

https://dspace.org/

Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness

Sono, Oscar James Hendrick

2021

University of the Witwatersrand, Johannesburg

https://hdl.handle.net/10539/41389

Sono, Oscar James Hendrick. (2021). Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness [Master's dissertation, University of the Witwatersrand, Johannesburg]. WireDSpace.

Downloaded from a DSpace repository. https://dspace.org/

Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness

Oscar J.H Sono

WITS Business School

Thesis presented in partial fulfilment for the degree of Master of Business Administration to the Faculty of Commerce, Law, and Management, University of the Witwatersrand

April 2021

DECLARATION

I Oscar J.H Sono declare that this research report entitled 'Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness' is my own unaided work. I have acknowledged, attributed, and referenced all ideas sourced elsewhere. I am hereby submitting it in partial fulfilment of the requirements of the degree of Master of Business Administration at the University of the Witwatersrand, Johannesburg. I have not submitted this report before for any other degree or examination to any other institution.



Oscar J.H Sono

Signed at Johannesburg on 30th April 2021

Name of candidate	**Oscar James Hendrick Sono**
Student number	**1133278**
Telephone numbers	**+21 76 815 8611/+27 72 390 3992**
Email address	**1133278@students.wits.ac.za/oscarsono@gmail.com**
First year of registration	**2019**
Date of proposal submission	**16 November 2020**
Date of report submission	**30 April 2021**
Name of supervisor	James George and Kambidima Wotela

ABSTRACT

Author: Oscar J.H Sono **Supervisor** James George

Thesis title: Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness

Presently, Metal Additive Manufacturing (MAM) has progressed to the stage where the manufacture of components for industries such aerospace, energy, automotive and medical industries, are possible to a high degree of reliability. The South African government has invested substantially on the technology's advancement through various government entities, publicly funding the research and development programmes and infrastructure developments. Yet the adoption of the technology remains slow, contrast to the USA and other European countries. Therefore, this thesis sought to explore the readiness of South Africa's manufacturing industry to adopt locally developed MAM technologies.

This was undertaken by employing a quantitative research approach, in which a cross-sectional design survey was used to conduct the interrogation, guided by innovation diffusion theories, particularly DOI. The study applies descriptive analysis to determine the current state of MAM adoption and the level of awareness about the technology within the industry. Backward multiple regression was used to determine if cost, organizational capability, and potential job loss have an impact on the adoption of the technology within the industry testing the three hypotheses.

The results indicated that the state of MAM adoption within the manufacturing industry was low, with only three machines owned/leased, and potential adopters that are likely to uptake the technology, believing it can bring value-add to their organisations. These potential adopters are familiar with awareness programmes driving MAM campaigns. On the other hand, they also indicated reasons they believed would lead to non-uptake of the technology, the non-adopters did too, with cost of material being the leading constraint. Furthermore, results of tested hypotheses inferred a causal relationship between the adoption of MAM technology and the variables, and the impact was significant on its uptake or non-uptake. However, it was important to note that the sample size was low to take a conclusive stance, hence the researcher recommends a continuation of the study.

Johannesburg, April 2021

TABLE OF CONTENTS

DECLARATION ..... **ii**
ABSTRACT **iii**
TABLE OF CONTENTS ..... **iv**
LIST OF TABLES ..... **vii**
LIST OF FIGURES ..... **viii**
LIST OF TABLES AND FIGURES IN THE APPENDICES ..... **ix**
ACKNOWLEDGEMENTS ..... **xi**
KEY TERMS **xii**
1 INTRODUCTION TO THE RESEARCH **13**
1.1 Background and context 13
1.1.1 Technology Adoption in South Africa 13
1.1.2 Synopsis of South African manufacturing sector 13
1.1.3 Additive Manufacturing 14
1.2 Research conceptualisation 15
1.2.1 The research problem statement 15
1.2.2 The research purpose (aim and objectives) statement 16
1.2.3 The research questions as well as accompanying research hypotheses 17
1.3 Delimitations and assumptions of the research study 18
1.4 Significance of the research study 18
1.5 Preface to the research report 18
2 LITERATURE REVIEW **19**
2.1 Global adoption of Metal Additive Manufacturing technology 19
2.2 Adoption of Metal Additive Manufacturing technology in South Africa 21
2.2.1 Poor adoption of metal additive manufacturing technology; symptoms, root causes, and consequences 23
2.3 Methods, data, findings, and conclusions of studies and evaluations of poor adoption of metal additive manufacturing technology. 31
2.3.1 Studies conducted in the past on AM adoption. 32
2.3.2 Summary of past studies 35
2.4 Determinants of poor adoption of MAM technology in the South African manufacturing industry. 36
2.4.1 Innovation Adopters 37
2.4.2 Knowledge dissemination 38
2.4.3 Cost, organizational capability, and potential job loss as determinants of MAM Adoption. 39
2.5 Established technology adoption frameworks. 42
2.5.1 Diffusion of innovation theory (DOI) 42
2.5.2 Unified theory of acceptance and use of technology (UTAUT) 43
2.6 Summary and conclusion 46
2.6.1 Summary of literature reviewed. 46
2.6.2 Proposed research strategy, design, procedure, and methods arising from the literature reviewed. 48
3 Research strategy, design, procedure and methods **49**
3.1 Research strategy 49

3.2 Research design 50
3.3 Research procedure and methods 52
3.3.1 Research data and information collection instrument 52
3.3.2 Research target population and selection of respondents 53
3.3.3 Ethical considerations when collecting research data. 55
3.3.4 Research data and information collection process 56
3.3.5 Research data and information processing and analysis 56
3.3.6 Description of the research respondents 57
3.4 Research strengthens - reliability and validity measures applied. 57
3.4.1 Reliability 57
3.4.2 Validity 58
3.5 Research weaknesses - technical and administrative limitations 59
4 PRESENTATION OF RESEARCH RESULTS 60
4.1 The level of MAM adoption in the South African manufacturing industry. 62
4.1.1 Ownership/leasing of MAM machine 62
4.1.2 Consideration of owning a MAM machine. 63
4.1.3 Reason/s for non-consideration of owning a MAM machine 63
4.2 Effective dissemination of MAM knowledge to the manufacturing industry. 64
4.2.1 Industry awareness of the knowledge developed about MAM technology in South Africa. 64
4.2.2 Industry awareness of the RAPDASA initiative 65
4.2.3 Industry awareness of other government initiatives 65
4.3 Impact of cost, organisational capability, and potential job loss on South Africa's manufacturing industry's adoption of MAM technology. 66
5 DISCUSSION OF RESEARCH FINDINGS 70
5.1 Introduction 70
5.2 State of MAM adoption in South Africa's manufacturing industry 70
5.2.1 Ownership/leasing of MAM adoption (Innovation adopters) 70
5.2.2 Potential adoption of MAM technology 71
5.2.3 Factors constraining MAM adoption. 72
5.3 MAM knowledge in South Africa's manufacturing industry 73
5.3.1 Awareness of the knowledge developed. 73
5.3.2 Rapid Product Development Association of South Africa (RAPDASA) Initiative 74
5.3.3 Other government initiatives 75
5.4 Cost, organisational capability, and potential job loss' influence on MAM adoption. 75
5.4.1 Impact of cost – Hypothesis 1 76
5.4.2 Impact of organisational capability – Hypothesis 2 77
5.4.3 Impact of potential job loss – Hypothesis 3 78
6 CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS 80
6.1 Conclusions 80
6.2 Limitations 82
6.3 Recommendations for future research 83
REFERENCES 84
APPENDICES 95

Appendix 1.1: Data collection instrument(s) 96
Appendix 2.1: One-page bio of the researcher including declaration of interest in the research and funders, if any 111
Appendix 2.2: Ethic documentation 112
Appendix 3.1: Dully filled in data collection instrument(s) 113
Appendix 4.1: Additional Results 150
Appendix 4.1: Additional Results 151

LIST OF TABLES

Table 1: Description of UTAUT's determinants and moderators 45
Table 2. Descriptive statistics - Characteristics of Sample.....61
Table 3. Survey questions linked to research questions. 62
Table 4. Ownership/Leasing.....63
Table 5. Consideration of owning MAM machines.....63
Table 6. Reason for non-consideration of owning a MAM machine.....64
Table 7. Effectiveness of trade publications in creating awareness.....65
Table 8. Effectiveness of RAPDASA in creating awareness.....65
Table 9. Industry awareness of other government initiative.....66
Table 10. Descriptive statistics for variables of knowledge dissemination 66
Table 11. Means, Standard Deviations and intercorrelation for ownership/leasing and the independent variables (cost, organisational capability, potential job loss) 68
Table 12. Forward multiple regression results 69
Table 13. Backward multiple regression results.....69
Table 14. Potential adopters' industry sub-sector and region (N=11).....72

LIST OF FIGURES

Figure 1: 2018 top ten manufacturing industry contributors. (Source: (statssa.(a), 2019)) 14
Figure 2: MAM Technology estimated to grow twice as polymer -AM (Source: (Wohlers, 2017)) 20
Figure 3: Adoption of AM per country 2019 (Source: (Karevska, et al., 2019)) 21
Figure 4: Problem tree analysis on poor adoption of metal additive manufacturing technology (Source: Author) 24
Figure 5. Adopter category based on innovativeness (Source: (Rogers, 2003)) 38
Figure 6: UTAUT model (Source: Venkatesh, Morris, Davis, & Davis, (2003)) 44

LIST OF TABLES AND FIGURES IN THE APPENDICES

Appendix Table 1. Trade publications subscriptions 150
Appendix Table 2. Listed government initiatives (other)..... 150
Appendix Table 3. Mann Whitney U Test - Flexible Skills..... 151
Appendix Table 4. Mann Whitney U Test - Technology Fit..... 151

ACKNOWLEDGEMENTS

This is dedicated to my wife **Maiphepi** and my three children **Tlotlego, Kamogelo, and Reamogetswe Sono**, thank you for your unconditional love & support. It was an exceedingly difficult journey having to balance between family, work, and schoolwork. However, I see all challenges as opportunities to grow.

To my parents and my three little sisters, "na khensa".

To my friend **Dr. Luyolo Mabhali**, who dared me to do the MBA after completion of my MEng. degree, "Bosso! Ashi nthwela". Thanks for taking interest in my professional life and for being a friend.

To the friendships that were built during the MBA degree studies. "Ekse leadership" **Mr Kgaladi**, big things are on the horizon.

To the Council for Scientific and Industrial Research (CSIR) thanks for providing me with an opportunity to study this degree, particularly the NLC and HCD units for the support.

