Digital Manufacturing for Spare Parts: Scenarios for the Automotive Supply Chain

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Abstract

Additive Manufacturing for spare parts is often discussed from a supply chain perspective, extoling the opportunities to reduce inventory and improve service in the supply chain. This paper examines possible scenarios for the mechanisms through which additively-manufactured automotive spare parts might be realised in the future, building on previous reviews of literature in this field. The paper also examines the technical challenges which may exist in the transition from traditional manufacturing processes to Additive processes for automotive spare parts.

1. Introduction

Additive Manufacturing (AM) is one of the fundamental technologies underpinning 21st Century Digital Manufacturing. Sometimes termed '3D Printing', AM is enjoying significant research, commercial, and media attention, and this has led to much speculation as to the applications for the technologies, and the related benefits that may be leveraged. One of the most interesting and frequently discussed applications for AM is in the production of spare parts. A pioneering exploration of this concept was provided by Walter *et al.* (2004), who provided a detailed evaluation in the context of aerospace parts; subsequently several detailed studies have severed to extend and refine this concept further (e.g. Holmström *et al.* (2010), Khajavi *et al.* (2014), Liu *et al.* (2014), Eggenberger *et al.* (2017)). Table 1 shows the main benefits discussed in literature, demonstrating a clear focus on distribution and centralized manufacturing options, a reduction of inventory, and on-demand manufacturing arising through the application of AM.

Table 1: Advantages of using AM for spare part production from academic literature

Article	Distributed Manufacturing	Reduced Inventory	Centralized Manufacturing	On-demand Manufacturing	Reduced Transportation	Better Responsiveness	Low Volume Manufacturing	Manufacturing in remote	Reduced Overall Costs	Sustainability Improvements	Improved Customer Satisfaction	Reduced Obsolescence Risk	Reduced Downtime	Better Flexibility	Robustness to Supply Chain Disruption	Production Capacity Buffer	Reduced Packaging	Manufacturing Postponement	Reduced Parts Shortage	Produce Obsolete Parts
Holmström *et al.* (2010)	X	X	X	X	X	X		X												
Garrett (2014)	X	X		X		X	X	X												
Khajavi *et al.* (2014)	X	X	X		X				X	X	X	X		X	X	X				
Liu *et al.* (2014)	X	X			X		X										X			
Holmstrom and Partanen (2014)	X	X	X					X				X						X	X	
Nyamekye *et al.* (2015)	X	X			X					X			X							
Tatham *et al.* (2015)	X			X					X				X							
Sasson and Johnson (2016)	X	X	X				X				X									X
Eggenberger *et al.* (2017)	X	X		X		X														

While possible implementations for AM in spare parts production have been discussed in the past, the development of scenarios for AM manufacturing developed by Ryan *et al.* (2017) has highlighted a wide range of possible manufacturing approaches which may develop for AM in the future. This paper examines these scenarios in the context of the automotive supply chain, and discusses the potential technical challenges associated with a conversion from traditional manufacturing methods to an AM manufacturing system.

2. Five Scenarios for Automotive AM

Ryan *et al.* (2017) uses a structured literature review alongside exploratory interviews, to examine, analyse and synthesise future scenarios for AM manufacturing. It employs the concept of 'Order Penetration Points' (Gosling et al., 2017) to delimit the nature of customer involvement in the supply chain, which in turn helps to understand the extent to which parts may be customized for individual orders. We build on this concept in this work to propose five scenarios for automotive spare part production.

Scenario 1: Personal Manufacturing. Future developments in cost, quality and ease-of-use for 3D Printers mean that most households will have AM capabilities. In response to this, OEMs will begin to make catalogues of a range of spare parts available online, where a customer can purchase a licence and digital model to manufacture the part at home for their own consumption. As a result, the supply chain is dematerialized; there is no need for inventory holding of spare parts by the manufacturer as customers will simply 'print their own'. Similarly, the role of supply chain intermediaries becomes less obvious; garages and dealerships will no longer be the source of parts for vehicles, though it is likely that they will remain involved in their installation.

Scenario 2: Retail Manufacturing. In the future the potential exists for AM facilities on the high-street to be commonplace. For automotive spares, rather than holding a large stock of spare parts, workshops and garages will access digital libraries and manufacture the parts on-site using AM, reducing waiting times and increasing part availability. As with personal manufacturing the supply chain is dematerialized, but in this scenario the intermediary role remains clear: garages supply and fit parts to vehicles on behalf of customers.

Scenario 3: Bureau Manufacturing. Based on existing expertise, regional centres of excellence for AM develop further in the future, producing low quantities of specialist parts. Rather than manufacturing and storing spare parts centrally, OEMs will begin to licence these bureaus to manufacture spares as required, near to the point of use. This reduces reliance on centralized warehouses, and by producing more local to demand, may lessen the extent to which material and parts need to be transported to the point of consumption.

Scenario 4: Factory Manufacturing. Factories begin to adopt AM technologies in mass production, improving the flexibility of the products that it can produce. Variations in adoption will emerge, ranging from the incorporation of AM machines into existing manufacturing systems, allowing some customization and flexibility, to a complete conversion to AM methods. Without the need for hard tooling and lengthy set-up times, producing spare parts using digital manufacturing methods becomes unobtrusive. The digital nature of AM means that changing the product is simply a case of loading a new design file to the machine, and so it becomes possible to incorporate spare parts in low volumes (even those for long-obsolete models) into the production system with a minimum of disruption.

