsidies for equipment acquisition, while the majority of OEMs would rather direct their efforts to the creation of certifications and standards for AM materials and processes.

Acquiring and installing metal AM equipment costs over $1 million, and the ROI is uncertain. It is very risky to invest in such a technology with no certification, no clients and no expertise. Unless a solid business case is built, investors are usually reluctant to loan money for this kind of investment (interview with CRD2). This explains why contract manufacturers have a need for AM-specific subsidies or incentives. There are fewer funding programs available in Canada than in the United States or some European countries, but Canadian businesses have the advantage of conducting collaborative research projects through sectoral clusters and consortiums in order to obtain interesting funding leverage and tax credits. However, this type of program is not usually intended to cover a significant portion of the cost of acquiring AM equipment (interview with CRD1).
The funding of AM equipment is a hurdle, but it is not the only cause of demotivation for manufacturers. Section 1.4 discusses other reasons why contract manufacturers have a low interest in investing in AM technologies.

From the OEMs' point of view, there is a will to put effort into the standards and certification process. To have approved and reliable international standards and certifications would clearly improve the industry's confidence in and understanding of the process and subsequently remove a considerable obstacle to the increase in demand for additively manufactured products. Should we therefore inject more money to accelerate the process? The interview with CRD2 taught us that it is worth the wait. There is a minimum amount of time required for the creation of standards. Bypassing certain steps would not help the deployment of the technology and it may hinder it if mistakes are made. ISO, ASTM and BNQ are already working on this case, and results will arrive when ready. Back in the day, moulding suffered problems at the standardization step because it was not properly carried out. Today, the industry still lives with these problems, and moulding requires significant safety factors because the process is considered

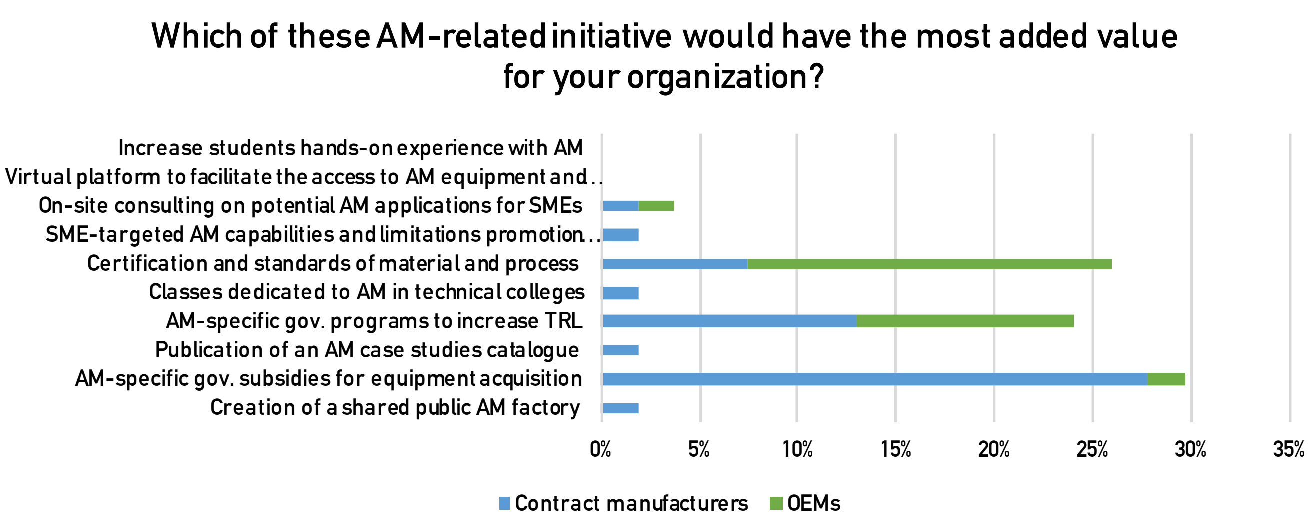

Figure 4: Importance given to multiple AM-related initiatives by OEMs and contract manufacturers

"less reliable" (interview with CRD2).

However, even though this process cannot take less than a given minimal amount of time, and what the industry can do is help ensure it proceeds as quickly as possible by sharing internal data. There may be a chance of seeing it arrive within the next five years if considerable investments are made and a great deal of collaboration is established between organizations and businesses. If enough entities contribute to the creation of standards by sharing the data they acquire through their R&D projects, everyone would benefit. However, if only a few businesses contribute while the others stand by and wait for the results to come, the idea will not be viable (interview with OEM2).

1.4. Low interest among contract manufacturers to invest in AM

During the analysis of the data, an interesting detail emerged with the question: What do you perceive as the 3 main opportunities for utilizing metal additive manufacturing (AM) in your organization? A considerable number of respondents from the contract manufacturers segment (i.e. the group that would most likely buy AM equipment) took the time to leave a comment stating that they "don't see any opportunity in AM for their business" or that "AM technologies are not profitable."

This disinterest among contract manufacturers can have many origins. According to AM equipment manufacturers (EM), it may come from a lack of knowledge. EMs realize, through their manufacturing clients, that there exists a lack of knowledge about AM opportunities and limitations (interview with CRD2, EM1 and EM2). Even some people who consider themselves "experts" have no machine and an inaccurate vision of the technical reality of AM (interview with EM2).