Finally, to my supervisor Mr James George thank you for your guidance.

KEY TERMS

Additive Manufacturing; Adoption; Awareness; Metal Additive Manufacturing; Commercialisation; Innovation; Industrialisation; Innovation adopters; Rapid prototyping, Research, and development, Value-add.

1 INTRODUCTION TO THE RESEARCH

1.1 Background and context

This research evaluates the readiness of the manufacturing industry to adopt locally developed Metal Additive Manufacturing (MAM) technology in South Africa. However, before getting to the research conceptualisation (Section 1.2), we briefly introduce the terms and concepts that we have used in conceptualising this research in Section 1.1 generally and broadly—while Chapter 2 has a more specific and detailed discussion on the research context. The research conceptualisation section provides for the research problem statement (Section 1.2.1) and subsequently the purpose of this research (Section 1.2.2) as well as the research questions (Section 1.2.3). The delimitations and assumptions of the research study are in Section 1.3 while we discuss the significance of the research study in Section 1.4 and provide a preface to the research report in Section 1.5.

1.1.1 Technology Adoption in South Africa

Adoption of new technologies in South Africa has been slow particularly within the manufacturing industry (Word-Bank, 2017). In comparison to other countries, the technology innovation gap has been constantly broadening. Countries such as Germany are advancing far ahead. With 4th Industrial Revolution (4-IR) technology advancement being key to global manufacturing markets, adoption in the South African industry becomes complicated due the level of unemployment and unskilled workers amongst others. Manufacturing processes such as MAM removes several processes in the production of components using the conventional methods (Word-Bank, 2017). Therefore, this has a knock-on effect in the inability to create sustainable jobs for unskilled job seekers.

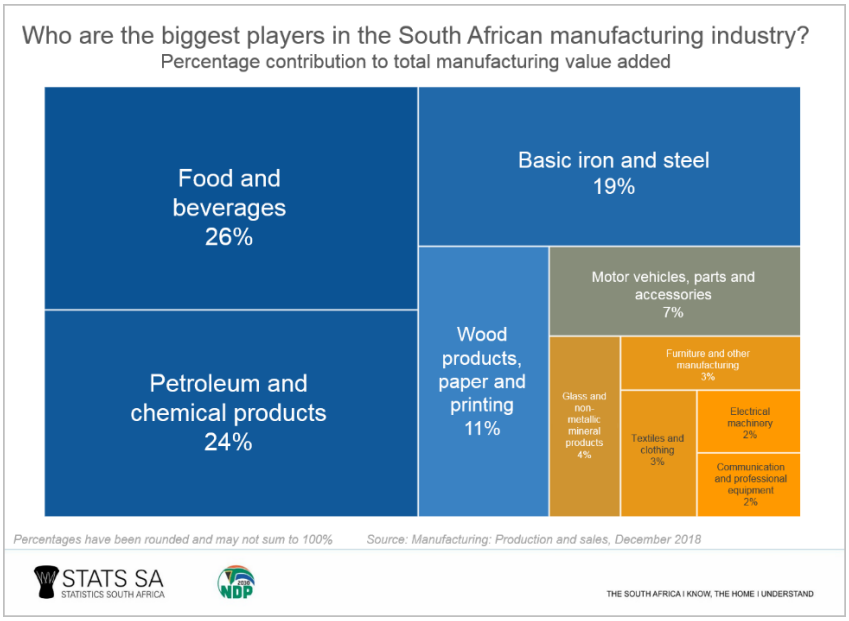
1.1.2 Synopsis of South African manufacturing sector

The South African Manufacturing industry contributes 14% to the Growth Domestic Product of the country, positioning it as the fourth largest industry (statssa.(a), 2019). In the first quarter of year 2020 the industry recorded an estimated 1706 000 number of persons employed in the industry, which indicated a decline of approximately 15000 compared to the last quarter of 2019 (statssa.(b), 2020). However, industry is under threat, with the largest risk being from low-wage high-productivity nations like China, India and

Brazil, as they have the ability to source highly skilled workforces at low wages to fill roles in the high-tech manufacturing market segment (Bizzconnect, n.d.).

The industry is divided into manufacturing categories, with Figure 1 listing the top ten industry components in which metal-based component manufactures will be the foci of this research study.

Figure 1: 2018 top ten manufacturing industry contributors. (Source: (statssa.(a), 2019))



1.1.3 Additive Manufacturing

Additive manufacturing (also known as 3D printing) is a technology platform of various processes that are used to build 3D components by fusing different layers of material upon another with each of them resulting from a cross section of a 3D CAD model of the part (Gibson, Rosen, & Stucker, 2015). Some of its advantages include saving time as the design can be easily changed on the CAD model, and complex geometries can be manufactured which would otherwise not be possible with conventional methods. The technology may be classified or categorized in terms of their material feed stock, energy source, build volume (Frazier, 2014). There are numerous types of additive manufacturing processes for different materials i.e., for polymers, cement, and metals. Metal based additive manufacturing forms the bases of this study.

Metal Additive Manufacturing (MAM) is regarded as part of the 4-IR, due to the technology used that can produce desired engineering components faster, more flexibly and more precisely than ever before, with less prototype construction, less dies, and less

post processing. Presently, MAM has progressed to the stage where the manufacture of components for industries such aerospace, energy, automotive and medical industries, are possible to a high degree of reliability.

1.2 Research conceptualisation

1.2.1 The research problem statement

In 1998, a National Research and Technology Foresight project was conducted by the South African Government's Department of Science and Innovation (then Department of Arts, Culture, Science and Technology) (Watt, 1998). One of the foresight aims was to evaluate technologies needed for SA's manufacturing industry to become globally competitive. Additive Manufacturing (AM) (then known as Rapid Prototyping) was highlighted as one of the key technologies amongst others that the industry should aim for, as global trends indicated that integrated product development, process and production system design to speed up production time were some of the drivers of competitiveness (Watt, 1998); (de Beer, et al., 2016).

Investment into AM were made by various government entities, publicly funding the research, development, and innovation (RD&I) programmes and infrastructure developments (de Beer, et al., 2016). The intention was to develop a sound knowledge base and capability in AM processes through use of imported equipment, which can lead to local manufacturing of own technology. This was done through (amongst other projects), the Aeroswift platform, which is a large-scale titanium AM machine, locally built at the Council for Scientific and Industrial Research (CSIR) partnered with Aerosud (Oyesola, Mathe, Mpofu, & Fatoba, 2018). The platform is meant to drive the awareness of metal AM technology for SA's manufacturing industry to adopt and to build its global competitiveness (Wohlers, 2015).

Although much developments have been made on AM (particularly metal based AM) through R&D and proven capability of technology building by the Department of Science and Innovation (DSI) through its agencies such as the CSIR and institutions of higher learning, adoption of the technology remains slow, contrast to European countries and the USA (Wohlers, 2015), as the driving factor is industry demand for such equipment (Kunniger, 2015). Therefore, this thesis seeks to explore the readiness of SA's manufacturing industry to adopt locally developed MAM technologies, as globally, manufacturing of components has progressed to a stage where a high degree of reliability

is possible through the technology. It intends to measure the current state of adoption in South Africa's manufacturing industry, how effective the knowledge developed is disseminated, and identify the driving or inhibiting factors of MAM uptake. While it examines the impact of these factors through hypotheses testing.

Literature mentions lack of knowledge and understanding of MAM technology and its cost structure (to mention a few) as some of the constraining factors for adoption (Cohen, 2014); (Savolainen & Collan, 2020). However, the DSI commissioned an additive manufacturing strategy for South Africa, with priorities around final part manufacturing for the medical and aerospace markets; AM technology for impact in the traditional manufacturing sectors; AM material and technology development; and development and support programmes (de Beer, et al., 2016). Therefore, DSI (through its agencies) has managed to cover some of the priorities, however, understanding of the industry readiness is imperative to the industrialisation and commercialisation process of the technology.

1.2.2 The research purpose (aim and objectives) statement

Immense progress has been made with the research and development of MAM technology in South Africa. The government warrants to kick-start the technology industrialisation and commercialisation process of the technology. The purpose of the study is to gain an understanding of how ready the South African manufacturing industry is to adopt locally developed MAM technology, as industry holds a very crucial role in this instance. This is done by employing a quantitative research approach, in which a cross-sectional design survey is used to conduct the interrogation, guided by innovation diffusion theories, particularly DOI. The study applies descriptive analysis to determine the current state of MAM adoption and the level of awareness about the technology within the industry. Backward multiple regression is used to determine if cost, organizational capability, and potential job loss have an impact on the adoption of the technology within the industry.

The aim of this research is to explore the readiness of SA's manufacturing industry in adopting locally developed MAM technology, with the objective of measuring the extent to which it occurs and under which manufacturing sector. Further, the study seeks to determine if knowledge generated about the technology in the country is disseminated effectively towards the industry. In addition, examine factors that may be driving or constraining the adoption of the technology within the industry. The focus is on

organisations that produce metal-based components using traditional manufacturing processes.

1.2.3 The research questions as well as accompanying research hypotheses

1.2.3.1 To what extent has the South African manufacturing industry adopted MAM technology?

1.2.3.2 Is knowledge of MAM technology effectively disseminated in South Africa, particularly in the manufacturing industry?

1.2.3.3 What impact does cost, organisational capability, and job loss have on MAM technology adoption in SA's manufacturing industry?

Hypothesis1

H o: Evidence indicate that cost does not have any impact on the adoption of MAM technology.

H a: There is clear evidence that cost has a significant impact on the adoption of MAM technology.

Hypothesis 2

H o: Organisational capability negatively impact the adoption of MAM technology.

H a: Organisational capability does not negatively impact the adoption of MAM technology.

Hypothesis 3

H o: There is no relationship between potential job loss and the adoption of MAM technology.

H a: There is a clear relationship between potential job loss and the adoption of MAM technology.

1.3 Delimitations and assumptions of the research study

The study focuses only on metal based additive manufacturing (MAM) instead of AM in its entirety, with the intention to gain an understanding of the preparedness of the South African manufacturing industry in adopting the technology. Other types of AM, such as those processing polymers, cement etc., will not be considered in this work.

The industry sector of interest to the study is that of organisations that manufacture or refurbish metal-based components using conventional manufacturing methods i.e., subtractive manufacturing. These organisations may not have homogeneity in the industry sectors they service as different metal components are used for various industry applications. The respondents representing the organisations are assumed to have influential characteristics with regards to decision making on new technology uptake or rejection, and they will range between manufacturing industry executives, directors, managers and non-managerial (technical) experts.

