Feasibility of Additive Manufacturing for the South African Rail Industry

S. Vilakazi
Transnet Freight Rail, Johannesburg, South Africa

N.R. Mathe & L.C. Tshabalala
National Laser Centre, Council for Scientific and Industrial Research, Meiring Naudé Road, Brummeria, Pretoria 0185, South Africa

ABSTRACT: Research and development in Metal Additive Manufacturing has advanced and there has been significant growth in adaptation prospects in the South African industry. However this research has been focused on the aerospace and medical applications. There is limited research on how the introduction of additive manufacturing might assist rail operators in South African in optimising the design, production and maintenance of various internal and customer- facing components. This paper reviews existing literature and industry sources to explore the adoption of this technology by the South African railway industry. The areas of design, manufacture and maintenance are explored as potential methods of application. The viability of the technology has been evaluated in this paper in terms of cost of production, production times and labour related issues as compared to conventional production methods. Case studies are used in this paper to demonstrate the application relevant to the South African Rail Industry.

1 INTRODUCTION

Additive manufacturing (AM) or Metal 3D printing is considered to be an essential area of Industry 4.0 especially with the integration of such smart manufacturing processes and advanced information technologies (Dilberoglua et al. 2017). Metal AM is a process of building 3D parts and components directly based on digital models by fusing metal powder layer by layer using a laser or electron beam as an energy source (Tofail et al. 2018). In South Africa, the Department of Science and Technology has commissioned a roadmap for additive manufacturing driven by high value components in the aerospace and medical industries and little or no railway involvement. Recently, equipment, technologies and materials in AM are driving down the costs of building parts. In the rail industry, the rolling stock and rail infrastructure consist of numerous high value complex metal parts, such as motor impeller, blower fan and motor casings and many other, that may be sparingly demanded for maintenance purposes but are difficult to produce economically given their irregular demand. Storage and transportation costs in these instances also pose a huge threat to the delivery of services. Rail engineers also face significant challenges in defining components for space-restricted applications and managing the overall weight design solutions.

According to reports from Parker Hannifin's in the United Kingdom, “increasing emphasis on 3D printing in the rail sector is on reverse engineering for components used on aging rolling stock parts for which production tools are no longer in use”. In 2014, Siemens opened a Competency Centre for Additive Manufacturing with the focus on producing individually adapted spare parts for the rail industry quickly and cost effectively.

AM is an attractive alternative manufacturing route for the production of parts in the locomotive industries and rail infrastructure, due to its high efficiency in material use and the ability to process high grade alloys. Equally, not everything can be built by AM and hence the technological limitations need to be fully understood. The focus of the collaborative research in South Africa has be on investigating the feasibility of AM for specific rail parts, optimizing material grade, developing manufacturing parameters towards industrialization of the technology. The objective of the paper is to demonstrate the feasibility of introducing additive manufacturing in the South African railway and for the Transnet Freight Rail (TFR) Rail Network production facilities. The research investigates the benefits for TFR in terms of minimizing waste and cost saving in using a mould-less process. It will also look at the advantages of introducing additive manufacturing in order to eliminate oversized inventories or waiting long times to replace components which may be very expensive. The methodology will be based on the desk research and identification of opportunities (components) in TFR for the application of AM.

2 BACKGROUND

AM can change the way that railway manufactures and operators interact with producers as the costs of these technology systems decrease. It presents the opportunities for the economy and society in South Africa. The technology allows for the introduction of designs that were not possible with previous manufacturing techniques without a need for expensive tooling. AM in the South African industry, therefore, has the ability to ensure that in-house multiple modifications using alternatives design process for product and parts development. Instead of stockpiling items, parts can be make as and when required.

The South African Department of Science and Technology commissioned the development of a South African Additive Manufacturing Technology Roadmap in 2013. This was intended to guide South African players in identifying economic opportunities, addressing technology gaps, focusing development programmes, and informing investment decisions. The rated opportunities were extensively evaluated by AM experts and these inputs were used to develop specific focus areas for South Africa to guide public and private sector investment in AM in South Africa. These focus areas, which are summarised in Figure.1, form the basis of the South African Additive Manufacturing Strategy.