The point of view of contract manufacturers is quite different. They consider the current state of the aerospace market as "unfriendly and unprofitable." The aerospace industry is a very conservative environment. Even if contract manufacturers were to invest in AM and begin offering products made using AM, their clients (OEMs) would not necessarily buy them (interview with CM2). Supply does not automatically create demand. According to CM2, given the usual learning curve, it is fair to estimate that a manufacturer will not be profitable with its new equipment for the first two years because of the mistakes and learning process of the operators (interview with CM2).

The interview with CRD3 provides insight into the financial struggle that comes with the viability of integrating AM into a business's manufacturing processes. First, we need to consider that AM is still an emerging technology that is evolving fast. An AM machine bought today may be outdated within the next five years or so. Contract manufacturers would therefore like to amortize the cost of acquisition over approximately three years. Considering the basic assumption that the acquisition and installation of equipment costs more than $1 million, that printing a metal part will take on average 24-36 hours, and that many parts and materials will be discarded through the learning process, a significant portion of the cost of each printed component goes towards paying for the acquisition of equipment and the inevitable technical errors. For now, this business case works for research centres and academia but not for the aerospace industry (interview with CRD3). Additionally, most contract manufacturers are SMEs that might be reluctant to invest such an amount of money in new equipment due to their limited revenue.

However, even if profitable business cases are not there yet, AM technologies present great potential opportunities, and manufacturers should start to develop AM-related knowledge and remain updated on the state of the technology and market in order to take the leap and integrate AM technologies as soon as it becomes cost-effective (interview with CRD3 and CM2).

A few funding programs exist (directly or indirectly related to AM), but they are regional. In the upcoming years, we hope to see a strategic positioning of Canada in terms of advanced manufacturing that would be beneficial to the AM industry. For the moment, there is no clear roadmap for advanced manufacturing at the federal level. With a roadmap that aligns and unites the efforts already being made at the regional levels, we could eliminate the duplication of efforts and establish a coherent national strategy (interview with CRD1).

Mohawk College, located in Hamilton, Ontario, decided to overcome this issue by partnering with surrounding manufacturing businesses to exchange AM knowledge and resources. The multiple partners have different AM machines, which are shared within the cluster, enabling students to get hands-on experience with AM and understand the industry's needs (interview with CRD1). This kind of partnership helps participating businesses become familiar with the many AM technologies before investing a significant amount of money in them, understand the technical challenges, better define their needs in terms of AM, and gain access to local qualified labour.

1.5. Who should own AM equipment?

In order to draw a profile of the respondents, OEMs and contract manufacturers were asked whether their manufacturing operations were conducted through additive or traditional manufacturing and whether these operations were done in-house or outsourced. As shown in Figure 5, when OEMs were asked how their metal parts were manufactured, none said they were doing in-house metal AM. The reason for this is that none have metal AM equipment in-house (in Canada).

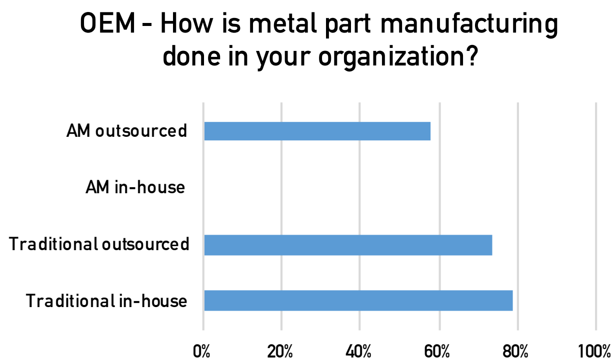

Figure 5: Metal part manufacturing methods for OEMs

In Canada, the industry's AM equipment is scattered among a handful of universities, research centres and contract manufacturers. At the moment, AM equipment is rare and used primarily for R&D purposes. As the technology matures, more AM equipment will enter the industry. It becomes interesting to ask ourselves:

In order to accelerate the deployment of AM, which segment of the supply chain should acquire AM equipment in the short term?

If support has to be given in order to stimulate technological development in the aerospace industry, it could be directed towards OEMs, manufacturers or both. In other words, should we boost supply (manufacturers) and expect demand (from the OEMs) to increase? Should we boost demand (from the OEMs) and expect supply (manufacturers) to follow? Or should link the two and boost both supply and demand?

According to OEM2, there is a lack of maturity on the part of manufacturers. As this participant puts it: No manufacturer with AM capabilities actually meets the aerospace quality requirements for AM parts. A few businesses, such as FusiA[4], Burloak and Edmit, are getting there, but the step between prototyping and production is huge. Given the low number of manufacturers with metal AM capabilities on the market right now and prices that are hard to negotiate, AM is not necessarily an attractive option for manufacturing.

Production of metal parts through AM will become conceivable when more certified contract manufacturers offering high quality services become available on the market (interview with OEM2).