1.4 Significance of the research study

The significance of the study is to advance MAM technology adoption literature and assist in establishing a basis for development of business model frameworks relevant to the technology in a South African context. Further, create awareness around MAM technology and assist business managers in developing an understanding of the potential benefits of MAM.

1.5 Preface to the research report

To this end, the report has six chapters. Following this introductory chapter, Chapter 2 provides a literature review covering the problem, the past studies, the explanatory framework, and the conceptual framework. Chapter 3 discusses the research strategy, design, procedures, reliability, and validity measures as well as limitations. Chapter 4 and Chapter presents and discusses the findings, respectively, to interrogating our research questions while Chapter 6 summarises and concludes the research.

2 LITERATURE REVIEW

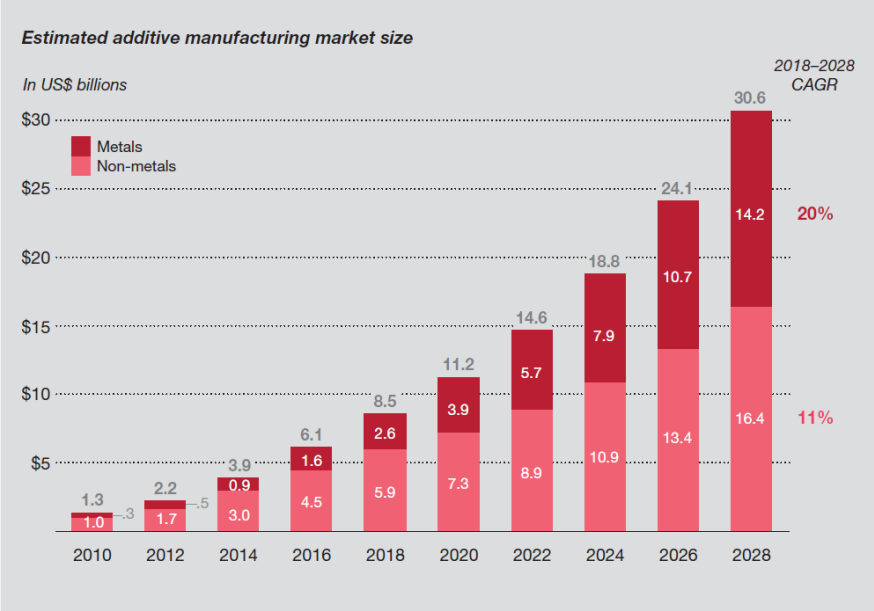
This chapter has three broad objectives; namely to understand the research problem, to identify the knowledge gap, and to develop a framework for interpreting the research findings. Specifically, in Section 2.2 it details the research problem. In Section 2.3, literature is reviewed on studies that have attempted a similar study or research. With information arising from Section 2.3, we identify and detail qualitative attributes or quantitative variables that are key to this research in Section 2.4 as well as a framework that we will use to interpret our research findings in Section 2.5.

2.1 Global adoption of Metal Additive Manufacturing technology

In 2018, AM had experienced a market growth of 18% globally compared to the previous year, reaching an estimated $9.3 billion (Akinsowon, 2019). The landscape comprised of OEMs (hardware manufacturers), software ecosystems, material suppliers, and service providers. The growth is attributed to organisations discovering value-add of the technology for application in new areas. With large companies and corporations entering the market, contributing with additional investment and research, forming strategic partnerships with machine manufacturers and solution providers (Roberti & Spasova, 2019). Industry sectors such as aerospace, automotive and medical devices are still at the forefront of adoption of the technology, thus, spearheading this growth (Akinsowon, 2019). However, there are emerging opportunities in sectors such as consumer goods, construction and power generation. It should be noted that the growth figure encapsulates the different types of AM technology.

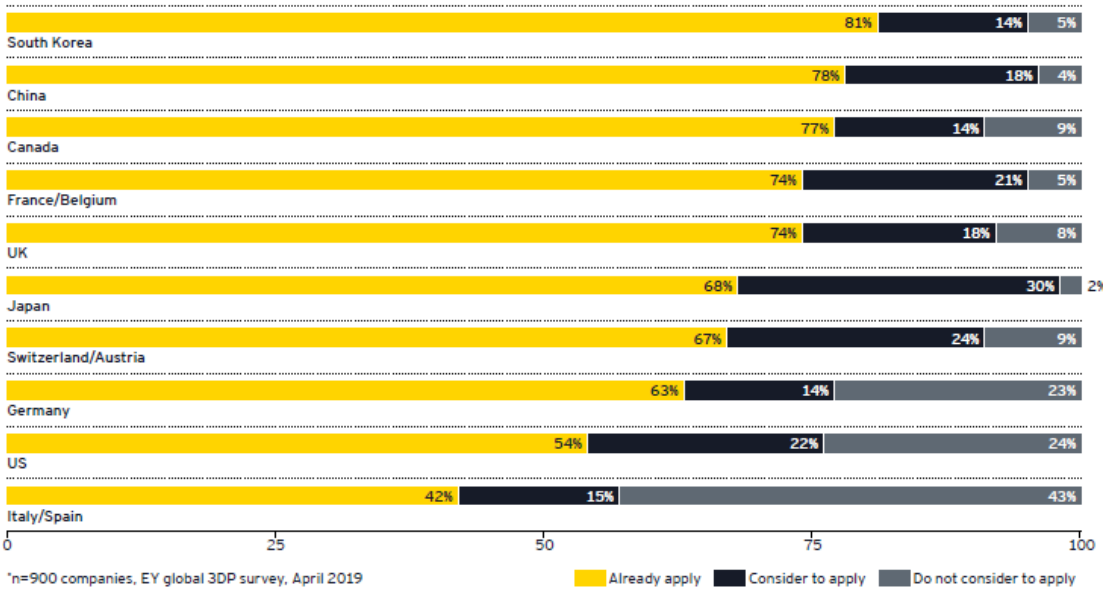
Dustman, Elwakil, & Smart, (2019) citing Wohlers, (2017) states that MAM technology's share of the wider AM market (inclusive of hardware, software, materials and services) is valued at approximately $2.6 billion with a ten-year compound annual growth rate (CAGR) of 20 %. The authors contend that this growth is almost twice as fast of AM-polymers as displayed in Figure 2. However, Karevska, et al., (2019) study indicates that polymer -AM desktop systems are still prefared in comparison to MAM technonogies due to their wide availability, low-cost prices and less complex processing of parts.

Figure 2: MAM Technology estimated to grow twice as polymer -AM (Source: (Wohlers, 2017))



MAM technology's market is still at its early stages and wider adoption is just beginning, with the current primary use of the technology in rapid prototyping, tooling, and production of replacement parts. However, global organisations are increasingly shifting their ideas about the technology as they not only view it as a substitute for conventional manufacturing, but also as a way of altering the supply chain to unlock more value (Dustman, Elwakil, & Smart, 2019). Karevska, et al., (2019) states that a sharp increase has been experienced on usage of MAM technology for production of functional parts since 2016. The authors' study shows that 18% of companies were using MAM technology for production of end-use components, 15% for tools and 14% for spare parts. The study was a survey of 900 companies from Asia, Europe, and USA, however, with regards to measuring the adoption of the technology per country, it looked at the wider AM technologies as shown in Figure 3.

Figure 3: Adoption of AM per country 2019 (%) - (Source: (Karevska, et al., 2019))



2.2 Adoption of Metal Additive Manufacturing technology in South Africa

There is limited information available about industry adoption of AM technology in South Africa, particularly for MAM technology. However, according to de Beer, et al. (2016), AM technology in South Africa began in the early 1990s, with the first machine imported by a private company called 3D Systems (Pty) Ltd. The CSIR followed suit, procuring two machines. The technology was then known as rapid prototyping, used mainly as prototyping tool for rapid product development. However, through its ability to provide flexibility in design and production of complex or customised parts, it later became known as additive manufcturing.

Additive manufacturing in South Africa was lagging behind other industrialised countries in those early years, as a result, in 1999, the Rapid Product Development Association of South africa (RAPDASA) was formed (de Beer D. J., 2011). The role of RAPDASA was to spearhead AM campaigns, to foster awareness and its importance for the benefit of the South African industry to become globally relevant and competitive (de Beer, et al., 2016). This was done through linking academia, research and development (R&D) institutions, and industry (Oyesola, Mathe, Mpofu, & Fatoba, 2018).

According to de Beer, et al. (2016) South Africa experienced an escalation in the use of AM in the few years preceding 2016. Growing from the initial single system imported in the early 1990's, to an estimated 5700 machines in 2018 (RAPDASA, 2019). The growth is attributed to industry uptake of the technology and by recognition in the Advanced

Manufacturing Technology Strategy for South Africa of its significance in enhancing the competitiveness of the manufacturing sector (de Beer, et al., 2016). However, many these machines are used for manufacturing applications of plastic or polymer components, while for metal-based applications the number is relatively low. The total number of metal-based systems in South Africa is approximately 18 as of year 2020, with 7 of them located at Higher Institutions, 6 at the CSIR, while 5 being industry based (Vermuelen, 2020). This quantification was obtained from an interview of an expert MAM technology machine manufacture in South Africa as there is no documented evidence of the number of machines in literature.

Amongst the 18 MAM systems in the country, five of them are locally developed (by the CSIR) and the rest have been imported. These five machines are based at the CSIR with 2 of them capable to produce metallic components from titanium powder, while the other three are dedicated for refurbishment applications (de Beer, et al., 2016). Through the support of DSI and collaboration with Aerosud, an aeronautical engineering and manufacturing company, project Aeroswift was realised at the CSIR. Project Aeroswift resulted in one of the largest laser-based metal-additive manufacturing system that builds titanium parts for the aviation manufacturing sector (Project Aeroswift, 2020). The system can also be used to manufacture parts for the power generation, automotive tooling, defence, and manufacturing sectors (Project Aeroswift, 2020). This system is part of the 2 abovementioned AM systems, with one being a commercially viable small-scale system.

The Areoswift project also forms part of the value chain for beneficiation of South Africa's mineral resources, particularly titanium. This beneficiation programme is part of the CSIR's Titanium Centre of Competence strategy, established as part of the light metals programme of the Advanced Metals Initiative funded by DSI (de Beer, et al., 2016). In this programme, developments were made that culminated into a construction of a titanium pilot plant at the CSIR to produce commercially pure grade titanium powder for production of titanium alloy powder and for the manufacture of titanium components for industry (Titanium Pilot Plant, 2020).

