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Sustainability of Additive Manufacturing for the South African aerospace industry: A business model for laser technology production, commercialization and market prospects

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Abstract

Ever changing products, technology and competition make manufacturing a challenging task with respect to responding to market opportunities. A key technology exploited for revolutionary change in the phase of manufacturing competitiveness is the additive manufacturing techniques. Additive manufacturing (AM) is a category of technologies, which is fast shifting from mere resource base to a knowledge base, transitioning from prototyping to manufacturing of end usable parts with defined mechanical properties. In South African industrialization context, technology development for value proposition is an encouraged phenomenon. This is being realized through the South African government's investment in research and equipment funding to science council and academia focusing on the full AM value chain for the aerospace and medical industries. However, despite the skills in the research and development space of AM, laser technology remain an unconventional process that lacks knowledge in terms of how the production techniques can be commercialized. The aim of this study is to evaluate technological capabilities that informs industrial manufacturing setup, and create a business prospects for the laser-based additive manufacturing segment of South Africa.

Keywords: Additive manufacturing; Laser technology; Commercialization

1. Introduction

Additive manufacturing (AM) is the technology of 3D prototyping that has raised many research interests in the academic and industrial sectors since its establishment in the past three decades [1] This manufacturing process has been making waves as a means of saving production costs and ensuring production sustainability [2]. The technology enables the manufacturability of highly complex parts which cannot be produced with conventional technologies of subtractive manufacturing processes such as milling or casting [3]. Although conventional technologies are still widely used, nevertheless manufacturers are exploring the application of AM technologies in the production of end-user products, parts or components. The benefits of AM is not only limited to new design possibilities, it also offers increased functionality of the products, less waste, and flexible production [3]. The manufacturing sectors currently employing this technology for metal functional parts are; the aerospace, biomedicine, automobile and mold manufacturing [4].

The strategic production nature of this disruptive technology has received massive attention globally especially in the developed countries such as the United States, and Germany where the technology has been actively promoted by companies such as Airbus, Boeing, General Electric, etc. [5]. Hence, as the technology continues to expand, it has evidently become a worldwide hotspot for advanced manufacturing for Industry 4. 0. Therefore, it is essential to pursue and identify opportunities that will enable localization and commercialization of this technology within South Africa. Specifically, competitiveness enhancement that empowers small, medium and micro enterprises (SMME) is very necessary. For instance, the

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innovative provision of affordable access to state-of-the-art laser manufactured products can positively contribute and rejuvenate time to market of aerospace parts locally and at a global level.

In spite of the numerous advantages and various benefits the production solution offers to the global manufacturers, finding the right business models and notable market entry poses a threat to the rapid advancement of the production technique in the manufacturing space of South Africa [3]. In other words, to maintain a brighter future for this manufacturing solution, provision of a structured market-oriented approach for the profitable use of the users industries like aerospace industry is required. This can be achieved with adequate road path to commercialization models.

Based on this, the significant views this paper shares are; present as section one, which discusses the general survey of the art of AM technology, a brief review of laser manufacturing techniques, and the roadmap to commercialization. Section two focuses on the South African initiatives in relation to laser technology advancement and how business approaches have been performed in manufacturing. While section three expresses business formation approach and the last section discusses the methods of product, process and services model approach.

2. The research status of AM technology in South Africa

2.1 Additive Manufacturing overview

Manufacturing in general plays an important role in the economic growth of developing and developed countries, and the desire to increase manufacturing output is always set against highly competitive global standards. The ultimate advanced manufacturing approach that can contribute towards the global competitiveness of the manufacturing industry is additive. Additive manufacturing (AM) is defined by the International Committee as a process by which data of Computer-Aided-Diagram (CAD) model is used to build up a component in layers by depositing, fusing and melting materials using a laser or electron beam [1]. Researchers further define AM as a suite of emerging technologies that fabricates components using successive layers of three-dimensional, functional, near-net-shape objects directly from digital modules [4]. For example, instead of milling a work piece from solid block, components are built layer by layer. As seen in Figure 1 showing the comparative analysis process of the basic concept of subtractive manufacturing and an additive manufacturing process. The AM technology has been extensively used in the construction of illustrative, demonstrative and functional prototypes, however with all the significant benefits, enterprises remains a priority.