The opposite thinking applies in persuading OEMs to better design their parts for AM, become comfortable with this new manufacturing process and in turn increase their demand in additively manufactured parts. EM2 shares this thinking by affirming that it is the new generation of engineers that will change the way OEMs think about and design their parts. Funding should go towards educating OEMs in rethinking their designs for AM. Contract manufacturers cannot move forward if their clients do not order products (interview with EM2). The contract manufacturer CMAM1, who has plans to invest more

4 FusiA says it is active in AM production in France, but not in Canada.

in AM, agrees with this point and says that for him, one of the biggest challenges is to assess the risk of investing in the acquisition of AM equipment. However, he adds that if clients (OEMs) would guarantee a significant volume of parts made using AM, his business would be ready to invest (interview with CMAM1).

Finally, a third option might be to meet somewhere in the middle. A basic supply chain notion states that a given supply chain cannot move faster than its slowest link. Giving support to the various segments of the aerospace supply chain according to the specific needs of each link may be an effective solution. If we simplify the situation, we arrive at two conclusions:

- OEMs need to:
  - Accept AM as a viable manufacturing option
  - Identify their own current designs that would be better suited to AM
  - Improve their understanding of AM
  - Increase their demand for AM parts
  - Re-think their future designs

- Contract manufacturers need to:
  - Improve their understanding of AM
  - Understand the role of AM as a manufacturing option
  - Invest in the acquisition of AM equipment and operator training
  - Meet aerospace quality requirements

In the AM industry, design and manufacturing are so intertwined that the most efficient way to improve both is to have collaboration between OEMs and manufacturers that allows many design iterations through a feedback process. The current state of the industry could thus be improved through a partnership between OEMs and contract manufacturers in which both stakeholders agree to work on their weaknesses. While the contract manufacturer would guarantee an investment in AM equipment and a given quality target, the OEM would provide new designs adapted to AM and guarantee a significant volume of parts produced using AM.

1.6. Are post-processing operations underestimated?

When contract manufacturers were asked: *What do you perceive as the 3 main challenges for utilizing metal additive manufacturing (AM) in your organization?*, there was contrast between the responses of the manufacturers with practical experience in metal additive manufacturing and those with no in-house metal AM capabilities. As can be observed in the figures below, manufacturers with no in-house metal AM equipment ranked post-processing operations as the sixth biggest challenge of nine options, while manufacturers with experience in metal AM rated post-processing as the biggest challenge.

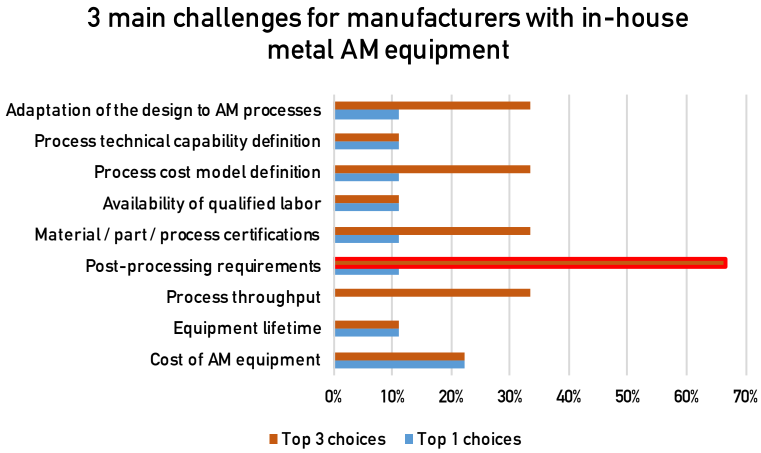

Figure 6: Main challenges for manufacturers with in-house AM capabilities

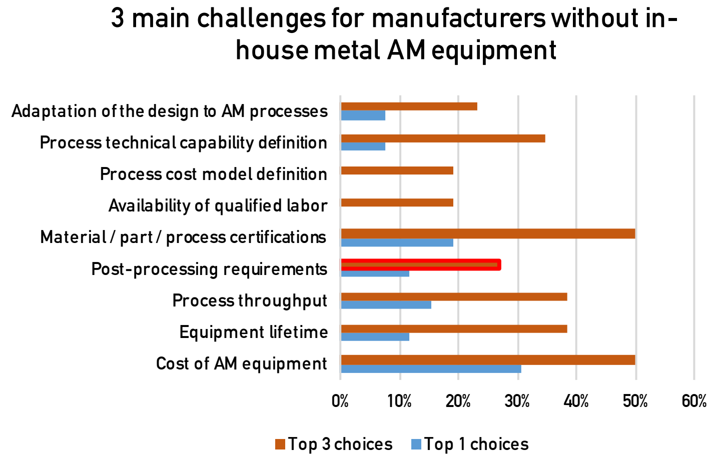

Figure 7: Main challenges for manufacturers without in-house AM capabilities

This observation highlights the fact that the challenge of post-processing operations is likely underestimated by manufacturers without AM capabilities, but it becomes a real struggle for those who have extensive experience with AM. Below are a few reasons why post-processing can be a considerable challenge.

Firstly, the chosen material has a significant impact on post-processing costs. Just as in traditional manufacturing, machining a soft metal (e.g. aluminum) is faster and cheaper than machining a harder one (e.g. titanium). Designers need to rethink not only their designs but also the materials in which they want to print a part (interview with OEM2).

