Advancing Additive Manufacturing into the Mobility Industry

Business Case: Mobility Consortium for Additive Manufacturing (MCAM)

CENTER FOR AUTOMOTIVE RESEARCH

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INTRODUCTION

Future cities will likely be dominated by automated, connected, electrified, and shared (ACES) vehicles.[1] Automotive customers are demanding greater vehicle personalization and unique ride experiences. Additive Manufacturing (AM) or 3D Printing is a revolutionary group of technologies that can help automakers cater to the desires of their customers by providing unique solutions for vehicle design, manufacturing, and the overall automotive business. However, for advancing AM towards applications in automotive mass production, AM's inherent challenges must be addressed. To obtain an industry perspective, CAR organized brainstorming sessions with representatives from multiple automakers and suppliers to discuss the advancement in AM, challenges to incorporating its adoption, and the path forward. This whitepaper consolidates a summary of the discussions from the meetings and an extensive literature survey performed by the CAR team.

ADDITIVE MANUFACTURING: THE TECHNOLOGIES

The phrase "additive manufacturing" describes a group of technologies that build 3-dimensional (3D) objects by adding layer-upon-layer of any material. The concept of AM is not new; however, its use in traditional manufacturing industries started only two decades ago. The phrase additive manufacturing is a broader term for the numerous technologies that fall under the same umbrella. Table 1 lists the seven families of AM technologies defined by the American Society for Testing and Materials (ASTM).

Table 1: AM Technologies as Defined by ASTM

Vat Photopolymerization	process in which a liquid photopolymer in a vat is selectively cured by light-activated polymerization.
Powder Bed Fusion	process in which thermal energy selectively fuses regions of a powder bed.
Binder Jetting	process in which a liquid bonding agent selectively binds regions of a powder bed.
Material Jetting	process in which droplets of material are selectively deposited and cured on a built plate.
Sheet Lamination	process in which sheets of material are bonded to form a part.
Material Extrusion	process in which material is selectively dispensed through a nozzle or orifice.
Direct Energy Deposition	process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

[1] Smith, Brett, Adela Spulber, Shashank Modi, and Terni Fiorelli. (2017). Technology Roadmaps: Intelligent Mobility Technology, Materials and Manufacturing Processes, and Light Duty Vehicle Propulsion. Center for Automotive Research, Ann Arbor, MI.

There are more than fifteen AM technologies that fall under these seven families. The raw material can be plastic, metals, wax, sand, or composite. Table 2 describes AM technologies, their family, raw material, and major applications.

Table 2: AM Technology Families, Typical Materials, Applications, and Example Companies

Family	Technology Examples	Typical Materials	Applications	Example Companies
VAT Photopolymerization	• Stereolithography (SLA) • Digital Light Processing (DLP) • Scan, Spin, and Selectively Photocure (3SP) • Continuous Liquid Interface Production (CLIP)	UV-Curable Photopolymer Resins	Injection mold prototypes, jewelry, dental applications, hearing aids	• 3DSystems • Formlabs • Carbon3D
Powder Bed Fusion	• Selective Laser Sintering (SLS) • Direct Metal Laser Sintering (DMLS) • Selective Laser Melting (SLM) • Electron Beam Melting (EBM) • Selective Heat Sintering (SHS) • Multi-Jet Fusion (MJF)	Plastics, Metal and Ceramic Powders, and Sand	Low run production parts, complex ducting	• HP • EOS • Renishaw • 3DSystems
Binder Jetting	• 3D Printing (3DP) • ExOne • Voxeljet	Powdered Plastic, Metal, Ceramics, Glass, and Sand.	Full-color models, sand casting, functional metal parts	• 3DSystems • ExOne
Material Jetting	• Polyjet • Smooth Curvatures Printing (SCP) • Multi-Jet Modeling (MJM)	Photopolymers, Polymers, Waxes	Full-color visual prototypes, medical models, low-run injection mods and prototypes	• Stratasys • 3DSystems • XJET • Solidscape
Sheet Lamination	• Laminated Object Manufacture (LoM) • Selective Deposition Lamination (SDL) • Ultrasonic Additive Manufacturing (UAM)	Paper, Plastic Sheets, and Metal Foils/Tapes	Full-color prints of visual mock-ups of simple parts, low-cost prototypes	• envisionTEC • Impossible Objects • Mcor
Material Extrusion	• Fused Deposition Modeling (FDM) • Fused Filament Fabrication (FFF)	Thermoplastic Filaments and Pellets (FFF); Liquids, and Slurries (Syringe Types)	Investment casting patterns, electronics housing, jigs and fixtures	• Stratasys • MakerBot • Ultimaker • Zortrax
Directed Energy Deposition (DED)	• Laser Metal Deposition (LMD) • Direct Metal Deposition (DM3D) • Laser Engineered Net Shaping (LENS)	Metal Wire and Powder, with Ceramics	Parts which require high dimensional accuracy in complex parts, repair work	• Sciaky • Optomec