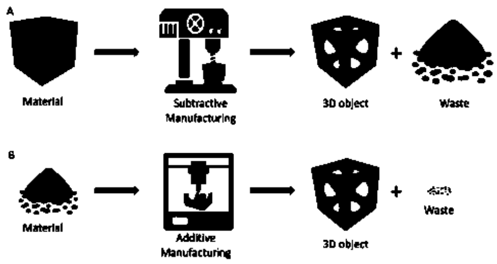

Fig. 1. Comparison of Conventional and Additive Manufacturing processes [4]

This additive manufacturing process offers promising market projection for industrial manufacturing sectors like tooling, automotive, aerospace, and medical, with different optimal levels of realistic production [5]. AM technology is in a strong growth phase and, broader research on the market prospects can contribute to the size, competitiveness and sustainability for the South African manufacturing industry.

2.2 Technology identification

Innovations in technology are well known for setting changes and adding value to market structures. Laser additive manufacturing (LAM) is an innovative driver of advanced direct digital manufacturing methods that enables production of metallic components and products [6]. There are several developed direct manufacturing methods for LAM, like fused deposition modelling (FDM), electron beam fusion (EBM), selective laser melting (SLM), selective laser sintering (SLS), and digital light processing (DLP) [7]. The technologies of laser based manufacturing are classified into two categories; directed energy deposition (DED), further divided into: laser metal deposition (LMD) referred to as laser engineering net-shape (LENS) or direct metal deposition (DMD). The other type is powder bed fusion (PBF), also divided into selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM) [6]. The essence of classification of laser and metal powder based manufacturing processes is to identify the different production techniques within laser based AM system. Gu et al., 2012, conducted five case studies of aircraft components manufactured by metal-based AM laser techniques using EBM, DMD and SLM. The processes have been used to achieve the production of high-value, customizable components with complex geometry and repair of damaged aero-based components as indicated in Figure 2 [9].

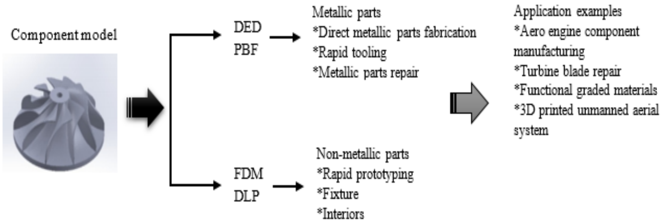

Fig. 2. Additive manufacturing methods for aerospace applications (adopted from [9])

Regardless of this different suite of laser-based manufacturing techniques, LAM will remain a mere fabrication process if the industrialization base is not adapted by Original Equipment Manufacturers (OEMs).

2.3 South African Commercialization Roadmap

Commercialization is regarded as conversion of idea from research and technology into a product aimed at establishing relationships with external enterprises or service that can be put for sale in the marketplace [10]. The adoption of cutting-edge manufacturing technology like additive manufacturing (AM) is one of a kind success manufacturers have achieved in the digital space globally in recent times. Internationally, a wide range of new application areas, new SMMEs popping up to perform production which could have been difficult conventionally have now successfully reported for places like the US, Europe, and Asia [11]. For instance, the European AM Platform identifies two distinct flourishing markets for AM: the industrial market which includes medical, dental, aerospace and automotive; and consumer market, which includes home accessories and entertainment [11].

In South Africa, the Department of Science and Technology (DST) commissioned a roadmap for AM in 2013, in order to increase expenditure and exploit core areas like aerospace and medical [3]. The drive for the roadmap was to identify the country's chances in terms of economics opportunities, addressing technology gaps, developing knowledge acquisition, and investment focus. On the other hand, the country is known for mining of abundant mineral deposits such as Aluminum and Vanadium, these are advantageous alloys of Titanium used in the medical and aerospace manufacturing industries for beneficiating laser-based AM [3]. The roadmap recommendations for the South African AM technology for future interventions are presented in Figure 3.

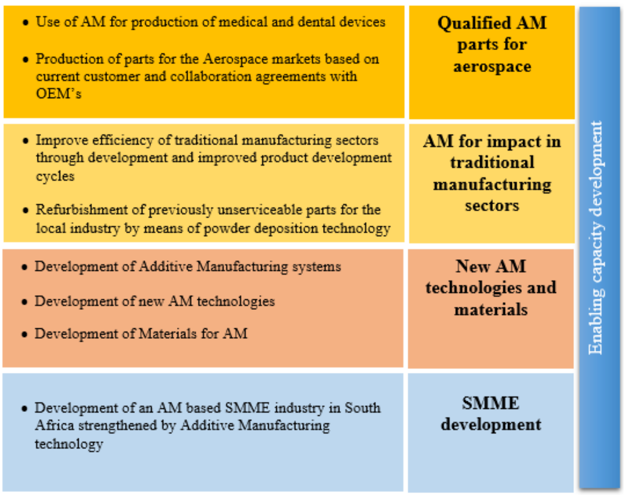

Fig. 3. Recommendations of the South African AM Technology Roadmap [3]

