Additive Manufacturing for 3D Printing using OEM in Automobile Industry

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Abstract: **Enhanced significantly in additive manufacturing technologies for 3D printing, over the recent years have transformed the potential ways in which by-products are design, development, manufacturing, and distribution. For the automotive industry, these improvements have made for newer designs; cleaner, lighter, and safer products; shorter lead times; and lower costs. In the automotive industry, the original equipment manufacturer (OEM) and suppliers primarily use additive manufacturing for rapid prototyping; the technical path of additive manufacturing makes a strong case for its use in by-product innovation and mass scale of direct manufacturing in the future. Further enhancement in additive manufacturing techniques, along with similar innovations in fields such as advanced materials, will benefit production within the automotive industry besides alter conventional manufacturing and chain of production. Hence additive manufacturing techniques can improve the competitive position of the automotive industry and explore the four paths OEM and suppliers can take to more broadly apply additive manufacturing techniques. Finally, analyze the drivers supporting the use of additive manufacturing for 3D printing using OEM and the potential challenges impeding its large-scale adoption in the automobile industry.**

Index Terms: **Additive Manufacturing (AM), 3D Printing using OEM and Automotive Industry**

1. INTRODUCTION

The international automotive manufacturing industry has high barriers to entry, especially at the top where the four largest OEMs accounted for a third of the international industry revenue of over 251.4-282.8 billion US$ expected to reach in 2026. On the other hand, the $1.5 trillion parts and accessories manufacturing sector is characterized by high competition among a large number of limited organizations. To survive and succeed in such a domain, companies should focus on specific capabilities that can lead to greater competitiveness. We believe there are two areas where additive manufacturing will have the greatest influence on competition between automakers and potentially be a game-changer. The Automotive industry has a great amalgamation of technology and industrial sector disrupts to make innovative solutions [1]. With the digitization buzz across the world, the automotive industry is also gearing up for an extensive change in 2021. The sector has seen tremendous ups and downs in the past decade. But, with all the technology adoption in the varied sector, the auto industry is gradually moving towards advancement wherein the industrialists will make more revenue and end-users will find more innovative driving techniques.

The automotive industry can produce components with fewer design restrictions that often constrain more traditional manufacturing processes. This flexibility is extremely useful although manufacturing products with custom features, making it possible to add improved functionalities such as integrated electrical wiring through hollow structures, lower weight through lattice structures, and complex geometries that are not possible through traditional processes. Besides, new Additive Manufacturing technologies are increasingly able to produce multi-material printed parts with individual properties such as variable strength and electrical conductivity. These additive manufacturing processes play an important role in creating faster, safer, lighter, and more efficient vehicles of the future. By drop the need for new tooling and directly producing final parts, additive manufacturing (AM) cuts down on overall lead time, thus improving market interest. Also, since AM generally uses the material which is necessary to produce a component, it can drastically reduce scrap and drive down material handling. Besides, AM-manufactured lightweight components can lower handling costs, although on-demand and on-location production can lower inventory costs [4].

Finally, additive manufacturing (AM) can support relinquished production at low to medium volumes. All these AM capabilities combined to drive significant change within the supply chain including cost reductions and the improved ability to manufacture products closer to users, reduce supply chain complexity, and better serve user segments and markets without the need for extensive capital adoption. Practically, product innovation and supply chain transformation have the potential to alter the business models of automotive companies. The extent to which the potential offered by AM is secured depends on the path chosen by individual companies. Four possible paths and their impact are described in the following framework are shown in Fig.1.