Source: Hybrid Manufacturing Technologies, 3D Hubs, CAR research

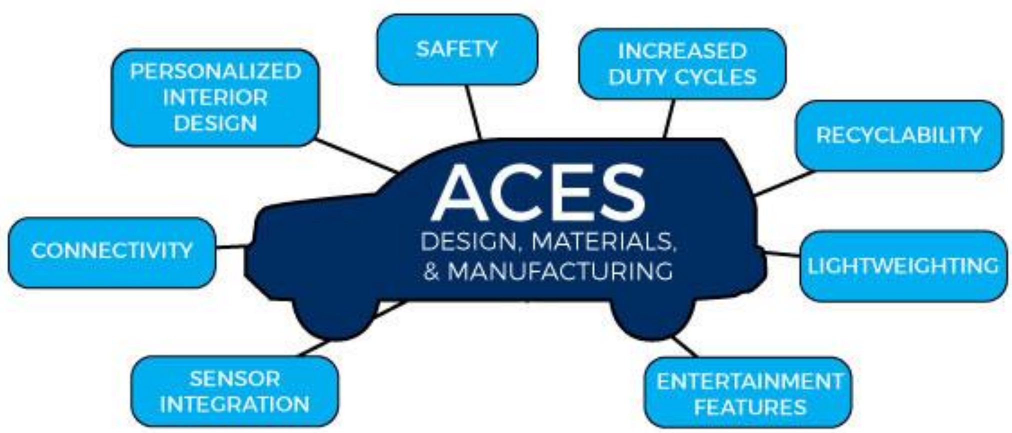
The AM process consists of the following six steps:[2]

1. Producing a digital model file – developing a digital model is the first step in any AM process. Parametric Computer Aided Engineering (CAD) and reverse engineering (blue light scanning, etc.) are the most common methods of generating a digital model.
2. Slicing the model and file manipulation – the digital model is sliced into standard simple shapes to describe the surface of the complex model. The most common is the Standard Triangle Language (STL) file which the AM machine can read. Object file extension (OBJ) and 3DP are other formats.
3. Printing – the actual printing of the part. There are different types of printing techniques as described in Table 1.
4. Removal of prints – removal of the print can be simple or highly technical depending on the printing technology.
5. Post processing – this step is compulsory for support removal and required for surface finish and aesthetics.

NEED FOR AM IN THE AUTOMOTIVE INDUSTRY AND CHALLENGES

According to CAR's research, by 2035 there will be worldwide adoption of robotaxis and automated shuttles in mixed traffic with SAE level-5 automation. By 2040, there could be market saturation of automated vehicles, and new mobility services could constitute a major share of auto industry revenues. In the evolving mobility ecosystem, customers are increasingly asking for more personalization, connectivity, safety, and infotainment features. Customers are also cognizant of the vehicle's exterior design, durability, recyclability for environmental sustainability, and overall performance (see Figure 1).

Figure 1: Expectations of future vehicle customers



Source: CAR Research

[2] The 3D Printing Handbook, 3D HUBS

For catering to the increasing desires of customers, automakers will need to make radical and fast improvements in vehicle design, manufacturing, and business models. These three areas are key to understanding how additive manufacturing can help automakers in meeting, or exceeding, customers' expectations.

> *Future cities will be dominated by automated, connected, electrified, and shared (ACES) vehicles.*

VEHICLE DESIGN

Vehicle design can be categorized into structural design, exterior design, and interior design.

Structural Design

Vehicle size, powertrain packaging, cabin configuration, crash and durability requirements, materials used, and available manufacturing technologies impact structural design in most cases. While all factors are essential, manufacturing technologies play a very significant role in driving structural design. Traditional subtractive manufacturing technologies put inherent constraints on part design. For example, metal casting requires draft angles, controlled cooling rates, and consistent flow of molten metal. AM allows greater part complexity because the parts are built layer by layer. AM can produce designs that are very difficult or even impossible to manufacture with subtractive techniques (see Figure 2 for examples).

Figure 2: AM Part Examples

Source: EOS

Source: Canada Makes

Source: Sirris

Source: BMW i8 roadster roof bracket

Aside from the capability of AM methods in fabricating components with complex geometries, there are four ground-breaking potential advantages of this manufacturing process:

1) **Part consolidation** - reduces part count which saves weight, lead time, cost, and improves functionality.

2) **Use of a variety of materials in a single production platform to make multi-material and composite products** - Implementation of multiple materials in integrated structures has proven to improve the functionality and provide weight reduction.[3] Also, AM makes it easier to integrate components such as sensors and wiring in structural parts, which simplifies overall assembly and improves aesthetics.

3) **Ability to create functionally graded materials** - Functionally Graded Materials (FGM) are materials that vary in composition or microstructure following a certain design criterion. A major benefit of these materials over composite and coated materials is that for FGM, the variation in composition is gradual, which reduces the stress concentration effects near the interface between different phases.[4]

4) **Flexibility in being combined with other production methods** – it is possible to use AM to print complex design features on a traditionally manufactured base material. This strategy reduces lead times and cost.

DESIGN CHALLENGES

- Not everyone is aware of the rules of part design for AM in the auto industry.
- Not all CAE design software are ready to handle simulations for AM parts. There is not enough real world test data to validate simulation results.
- Post-processing is time-consuming and expensive. For example, powder removal, heat treatment, surface finish, inspection, and testing. Designing to reduce or eliminate support structures in complex parts is challenging.