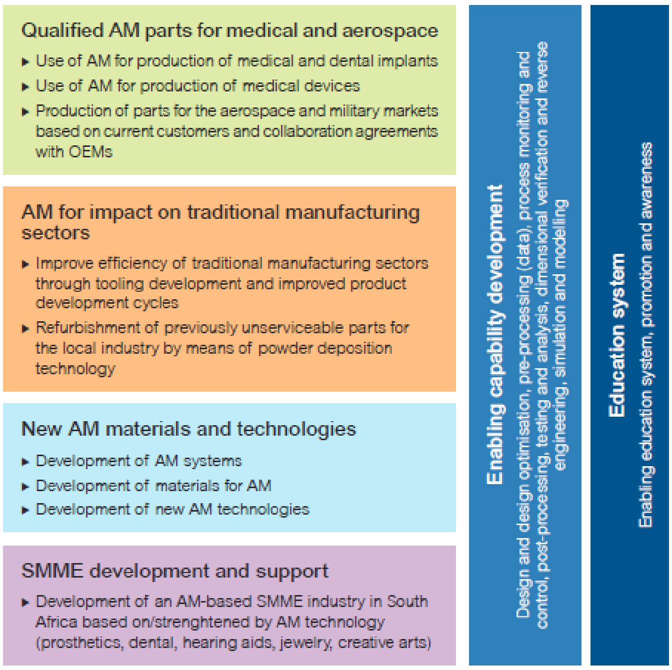

Figure 1: Opportunity grouping into focus areas (DTI, 2016)

The Additive Manufacturing Centre of Competence (AMCoC) is the primary implementation vehicle of the South African Additive Manufacturing Technology Roadmap. The South African AMCoC maximises the potential for success and impact by aligning existing and future AM research and development activities. The AMCoC has the mandate to develop, industrialise and commercialise the technologies needed to grow a vibrant and internationally-competitive manufacturing industry in South Africa.

It supports the establishment of a vibrant, growing, and internationally-competitive AM supplier sector. This supplier industry would serve end-use markets, such as chemical, power generation, aerospace, medical, transportation, and consumer goods. For this to be realised, South African suppliers to these industries have to be established and supported with the technologies that would ensure their global competitiveness. Based on the recommendations of the South African Additive Manufacturing Technology Roadmap, the technology platforms that have to be developed, industrialised, and commercialised. Higher education institutions and research institutions have been key players in different technology focus areas (du Preez & de Beer 2015).

3 ADDITIVE MANUFACTURING FOR THE RAIL INDUSTRY

The South African Rail network comprises of almost 21 000 kilometres (km) of track, although there are over 30 000 route km of the track allowed as primary routes with double track. The core network consists of 13 000 km route of which some 2200 km are accounted for by commuter rail networks. The remaining 8000 km form the under-used branch line network. About 60% of the network utilises electric power with the remainder being diesel. The commuter network is largely electrified. The inter-city tracks and some urban networks are owned by Transnet. However, the majority of the urban rail infrastructure is owned by the Passenger Rail Agency of South Africa (PRASA). The heavy haul is owned and operated by Transnet (Development Bank of Southern Africa Limited, 2012)

3.1 *Current AM applications*

There is currently limited research on how metal additive manufacturing method might assist the South African rail operators with design and production optimisation as well as the maintenance of various internal components.

There is some activity that is taking place in other countries. Additive manufacturing is also already being utilised by various rail operators to reduce maintenance times and refurbishment or replacement cycles, these includes:

- The 'MODTRAIN' project, financed by the European Union between 2001 and 2008, which explored the standardization of parts to reduce maintenance, manufacturing and reliability costs associated with intercity and freight trains.
- The 'Run2Rail' project in Europe investigated 3D printing of carbon fibres to design lighter quieter trains (Grey, 2018)
- Dubai's Road Transport Authority's maintenance team in 2016 implemented initiatives which included investment and application of additive manufacturing with respects to various metro assets within their network, such as printing parts for ticketing machines and ticket gates.
- Deutsche Bahn in collaboration with Siemens have 3D printed parts for their older fleets, of the first generations of ICE high-speed trains, which are no longer in large-scale production. The use of AM has also been used to prototype and trial design updates across Deutsche Bahn's network and fleet. Engineering parts such as ventilation grills and transverse damper consoles have been printed using AM (Killen et al. 2018).