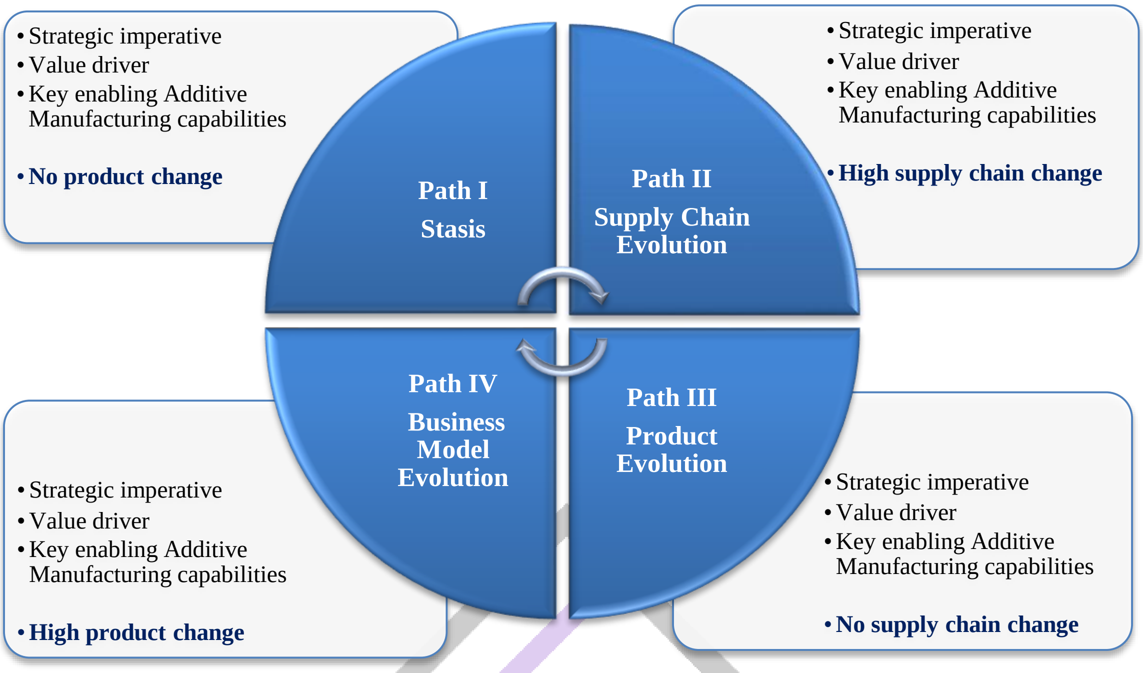

Fig.1 Framework for understanding Additive Manufacturing paths and value

2. FUNDAMENTAL PERFORMANCE OF ADDITIVE MANUFACTURING

Additive Manufacturing (AM) is a key technology innovation whose origin goes back nearly three decades. Its significance is derived from its ability to break existing performance trade-offs in two fundamental ways. Firstly, AM reduces the capital required to achieve economies of scale. Secondly, it increases flexibility and reduces the capital required to achieve scope [2].

Capital versus Scale:

Estimations of minimum efficient scale shape the supply chain. AM has the potential to reduce the capital required to reach a minimum efficient scale for production, as a result lowering the barriers to entry to manufacturing for a given location.

Capital versus Scope:

Regulation of scope influence how and what products can be made. The flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, reducing the costs associated with production changeovers and customization and/or the overall amount of capital required. Changing the capital versus scale relationship has the potential to impact how supply chains are configured, although changing the capital versus scope relationship has the potential to impact product designs. These impacts present companies with choices on how to deploy AM across their businesses.

The four tactical paths that companies can take are outlined in the framework below:

- **Path I:** Companies do not require radical alterations in both supply chains and products, to enhance further by using AM technologies to improve value delivery for current products within existing supply chains.
- **Path II:** Companies take advantage of the economics scale presented by AM as a potential enabler of supply chain transformation for the products.
- **Path III:** Companies take advantage of the economics scope presented by AM technologies to achieve new levels of performance or innovation in the products.
- **Path IV:** Companies alter both supply chains and products in the pursuit of new business models.

2.1 State-of-the-art Additive Manufacturing Path in Automotive Industry

Within the automotive industry, Additive Manufacturing (AM) has largely been utilized to break the capital versus scope trade-off to enhance performance. High-volume automotive, the original equipment manufacturers (OEMs), and suppliers have long applied AM to enhance overall manufacturing capabilities and reduce costs which categorizes them as following a path I of our framework [3]. Most OEMs and suppliers are currently on a path I (stasis) AM can produce prototypes without creating tools, thus accelerating design cycles and lowering costs. Both OEMs and suppliers use AM to enhance existing operations: to support decision-making at the product design stage is shown in fig.2, to establish quality at the preproduction stage, to develop custom tools, and to reduce the overall time to market.

Fig.2 Additive Manufacturing Design Stage

2.2 Design Phase of New Product Development

In the product design stage, companies endure several replications before authorizing the final design. The AM's greatest advantage is to produce multiple revisions of a product with little additional cost, allow auto companies to improve their product designs with the support of physical models. For example, a prominent tire company uses AM techniques to promptly create prototypes during the design process and select the best design after verifying the touch and feel of various alternatives. Meanwhile, the prototypes benefit the company by not only customizing options based on OEM needs but also enabling brand differentiation. The physical model provides more advantage over competitors and limited to design specifications and plans alone when sharing new products with their OEM customers [5].