Automakers have been using AM for rapid prototyping for two decades. For example, General Motors has a lab manned by several specialists who work three shifts, six days a week, taking part orders from GM design centers all over the world to 3D print 20,000 unique parts a year. Parts are built from one of two additive technologies: SLS, where a laser fuses layers of powdered material together, or SLA, where a laser cures liquid polymer, layer by layer. Parts are built within hours and then express shipped to their destination, allowing designers and engineers to spend more time evaluating changes and less time waiting for parts, compared to conventional prototyping methods.[5] A few manufacturers are now taking AM to the next level in the creation of production parts. Current uses of AM in vehicle production

[3] M. Toursangsaraki, A Review of Multi-material and Composite Parts Production by Modified Additive Manufacturing Methods, Shanghai Jiao Tong University
[4] Mahmoud, D. and Elbestawi, M.A. (2017). Lattice Structures and Functionally Graded Materials Applications in Additive Manufacturing of Orthopedic Implants: A Review. Journal of manufacturing and materials production.
[5] AD&P. (2011). Rapid Prototyping: How It's Done at GM. https://www.adandp.media/articles/rapid-prototyping-how-its-done-at-gm

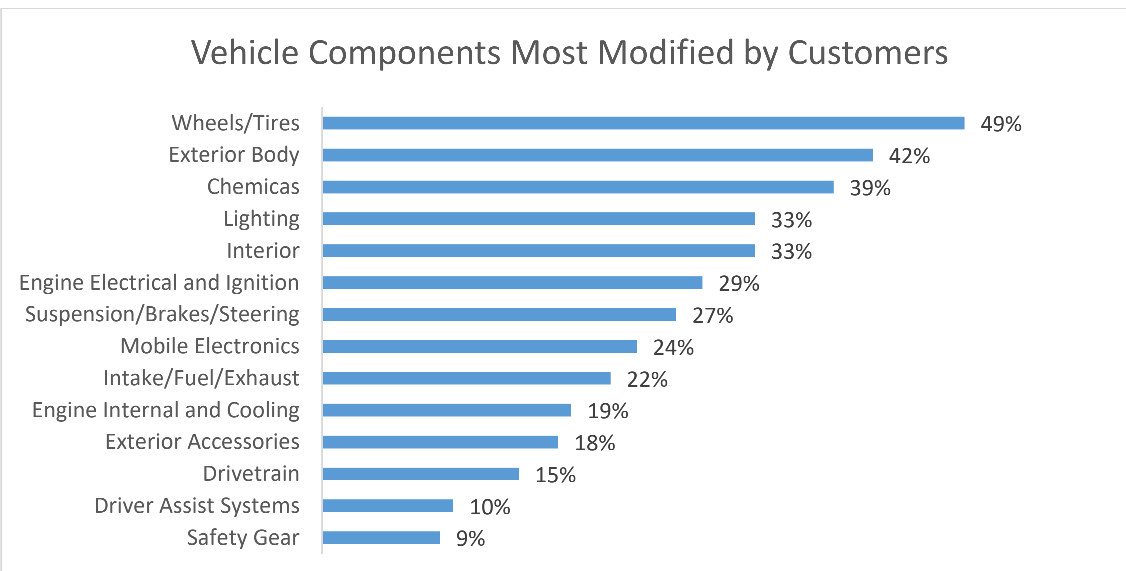
include cooling vents, pumps and valves, windbreakers and bumpers, and customized tooling. Recent examples of in-production AM parts are BMW i8's roof bracket, and Mini Cooper side lamp bezels. Possible future uses of AM could be in the production of small interior and structural parts, engine and suspension components, small parts with embedded sensors, dashboard components, and seat frames.

Exterior and Interior Design

For automotive customers, once cost and functional needs are met, personalization options are endless. A report by the Specialty Equipment Market Association (SEMA) states that in 2017, 62 percent of young people (16 to 24-years-old) in the United States are drivers. Out of this pool of drivers, 7.9M accessorized and spent $7.2B modifying their car, i.e. $911 per car on average. The report also states that 52 percent of surveyed 16 to 24-year-old customizers plan on making additional modifications to their vehicles in the next year.[6] Figure 3 shows that wheels are the most modified component; vehicle interiors and exteriors are the most modified sub-systems.

Additive manufacturing can be a game-changer technology for mass customization of vehicle interior and exterior components.

Figure 3: Vehicle Components Most Modified by Customers



Source: SEMA

The concept of mass-customization is not new. Though, the execution in the past has been disappointing so far due to technological and business constraints. For example, Toyota's Scion teamed up with aftermarket suppliers for its mass customization program called Optomize. The program allowed

[6] SEMA Young Accessorizers Report (2018), SEMA Market Research

customers to pick and approve 150 possible parts to be added by dealers at the time of purchase, and were covered by the manufacturer's warranty. However, the mass customization program was short lived.

Additive manufacturing can be a game-changer technology for mass customization of the vehicle interior and exterior components.[7] Since AM only requires digital design (CAD) files and a printing machine, there is no need for expensive tooling for each part. Also, the raw materials come in easy-to-handle forms such as pellets, wires, powders. No requirements for tooling enables the business case for unique part designs for each customer; parts can be manufactured at AM enabled micro-factories. Recently, BMW has started offering its Mini customers an option to design, purchase, and 3D print parts for their vehicle (see Figure 4 for examples). Their online shop guides the user through the various design and operation steps, giving them free creative rein of the entire process.