Secondly, designers need to consider the design of their part according to its functionality as well as its “manufacturability.” Too often, AM manufacturers receive parts that are designed and optimized for traditional manufacturing from their clients. Besides missing the full potential of AM technologies, the amount of required post-processing will needlessly increase the cost of the manufactured part (interview with CMAM1). An easy solution to lower the cost of post-processing is to reduce the required post-processing operations as much as possible. Considering post-printing operations in the design will reduce the overall cost. Added to this, according to EM2, there is a lack of knowledge in the area, but we have the necessary tools to conduct all of the required post-processing operations (interview with EM2). A recent experiment by OEM1 revealed that post-processing can represent over 50% of the price of a part that has been outsourced to a specialized supplier. It was also revealed that the post-processing cost could be significantly lowered if all heat treatments and other related operations were done by the OEM itself (interview with OEM1). This might open the door for collaborative manufacturing between OEMs and contract manufacturers for certain AM products.

Finally, another point that was discussed with OEM1 is the consequence of having an incomplete AM supply chain in Canada. The need to outsource some services outside of Canada increases the lead time and cost of a manufactured product. For example, most of the products manufactured through metal AM will require hot isostatic pressing (HIP) to increase their density (reduce the amount of air in the metal), but there are no commercial providers of HIP in Canada. In fact, there is only one commercially available provider of large HIP in northeast North America, and it is located in Boston. Any printed metal requiring this treatment will cross the Canada-U.S. border twice and pay customs fees twice. In the future, if the volume of metal parts made using AM increases significantly, HIP could become a bottleneck.

1.7. Recommendations

Recommendation #1: Improve the general understanding of AM and design expertise, through education, research and consulting

This recommendation is the logical first step of a successful technology deployment: making stakeholders aware of the true potential and limitations of the technology. AM experts are clear on this point: it is evolving very quickly, and the upcoming technological breakthrough will change the manufacturing landscape. Manufacturers and OEMs should remain aware of new developments and business case opportunities if they want to retain their competitive edge or position themselves in a new niche. This education can be done through research, attendance at advanced manufacturing shows and specialized consulting.

The next step is improving design expertise. Over the short term, it should focus on training current employees to consider the particularities of a given AM process when designing a product. Most such products will likely already exist as parts that require topological optimization. Over the medium term, a new generation of designers will graduate and bring with them a new design approach. The mandate of academia will be to shape these designers to fulfill the needs of the industry through new and innovative products and assemblies.

Recommendation #2: Make innovation more attractive and reachable

Given the conservatism of OEMs and the current level of performance of AM equipment, most manufacturers are not interested in integrating this technology into their processes. The investment is too high and too risky, given the rapidly evolving technology and the low demand by OEMs. For AM deployment to happen, manufacturers must become interested in the technology. This objective could be reached by:

- Stimulating the demand from OEMs for additively manufactured products through incentives such as R&D tax credits
- Adapting industrial R&D financing programs to allow more funding for equipment acquisition in order to de-risk this considerable investment in the case of AM
- Encouraging collaborative R&D and partnerships similar to the Mohawk College cluster or OEM-supplier contracts that share the investment and risk (see recommendation #5)

Recommendation #3: Increase efforts for material and process characterization

Material and process characterization will have to be developed as soon as possible for the deployment of AM to happen. In order to keep the development timeline as short as possible, collaboration by the entire industry in contributing their data on processes and material characterization would be beneficial for all, provided everyone participates. What usually holds businesses back from participating in projects with higher TRL are the high risk of IP leakage and the need to retain a competitive advantage. However, this characterization would lead to an increased understanding of AM process capabilities and subsequent growth in the demand for AM products by OEMs.

Recommendation #4: Provide each segment with support adapted to its situation

As noted previously, the needs of the different industry segments vary according to the challenges they face. Academia and research centres would like to ramp up the efforts being made to increase the TRL of the technology; contract manufacturers want the investment in equipment to be less risky; and OEMs would like efforts to focus on material and process certifications and standards. None of these is necessarily more important than the next. In fact, since they are all linked, they need to evolve in tandem. A supply chain can never work faster than its slowest link (bottleneck); therefore, multiple efforts should be made in research, design techniques & tools, certifications & standards and the creation of profitable business cases.

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Recommendation #5: Improve collaboration incentives between the industry segments

Collaboration and partnership between the supply chain segments will enhance not only the general understanding of AM technologies but also the mutual relationships businesses have with one other. Linking businesses together to have them share the risks and benefits of AM can increase the commercial activities they share. Consortiums such as CRIAQ and CARIC are already leading the aerospace industry in this direction by providing attractive financial leverage for R&D projects that bring together academic and industrial organizations. This collaboration model works very well for low TRL projects but becomes impractical for high TRL projects due to intellectual property protection (IPP) concerns.

Another idea would be to encourage partnerships where OEMs and contract manufacturers co-develop a product manufactured using AM. In a case such as this, the IP would be shared, and the OEM would commit to order a given quantity of the co-developed product. This type of collaboration would streamline the characterization process for the supplier and would allow for a better mutual understanding between designers and manufacturers.

Finally, a concept that may help in reducing the price of an AM product and the investment for the contract manufacturer would be to have a dynamic where the OEM is the owner of the raw material (metal powder) and lends it to its supplier to manufacture the ordered parts. This way, the OEM has better control over the price, and the investment of the contract manufacturer is reduced.