2.3 Enhancing Quality via Rapid Prototyping

By using AM to design prototype models before the final production, automakers can test for quality ahead of actual production schedules. The design flexibility of AM provides, companies can build and test a large variety of prototypes [7]. For example, uses the AM technologies of selective-laser-sintering (SLS) and stereo-lithography (SLA) extensively in its preproduction and design processes across its functional areas design, engineering, and manufacturing with its speedy prototyping department producing test models of more than 20,000 components. Similarly, a Dana supplier of driveline, sealing, and thermal-management technologies for OEMs. It uses a combination of speedy prototyping and simulation to create prototypes that can be tested for form and fit.

2.4 Customized Fabrication of Tooling

For automakers, tooling plays a vital role on the assembly line by producing consistent, high-quality products. AM allows for the fabrication of customized tools to enhance productivity on the shop floor. BMW, for example, has used AM in direct manufacturing to make the hand tools used in testing and assembly. These custom-designed hand tools have a better ergonomic design and are 72 % lighter than traditional hand tools. According to BMW, the customized tools helped save 58 % in overall costs and reduce project time by 92 % in the recent source.

2.5 Reducing Tooling Costs in Product Design

In a few automotive components, tooling and investment castings are set up for specific designs before production runs. Each change of design, tooling as effectively adjusted or remade a time-consuming and expensive process. OEMs have reduced their requirements on tooling and casting in the design phase by using AM techniques. By Ford, the company saved millions of dollars in product development costs by selecting to create prototypes using AM techniques and avoiding the need for tooling. The additive manufacturing (AM) prototypes of components such as cylinder heads, intake manifolds, and air vents, the company also minimizes drastically to create investment castings. For a single component such as an engine manifold, developing and creating the prototype usually cost arises $500,000 approx and takes about four months to complete. By using AM, Ford developed multiple iterations of the component in just four days at $3,000.

3. FUTURE PATHS OF AM IN DRIVING PERFORMANCE AND GROWTH

The use of conventional manufacturing methods is mainly limited by the size of the production run and the geometrical complexity of the component, and as a result, we are occasionally forced to use processes and tools that increase the final cost of the element being produced. Additive manufacturing techniques provide major competitive advantages since they adapt to the geometrical complexity and customized design of the part to be manufactured. The following may also be achieved according to the field of application, lighter weight products, multi-material products, ergonomic products, efficient short production runs, fewer assembly errors and, therefore, lower associated costs, lower tool investment costs, a combination of different manufacturing processes, optimized use of materials, and a more sustainable manufacturing process. Additive manufacturing is seen as being one of the major revolutionary industrial processes of the next few years. The four tactical paths that companies can take are outlined in the framework.

3.1 The Path I: Scope to Improve their Additive Manufacturing Strategies

This analysis estimate AM's major role in the auto industry over the long term is along with path IV business model evolution. However, this route also includes product innovation typically associated with path III. The automotive business model of the future will likely be characterized by OEMs working closely with a smaller, more tightly knit supplier base and supporting faster refresh rates for automobiles with innovative characteristics [6]. OEMs can achieve this business model by continuing to rationalize their supplier base and enhancing their partnerships with what are called "tier 0.5" suppliers. Currently, it takes few years from initial design to final production before a vehicle hits the market. With AM, automakers can significantly shorten the development phase of the product life cycle and expand the growth and maturity phases.

3.2 Path II: Supply Chain Transformation for Products offered by Additive Manufacturing

Although OEMs will seek to drive product innovation, aftermarket parts suppliers, who deal with standardized product designs, are expected to be impacted more by AM's altered economies of scale. Using AM, automotive suppliers can produce components on demand and at locations closer to the point of use. This affords them the added benefit of balancing demand and supply and drastically lowers the cost of inventory. Fig.3 shows the Illustrative applications of Additive Manufacturing in an automobile. In addition, maintenance and repairs of automobile parts can be done in entirely new ways using newer AM technologies, which can potentially reduce long lead times to get cars back on the road.