Figure 4: Mini Cooper Owners Can Design Custom AM Part

Side scuttle with custom name | Interior custom trims | Personalized door light projectors

Source: BMW

MANUFACTURING

The first application of additive manufacturing was in rapid prototyping and automakers have been using it for several decades. AM enables part designers to quickly visualize and physically touch their designs by significantly reducing the time for prototyping. Faster prototyping is possible since AM requires no tooling and offers fewer design restrictions; and since prototypes are one-off parts for testing, automakers do not care much about the cycle-time for printing and post-processing. Prototyping is still one of the primary applications of AM in automotive. Most of the automakers have rapid prototyping centers powered by AM machines across the globe.

Apart from rapid prototyping, tooling production is also one of its major applications. The use of AM to produce tooling is especially advantageous at low production volumes, as it eliminates some of the expensive up-front costs caused by design changes. Interviews with experts reveal that AM-enabled tooling has a bright future in automotive because it can significantly reduce time to market and save cost. AM equipment providers claim that their systems can be used to reduce lead times for the fabrication of tooling by 40-90 percent. Moreover, it can eliminate some of the expensive up-front costs

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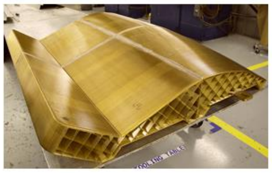
[7] Mass customization is the process of delivering wide-market goods and services that are modified to satisfy a specific customer need. Mass customization is a marketing and manufacturing technique that combines the flexibility and personalization of custom-made products with the low unit costs associated with mass production. Investopedia, https://www.investopedia.com/terms/m/masscustomization.asp

caused by design changes and reduce scrap by up to 90 percent.[8] Figure 5 shows examples of tooling created using AM.

Figure 5: AM Tooling Examples



A printed composite layup tool (Stratasys)

Printed Sand Mold (source: PennState University)

Printed Forming die (Sciaky)

In some cases, AM can also improve tooling functionality. For example, in injection molding, the cooling time of a finished product can constitute up to 70 percent of the cycle time in series production. One primary reason is that in conventional mold making, temperature control or cooling channels can only be drilled in a straight line.[9] AM makes it possible to integrate optimized, conformal cooling channels into the mold during the production process (see Figure 6). Conformal cooling ensures faster and more even heat dissipation. It reduces thermal stress in the mold and prolongs service life. Conformal cooling channels for hot forming and warm forming metal dies can also be created using the same technology.

Tooling is seen as one of the major applications of AM in automotive because AM could significantly reduce time to market and save cost.

MANUFACTURING CHALLENGES

Materials

- Materials for AM are not widely available commercially.
- Raw material quality is not standardized throughout the industry.
- Current material qualification processes and decision matrices are optimized for traditional manufacturing.

Quality Control

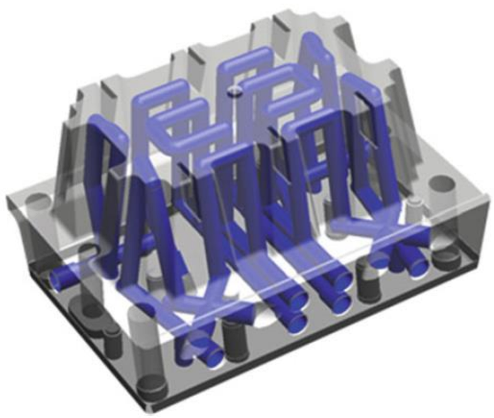
- There are variations in product quality from machine to machine and between batches of production.
- Lack of fundamental understanding of the impact of operational variables on part quality.
- Nondestructive evaluation (NDE) techniques are not developed for AM parts.

Production Parts

- Cycle times are currently not suitable for high volume part production.
- Post-processing is a time-consuming and expensive operation.

[8] 3D opportunity in tooling: Additive manufacturing shapes the future, Deloitte University Press
[9] Optimizing injection molding operations with DMLS. EOS, https://www.eos.info/industries_markets/tooling/injection_moulding

Figure 6: A tool insert design, showing the location of conformal cooling channels



Source: A Medium Corporation

At the current stage, additive manufacturing might not make sense for high volume parts or simple parts. Traditional manufacturing techniques such as casting, forging, injection molding, and machining, for examples are very mature and can produce parts at high volumes for much lower cost. However, in traditional manufacturing techniques, the cost and lead time increase exponentially with part complexity.

On the other hand, AM part production costs do not increase significantly with part design complexity (see Figure 7). And since the material is added just where it is needed, material scrap is minimized. Taking note of AM's benefits and current limitations, experts believe automakers may soon benefit from AM for production of complex parts for low-volume vehicle programs (less than 10,000 parts per year). As technology progresses, AM may eventually be used for the production of high-volume automotive parts (more than 50,000 parts per year).

MANUFACTURING CHALLENGES

Technical Issues with Printing

- There is warping of parts as different sections of the print cool at different rates, they contract and shrink. This creates dimensional inaccuracy.
- Issues with improper layer adhesion and stress concentration.
- There are challenges to print mixed-materials. Only few AM machines can do it.