In a bid to position the country as a key producer of aerospace products of AM laser-based manufacturer at an international level, industrialization of this niche technology can be reviewed from the point of technology readiness level (TRLs). TRL is a practice of scoring technology maturity, assessment based on a scale of one to nine that is useful for manufacturing and researchers [11]. Presently, with AM application, appearance in industrial sectors such as; tooling, automotive, medical and aviation can be assessed for the TRL readiness. The TRL in tooling is at (seven to nine), automotive is (four to six), medical is at (five to seven), and aviation is at (seven to nine), which denotes that these various systems have shown the general capability of AM application for real production settings [6]. In the quest to increase the country's competitiveness in terms of technical, economic and value wise, seven steps were outlined from reviews within roadmap to commercialization [12];

- Develop market offerings
- Open up the value chain
- Accelerate materials development
- Increase flexibility
- Improve resource efficiency
- Reduce environmental consequences
- Boost industrial competence and appeal

The full description of the indicated points are the root knowledge often leveraged into commercialization initiatives to reach time target of market stream.

2.4 Laser technology initiatives in South Africa

The use of AM has grown at an unforeseen rate over the years. In South Africa, an association that play a linking role for the interest of AM from academia, research and development (R&D) institutions, and industry since 2000 is the Rapid Product Development Association of South Africa (RAPDASA). RAPDASA's effort is channelled towards the awareness of AM technologies for the manufacturing industries in South Africa and to uphold international recognition enhanced for competitiveness [3]. Though this association has been valuable for the progress of the country, the challenge remains for the established AM firms or companies to implement approaches that will maximize the impact of this technology within the shortest possible time. The other organizations and sustainable initiative platforms placing South Africa at the forefront of this technology are found within the Research and Development (R&D) organization and Higher Education Institutions (HEIs).

There are some parallel initiatives established by the South Africa Government to support AM ventures in aerospace, medical, science and technology fields as presented below [3].

- The Council for Scientific and Industrial Research (CSIR), laser metal deposition focusing on laser-engineered net shaping (LENS) technology, this was developed along with academia, industry and relevant government agencies. The system uses a high power laser (500 W to 4 kW) to fuse powdered metals into fully dense, three dimensional structures. The target market is aerospace and medical industry for manufacturing, repair and refurbishment of components.
- The Aeroswift (Figure 4a), a high speed large area selective laser melting AM platform that started as a feasibility study in collaboration between CSIR,

Aerosud and the DST. The target of this platform is to build aerospace components with dimensions within a range of 2.0 x 0.6 x 0.6 m. As a result, owing to a variety of components that falls within these dimensions, the initiative is envisioned to have a niche market with high impact since such system is currently not available commercially.

- The Titanium Centre of Competence (TiCoC) was established by the DST, CSIR, HEI's and industry as part of the light metals programme of the Advanced Metals Initiative with the aim of producing Ti powder for AM.
- Collaborative Programme on Additive Manufacturing (CPAM) was also initiated to stimulate the growth of AM in the South Africa manufacturing environment from research and development community. The participating members includes research institutes as well as some notable Universities within South Africa with respect to government obtained funds. The aim is to investigate the different aspects of AM addressing the full value chain from design to final part qualification.
- Recently (2016), a MetalHeart company acquired an SLM Solutions SLM 280 system through government funding agency Industrial Development Corporation (IDC) with the aim of producing components for the tooling industry and prototypes for the other sectors.

This demonstrates the initiative and investment made by the South African government in realizing the adoption of AM and increasing the country's participation towards Industry 4.0. This set to be a tremendous boost to the manufacturing sector in South Africa. Figure 4 shows the cutting-edge machine technology of Aeroswift and current state-of-the-art technology of laser metal deposition machine from SLM Solutions respectively.

Fig. 4. (a) The Aeroswift technology and; (b) Selective laser melting system from SLM Solutions [3]

2.5 Business segmentation in manufacturing market structure

The development of an innovative product service strategy is a clear response to the global market and the increase of service content [2]. In order to support the South Africa manufacturing industries to enhance commercialization of LAM technology, business strategy knowledge is needed to fill the opened market gap. The current focus is ensuring a move forward from demonstrative near net shape product of LAM to flight-ready parts with response to market. A number of authors propose different phases that determines business cycle in manufacturing [12]; these are in R&D, Implementation/Roll-out and Commercialization. However, there is no satisfactory roadmap approach found in the literature towards commercialization. The task that must come first is to identify the elements of existing approaches that might serve as business model architecture and route to commercialization effort for this study. A unique approach is to map the business model that offers any prospective industries different options. A similar step undertaken in [12] shows business model division into nine components as seen in Figure 5. These includes: 1 - customer segmentation, 2 -value propositions, 3 - customer relationships, 4 - channels, 5 - key resources, 6 - key partners, 7 - key activities, 8 - cost structure and 9 - revenue streams.