With all the developments locally around metal additive manufacturing, industry adoption of technology remains slow. However, the CSIR has reached the stage where it needs to commercialise and transfer knowledge of the technology. It has formed alliances with South Africa's small medium enterprises (SMEs) to build small scale commercially viable local metal additive manufacturing machines based on the knowledge acquired through

the Areoswift project, to compete in the machine building space. The organisation has already internally built a small-scale machine for commercial purpose. Hence this study seeks to gain an understanding of the readiness of the South African manufacturing industry to adopt locally developed metal additive manufacturing technology.

2.2.1 Poor adoption of metal additive manufacturing technology; symptoms, root causes, and consequences

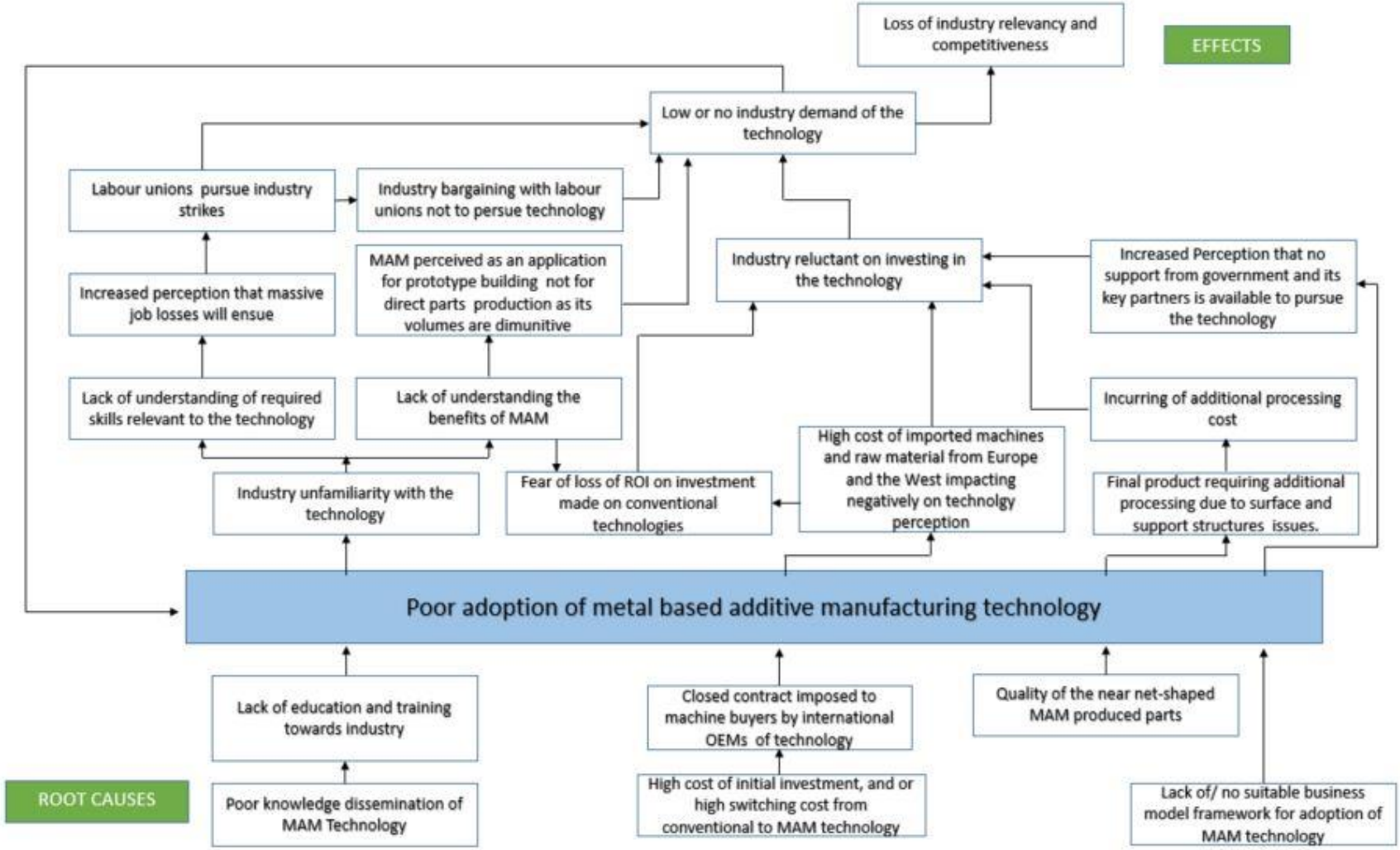
Metal additive manufacturing in South Africa has been having traction within the research and development area through higher education and research institutions, supported by government initiatives (du Preez & de Beer, 2015). However, with much of the developments made, there still seems to be reluctance from industry to adopt the technology. According to Vermuelen, (2020) out of a total of 18 MAM system available in the country, only 5 of them are industry based.

With the little information available about MAM adoption in South Africa, literature that seemed relevant to this study is reviewed to analyse the challenges that may be influencing the industry's reluctance in adopting MAM technology. The sourced literature focused on the adoption of AM technology, not distinguishing it to MAM or any other type.

2.2.1.1 Symptoms of poor adoption of metal additive manufacturing

Lack of awareness or familiarity, cost, perception of the technology application, and industry demand are symptoms that have been identified in literature that coincide with those deduced in the problem tree analysis, Figure 2.

Figure 4: Problem tree analysis on poor adoption of metal additive manufacturing technology (Source: Author)



I. Lack of awareness or familiarity

Several authors agree that awareness or familiarity is imperative in the adoption of additive manufacturing technology. According to Cohen, (2014), lack of awareness and organisational readiness are seen as key enablers of poor adoption rate of AM technology. Cohen, (2014) substantiates this by citing a McKinsey and Company survey that indicates unfamiliarity of the technology by industry beyond press coverage having impact on adoption, and how there is still a need from prospective adopters to learn more about AM. Generally, managers lack awareness of the value the technology can bring, and its application.

In 2014, lack of greater awareness within the global manufacturing community and limitations of existing technology, has seen the technology having a market penetration of less than 8% (Bhattacharjya, Tripathi, Taylor, Taylor, & Walters, 2014). Kunniger's (2015) study conducted in South Africa's province of Gauteng indicated that organisations within the manufacturing cluster had not conducted sufficient research about the technology. Therefore, the level of knowledge about the technology was very inadequate and it would be difficult for organisations to motivate for adoption of AM.

However, Schniederjans (2017) suggest that there has been much development in terms of adoption of the technology, as the coverage of it in the news and social media has spread its knowledge and capabilities. However, the author cites an article that was published around the same time as those who indicate that awareness was poor. The differences may stem from aspects such as the industry sector and or geographical region the studies were conducted, consequently, with each area having a different rate of adoption.

Familiarity with the technology and its applications is vital in assisting managers of organisations to consider its adoption (Alabi, de Beer, & Wichers, 2019). However, in this instance, literature suggest that adoption of additive manufacturing lacks due poor industry awareness and familiarity. This agrees with the suggested symptom of "industry unfamiliarity with the technology" that is indicated on the problem tree analysis in Figure 2.

II. Lack of investment

Similarities from literature lie mostly within issues of cost drivers associated with the adoption of the technology by organisations. Lack of investment in this instance is highly

driven by costs associated with the system, material, and operations (Thomas, 2016). Fried, (2019) further substantiates that the biggest cost driver of AM is the initial investment in production equipment and its installation as these account for approximately 45 to 74 % of the total cost of production using the technology. Materials consumption is also the greatest driver, particularly with MAM, however, this is reliant on the type of MAM technology category the potential adopter may be targeting (Huckstepp, 2019). In the case of laser based MAM technology, the process require small and highly spherical powders which are expensive to produce, and this have an impact on the price of the material per kilogram (Huckstepp, 2019).

Further, capabilities of the organisation and that of the technology is also addressed as another aspect that expedites the reluctance of investment (Thomas, 2016). Savolainen & Collan, (2020) suggests that in terms of technonology capability, there is a limited number of materials that are suitable for processing using AM. Only a fraction of existing metal alloys can be used, however, machine patents often become a barrier when new materials are introduced. For example, some of the machine developers tie buyers into closed contracts, meaning that, the purchaser of the machine can only use material supplied by the developer of the system (Kunniger & Walwyn, 2017; Huckstepp, 2019). These are some of the uncertainties about the relevancy to employ additive manufacturing technologies in organisations (Otettmeier & Hofmann, 2017).

However, with regards to the firm's capability, Proff & Staffen (2019) denotes that skills shortage stand as a prohibiting factor for adoption of AM. They suggest that new management and multidisciplinary engineering skills will be required by industry in order to fully benefit from the technology. Unfortunately, the cost factor shows up again, due to the overhaul of the workfoce that may be required (Thomas, 2016). Hence, cost benefit analysis is emphasised as a measure for potential adopters of the technology (Schniederjans, 2017)

Additive manufacturing technology is still in its infancy stage, particularly metal based additive manufacturing in South Africa (Mellor, Hao, & Zhang, 2014). Organisations may find it hard to invest in the technology due to the cost associated with it, and fear of not gaining returns from it, and further, fear of loss on gains that were being achieved through conventional manufacturing methods (Thomas, 2016). Other probable challenges presented in line with capability of the technology in comparison to conventional methods is, slow production speeds, finished parts produced requiring post processing,

and quality assurance issues (AMFG, 2019). The latter is driven by lack of technical standards for product qualification to assess and ensure accuracy of the near net shape part, its surface finish, and detail features, hence, post processing cost become incurred to address these issues of quality (Thomas & Gilbert, 2014). However, a recent study indicates AM specific standards have been produced through collaborations efforts between ISO and ASTM International amongst others, nonetheless, the industry's perception that little AM standards exist essentially leaves the technology unstandardized (Duvenage, 2019).

III. Perception on technology application

There is an indication from literature that additive manufacturing technology is understood to be an application for prototyping. Mellor, Hao, & Zhang (2014) argues that AM is tainted by an inherent rapid prototyping legacy that forms a psychological barrier to its adoption. The outcome of this barrier leads to managers viewing the relevance of the technology only from a rapid prototyping applications perspective.

Another argument deduced is that AM technology is challenged in terms of high-volume manufacturing. For example, Cohen, (2014) suggests that AM technology can produce only low production volumes when compared to conventional manufacturing. This is because the technology is still far from being able to mass produce especially in direct part production. Although, the technology is limited on high volume production, it has been applied to produce parts for final products on a small scale (Otettmeier & Hofmann, 2017).