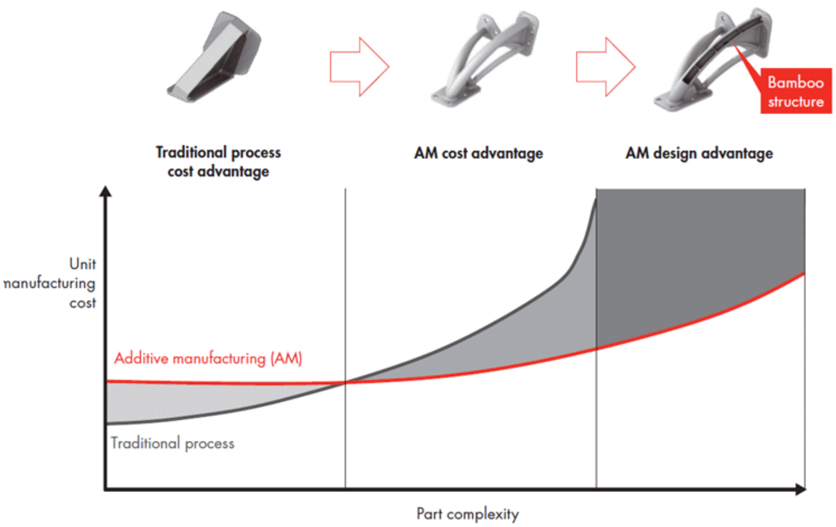
Equipment

- Each AM technology and machine has its advantages and limitations. Not everybody in the industry understand the differences.
- Machine reliability is not proven.
- Machine servicing is highly specialized.
- As the technology is evolving fast, obsolescence of AM printers is an investment risk.
- The preventive maintenance requirements are unknown.

Worker Safety

- Powder metal poses a health hazard. For example, Aluminum dust is flammable.

Figure 7: AM cost advantage for a complicated part



Source: Brain & Company

As stated above, AM is a broad term for various technologies that can produce parts by adding materials in layers. Choosing the right AM technology and machine is paramount in improving final part quality and minimizing cost. As described in Table 2, there are numerous technologies under the AM umbrella. Choosing the right technology and machine brand depends on various factors including:

- part material
- feedstock type and availability
- the speed of printing
- cost
- post-processing requirements
- service technician availability, and other factors.

Over the years, the cost of AM machines has come down significantly. Today, it is possible to buy an AM printer over the internet for $500 or less. However, industrial machines are still expensive, costing more than several hundred thousand US dollars.

AM part production costs do not increase significantly with part complexity.

BUSINESS

The automotive industry is always looking for technologies and business models that can help in manufacturing the next generation product while controlling the overall cost and quality. Interviews with experts revealed a positive future outlook for AM in automotive. Experts believe AM is a revolutionary technology that will not only revamp the factory floor but may change the entire manufacturing business models affecting all stakeholders in the supply chain. Below are the major business advantages of AM for automotive:

On-demand and on-location production

Throughout the history of mass manufacturing, the suppliers have used customer demand to plan for how much of their products will be needed at a certain time and a certain place. Suppliers produce products, ship them, and store their inventory near their customers to protect for potential demand fluctuations.[10] Currently suppliers locate their manufacturing facilities closer to high-volume customers for Just-In-Time (JIT) delivery. Additive manufacturing has the ability to change the configuration of supply networks for lower volumes. AM will enable low-volume parts to be produced on-demand, right next door to the customer, thus increasing the overall resource efficiency of the production process.[11] Since AM technology needs no tooling to produce parts, the production process can start immediately after the customer has committed to buying the product. This would reduce tooling inventory and unnecessary cost of production, storage, and transportation. Other industries such as medical are already embracing this AM advantage for on-demand tissue and organ fabrication; creation of customized prosthetics, implants, and anatomical models; and pharmaceutical research.[12] Aerospace industry is also leading the initial

AM will enable production sites to be located closer to customers because of the small footprint of AM machines, and lack of hard tooling.

BUSINESS CHALLENGES

General

- Automakers are extremely careful in selecting unproven technologies for production because the automotive business is high investment, high risk.
- Lack of understanding on AM's benefits and applications.

On-demand Production

- Undefined and unproven automotive supply chain models for distributed manufacturing.
- Inadequate digitalization of product design, production control, demand and supply integration, that enable effective quality control at multiple and remote locations.
- Fear of intellectual property being stolen in digital transfer. Parts can be reproduced using only the design files since AM does not require expensive tooling.

[10] On-Demand Additive Manufacturing is a Logistics Solution. Freight 2025. FreightWaves, https://www.freightwaves.com/news/from-freight-2025-on-demand-additive-manufacturing-is-a-logistics-solution
[11] Barz, A., et. al (2016). Quantifying the effects of additive manufacturing on supply networks by means of a facility location-allocation model. Logistics Research, https://doi.org/10.1007/s12159-016-0140-0
[12] Ventola C. L. (2014). Medical Applications for 3D Printing: Current and Projected Uses. P & T : a peer-reviewed journal for formulary management, 39(10), 704-11.

investment in AM. Primary aerospace applications include engine components such as fuel nozzles, turbine blades, structural components using titanium and other metals. Laser sintering is the most popular method to create metal parts in aerospace. The automotive industry can learn a great deal from the medical and aerospace experience in AM.

Decentralized production at low to medium volume

The assembly line is one of the most significant 20th-century innovations in manufacturing. Distributed manufacturing could have a similar impact in the 21st century. Distributed Manufacturing (DM) is a form of decentralized manufacturing practiced by enterprises using a network of geographically dispersed manufacturing facilities that are coordinated using information technology.[13] DM implies a shift from long, linear supply chains, economies of scale and centralization tendencies, and a move towards a networked paradigm. Key benefits of DM include inventory-light manufacturing models, enhanced user and producer participation, improved accessibility to new customers and markets, shared resources, and overall cost reduction.[14] Additive manufacturing is one of the key enablers of distributed manufacturing.