Scenario 5: Mobile Manufacturing. Production systems will emerge which allow parts to be manufactured using AM whilst in transit. Traditionally, shipping time is a "lost" time in manufacturing, however the advent of mobile production systems, which allow spare parts to be made while they are in transit. This allows a reduction in central stock holding, and reduced lead times, as "shipping" can begin as soon as the order is placed, with manufacturing taking place en-route.

3. Analysis of Scenarios

Using the criteria identified in Table 1, the scenarios proposed above have been examined, and an expert assessment undertaken by the authors. Table 2 shows the results of this assessment, indicating how each of these scenarios aligns with the proposed benefits of AM production for spare parts.

Table 2: Analysis of scenarios proposed for AM production of automotive spares

Potential Benefits of AM	Scenario 1: Personal Manufacturing	Scenario 2: Retail Manufacturing	Scenario 3: Factory Manufacturing	Scenario 4: Factory Manufacturing	Scenario 5: Mobile Manufacturing
Distributed Manufacturing	X	X			X
Reduced Inventory		X			X
Centralized Manufacturing			X	X	
On-demand Manufacturing	X	X	X	X	X
Reduced Transportation	X	X			
Better Responsiveness	X	X	X		
Low Volume Manufacturing	X	X	X		
Manufacturing in remote locations	X				X
Reduced Overall Costs			X	X	
Sustainability Improvements	X	X			
Improved Customer Satisfaction	X	X	X	X	X
Reduced Obsolescence Risk	X	X	X	X	X
Reduced Downtime			X	X	X
Better Flexibility		X	X	X	
Robustness to Supply Chain Disruption		X	X		
Production Capacity Buffer		X			
Reduced Packaging	X				X
Manufacturing Postponement	X	X	X	X	X
Reduced Parts Shortage	X	X	X	X	X
Produce Obsolete Parts	X	X	X	X	X

4. Technical Challenges of AM for Spare Parts

Whilst the existing literature suggests that there are clear benefits to the application of AM for spare parts production, many technical challenges remain in the conversion from traditional manufacturing methods to digital technologies. Those considered most critical to such a system are discussed below.

Digitization of Design

Although the use of 3D CAD in product design has become a standard, many legacy products are stored in more traditional formats (i.e. 2D electronic drawings, or paper-based records). Where 3D digital designs are readily available, the conversion of the part to make it ready for AM is a simple process. Where these digital designs do not exist, however, it is necessary to "digitize and publish searchable, printable component files" (Sasson and Johnson, 2016), either from existing drawings, or from examining existing items. Improvements in 3D scanning technologies makes this process easier, but 3D scans still require manual design verification.

Design for AM

Manufacturing spare-parts presents an interesting design dilemma. "Design for Additive Manufacturing" is often discussed (e.g. Gibson *et al.* (2010)), extoling the possibilities of designing for a manufacturing technology with few geometric considerations. Parts designed for traditional manufacturing do not take advantage of these design freedoms, and can therefore be inefficient to produce using AM (for example, including unnecessary material in the design as a consequence of restrictions in the previous manufacturing method). Spare-parts, however, must interface with the remainder of the existing product, and match the performance of the previous part exactly, restricting the design changes that can be made. The designer must therefore consider how to produce a part which can take advantage of the AM system, whilst producing the same performance of the mass-produced component it replaces.

Materials for AM

Whilst it is desirable for a spare part to match the original part in as many ways as possible, the material choice available for use in AM processes is far more restricted than in traditional manufacturing processes. For many components, where functional performance is nether taxing nor critical, the available materials are unlikely to cause many problems. Where performance is key, however, in mechanical or safety-critical components, materials must be carefully considered, and any necessary re-engineering carried out where the available materials differ significantly from the originals.

5. Further Considerations

Certification

In an industry as safety-conscious as the automotive industry, parts, materials and processes require certification, particularly where warranties must be considered. Whilst the concept of remote producers creating spare parts near to the point of use may be highly appealing from an operations perspective, it creates several quality control (and possibly legal) problems. Whilst the same product can be produced on a range of machines, the properties of that product are unlikely to remain consistent across these varying platforms. Similarly, machine settings, material handling and recycling, and even atmospheric conditions can potentially affect the properties of the final product. Until the effect of each these changes is fully understood, the ability to guarantee a design while having little control over the manufacturing, will be severely limited. Quality systems for automotive components exist in the form of IATF 16949:2016, which has a particular emphasis on "defect prevention and the reduction of variation and waste in the supply chain". A comprehensive understanding of both the AM product and process is required to enable compliance with this standard.

"Smart" Spare Parts

Using traditional manufacturing methods, upgrading a troublesome component in the spare parts catalogue is a long, expensive process; data on failures in the field is often scarce, and replacing or modifying tooling is a costly endeavour. With the plethora of sensors in modern cars, improved connectivity between the vehicle and the OEM might fill this data gap, allowing engineers to access the data they need to improve the parts; however, manufacturing remains a problem. With AM system, all design changes are made digitally - as simply as uploading a new file - allowing the potential to monitor, refine and upgrade parts in real-time.

6. Conclusion

Discussions are ongoing regarding increased use of AM in production. When considering spare parts, the supply-chain implications are substantial, offering opportunities for reduced stock-holding, distribution of production, and improved part availability. Using previous work on scenarios for AM production it is possible to generate various possible scenarios for the future of spare parts supply chains. Despite these discussions, little consideration has been given to date to the engineering implications of such a change. The spare-parts case is unique, as the components are likely to have been designed for a traditional manufacturing process, and yet the AM replacements must behave in exactly the same way as the original parts while in use. Substantial opportunities therefore exist for engineering and supply chain research, to enable the transformation of these propositions into reality.

7. References

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