The challenge of mass production migrating to developing countries, has led to most European and US firms to swiftly adapt to low volume production of high value products that are innovative, bespoke, and sustainable (Mellor, Hao, & Zhang, 2014). However, South Africa as a developing country is facing the same fate as the latter countries, and unfortunately the psychological barrier that Mellor, Hao, & Zhang (2014) posits, has an effect on its manufacturing industry, as indicated from Kunniger's (2015) study as well.

The perception being held, that AM technology is more of a tool for prototyping impedes on the prospects of being adopted by organisations within industries accustomed to the use of conventional methods of manufacturing. This clouds the managers' judgement against the technology, leading to failure to garner an understanding of the benefits that comes with AM versus its drawbacks.

IV. Lack of demand

Demand for mass customised, tailor-made products is an important indicator for the willingness of industry to adopt AM technology (Kunniger, 2015). Several authors seem to have a consensus, that demand is driven by compatibility of the technology to the organisations and the costs associated with it, as Otettmeier & Hofmann (2017) suggests. However, the industry outlook on the technology is that there are high-cost implications which negatively impact the demand of the technology (Kunniger, 2015).

The other aspect that may be contributing to lack of industry demand of AM technology is its potential to enable ease of imitating parts, therefore, organisations will increasingly be subjected with additional costs for enforcement of their patents (Campbell & Ivanova, 2013). The risk to intellectual property design is exacerbated by availability of 3D models of generic parts online, and a combination of enhanced 3D scanning capabilities and reverse engineering (Weller, Kleer, & Piller, 2015). Wei, Sun, Huang, & Li (2018) indicates that the aerospace, automotive, and medical industries in the US have been experiening a rise in illegal counterfits. Although in the South african context there has not been any information regarding this element, the assumption of it being a contributor for lack of demand of AM can still be made, as the country is not under a silo.

Compatibility and demand are regarded to be the main drivers of potential adoption of the technology. However, the cost implications of AM technology have a high impact on industry demand of the technology as they can hinder the willingness of adoption, even though there may be a demand for its capability.

2.2.1.2 Root causes of poor adoption of metal additive manufacturing

The root causes determined are knowledge dissemination, and cost and capability which directly affect all four symptoms identified in the previous section.

I. Knowledge dissemination

AM technology is "part of a disruptive and emerging industry with innovative and complex products whose business models' dynamics is not yet fully understood" (Godina, Ferreira, Brás, Espadinha-Cruz, & Matos, 2019, p. 38). How knowledge of the technology is disseminated to industry is critical for its adoption. Lack of awareness or familiarity inhibits the adoption of AM technology (Cohen, 2014); (Kunniger, 2015) and (Alabi, de Beer, & Wichers, 2019) . This is indicated by surveys conducted in these studies, which highlight that the subject knowledge by incumbents does not go beyond cover press or

digital platforms (Cohen, 2014); (Kunniger, 2015). In addition, for those who are aware, lacks in training and the support required for implementation and operation of AM technology (Otettmeier & Hofmann, 2017) (Alabi, de Beer, & Wichers, 2019).

The literature varies on how knowledge of the technology is disseminated, for example Cohen, (2014); Kunniger, (2015) and Schniederjans, (2017) deduced media platforms as being one of the vital forms that AM knowledge is disseminated, however, this medium has not been effective. While Bhattacharjya et al (2014); Thomas, (2016); and Oettmeier & Hoffman's, (2016) highlight the method of training as a requirement for preparing organisations. Alabi, de Beer, & Wichers, (2019) suggests that this training needs to be facilitated in HEIs to increase professional experts in AM, as lack of AM educators inhibits the advancement of the technology in South Africa.

Knowledge dissemination is an important factor in the adoption of AM technology by industry. How knowledge is transferred assists in communicating relevant information to targeted audiences to use it for leading change (Ordoñez & Serrat, 2009). However, literature reveals that the knowledge of AM technology has not been disseminated effectively, hence there is a high indication of lack of familiarity or awareness within the manufacturing industry (Alabi, de Beer, & Wichers, 2019). Ordoñez & Serrat, (2009) attribute challenges to dissemination of knowledge to psychological or social factors, "but where efforts to disseminate knowledge products are earnest low impact is mainly attributable to poor planning and the absence of a dissemination strategy" (p. 2).

II. Cost and Capability

High cost and capability are barriers for adoption of AM technology, and this leads to lack of investment, and demand from industry. Cost factors put forward as being influential are categorised into high initial costs, and marginal cost (Otettmeier & Hofmann, 2017). Weller, Kleer, & Piller (2015) highlights high material costs and energy intensity as key drivers of marginal cost of production for AM in comparison to traditional manufacturing citing Gibson et al., (2010). However, the author clarifies that this could be circumvented should there be growth in the material supplier network.

Thomas, (2016) splits capability issues into the organisation's knowledge and ability to use the technology; and the systems capability to produce parts that fit to the relevant organisational requirement and objectives. He argues that AM can have major impact on capabilities of an organisation when compared to conventional manufacturing. For

example, firms seeking to place themselves in a high flexibility position sacrifices control of their processes, therefore, risks of losing efficiency increases and can lead to high costs being incurred. The other aspect that is noted, is from a viewpoint that AM may drive organisations to abandon many of their current individual functions to adopt this new production method (Thomas & Gilbert, 2014). As firms have made significant investments to fully develop these functions, therefore, in adopting the technology it poses risk of losing returns on investment from those functions (Thomas & Gilbert, 2014); (Huckstepp, 2019).

Cost and Capability has high significance in firms adopting AM technology. Lack of understanding of AM cost structures leads industry to become hesitant to invest in the technology (Kunniger, 2015). Further, the firm's fear of incurring switching cost and potential loss of investment made towards their current capabilities exacerbates reluctance for adoption of AM (Thomas, 2016). The other factor is, organisations seem not to be prepared internally to undertake this technology, as they note that their capabilities are limited when it comes to AM (Cohen, 2014). They fear that a complete overhaul of the organisations processes would be required to suit for AM.

2.2.1.3 Consequences of poor adoption of metal additive manufacturing

Loss of industry relevance and competitiveness was recognised as a consequence that can have detrimental effects towards the South African manufacturing industry and in turn proliferate the economic problems of the country, as the industry is one of the highest contributors to GDP (statssa.(a), 2019).

I. Loss of industry relevance and competitiveness in the global environment

Williams, Cunningham, & de Beer (2014) argues that the dynamics determining contemporary manufacturing competitiveness are linked to suitably skilled labour force, industry adaptability to technological change which results in innovative products and production processes, and creation of highly skilled and well paying jobs. AM is one such contemporary manufacturing process with a "potential to disrupt traditional supply chains through customisable, on-demand and cost-effective single unit production manufacturing in the consumer's home" (p. 6).

However, AM technology is perceived to have conditional impacts on competitiveness which are depended on the industry/organisation and product characteristics (Niaki & Nonino, 2017). The authors argue that, "competitiveness obtained by AM technologies

is mostly influenced by company size, time of use and aim of use" (Niaki & Nonino, 2017, p. 68), and therefore, suggests that organisations or industries with longer involvement in AM are inclined to increase their competitiveness.

Industrialised countries such as the US and in Europe have rapidly adapted to low volume production of high value products that are innovative, bespoke, and sustainable, due to challenge of mass production migrating to developing countries (Mellor, Hao, & Zhang, 2014). Countries such as China, India and Brazil are currently posing a threat to the global manufacturing industries, due to their ability to source highly skilled workforces at low wages to fill roles in the high-tech manufacturing market segment (Bizzconnect, n.d.). Adoption of AM technology befits the approach that the industrialised countries, such as US and those in Europe , have taken in order to stay relevant and competitive. In addition, AM approach, as part of advanced manufacturing technologies should be fostered in the industry in order to stay globally relevant and competitive (Williams, Cunningham, & de Beer, 2014).

South African Government interventions such as the Collaborative Program in Additive Manufacturing (CPAM) (amongst others) which serves as a vehicle for implementation of the South African additive Manufacturing strategy is intended to engender the manufacturing industry adoption rate of AM, therefore, improve their competitiveness (Duvenage, 2019). Nevertheless, non-adressing of the prohibiting factors that influence poor adoption of the technology will defeat the purposes of such inteventions and investments made by the government to align the industry competitiveness with the manufacturing trends globally. Hence the aim of this study is to evaluate the readiness of South Africa's manufacturing industry to adopt locally developed MAM technology.

2.3 Methods, data, findings, and conclusions of studies and evaluations of poor adoption of metal additive manufacturing technology.

This section seeks to identify the knowledge gap that exist on this subject matter particularly within the South African context. However, as mentioned in the previous section that there is little to no information about industry adoption of MAM technology in South Africa, especially empirical studies on AM technology in general. Therefore, similar studies that seemed relevant to this study are reviewed and described to provide methodological options that can be utilised for the empirical part of this research. Hence,

research strategies, designs, procedures, and methods applied, as well their findings and conclusions discerned are indicated.

2.3.1 Studies conducted in the past on AM adoption.

Several authors conducted studies relating to AM technology adoption, with most of them interrogating the determinants that might be key to influencing organisations or industries acceptance or reluctance of the technology. For example, lack of awareness, capital and operations costs were highlighted as some of the key variables linked to lack of adoption of AM technology (Cohen, 2014); (Kunniger, 2015); (Proff & Staffen, 2019); (Huckstepp, 2019); (Alabi, de Beer, & Wichers, 2019). While some studies such as that of Niaki and Nonino, (2017) focused on identifying impacts of the technology in relation to "manufacturing, business strategies and performance, and to determine contingent factors driving performance" (p.56). The study also sought to obtain clarity of the relationship between these impacts and characteristics of the organisation and products.

Cohen, George, & Shaw (2014) undertook a study surveying a global sample of 100 manufacturing executives and experts to evaluate industry readiness to adopt AM technology. The geographical coverage of the study was split across 30 organisations from North America; 26 from Europe; 19 from Asia; and the remainder were between Middle East, Africa, and South America. The study indicated that most of the targeted population were generaly unaware of the technonology's applications and value, and were poorly organised to exploit the benefits that results from AM. Hence, Cohen's, (2014) argument that organisations will face challenges "that require new management processes, alignment across business units, proactive executive champions, and fresh employee capabilities"(p.63), once the technology proliferates. Hence, the development of an evaluation tool (rubric) in order to assist organisatons in formulating dialogue regarding AM benefits, their capabilities and readiness to adopt AM technology.