Customer level customization in short lead time

A major advantage of on-demand, on-location manufacturing for the end-users is mass-customization. With AM, part design complexity does not significantly affect the cost, therefore, automakers can offer unrestricted design freedom to the customers due to the lack of hard tooling and fewer manufacturing constraints. In future, customers will be able to design certain vehicle parts over the internet and these custom parts will be printed just-in-time at micro-factories and dealerships.

BUSINESS CHALLENGES

Decentralized Production

- DM faces a number of regulatory and governance challenges that will need resolution in order to facilitate its socio-economic-policy acceptance and spread. These will entail challenges related to liabilities, coordination and governance, intellectual property, tariffs, regulatory approval both for production technologies and urban landscapes, etc.[12]
- Lack of user-friendly software to support mass product customization. A layman must be able to quickly learn and use the software.

In the future, customers will be able to design parts for their vehicles using online software. AM printers at micro-factories or dealerships will be used to print the parts.

[13] Wikipedia

[14] Srai, Jagjit Singh et. al. (2015). Distributed Manufacturing: scope, challenges and opportunities. ResearchGate

Vehicle Maintenance

Automakers and suppliers keep inventories of replacement parts and tools for 10-15 years. Also, repair shops either carry a big inventory of commonly used service parts or order parts for which customers need to wait. AM can overhaul the vehicle service parts industry by giving repair shops the power to print parts on demand. This may also take pressure off suppliers to maintain and store the production tools of obsolete parts for future service part requirements.

For vintage vehicles, defined as 25 years or older[15], and customized vehicles, AM can also be very beneficial since parts for such vehicles are not generally commercially available. Supplier organizations such as Specialty Equipment Market Association (SEMA) is optimistic about additive manufacturing use in aftermarket parts.

Attract young talent

The US Bureau of Labor Statistics data shows that half of manufacturing workers are 45 years or older and younger people are not entering manufacturing at the rate necessary to replace the retiring workforce.[16] A major contributor to this trend is the "old-fashioned" and "rust-belt" image of the manufacturing industry in the minds of the young generation. A 2018 survey by ManpowerGroup found that skilled trades – electricians, welders, mechanics and more – as well as sales representatives, engineers, drivers and technicians, have ranked among the top five hardest roles to fill for the past ten years.[17]

AM technology, if marketed well, has a "coolness" factor that may attract young students into the manufacturing industry.

BUSINESS CHALLENGES

Vehicle Maintenance

- Lack of process to control quality of parts printed in small shops.

Human Resources

- Finding right marketing strategies for AM in manufacturing to attract young talent.
- Retraining mid to senior level employees.
- Lack of certification courses

[15] According to The Antique Automobile Club of America

[16] Financial Times (2018), US manufacturers struggle to attract 'cool' millennials, https://www.ft.com/content/ee5ec0b6-91c9-11e8-b639-7680cedcc421

[17] Solving the Talent Shortage (2018). ManpowerGroup.

Current Status

As of today, the applications for AM in automotive is mainly limited to rapid prototyping. While it is evident that a few automakers are seeing the potential of AM and have started to invest, the industry, in general, is slow to adapt compared to the aerospace and medical industries. Table 3 summarizes the reasons for the slow growth in automotive discussed in the previous sections.

Table 3: Reasons for Slow Growth of AM in the Automotive Industry

Reasons for Slow Growth of AM in the Automotive Industry	
Technical Reasons	**Business Reasons**
Long cycle time	Skill Gap
Part-size limitations	Intellectual Property Protection
Limitations on mixed-material printing	High Initial Investment
An unestablished material qualification process	Return of investment measurement
Difficulties in controlling part quality	Obsolescence of equipment
Machine reliability	Lack of large scale industry collaboration

Source: CAR Research

Nonetheless, the analyst community remains enthusiastic about AM's future in the automotive industry. The forecast from various organizations predicts exponential growth between 2020-2030. Research by various market consulting firms shows the AM global automotive market size was estimated to be more than 1.4 billion in US dollars in 2017 with the annual sales of more than 110 thousand 3D printers. The AM global market is anticipated to grow at a compound annual growth rate (CAGR) of more than 25-30% from 2018-2024.[18]

The additive manufacturing (AM) market is expected to grow due to:

- Availability of faster and reliable machines and simulation software
- New materials designed for AM
- Standardization of material qualification processes
- Quality checks with new NDT methods
- Growing awareness of AM benefits
- Wide-scale industry collaboration to tackle technical challenges with AM
- Fast growth in USA and EU, technology transfer to Asia Pacific region, and
- Use of AM in production parts

[18] Global Market Insights, SmarTech, Mordor Intelligence

Major automakers have recently started experimenting with AM for tooling and part production and are creating specialized AM R&D departments within their organizations. Table 4 lists recent AM initiatives by these automakers.