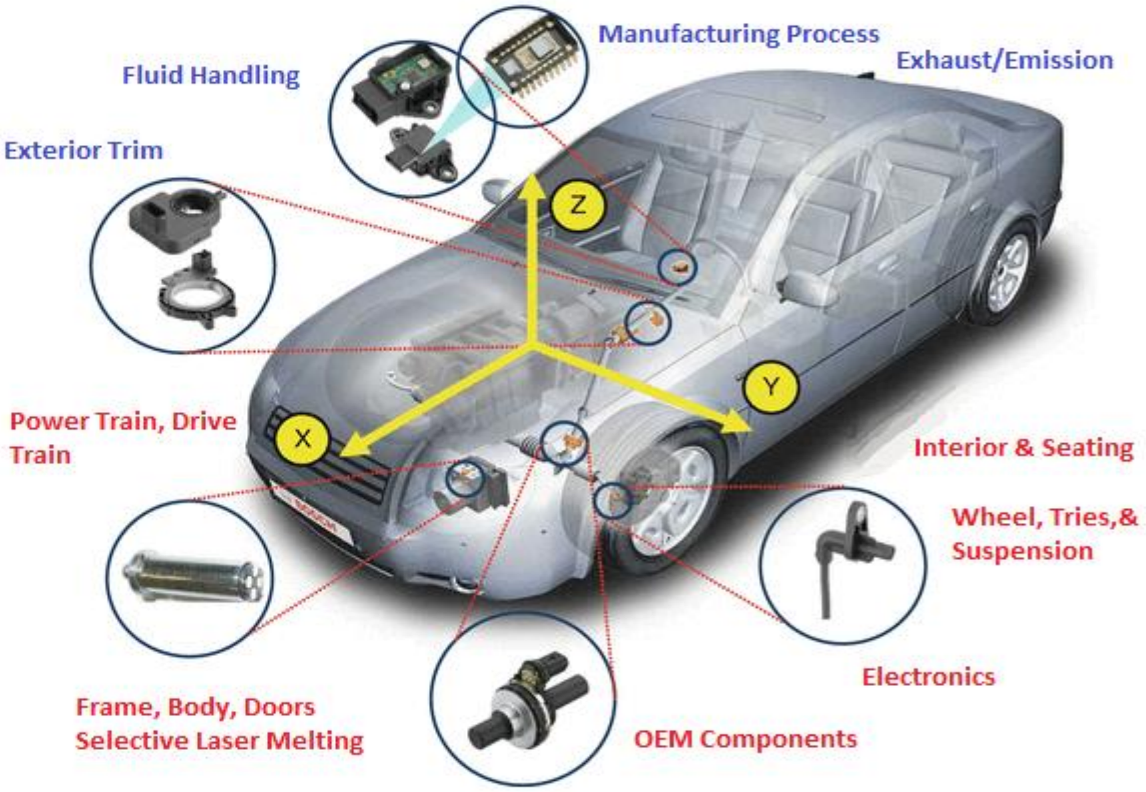

Fig.3 Illustrative applications of Additive Manufacturing in an automobile

Cut down service, spare, and aftermarket part inventory. Delivery time and parts availability are important bases of competition in the aftermarket segment of the automotive industry. Owing to high costs of carrying inventory, most automotive part distributors and retailers hold only commonly sold parts, maintaining stockpiles of low-demand or expensive components only at more remote, consolidated locations. AM can help match supply with this demand for "long-tail" components parts that are in demand but only in small volumes through on-demand production. Closely related is the performance parts segment of the market [8]. This segment, accounting for approximately 20 % of retail auto part sales, is considered a discretionary expense by most consumers, and therefore its demand pattern is not uniform. We imagine a day when (as AM system and material costs fall) auto part providers can maintain performance parts availability. Although, holding less inventory. Distributors may also be able to reduce costs and turnaround times by using AM, thus reducing operational expenditure.

Finally, when combined with 3D scanners, AM might also prove ideal for producing components for out-of-production models where the computer-aided designs (CAD) of the parts may not be available.32 3D scanners can create the CAD file for the base design of the component, and AM can then produce the component from the CAD file. One of the most well-known examples is the use of Rapid form to reproduce parts of vintage cars from the garage of the popular talk show host, Jay Leno. Eventually; we might see the creation and growth of a market for CAD files, which act as a central repository, for all parts. The user could then purchase the digital design for a part and print it on their personal AM device or make use of a local AM device or service company.

On-site fabrication to accelerate maintenance and repair certain automotive parts, such as drive-train or engine components, may be expensive to replace when they wear out. In such cases, they could be repaired using AM at service locations. Laser metal deposition (LMD) is a technology that has high net-shape accuracy and can be used to repair small-to-medium-complexity parts on site. Developed for aerospace applications, LMD is known to extend the overall life of products, avoiding the expense of replacement. The technique is beneficial in cases where costlier, high-performance alloys are used. Although the technology is already substantially advanced in A&D, cost remains a prohibitive factor for the automotive industry. As the volume of applications rises, we expect the overall costs to decrease and the technology to become commercially viable in the long term.