Kunniger, (2015) applied a concurrent research approach composed of a mix-method design for cross-sectional data that was collected using a cluster sampling technique for a comprehensive analysis of potential constructs that affected AM technlogy diffusion and adoption in the province of Gauteng, South Africa. The technique had characteristics of probability sampling, as the selected sample was that of a single industrial area randomly selected within a specific geographical location, in which an online survey questionnaire was used for data collection. Various diffusion of innovation theories were applied to

assess the state of AM adoption at that moment, as the diffusion process is interlinked with the adoption process (Straub, 2009). Although, there was an indication of AM diffusion occuring in the cluster, accurate information and knowledge was considerably limited, hence, seen to be influencing the adoption rate of the technology (Kunniger, 2015). Some of the primary findings in terms of constructs affecting adoption of AM technology within the cluster sample identified were finacial justification, and knowledge about technology which related to the human element. However, the study was at an abstract level, and was not intended for proving any hypothesis or proposition, hence, Kunniger, (2015) suggestion that further studies be conducted at an empirical level.

Kianian, et.al. (2016) conducted a quantitative research study that sought to understand the rate of adoption and utilization of AM technology in Sweden. This was done through investigating the user application of AM technology in the country, and the explanatory determinants that drive the application adoption choice amongst them. The elements of the study were approached differently, with the descriptive method of analysis used for user application, and the regression analysis for the explanatory determinants. Findings of the study revealed that user application of AM technology varied in Sweden, with almost two thirds of the sample size increasing usage of the technology beyond rapid prototyping. Further, the explanatory factors for the industry's decision to go past rapid prototyping were found to be multiple usage of AM technology and being an organisation falling in a small size grouping. SMEs seem to be key in driving adoption and utilisation of AM technology in Sweden, whereas academic and R&D lagged. The study was limited to measuring user application of AM technology and determination of reasons for the choice of application, while factors impacting the non-uptake of the technology were not considered. However, other limitations highlighted pertaining to the research were in terms of the unavailability of information, and the limited number of observations from the study with regards to AM users in the country.

Niaki and Nonino's, (2017) study was of an exploratory nature with multiple case research approach being used, and applying a purposive sampling technique to sample heterogeneous organisations on the basis of the theoretical replication methodology. Theory that was considered in determining the possible impacts of AM technology and key perfomance factors was arisen from AM, Technology Management, and Advanced Manufacturing Technology literature. The study revealed that AM technology not only brought process innovation in organsations, but also product innovation to enhance

competitiveness. This was in agreement with Cohen, (2014), who indicated AM benefits that potential adopters needed to consider, such as, the ability to build highly complex and bespoke parts, reduced time to market with regards to introduction of new components, and reduced tooling and assembly costs amongst others. However, challenges similar to those that authors such as Cohen, (2014); Thomas & Gilbert, (2014); Thomas, (2016) Otettmeier & Hofmann, (2017) suggested as having impact on the adoption of AM technology, were also identified. Some of these impacts were found not to be limited to AM technology, and some were not examined such as those in large scale products and in high volume productions. The impacts were only measured qualitatively, hence, the requirement for use of quantitative measures in order to overcome such limitations.

Otettmeier & Hofmann's, (2017) study identified a range of diverse factors that determines the industry's decision to adopt AM technology for manufacturing of parts in Switzerland. These were classified into four interdisciplenary categories relating to technological, organisational, market structure, and supply chain factors. However, particular focus was on the latter, with the authors arguing that AM potentially offers distinct opportunities for the supply and demand sides of an organisation's operations. The study considered diffusion of innovation theory, employed a quantitative strategy and used a survey design for data collection to sample the reality in terms of industry adoption of AM. The authors found significant variences between up-takers and non uptakers of the technology in terms of the interdsciplinary determinants. Factors such as technology compatability and demand-side benefits are highlighted as distinguishers of users from non-users. This is due to the strong opinion that users have of AM having a fit within their structures and processes. Furthuremore, AM was seen by users as a enabler of a decentralised and customised production processes, while improving customer experience.

Schniederjans', (2017) study considered diffusion of innovation theory (DOI) and unified theory of acceptance and use of technology (UTAUT) to gain understanding of the factors that motivate or hinder the adoption of AM technologies from a manufacturing perspective. Quantitative strategy was adopted for this study with data acquired from a third-party organisation who applied a survey method. The key finding of the study was that "top-management adoption category significantly impacts potential adoption speed, but it doesn't significantly impact on the actual speed of adoption" (Schniederjans, 2017,

p. 293). Managerial perception of innovation was indicated as key for potential adoption of AM, along with relative advantage, compatibility, facilitation conditions and performance expectancy; while complexity and effort expectancy perceptions found to be minimising adoption (Schniederjans, 2017). The method of sampling in this study may have attributed potential biasness with regards to population sample, as it was noted that most respondents were from larger manufacturing companies in the US, with resources that simplified adoption of AM technology (Schniederjans, 2017)

2.3.2 Summary of past studies

In summation, the research studies briefly described above reveals that adoption of AM technology is driven by the perceived benefits that actual and potential adopters believe that they can exploit to maximise their competitiveness. This is due to their familiarity and understanding of the technology that may be brought through by interactions between knowledge holders and industry. Knowledge about the technology is picked out as an imperative indicator by authors such as Cohen, (2014), Kunniger, (2015) and others, however, other facets that have significant impact on adoption of AM technology were identified. They may be secondary to knowledge, but becomes equally integral once the potential adopter has developed an understanding of what the technology is about. These are business related impacts, which Niaki and Nonino's, (2017); and Otettmeier & Hofmann's, (2017) were focused on, such as business strategy, performance, supply and demand side benefits (just to mention a few). Kianian, et.al. (2016) focused on measuring the user application of AM technology and determination of reasons for the choice of application, while factors impacting the non-uptake of the technology were not considered. Schniederjans, (2017) determined that top manager's perceptions for innovation have an impact on the adoption of AM, however this is depended on their innate individual characteristics.

Through interrogation of the past studies there is an indication of various research strategies employed, with four applying quantitative and the other two using qualitative and mixed-method approach, respectively. The quantitative strategy's advantage in this instance assist in providing an opportunity to understand factors that have impact on decisions to adopt AM technology by organisations within the manufacturing industry. The population targeted in these studies were commonly within the manufacturing industries, however, Kianian, et al. (2016) included R&D institutions and universities.

Most of these studies were conducted in developed regions/countries in which their flexibility with regards to adoption of innovative technology is higher than in areas that are still developing. The general determinants of innovation adoption from these developed regions may be the same or similar with those in less developed areas. However, this cannot be assumed to be so, as there are other macro environmental factors that affect developing countries such as South Africa. Although, Kunniger's, (2015) study suggested possible construct that are similar to the impacts identified by other studies above, there seem to be no consideration of effects of the macro environmental factors. For example, South Africa is a highly unionised country and technology innovation is treated as a contested terrain by labour unions (Hlatshwayo, 2017). AM technology is less labour intensive in comparison to traditional manufacturing methods and its adoption may well cause labour action against adopters of the technology, as historically, technological advancement has been indicated to have led to job losses (Hlatshwayo, 2017) . This may further escalate the inequality issues experienced in South Africa (Sutherland, 2020), which may be another aspect that can have an impact on the adoption of AM technology.

Kunniger's, (2015) research was confined to Gauteng province in South Africa and the study was at an abstract level not empirical level, which used a mixed-method design for cross-sectional data collected for the identified possible constructs. Therefore, this research proposes a quantitative approach and a survey design to establish the factors that impact adoption of MAM technology by South Africa's manufacturing industry in order to explore its readiness for the uptake of the locally developed technology. This will be conducted at an empirical level and in a South African context.

2.4 Determinants of poor adoption of MAM technology in the South African manufacturing industry.

In this section, key variables in relation to poor technology adoption are recognised and discussed with the intention to identify established frameworks (theoretical or otherwise) that can be considered for interpretation of findings for this research study. Technology and innovation are used interchangebly in this section.

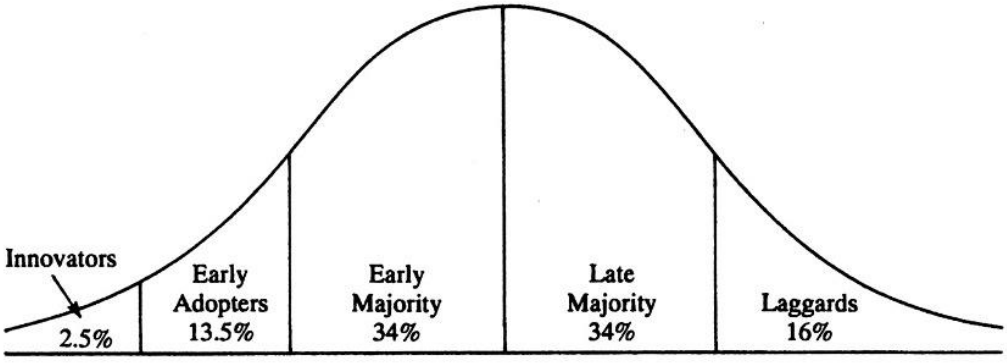
The purpose for interrogating the literature (theory) above (though not very comprehensive) in addition to past studies, was for attainment of a better understanding on how to identify relevant variables that this study will measure.

2.4.1 Innovation Adopters

There are various definitions of innovation in literature, however, in this study, Rogers', (2003, p. 38) definition is considered due to its relevancy, "An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption". He further expressed that the response towards an innovation by the individual is determined by how they perceive its newness. Consequently, it becomes irrelevent on whether the innovation is objectively new or not since its discovery, as far as human behaviour is concerned. Straub, (2009) in addition to the above definition, emphasises that "Whereas innovation can refer to some- thing abstract, like an idea, it can also be concrete, like a new piece of technology" (p. 626). From this innovation definition, one can describe innovation adopter/s as an individual or entities that are in pursuit of applicable solutions relevant to their respective needs, nevermind the newness of the solution.

In detemining the extent to which adoption of an innovation is occuring in a social system i.e manufacturing industry, the number of innovation adopters become vital in indicating the level of adoption. Rogers, (2003) classifies these adopters into time based adoption categories on the basis of innovativeness which are innovators, early adopters, early majority, late majority, and laggards, as displayed on Figure 3. The innovators are described as entities that adopt innovations independent from the influence of the social system and are neither risk seeking nor risk averse. While, early adopters' innovation uptake reduces uncertainties that comes with it due to the influence they hold in the system. The early majority are reasonably risk averse, therefore, they are distinctively positioned to either adopt early or very late. While, the late majority are very skeptical when coming to innovation adoption, as they are more risk averse, and the laggards are last to adopt as their decision is commonly based on past occurrences . However, Bass, (2004) combined the adopter categories that Rogers established into innovators and imitators. The imitators category consist of the early adopters to laggards, which he emphasised that the pressures of the social system higly influence this group.