Designed parts that involve customer interaction have also been printed, such as new headrests for their regional rail fleet seats, as well as vision impaired braille signage on handrails (Killen et al. 2018).

3.2 *Design optimisation*

Turning and milling, which are conventional manufacturing methods, impart limitations on the component geometries that can be produced. These limitations often result in structures that are inefficient, as many areas of a component have excess material that cannot be removed physically or cost effectively through conventional methods. Salonitis & Zarban (2015) examined the principles of additive manufacturing, design guidelines, capabilities of the manufacturing processes and structural optimisation using topology optimisation. The work has also proposed a redesign methodology to fulfil the research gap in conventional manufacturing. Figure 2 presents the proposed methodology for redesigning an existing part designed for conventional manufacturing into an optimised part designed for AM. The key objective was to take into account the manufacturing constraints, objectives and AM technology capabilities.

The research team in South Africa has presented a South African case study on Designing for Additive Manufacturing discussing the value of using topology optimization when designing for AM applying similar principles (Minnaar & Prinsloo, 2018).

3.3 *Maintenance, manufacture and costs*

In maintenance, potential applications also exist within refurbishment or replacement processes. It is essential to explore the maintenance frameworks in which such applications will be implemented. Railway rolling stock and infrastructure has a long service life which means that there is continuous effort to improve the balance between the availability of spare parts and stock level optimisation. Due to the weakening manufacturing industry in South Africa, most of the spare parts are imported from overseas,

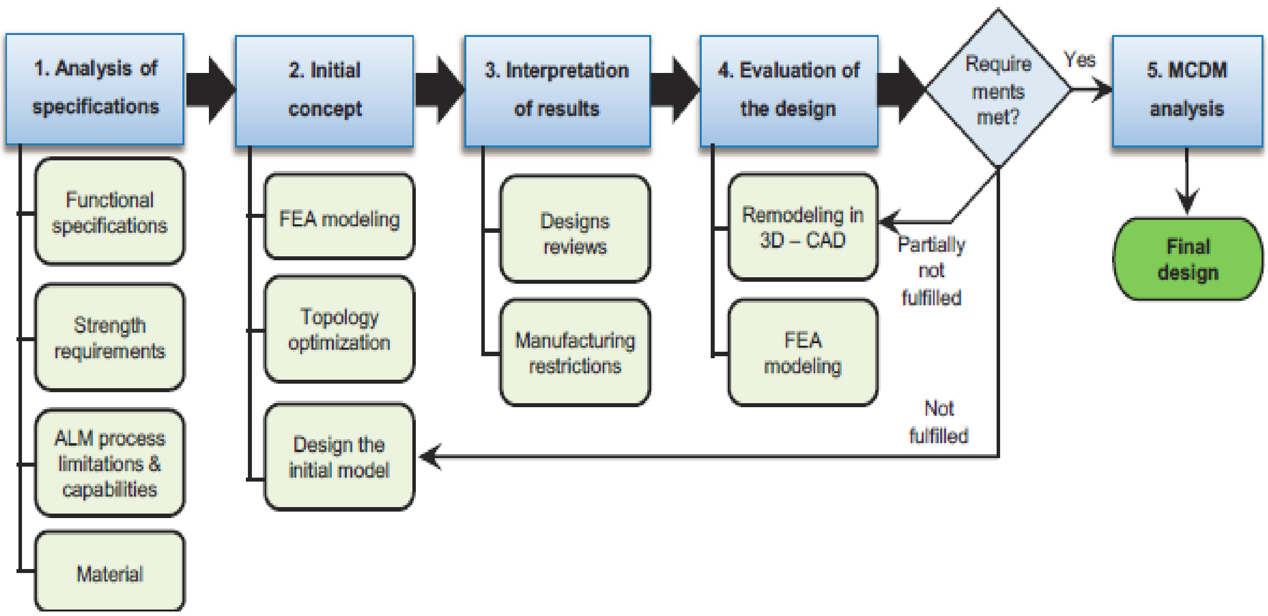

Figure 2: Methodology for redesign arts or ALM (Salonitis, 2015).

leading to long lead times and high costs. This affects the operation and has a negative effect on the bottom line of the railway operators.