Table 4: Recent Examples of AM Initiatives by Automakers

Automakers	Recent Examples of AM Initiatives from the News
Audi	• Audi is partnering with EOS and SLM Solutions to implement additive manufacturing. • Audi is using Stratasys multi-color, multi-material printer to prototype tail light at 50 percent faster pace.[19]
BMW	• BMW has invested €10 million (approximately $12.3 million) in a specialist Additive Manufacturing Campus. • BMW has printed one million parts since 2010. Examples of parts include window guide rail and metal convertible roof bracket for the i8 Roadster. • BMW is leveraging 3D printing to allow vehicle owners to customize a BMW MINI using printed inlays to augment their side scuttles, interior trim, LED door sills, LED door projectors, and more.
Ford	• Ford's new Advanced Manufacturing Center incorporates 3-D printing, collaborative robots, and virtual reality into production processes. Ford invested $45 million in the center. • Ford will include 3D printed small brake parts in Shelby Mustang GT500.[20] • Ford has invested $65 million in 3D-printing startup Desktop Metal.[21] • Ford is using AM prototyping heavily to enhance production of Lincoln Navigator and Ford Expedition SUVs.[22] • Ford is testing Stratasys Infinite Build System for large-scale 3D printed auto parts.[23]

[19] 3D Print (2018), https://3dprint.com/215995/audi-and-the-stratasys-j750/
[20] Automotive News (2018), https://www.autonews.com/article/20181204/OEM01/181209873/mustang-shelby-gt500-to-include-two-3d-printed-brake-parts
[21] CNN (2018), https://www.cnbc.com/2018/03/19/ford-future-fund-invest-65-million-in-desktop-metal-3-d-printers.html
[22] 3ders (2018), https://www.3ders.org/articles/20180212-ford-using-3d-printing-on-navigator-expedition-suvs-to-meet-increased-demand.html
[23] ZDNet (2017), https://www.zdnet.com/article/ford-to-trial-stratasys-system-to-use-3d-printing-of-one-piece-auto-parts/

Automakers	Recent Examples of AM Initiatives from the News
General Motors	• GM saved $300,000 over two years on tools and other accessories using AM at Lansing Delta Township plant.[24] • GM has announced that it will start making 3D-printed components to hit the goal of expanding its current lineup to 20 new electric and fuel cell car models in the coming five years.[25]
Mercedes	• Mercedes Benz is using AM to create metal parts for older truck models, removing the costly and time-consuming process of casting molds for these lesser used parts.[26]
Volkswagen	• VW has opened a new advanced 3D printing center. Located in the automotive hub of Wolfsburg, the facility occupies 3,100 m^2 of floor space and houses a range of cutting edge metal additive manufacturing machines. Target production of 100,000 units per year. • VW is collaborating with HP and GKN Powder Metallurgy to establish an AM automotive process chain.[27] • Bugatti is using 3D-printed titanium brake caliper

Source: CAR Research

NEED FOR INDUSTRY COLLABORATION

Government, industry, and academia collaboration and teamwork can solve AM's challenges faster and cost effectively. There is a strong need to engage the right experts representing a broad section of the industry, assemble teams, collaborate on pilot projects, deliver and publicize results across the industry, and create a Plan-Do-Check-Act (PDCA) loop.

Organizations such as the Edison Welding Institute (EWI) and professional organizations such as the Society of Manufacturing Engineers (SME) have existing working groups on additive manufacturing. However, most of the group membership is from the aerospace and the medical industries. While some of the issues such as part-size limitations, part quality, and skill gap are equally important across the industries, there are cost drivers such as long cycle time, and return on investment (ROI) measurement

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[24] Automotive News (2018), https://www.autonews.com/article/20180620/OEM01/180629990/gm-steps-up-3d-printing-efforts-to-find-new-plant-efficiencies

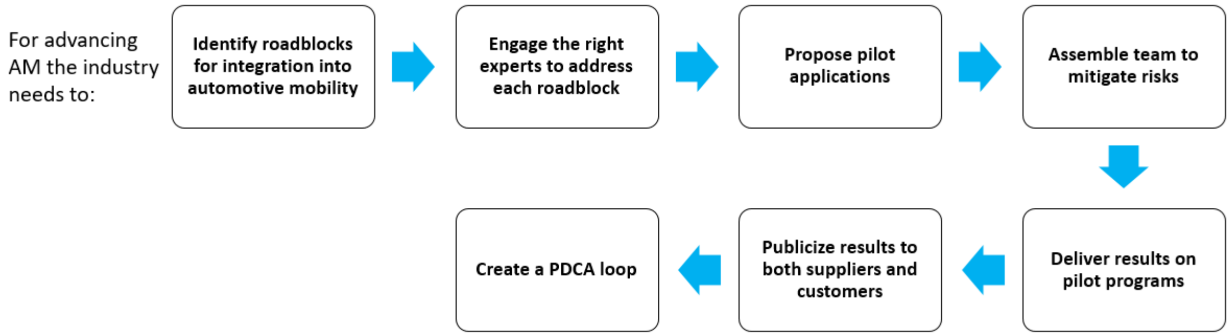
[25] Popular Mechanics (2018), https://www.popularmechanics.com/cars/car-technology/a20135593/gm-autodesk-3d-printed-parts/

[26] Daimler, https://media.daimler.com/marsMediaSite/en/instance/ko/Premiere-at-Mercedes-Benz-Trucks-New-from-the-3D-printer-the-first-spare-part-for-trucks-made-of-metal.xhtml?oid=23666435

[27] 3d Printing Industry, https://3dprintingindustry.com/news/volkswagen-moves-to-mass-customization-aims-for-over-100000-3d-printed-units-per-year-139604/

that pose more challenges in the automotive ecosystem. CAR's mission is to promote the sustainability of the automotive industry so the newly developed working group under CAR's leadership will focus on specific AM issues dominant in the automotive industry and related mobility industry. CAR expects to collaborate with existing working groups to leverage their experience in the field.