Figure 5. Adopter category based on innovativeness (Source: (Rogers, 2003))



From studies related to this research, commonality was found with regards to the type of innovative adopters that are inclined to pursue adoption of technology. For example, authors such as Cohen, George, & Shaw, (2014); Kunniger, (2015); Schniederjans, (2017) targeted population was within the bounds of entities having influential characteristics with regards to decision making on AM technology uptake or rejection, these comprised of manufacturing industry executives, directors, managers and non-managerial experts. However, Schniederjans, (2017) further broke them down into categories of actual and potential adopters, in which it was found that with these type of entities, their perception of innovations have an effect on the extent that AM adoption occurs within the manufacturing industry. Therefore, in this study, a number of innovation adopters will be measured to help determine the answer for the first research question.

2.4.2 Knowledge dissemination

How knowledge of AM technology is disseminated to industry is critical for its adoption. Green, Ottoson, García, & Hiatt, (2009, p. 152) points out that "dissemination concerns itself with the conscious efforts to spread new knowledge, policies, and practices to target audiences or the public at large". The message, its source, target audience, and the channel to be used are key elements of the dissemination efforts (Brownson, Eyler, Harris, Moore, & Tabak, 2018). The efforts' purpose is in threefold, that is, awareness creation, development of understanding, and practical applications of the knowledge product, and therefore, all three require addressing in order to get to utilisation (Ordoñez & Serrat, 2009). Interest for better understanding of the knowledge product might be engendered by awareness, which can result in providing a foundation for action (Ordoñez & Serrat, 2009).

Ordoñez & Serrat, (2009) argues that effective dissemination of a knowledge product to its targeted audience brings value to the product. Thus, dissemination is an essential function for institutions or organisations (change agents) tasked with establishing and sharing of knowledge products, particularly the newly generated and distinct content which can be accessible and practically applied. However, ineffective dissemination is one of the explanatory factors of the existing gap between knowledge and practice. Lack of disseminations strategies and poor planning are highlighted as the main contributers to poor dissemination. The process of dissemination is interactive in its nature and requires reciprocity in order to gauge its effectiveness, for example, feedback from the knowledge user should be communicated back to the change agents (Gagnon, 2011).

The knowledge stage in the adoption-decision process is the first step that occurs as Rogers, (2003) highlights. The stage constitutes an entity's first awareness or exposure to the existence of an innovation and its benefits, while forming some understanding of its functionality (Rogers, 2003); (Straub, 2009). This initial stage relies on the dissemination efforts established for the innovation. However, Hassinger, (1959) argued that prior to an information seeking process an innovation need is necessitated which establishes the process of awareness for an entity as cited by Rogers, (2003) and Larsen, (2011) amongst others. Nevertheless, since then, there has been alternative arguments which indicate that an entity's awarness is driven by behavioural characteristics and or choices available, which are usually limited (Larsen, 2011). Thus, socioeconimic aspects and other factors brought by change agents through communication channels such as mass media, interpersonal channels have an impact on the awareness of inovation (Straub, 2009).

2.4.3 Cost, organizational capability, and potential job loss as determinants of MAM Adoption.

There are several inhibiting factors that have impact in the adoption of AM technology which have been indicated in prior studies relavent to this research. These factors mostly have to do with issues of knowledge and financial justification. Authors such as Cohen, George, & Shaw, (2014); Cohen, (2014); Kunniger, (2015) indicated that most incumbents lacked awareness or were unfarmiliar with the significance and value of the technology. While, some of those who were aware or familiar, their reluctancy stemmed from issues relating to costs, organisational capabilities, potential loss of investment made towards current capabilities, and the perception of the technology being only applicable for rapid

prototyping, amongst others (Mellor, Hao, & Zhang, 2014); (Thomas, 2016); (Otettmeier & Hofmann, 2017); (Huckstepp, 2019), (Alabi, de Beer, & Wichers, 2019).

In this study some of the abovementioned factors such as cost and organisational capability will be interogated. In addition, the perception that MAM technology adoption may aggravate the already high unemployment rate in the country will also be explored, as it requires highly skilled workers and minimal labour, therefore, diminishing further the demand for low skilled workforces (Sutherland, 2020). The awareness factor coincide with the knowledge dissemination aspect.

2.4.3.1 Cost

There is consensus found amongts various authors that cost is one of the biggest barriers in the adoption of MAM technology within manufacturing industries. Thomas, (2016) categorises this into machinery, material and operations costs, similarly, Otettmeier & Hofmann, (2017) classified them into high initial investment costs and marginal costs. The major cost driver of MAM technology is the initial investment on machinery and its installation which account for approximately two thirds of the total cost of production (Fried, 2019). Another driver mentioned is the cost of material and its accessibility, as most technologies require sole source purchasing of feedstock from their developers at high margins due to the intellectual property attached to the equipment (Huckstepp, 2019). However, there are equipment manufactures that have an open system that allows for material sourcing from third party suppliers for their machines at reasonable costs, nonetheless, challenges of material availability and procurement will creep-in (Kunniger, 2015). This is due to the laser based MAM technology's common usage of metalic powdered materials (Frazier, 2014). Flor & Hansen, (2013) suggests that these are some of the issues that have impact on an organisation's decision to accept or reject the technology advances.

2.4.3.2 Organisational Capability

Nussbaum, (2011) refers to capability in terms of human development as a combination of abilities and macro environmental factors that creates freedoms or opportunities that engender achievement of valued outcomes. Essentially, capability is a holistic attribute, for example, capable individuals are inclined to learn and collaborate with others; have creative abilities; have a high level of self-efficacy; and can apply skills in unconventional and conversant situations (Hase, 2000). With the latter description, it can be deduced that capability is a combination of competencies and abilities that can lead to achieving valued

results. With regards to organisational capability, these competencies and abilities require effective managing for a firm to gain a competitive advantage (Smallwood & Ulrich, 2004); (Johnson, Whittington, Scholes, Angwin, & Regnér, 2017). Cohen, (2014) argues that "companies will face organizational challenges that require new management processes, alignment across business units, proactive executive champions, and fresh employee capabilities" (p.62), should consideration be taken to adopt AM technology. These are some of the implications that might impact the decision for manufacturing organisations to adopt the technology. Proff & Staffen (2019) concurs with Cohen's, (2014) suggestion, stating that new management and multidisciplinary engineering skills will be required by industry to fully benefit from AM technology.

In addition, Thomas, (2016) argues that organisations seeking to place themselves in a high flexibility position sacrifices control of their processes, therefore, risks of losing efficiency increases and can lead to high costs being incurred. The other aspect that is noted, is from a viewpoint that AM may drive organisations to abandon many of their current individual functions to adopt this new production method (Thomas & Gilbert, 2014). As firms have made significant investments to fully develop these functions, therefore, in adopting the technology it poses risk of losing returns on investment from those functions (Thomas & Gilbert, 2014); (Huckstepp, 2019). Therefore, requiring organisations to reconsider business strategies and self-cannibalisation of business models (Sutherland, 2020).

2.4.3.3 Potential Job loss

Sutherland, (2020) argues that technology advancement in developed countries is expected to promote national competitiveness and draw manufacturing activities back locally, thus, impeding on developing states from "creating jobs through attracting labour-intensive manufacturing"(p.33). AM technology being less labour intensive in comparison to traditional manufacturing methods, its adoption may well lead to job losses. Historically, technological advancement has been indicated to have led to job losses (Hlatshwayo, 2017). The adoption impact will heighten the unemployment rate in countries such as South Africa, diminishing the demand for low level skills, while escalating the level of inequality (Sutherland, 2020). Sutherland's, (2020) argues further that the impact of the previous political regime has contributed to the significant skills shortage in South Africa, attributable to the inferior education system that is yet to be improved. The system has increasingly limited the supply of highly skilled workforces in

the country. However, Williams, Cunningham, & de Beer, (2014) argued that non investment in innovation and low use of advanced technologies such as AM can lead to further job loss, and may well impact the competitiveness and relavency of the South African manufacturing industry.

In a South African context it is imperative that an understanding be developed on whether the perception of job loss can also be a possible aspect that might be contributing to poor adoption of MAM technology.

2.5 Established technology adoption frameworks.

In this section theoretical frameworks relevant for this study are discussed. The frameworks considered are Rogers', (2003) Diffusion of innovation theory (DOI), and the Unified theory of acceptance and use of technology developed by Venkatesh, Morris, Davis, & Davis, (2003). Literature indicates that both theories have been effective in determining factors that affect adoption of technology in various contexts (Straub, 2009); (Venkatesh, Thong, & Xu, 2016). However, the theories have their own limitations with regards to their applicability in certain research contexts. Consequently, other studies modified the original forms of these theories to suit their context.

2.5.1 Diffusion of innovation theory (DOI)

Adoption or rejection of an innovation is usually preceded by a series of stages which a decision-maker/s go through after recognizing existence of a need, and searching for an applicable solution (Wisdom, Chor, Hoagwood, & Horwitz, 2014); (Taherdoost, 2017). Rogers, (2003) referred to this stage as the innovation-decision process (also known as adoption decision process (Straub, 2009)) which is comprised of knowledge, persuasion, decision, implementation, and confirmation stages for innovation adoption. The fundamental basis of this process is on activities relating to information seeking and processing to ease uncertainties about the advantages and disadvantages of the innovation which the decision-maker/s may have. In simple terms, this process is a framework that describes how a decision-maker's choice is made on adoption or rejection of an innovation (Straub, 2009). The adoption process emanates from Everette Rogers' diffusion of innovation theory (DOI) first published in 1962, which has influenced most of the available adoption and diffusion theories (Straub, 2009). DOI integrates the decision process with two other major components which have an influential role in

technology adoption, these have to do with charecteristicst of the innovation, and that of the adopter (Taherdoost, 2017).

DOI provides four key elements influencing the diffusion of innovation, which are the innovation, communication channels, time and social system, these are visible in every diffusion study (Rogers, 2003). Interaction of these elements describe how a combination of individual adoptions results in diffusion (Straub, 2009). Therefore, the adoption process is interlinked to the diffusion process. The DOI theory is more centered around characteristic of an innnovation, organisation and environment that the adoption process would be effected. Wisdom, Chor, Hoagwood, & Horwitz, (2014), through their study that interrogated innovation adoption theories and constructs within, found commonality within the theories assessed and deduced characteristics that are similar to those of Rogers, (2003). These are categorised into contextual mechanisms which are inclusive of external sytems, organisational, innovation, and individual (Wisdom, Chor, Hoagwood, & Horwitz, 2014).