AM of spare parts therefore has the opportunity to reduce supply chain cost by reducing reliance to overseas manufacturers and contributing to the increased demand local additive manufacturing. Beiderbeck et. al (2018) has investigated potential benefits and the applicability of AM technologies for spare parts management in the automotive industry. The analysis identified potential benefits in the automotive aftermarket to transform this business by providing individualised spare parts on demand and on location without a necessity for expensive tooling.

The replacement of parts within the railway rolling stock and infrastructure can prove to be an expensive and complicated process, as they may no longer be manufactured and therefore expensive to reproduce using traditional manufacturing techniques. AM can also refute the upfront cost of producing tooling or moulds for parts which are no longer being produced. The potential to prototype and update railway rolling stock and infrastructure designs outside of traditional mid-life refits, providing a more flexible and iterative operational production method.

4 SOUTH AFRICAN RAILWAY CASE STUDIES

In 2016 Transnet announced that it has set a target of securing 40% of its revenue from third-party orders by 2021. The strategy is designed to enable Transnet to transition from being an in-house engineering service provider to an original equipment manufacturer (OEM) of locomotives, passenger coaches and wagons, as well as a leading African provider of maintenance, repair and overhaul (MRO) services for both rolling stock and rail infrastructure. It has been shown that there advantages of AM within MRO processes (Wits, 2016). This technique provides the ability to easily and efficiently replace or restore damaged components. The South African government with the stakeholders in the railway industry such as Transnet, have the challenge to therefore invest in national initiatives to promote research in AM for the rail sector and to educate industry about the potential it offers.

There exists potential for success and impact of AM in the rail industry, if South African programs can be aligned to existing and future AM research activities. This will encourage the railway operators, manufacturers and suppliers to put a focus on AM industrialisation needed to grow a vibrant and internationally-competitive railway sector manufacturing industry in South Africa.

4.1 *Case Study 1*

The following case study on Transnet Freight Rail is used to demonstrate the benefits and opportunities for AM. Transnet Freight Rail has a fleet of 24 rail inspection trolleys which were built on MK5 Luxrailer chassis. These trolleys were manufactured between 1994 and 1998. They were then refurbished between 2005 and 2008 as is required to refurbish trolleys every 10 years. These trolley vehicles were designed and manufactured by Transnet Freight Rail, see Figure 3.

Figure 3: Luxrailer inspection Trolley

The trolley wheels consist of key components which need to be maintained and replaced from time to time. These key components are wheelsets, chassis and drivetrain, suspension, braking system, pantograph, paperwork and the cab. The front wheelset consist of a differential. In Figure 4, the various section for the mechanical assembly of the wheelset with the differential are illustrated.

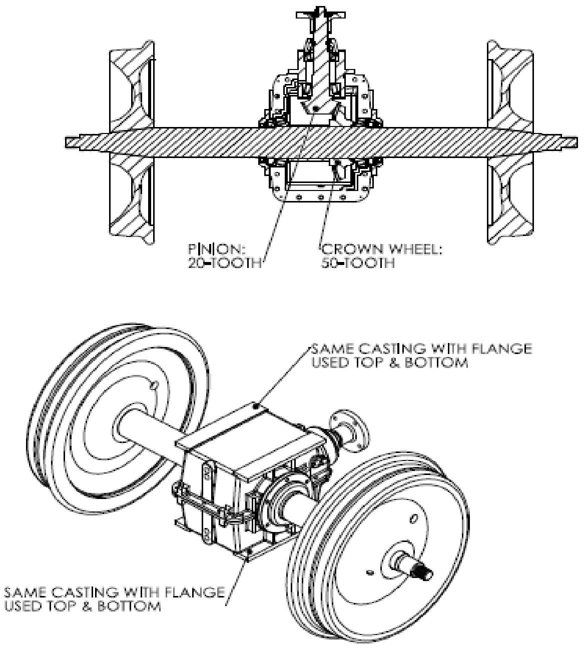

Figure 4: Mechanical Assembly drawing of the front wheelset with the differential