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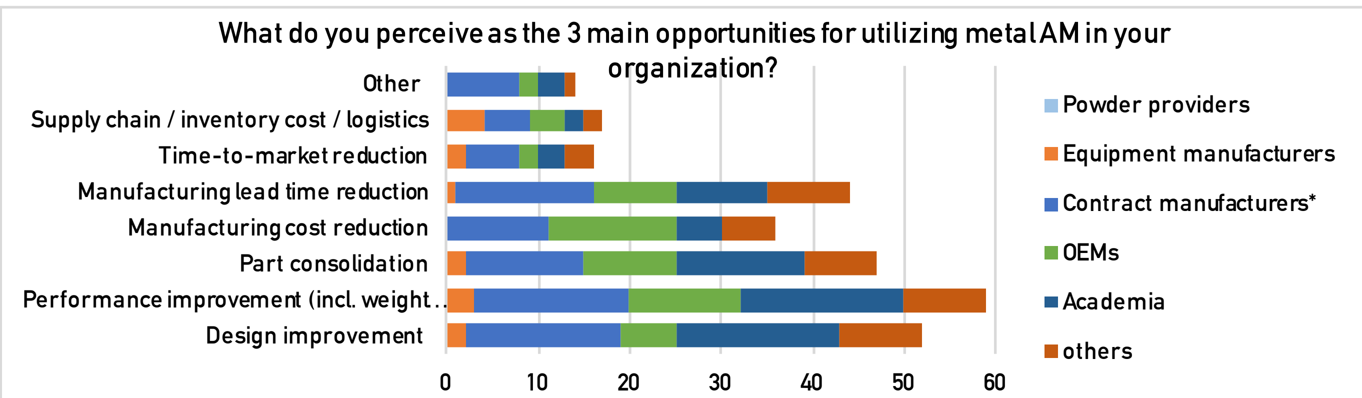
APPENDIX : SURVEY RESULTS

What do you perceive as the 3 main opportunities for utilizing metal AM in your organization?

Suggested Opportunities	Powder providers	Equipment manufacturers	Contract manufacturers without AM	Contract manufacturers with AM cap.	Contract manufacturers*	OEMs	Academia	others
Design improvement	0	2	13	4	17	6	18	9
Performance improvement (incl. weight saving)	0	3	12	5	17	12	18	9
Part consolidation	0	2	11	2	13	10	14	8
Manufacturing cost reduction	0	0	10	1	11	14	5	6
Manufacturing lead time reduction	0	1	11	4	15	9	10	9
Time-to-market reduction	0	2	5	1	6	2	3	3
Supply chain / inventory cost / logistics	0	4	4	1	5	4	2	2
Other	0	0	6	2	8	2	3	1

*The data associated with "Contract Manufacturers" is the sum of the 2 previous columns. Only data from "Contract Manufacturers" is shown in the chart below



**The horizontal axis represents the absolute number of participants which voted for a given category

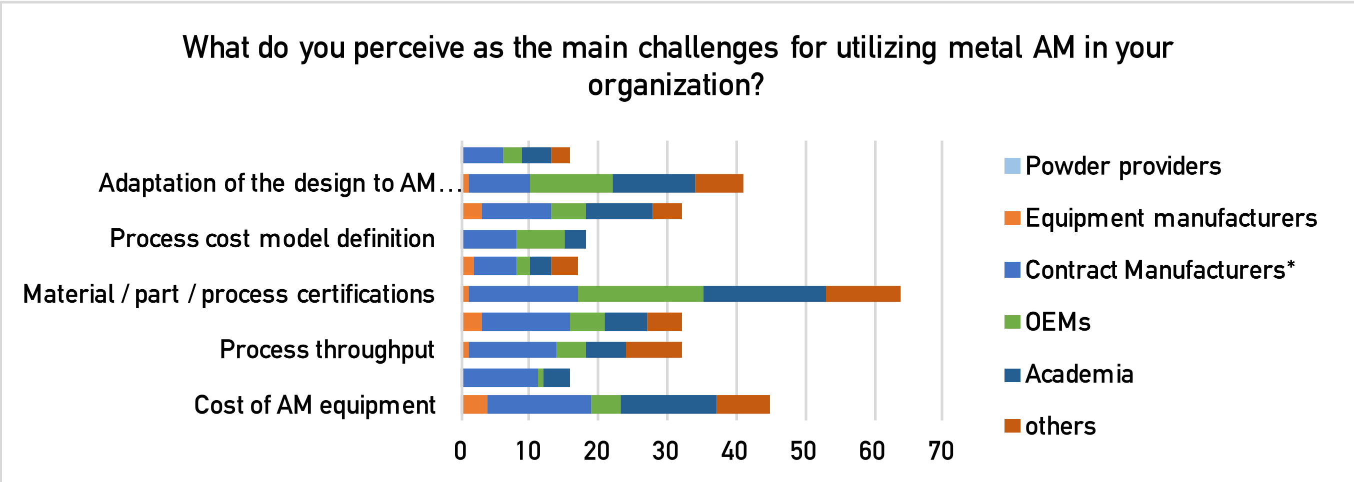
What do you perceive as the top 1 opportunity for utilizing metal AM in your organization?