3.3 Path III: Product Innovation Enhancement

The Additive Manufacturing (AM) capabilities along this path break the traditional capital versus scope trade-off, driving down the capital intensity required for innovation. Critical advantage in the near term of using AM is the potential production of components with lower weight, leading to vehicles with improved fuel efficiency. Over the longer term, AM-enabled part simplification and associated reductions in the complexity of assembly could fundamentally change design development assembly processes.

More complex designs that drive weight reduction. Automakers are constantly seeking ways to improve the fuel efficiency of vehicles not only because of increasing demand for compliance with fuel standards such as Corporate Average Fuel Economy but also as a way to grow revenue by delivering greater value to consumers. One of the routes that automakers are taking to improve mileage is through weight reduction in automobiles. Over the years, OEMs have sought to incorporate lighter materials such as carbon fiber and aluminum into the vehicle body. The 2021 Ford F-150 is a good example. Unveiled in January 2020, the F-150's body is made almost entirely of aluminum cutting vehicle weight by as much as 700 pounds (around 317 kg). Another way to reduce weight is through alterations at a structural level. The ability of AM to create complicated configurations plays an important role in reducing the weight of parts using lattice structures without compromising structural strength. In this regard, the automotive industry can take cues from the aerospace and defense (A&D) industry, where a third of the revenues are spent on fuel, and reducing components and the overall weight is critical. Driven by this need, major A&D companies incorporated AM in production to produce lightweight versions of components such as nacelle hinge brackets and complex parts used in unmanned aerial vehicles.

Reducing assembly and production cost by parts simplification. Conventional manufacturing techniques impose design limitations that can proliferate the number of parts required to produce a component. As the number of parts increases, the length and complexity of the assembly process also increases. AM can produce parts with complex designs that can overcome the need for multiple parts. Fewer parts translate into a shorter assembly process, and consequently, there is less chance that a quality problem will arise. Some auto companies are already making use of these attributes of AM, albeit in a limited fashion.

Delphi, a tier 1 automotive supplier, currently uses selective laser melting (SLM) instead of traditional machining of aluminum die castings to make aluminum diesel pumps. Through the use of SLM, Delphi not only was able to make the pump as a single piece drastically reducing the part count and simplifying the assembly processes it also reduced overall production costs. Producing pumps as a single piece also helped Delphi avoid several post-processing steps, resulting in a final product that is less prone to leakage. Greater application of AM freeform capability in the future can simultaneously reduce assembly time and cut down on assembly costs, with the integration of individual parts such as flow control valves, mounts, and pumps into a single-part design. This way, even complicated systems such as complete engine blocks can be built as a single part, with integrated electrical and cooling channels. The optimized engine design can improve fuel efficiency and lower weight [9]. AM makes it possible to produce designs that have "conformal cooling," which directly integrate fluid-handling channels into the component, avoiding the need for separate cooling channels. In the future, automakers can benefit from the potential integration of mechanical and electrical functions through multi-material printing.

3.4 Path IV: OEMs' Long-Term Advantage will Emerge Business Model Innovation

The eventual path for automotive OEMs is business model evolution through a combination of product innovation, rapid turnaround, and market responsiveness, leading to AM-supported supply chain disintermediation. Business model innovation will incorporate the current-use (path I) advantages of AM improved design and reduced time to market along with the intermediate product innovation (path III) advantages part simplification, reduced need for assembly, and weight reduction of components that we have previously discussed; it can then combine these with a more geographically distributed supply chain to alter business models in important ways related to market responsiveness and supply chain disintermediation.

Customization and improved market responsiveness: Advances in AM technology and adoption are leading to product innovations that will transition AM from a product design support tool to a conduit for the direct production of high-performance parts with a fast turnaround. Although automotive companies have conventionally used modularity and postponement to support customization, AM provides greater flexibility. An interesting segment of the auto industry that has already adopted AM is the ultra-luxury segment. In this segment, where production runs are small, AM is being used to customize and manufacture parts for use in final assembly. Some ultra-luxury carmakers already use AM to deliver designs specialized to customer requirements. Bentley, for example, used its in-house AM capabilities to customize the dashboard in a case where manual modification would have been time-consuming.