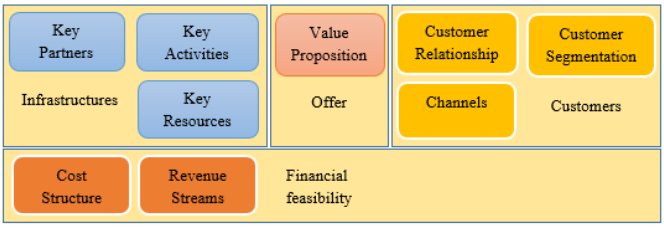

Fig. 5. Business model components map [12].

Business intellectuals usually classifies these systematic components that divide business into segmentation description of market structure. Provided the segmentation of the key infrastructures have been met as the case is in this study, the technology value proposition is the next core component in the market structure. Value propositions can be competition-based, cost-based, and quality-based [13]. These are an independent network of goals for maintaining social and sustainability in manufacturing, also value proposition can be feasible from customer and stakeholder's point of view. This can be achieved by defining the manner in which enterprises deliver value to customer and enticing to the stakeholders outlined by Chesbrough et al. [13]. In order to have a full operation of the business model, some key activities must be performed. These activities are categorized into two types: production, namely; design and deliverable, and market problem solving; cost structure and revenue streams [12]. The cost structure and revenue stream are described according to execution of business formation, how industry generate a cash flow from customer segment at a minimized cost [13]. The next section discusses business models strategy to implement commercialization in the South African.

3. Business models strategy to commercialization

Technology know-how, products and resources are not enough measures to make profits if an adequate business model is not properly adapted in a competitive environment [14]. A successful business model has to be innovative, meet market needs, show new technology, provide new products to the market that changes market streams, or create a new entirely ones [2]. Therefore, it is essential to figure out how to capture value from the innovative LAM products. However, to define and implement a business model in a proper way it could be easier if there are guidelines. A methodological approach that defines deployment of product, process, and services (PPS) is proposed. This entails model development of detailed laser product characterization that is shared across enterprises, i.e. academia, science councils and industry; to enable seamless, rapid, and affordable disposition of products from concept to market. The context of new products, processes, and services is guided by technological competences and a deeper knowledge of market needs. Underneath this assuming methodology is a more elaborate view of the mentioned strategy.

3.1 The Linear Model

The application of environmental thinking and the narrow framework of new PPS for sustainability is to implore the Linear Model of Innovation tool [14]. In its simplest form, this model postulates that innovation begins with new scientific research, proceeds sequentially through stages of product development, production, and marketing, which terminates with the successful sale of new products (see Figure 6). General opinion in public policymaking regarding innovation has long been based on the linear model of innovation [16]. Though the model recognises that development, production, and marketing activities lie between research and product sales, these processes are regarded more as part of the innovation channel than as major obstacles to commercial success.

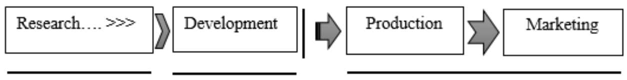

Fig. 6. The Linear Model of Innovation [16]

3.2 Limitations of the Linear Model

Regardless of its prevalent use, the linear model suffers from drawbacks that limit its applicability because of its one directional nature. Many innovations derive not from advances in science and technology only, but from exploiting existing scientific knowledge and from recognising potential new markets for certain types of PPS [14]. Hence this is at times seen as an oversimplified approach. Science nevertheless plays an important role throughout the innovation process by providing information with which to solve problems identified in design, manufacturing, or other stages of the innovation process. Innovation is usually an iterative process in which designs must be continually tested, evaluated, and reworked before an invention achieves market success [15]. In this regard, the linear model is almost incapable of further advancement in the present competitive environment. Recent theoretical strategies has sought to emphasize and embrace concepts that give substance to corporate and stakeholder's duty, business ethics, and product stewardship. This led to the field of theoretical and methodological field of industrial ecology, using an integrated feedback tool proposed by Landau et al, [16], in order to offer alternative business models.