Suggested Opportunities	PP	EM	CM w/o AM	CM w/ AM	CM*	OEM	ACAD	others
Design improvement	0	1	8	2	10	4	11	8
Performance improvement (incl. weight saving)	0	1	4	3	7	6	6	3
Part consolidation	0	0	1	0	1	2	4	0
Manufacturing cost reduction	0	0	2	1	3	2	2	2
Manufacturing lead time reduction	0	0	5	1	6	4	0	1
Time-to-market reduction	0	1	1	0	1	0	0	0
Supply chain / inventory cost / logistics	0	2	2	0	2	1	1	2

What do you perceive as the main challenges for utilizing metal AM in your organization?

Suggested Challenges	Powder providers	Equipment manufacturers	Contract manufacturers without AM	Contract manufacturers with AM cap.	Contract Manufacturers*	OEMs	Academia	others
Cost of AM equipment	0	4	13	2	15	4	14	8
Equipment lifetime	0	0	10	1	11	1	4	0
Process throughput	0	1	10	3	13	4	6	8
Post-processing requirements	0	3	7	6	13	5	6	5
Material / part / process certifications	0	1	13	3	16	18	18	11
Availability of qualified labor	0	2	5	1	6	2	3	4
Process cost model definition	0	0	5	3	8	7	3	0
Process technical capability definition	0	3	9	1	10	5	10	4
Adaptation of the design to AM processes	0	1	6	3	9	12	12	7
Other	0	0	5	1	6	3	4	3

*The data associated with "Contract Manufacturers" is the sum of the 2 previous columns. Only data from "Contract Manufacturers" is shown in the chart below



**The horizontal axis represents the absolute number of participants which voted for a given category

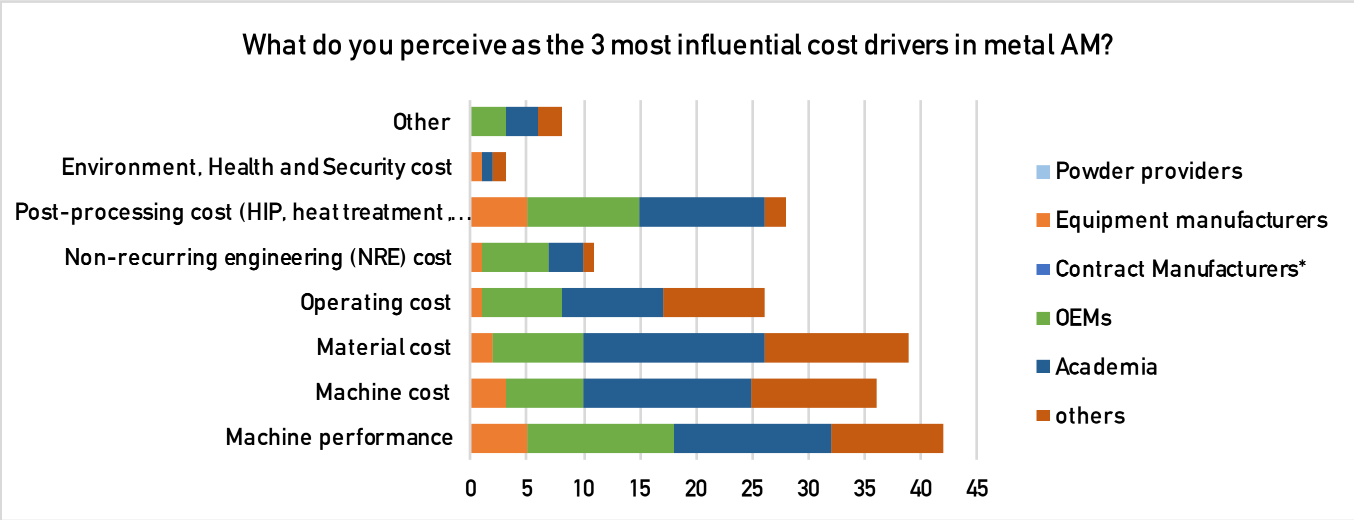
What do you perceive as the top 1 challenge for utilizing metal AM in your organization?

Suggested Challenges	PP	EM	CM w/o AM	CM w/ AM	CM*	OEM	ACAD	others
Cost of AM equipment	0	2	8	2	10	2	13	3
Equipment lifetime	0	0	3	1	4	1	0	0
Process throughput	0	0	4	0	4	1	1	4
Post-processing requirements	0	1	3	1	4	1	2	2
Material / part / process certifications	0	0	5	1	6	14	4	5
Availability of qualified labor	0	0	0	1	1	0	1	2
Process cost model definition	0	0	0	1	1	1	0	0
Process technical capability definition	0	1	2	1	3	1	2	1
Adaptation of the design to AM processes	0	1	2	1	3	1	3	2
Other	0	0	0	0	0	0	0	0

What do you perceive as the 3 most influential cost drivers in metal AM?