Using AM for the rapid turnaround of application-specific parts is presently prominent in the proving ground of new auto technologies motorsports. With lead time becoming a precious commodity, lessons learned in motorsports can be applied to mass production to reduce turnaround times a competitive capability that will likely become increasingly critical for all automakers. One of the best motorsports examples comes from Joe Gibbs Racing, which used AM to produce a duct outlet and reduced the design and machining time from 33 to just 3 days.

4. Challenges in Automotive Industry using Additive Manufacturing

The success of AM's future applications in the automotive industry will depend largely on how AM technology evolves over the coming years. We have identified two drivers and four challenges that have the potential to shape the future of AM adoption. More materials amenable to Additive Manufacturing, a wide variety of materials allows a greater number of properties to be embedded into final products. Traditionally, AM applications have been restricted due to the limitations on the materials that can be used [10]. Although conventional manufacturing currently uses a wide variety of materials such as metals, alloys, and composites, AM has not been around long enough to see similar developments. With the limited application of novel materials in AM so far, these materials remain costly.

Improved AM manufactured product quality and reduced post-processing. Parts produced through most additive manufacturing (AM) technologies occasionally show variability due to thermal stress or the presence of voids. This results in lower repeatability, which is a challenge for high-volume industries such as automotive where quality and reliability are extremely important. Fig.4 shows Improved Additive Manufacturing in an automobile. One way to tackle this challenge is through machine qualification, where companies follow industry standards as well as those of the AM technology providers.

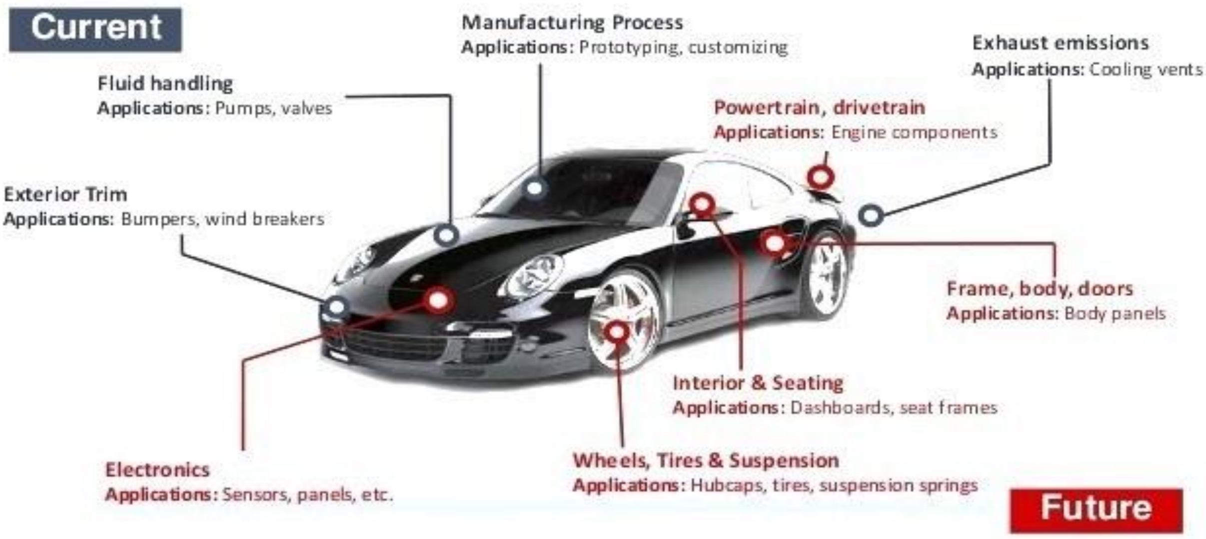

Fig.4 Improved Additive Manufacturing in an automobile

5. CONCLUSION

Despite the challenges, the fact remains that AM is a versatile set of technologies that can support auto industry companies in their pursuit of the strategic imperatives of performance, growth, and innovation. Considering the breadth of capabilities unlocked by AM, leaders of automotive companies should consider taking advantage of AM technologies to stay ahead of the competition. At present, automotive companies are using AM in the most traditional capacity, along the path I, for rapid prototyping. We do not currently see significant product evolution or supply chain applications (with the possible exception of the luxury segment of the market). However, automotive companies should consider exploring other paths to derive greater value. The freeform capabilities of AM and the drastic reduction in design-to-final production time will allow OEMs to produce complex, high-performance parts for end-use. Finally, the automotive industry is a low-margin, capital-intensive industry.

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