Figure 8: Need for Collaboration to Advance AM



Source: CAR Research

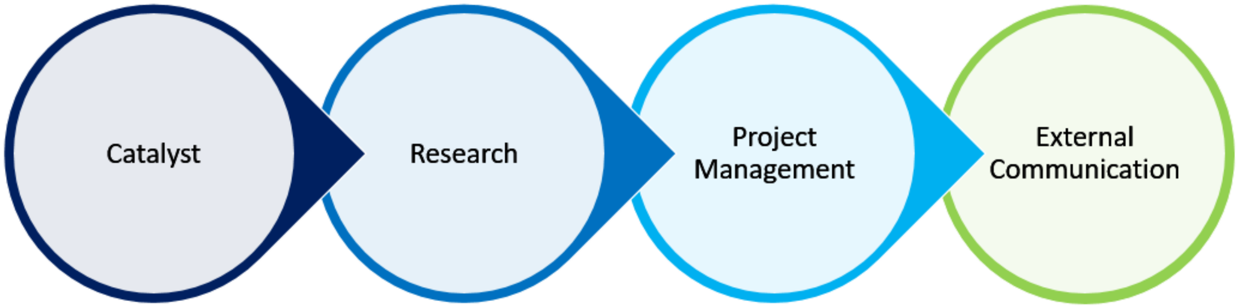
MOBILITY CONSORTIUM FOR ADDITIVE MANUFACTURING (MCAM)

For advancing additive manufacturing in the automotive industry, CAR will act as a catalyst to bring the industry together, support research, manage projects, and play a primary role in communicating the finding of the projects through publications and presentations at various industry events including the annual CAR Management Briefing Seminars which draws more than 1,000 automotive executives.

Developed by CAR, this new automotive-focused additive manufacturing working group's mission would be to:

- Identify roadblocks, research solutions, develop prototypes, and provide visibility and direction to integrate AM technologies into the mobility industry in a cost-effective manner.
- Increase awareness among the automakers and tier-1 suppliers about various AM technologies and application possibilities.
- Serve as a unified voice to drive the creation of AM quality and inspection standards for materials, processes, and end products.
- Facilitate knowledge and technology transfer from other industries into automotive.
- Research and disseminate information about the effects of technological changes such as part consolidation and business changes such as decentralized production on the supply chain.
- Leverage other organizations such as America Makes, Oakridge National Lab (ORNL), Lightweight Innovations for Tomorrow (LIFT), Institute for Advanced Composites Manufacturing Innovation (IACMI), EWI, university labs, etc. for projects.

Figure 9: CAR's Role in AM Working Group



CAR is an independent nonprofit producing industry industry-driven research and fostering dialogue on critical issues facing the automotive industry. Due to CAR's unique position and outreach, it is effective as an industry convener and has a growing share of media voice. CAR has broad experience in bringing corporations, governments and academia together to work on pre-competitive, unbiased projects. CAR leads and hosts several working groups on focused topics such as lightweighting, powertrain, autonomous vehicles, and economic developers.

Future Research

In December 2018 and February 2019, CAR organized and hosted two meetings to discuss the challenges faced by the automotive industry in using AM; meeting attendees spent time brainstorming ways to address those challenges. Attendees included representatives from machine suppliers, material suppliers, technology users including automakers and tier-1 suppliers, government, and academia.

In the meeting, there were several pre-competitive, collaborative projects proposed for increasing AM's use in automotive. The attendees also voted on the ideas to show their support and interest. Below is the list of project categories and the proposed projects in each category.

The list within each category is prioritized based on the voting by the meeting attendees.

METAL TOOLING

1. Reduce lead time for hot stamping dies by eliminating machining operation for cooling lines.
2. Create 3D printed die working surface with a casted base.
3. Reduce lead times for large molds by eliminating machining operation for runners.
4. Replace perishable die details using AM.
5. Develop online education resources on existing AM tooling.

PLASTICS TOOLING

1. Achieve complex geometries in injection molds using AM with short lead times
2. Develop short run, prove-out tools using AM
3. Explore production of rapid, lower cost vacuum forming molds using AM

PART PRODUCTION

1. Provide recommendations on choosing the right AM machine type
2. Research and publish design strategies for AM
3. Reduce post-processing times for small 3D printed parts
4. Convert a high-volume traditionally manufactured part to AM at comparable cost
5. Research and publish potential AM application areas in automotive

BUSINESS MODELS

1. Create business models/techniques for high-volume production part
2. Provide recommendations for on-demand, on-locations vehicle repair/maintenance
3. Define the AM supply chain – current state and recommendations for the future requirements
4. Develop recommendations for certification and standardization of AM protocols

OTHER PROJECTS

1. Investigate and catalog database of current technology. Make database available online.
2. Showcase case studies of failures in using AM technology and investigate new technologies that can address the reasons for past failures.
3. Develop case studies profiling automotive companies that adopted AM and the reasons behind the decision.
4. Create recommendations for inclusion of AM in the academic curriculum of community colleges and universities.
5. Rank AM technologies based on cost, build speed, and post-processing time.

To learn more about, or to join the Mobility Consortium for Additive Manufacturing (MCAM), please contact:

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