Suggested cost drivers	Powder providers	Equipment manufacturers	Contract manufacturers without AM	Contract manufacturers with AM cap.	Contract Manufacturers*	OEMs	Academia	others
Machine performance	0	5	14	2	16	13	14	10
Machine cost	0	3	15	2	17	7	15	11
Material cost	0	2	12	2	14	8	16	13
Operating cost	0	1	9	3	12	7	9	9
Non-recurring engineering (NRE) cost	0	1	6	1	7	6	3	1
Post-processing cost (HIP, heat treatment , etc.)	0	5	5	5	10	10	11	2
Environment, Health and Security cost	0	1	2	0	2	0	1	1
Other	0	0	5	3	8	3	3	2

*The data associated with "Contract Manufacturers" is the sum of the 2 previous columns. Only data from "Contract Manufacturers" is shown in the chart below

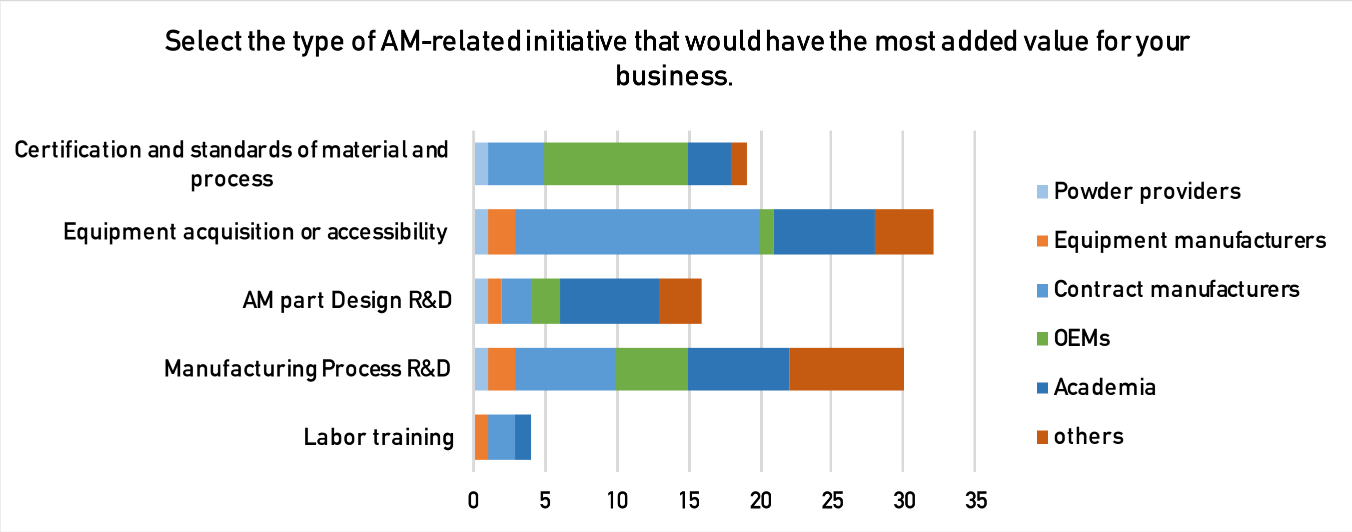


**The horizontal axis represents the absolute number of participants which voted for a given category

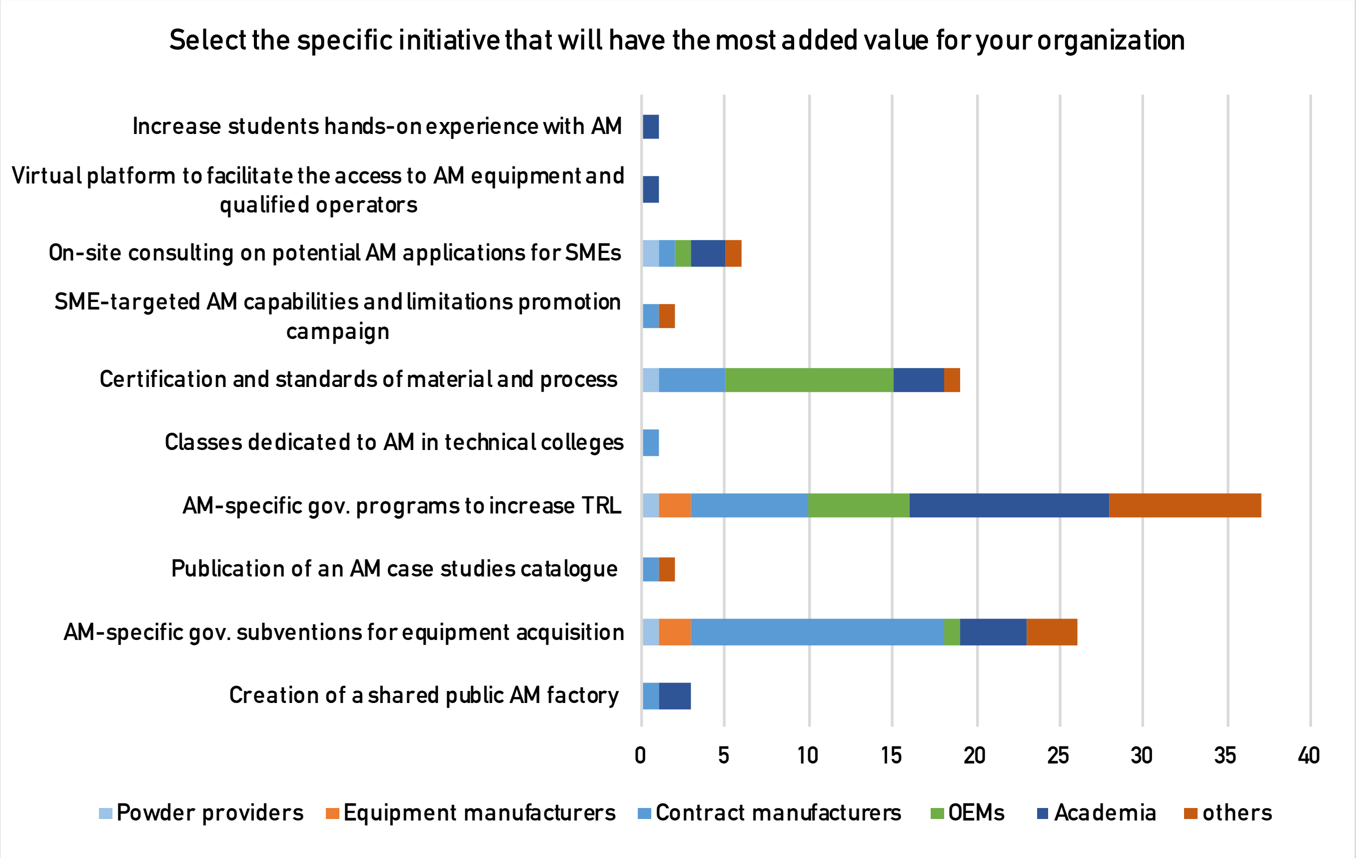
What do you perceive as the most influential cost drivers in metal AM?