Various components were chosen to compare conventional manufacturing and AM of these components. The type of material, methods of manufacturing, tooling needed, manufacturing time, suppliers lead times, stockholding, demand frequency and part price costs was compared.

The results proved that there is a viability in applying AM for the application of maintaining and redesigning some of the components in the differential. AM capabilities provide an opportunity to optimise the design, maintenance and manufacturing methods by allowing for customisable, on-demand components that can be quickly and effectively repaired or replaced. The ability to replicate components on-demand eliminates the involvement of OEMs, transportation requirements and storage facilities. The elimination of tooling results in a significant reduction in development wait time and costs.

4.2 *Case Study 2*

A requirement to measure incremental lateral rail displacement as a result of passing trains was identified. An electronic device was recommended for use, this being a DVRT. Since this device was to be used under a railway environment, a specific casing was needed to protect the electronic device as well as allow for the measurements to be recorded. Both design and additive manufacturing was used to create a robust casing for the DVRT unit. The casing for the measuring device is broken up into two parts, the top half which houses the steel rods for guiding the measuring arm of the DVRT and the bottom half which houses the measuring tube of the DVRT unit. The functionality of the design allows for the top casing to displace into the bottom casing thus allowing for measurements to be recorded. Figure 5 illustrates the design of the 3D printed device.

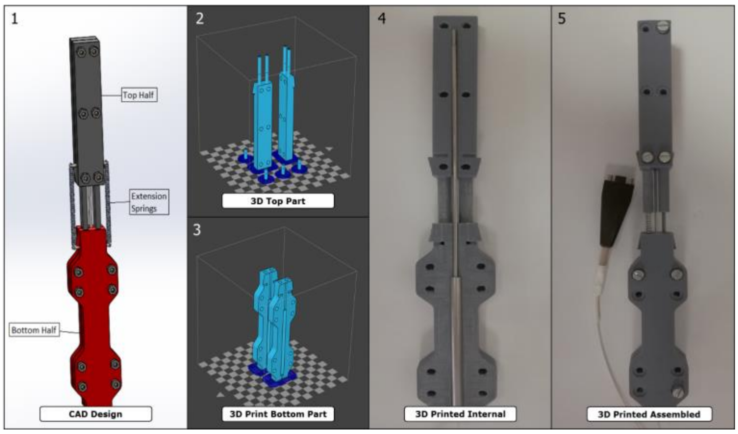

Figure 5: Design Process of the 3D Printed DVRT Casing

Table 1: Illustrates the combined print properties of the DVRT housing units.

Material	Material Used	Print Time	Layer Height
AS+	111.12 g	20 hours	0.15 mm

The casings were printed solid (a 99 % infill setting) due to its intended operation. This resulted in the extended print time. As this is a prototype design, further designs will be generated and 3D printed to improve the overall efficiency of the device.

5 CONCLUSION

Current focus in South Africa is in the application of AM in industries such as medical, aerospace, power generation, automotive, and chemical processing. In this paper it has been proposed how the collaboration of railway operators and manufacturers in South African will give South Africa the best possible chance of having a significant impact in the rapidly-growing field of AM.

6 RECOMMENDATIONS

- Engage with the South African Department of Science and Technology to add the railway industry into the commissioned roadmap for additive manufacturing.

- Continue with research of introducing AM into the South African industry.

- Couple AM alongside traditional design, maintenance and manufacturing to provide further areas of opportunity for South African rail operators.

7 ACKNOWLEDGMENTS

The authors wish to thank Molefi Moeketsane, for his insight and assistance with Case Study 1 as well as Ashley Toth, for designing, printing and compiling Case Study 2.

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