4. Description of the product, process and services development model

A more creative solution has been hypothesized that suggest an intuitive leap in view of alternative approaches to business model offerings. One attempt to model the complex interactions between technology, research and development as well as technological invention is the establishment of Chain-Link Model of innovation known as the Kline-Rosenburg Model [16]. In contrast to the linear model, the chain-link model tolerates feedback between stages of the development process to highlight the multiple roles of innovation integration. The chain-link model breaks down the process of developing new PPS into five stages: 1. Recognition of a potential market; 2. Invention or the production of an analytical design for a new product; 3. Detailed design, test, and redesign; 4. Production; and 5. Distribution and marketing, as presented in Figure 7.

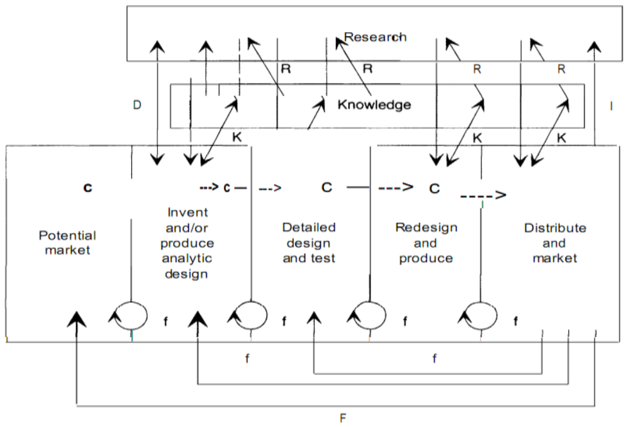

Fig. 7. Kline-Rosenberg Chain-Link Model of Innovation [16]

KEY: C = central pathway of innovation; D = research discoveries that generate radical innovations, F = market feed-back, f = iterative feedback between stages; I = innovations that contribute directly to scientific research, such as the processes of LAM; K = contributions of existing knowledge to the redesign process, R = research used to solve problems encountered throughout different stages of innovation.

Hence, in this instance the redefinition of the business model preceded the redefinition of the product and process technology. It is relatively straightforward to translate these ideas to the aerospace industry for laser additively manufactured products.

4.1 Business case creation

In South Africa, the uptake of this technology is rapidly growing. By using data that quantifies the cost and benefits of AM compared to traditional manufacturing, organization can readily deploy the feedback chain link innovation model into a business case that calculates the return on organizations projected AM investment. To meet the dynamic industry demand of aerospace, an initiative to foster tightened collaboration among product manufacturer, development and production is to maintain a chain link model. Figure 8 presents a market driven innovation development for PPS for LAM.

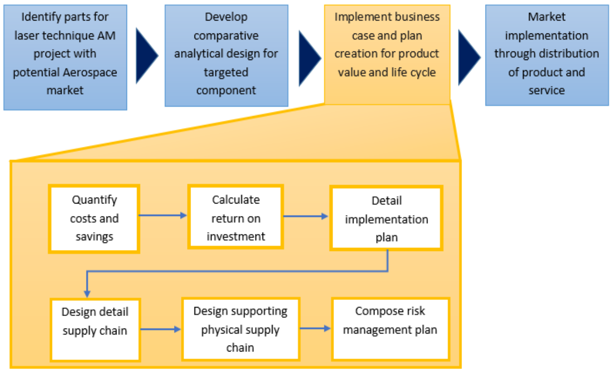

Fig. 8. Model for product, process and business development for LAM technology

With the business case, organization can plan the implementation of its AM pilots. Implementation plans should include the following:

- Governance plans to manage all AM activity on the organization
- Training plans for all occupational specialties that will handle production system
- Capacity plans for all AM machines involved
- Risk management plans that address challenges such as intellectual property, cyber security, and part certification
- Plans for sequencing or phasing parts from additional systems platforms

Once the outcomes of production in a standardized organization is met for the manufacturing of AM using laser technology, a scoreboard can track results using key performance indicators (KPIs) for continuous improvement. Implementation is the final step to meet a successful on demand, seamless, fast, and affordable product to off-the-shelf.

5. Conclusion

The purpose of this study was to address future market opportunities for LAM based products that will position South Africa as a competitor in the global market. The expected outcomes of this study is to see;

- In the short term, South Africa AM industries produce products that saturate aerospace market both locally and internationally;
- In the longer term, South Africa to be a major and lead producer of LAM products to the aerospace industry.
- New SMMEs created that provide metal AM services and products to industry.

This survey closes the knowledge gap from the business perspective for a value proposition by understanding AM's inherent impact and harnessing its potential benefits using a systematic and dynamic approach of product, process and services for relative improvement. The potential impact of scaling advanced manufacturing of LAM across aerospace enterprise cannot be overstated with profound business model.

Further research is needed to develop a detailed method in line with the presented framework. Particularly the modelling of the multivariate demand uncertainty when full market competition is met and its integration into the optimization problem is of great importance.

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