Suggested cost drivers	PP	EM	CM w/o AM	CM w/ AM	CM*	OEM	ACAD	others
Machine performance	0	2	9	1	10	6	9	7
Machine cost	0	2	5	2	7	3	10	4
Material cost	0	0	1	1	2	3	3	3
Operating cost	0	0	1	0	1	2	0	0
Non-recurring engineering (NRE) cost	0	1	2	0	2	2	0	1
Post-processing cost (HIP, heat treatment , etc.)	0	1	3	1	4	1	1	0
Environment, Health and Security cost	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0

The following fields have been brought up as challenges over which governmental support could accelerate metal AM deployment. Please select the type of AM-related initiative that would have the most added value for your business.						
Suggested type of initiative	Powder providers	Equipment manufacturers	Contract manufacturers	OEMs	Academia	others
Labor training	0	1	2	0	1	0
Manufacturing Process R&D	1	2	7	5	7	8
AM part Design R&D	1	1	2	2	7	3
Equipment acquisition or accessibility	1	2	17	1	7	4
Certification and standards of material and process	1	0	4	10	3	1



Please select the specific initiative that will have the most added value for your organization.						
Suggested specific initiative	Powder providers	Equipment manufacturers	Contract manufacturers	OEMs	Academia	others
Creation of a shared public AM factory	0	0	1	0	2	0
AM-specific gov. subventions for equipment acquisition	1	2	15	1	4	3
Publication of an AM case studies catalogue	0	0	1	0	0	1
AM-specific gov. programs to increase TRL	1	2	7	6	12	9
Classes dedicated to AM in technical colleges	0	0	1	0	0	0
Certification and standards of material and process	1	0	4	10	3	1
SME-targeted AM capabilities and limitations promotion cai	0	0	1	0	0	1
On-site consulting on potential AM applications for SMEs	1	0	1	1	2	1
Virtual platform to facilitate the access to AM equipment an	0	0	0	0	1	0
Increase students hands-on experience with AM	0	0	0	0	1	0



Contract manufacturers - manufacturing methods per activity sector

manufacturing method	Prototyping	Metal part manufacturing	Plastic and composite part manufacturing	Post-processing operations	Jigs & fixtures	Tooling & die	Maintenance and repair
Traditional in-house	24	25	15	18	26	17	13
Traditional outsourced	5	10	8	10	9	6	3
AM in-house	19	9	7	9	12	8	5
AM outsourced	10	6	7	7	5	3	2
AM in-house & outsourced	0	1	0	0	0	0	0

OEMs - manufacturing methods per activity sector

manufacturing method	Prototyping	Metal part manufacturing	Plastic and composite part manufacturing	Post-processing operations	Jigs & fixtures	Tooling & die	Maintenance and repair
Traditional in-house	14	15	9	12	13	11	9
Traditional outsourced	14	14	14	14	16	14	15
AM in-house	13	0	4	0	5	3	1
AM outsourced	12	11	9	9	7	6	5

Participation of individuals		
Participation of individuals	Nb. of participants	
Total population contacted	307	individuals
Complete Answers	107	individuals
participation rate	35%	

Participation of organizations		
Participation of organizations	Nb. Of organizations	
Total number of enterprises contacted	185	org
Minimal quantity of org. who participated	71	org
Maximal quantity of org. who participated	86	org
Minimal participation rate	38%	
Maximal participation rate	46%	

Participation per SC segment		
Segment	Nb. of organizations	Nb. Of participants
Metal Powder provider	2 to 4	4
AM Equipment manufacturer	4 to 5	6
Contract manufacturer	30 to 34	35
OEMs	10 to12	19
Academia (universities and colleges)	11 to 15	25
Others	12 to 16	18
Total	71 to 86	107