Numerous critisims has been thrown towards Rogers' DOI, with Zanello, Fu, Mohnen, & Ventresca, (2016) stating that the "framework was heavily centred on developed countries with homogeneous environments and economic structures"(p.888). The authors' argument is substatiated by citing Strang and Meyer, (1993); Strang and Soule, (1998) who's critisim of DOI was that it neglected the geographical context in which the diffusion occurs, thus, fails to assess factors of developing countries that impact the diffusion of innovation. Straub's, (2009) concerns are, the difficulty that DOI brings in terms of framing a single study within a structure; and its failing to explain how to facilitate adoption instead of why it happens. Nevertheless, DOI is applicable to adoption environments that are formal and informal.

2.5.2 Unified theory of acceptance and use of technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) was established through evaluation of eight technology acceptance frameworks which were used to develop an understanding of technology adoption, particularly in the context of information technology (Venkatesh, Morris, Davis, & Davis, 2003). The reviewed frameworks were inclusive of DOI (Rogers, 2003), technology acceptance model (TAM) (Davis, 1985), theory of reasoned action (TRA) (Sheppard, Hartwick, & Warshaw, 1988),

the theory of planned behaviour (TPB) (Ajzen, 1991), the model of PC utilization (MPCU) (Thompson, Higgins, & Howell, 1991) combination of TAM and TPB (C-TAM-TPB) (Taylor & Todd, 1995), the motivational model (MM) (Vallerand, 1997), and the social cognitive theory (SCT) (Bandura, 1986). The basis of these frameworks is in sociology, psychology, and information systems (Taherdoost, 2017). UTAUT was established under the premise of providing a unified theoretical foundation from the prominent characteristics of these models as it was argued that they were similar (Williams, Rana, Dwivedi, & Lal, 2011).

Four attributes which are direct key determinants of behavioural intention and actual use behaviour of technology are postulated in this theory (Venkatesh, Morris, Davis, & Davis, 2003). These characteristics are performance expectancy, effort expectancy, and social influence as behavioural intention determinants; and facilitating conditions as a user behaviour determinant, which are found to be influenced by four key demographic variables (gender, age, experience, and voluntariness of use) of users that may be inclined to adopt the technology (Venkatesh, Morris, Davis, & Davis, 2003). An illustration of the complex nature of the theory (Straub, 2009) is displayed in Figure 3, while the description of the key determinants is represented in Table 1.

Figure 6: UTAUT model (Source: Venkatesh, Morris, Davis, & Davis, (2003))

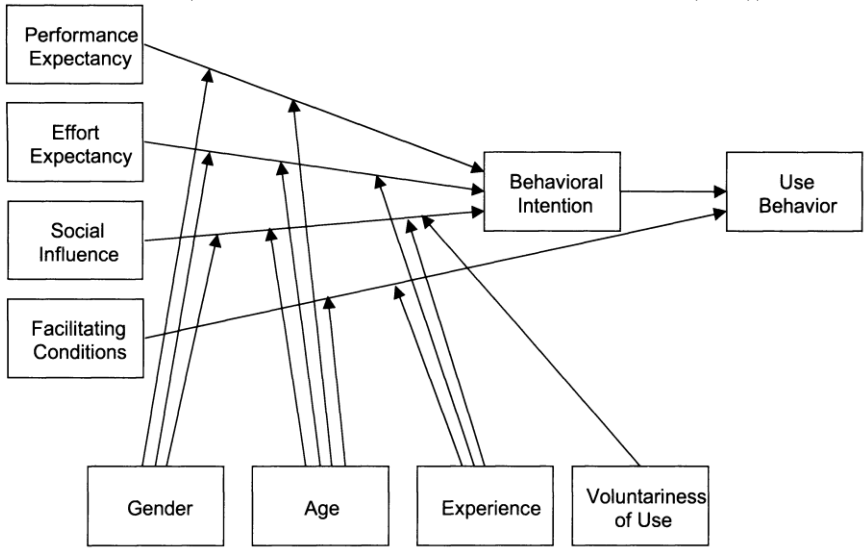


Table 1: Description of UTAUT's determinants and moderators

Key determinants	Description	Moderator
Performance expectancy	"the degree to which an individual believes that using the system will help him or her to attain gains in job" (Venkatesh, Morris, Davis, & Davis, 2003, p. 447). This is influenced by the perceived usefulness (TAM and C-TAM-TPB), extrinsic motivation (MM), job fit (MM), relative advantage (DOI), and outcome expectations (SCT) (Venkatesh, Morris, Davis, & Davis, 2003).	Gender; age
Effort expectancy	The degree to which a technology is perceived to be easy to use, which is adapted from similar constructs from TAM - perceived ease of use, MM-complexity, and DOI - ease of use (Venkatesh, Morris, Davis, & Davis, 2003).	Gender; age; and experience
Social influence	The degree to which social pressure is perceived to be exerted to an individual to use the subjected technology. Social influence guiding attributes are social norm (TAM, TPB, and C-TAM-TPB); social factors (MPCU); and image (DOI) (Venkatesh, Morris, Davis, & Davis, 2003)	Gender, age, experience, and voluntariness of use
Facilitating conditions	"The degree to which an individual believes that an organisational and technical infrastructure exists to support use of the system" (Venkatesh, Morris, Davis, & Davis, 2003, p. 453). Perceived behavioural control (TPB, C-TAM-TPB), facilitating conditions (MPCU), and compatibility (DOI) are influential in this instance.	Age, and experience

Williams, Rana, Dwivedi, & Lal, (2011) conducted a literature review study, in which usage of UTAUT and its attributes as a theoretical foundation to conduct empirical research was evaluated. The authors found that there were a number of studies that fully used the theory's constructs but did not consider using the moderating factors, while majority used UTAUT partially in their studies, often using only a few constructs. Other studies showed usage of UTAUT together with external variables and other theories to explore the behavioural intention and user behaviour for acceptance and use of information system technologies. Venkatesh, Thong, & Xu, (2016) also reviewed UTAUT's application in similar studies, thus, found that only one study applied the theory in its original form in formal organisations, between September 2003 and December 2014, while, agreeing with Williams, Rana, Dwivedi, & Lal's, (2011) on the abovementioned findings. Through the

study, the authors argue to have found numerous advantages on the application of UTAUT, stating that "UTAUT performs well in defining and articulating its parts (the focal class of things, the attributes in general, the associations, and the state space: see Table 4). Given that it synthesizes existing theories, UTAUT as a whole also performs well in the importance, novelty, and falsifiability dimensions: it focuses on the important phenomenon of technology acceptance and use, makes important changes to existing theories by introducing higher-order moderation effects in the model, and it is subject to rigorous empirical validation (Table 5)" (p.338). However, they argued that these advantages have limited further theoretical developments in technology acceptance and use research studies.

UTAUT has been applied in various research context other than information system, for example, Schniederjans, (2017) combined UTAUT and DOI to interrogate factors that impact AM adoption in the manufacturing industry. Construst from UTAUT found to have a positive correlation with the intention to adopt AM technology were perfomance expectancy and facilitation conditions, while contrasting results about effort expectancy were achieved. The conflicting results show that the intention to adopt AM varies between the innovation adopters category due to the higher level of effort expectancy, meaning, innovators and early adopter intension increases, while late majority and laggards decreases.

Dwivedi, Rana, Jeyaraj, Clement, & Williams, (2019) attempted to critically review the UTAUT model and refine its original form for further theoretical developments and identification of future research directions. The authors argue that the theory's moderators may not be applicable in all contexts, and the omission of facilitating conditions as a key determinant of behavioural intention wanes some relevancy of the theory. They further argue that UTAUT ignored the individual intending to use or actually is using the technology, therefore, requiring that attitude be included as another construct in the theory for prediction of behavioural intention and usage behaviour.

2.6 Summary and conclusion

2.6.1 Summary of literature reviewed.

Literature on AM technlogy adoption was interrogated in order to develop an understanding of the causal factors and the potential effects of poor adoption of MAM technology. MAM is a type of AM technology and its adoption is not singled out in the

literature available, as most studies conducted on adoption of this innovation is generally on AM as a whole, hence its use for this study. However, it can be implied that certain studies are reflective of MAM technology, though not explicitly stated.

Past studies explored indicates that there are varying factors that attribute to the poor adoption of AM in manufacturing industries. Several authors conceded that factors such as lack of knowledge (Cohen, George, & Shaw, 2014); (Cohen, 2014); (Kunniger, 2015), its cost (Thomas, 2016); (Otettmeier & Hofmann, 2017); (Huckstepp, 2019), and organisational readiness (Cohen, 2014); (Otettmeier & Hofmann, 2017); (Niaki & Nonino, 2017) amongst others were key to the lack of adoption of AM. According to the stages of the innovation decision process DOI theory, the knowledge step is very crucial in the adoption of technology, as it has impact on other decision making stages. At this stage, potential adopters become aware or exposed to the exisitance of the technology/innovation and its benefits, while forming some understanding of its functionality after seeking solutions for their needs. (Rogers, 2003). However, this relies on the effectiveness of the established dissemination efforts (Ordoñez & Serrat, 2009).

Other studies focused on the adopters perceived characteristics which are deemed to be key enablers of technology acceptance behaviour. These are derived from DOI and UTAUT theoretical frameworks which are regarded as fundamenal models relevant in studies pertaining to the adoption and diffusion of innovation (Straub, 2009). Studies that explored the relationship between the perceived characteristics of adopters and AM technology acceptance behaviour is that of Schniederjans, (2017) – DOI & UTAUT; Otettmeier & Hofmann, (2017) - DOI.

Further review on literature was conducted to identify the relevant theoretical framework for this study. DOI and UTAUT are considered for this research, for instance, Rogers, (2003) theory identified five stages that innovation adopters go through in terms of adoption or rejection of the technology, referring to them as the innovation decision process (adoption decision process). In addition, emphasis is placed on the importance of innovation adopters when measuring the extent to which adoption of an innovation occurs in a social system. The adopters are classified into time based adoption categories in which different factors apply on influencing their adoption decisions. Venkatesh, Morris, Davis, & Davis', (2003) UTAUT theory suggests four key determinants of behavioural intention and usage behaviour of technology, and their moderators.

In reviewing literature of both theoretical frameworks, DOI is identified to be relevant in guiding the interrogation of this study. The link between the framework and this research is due to the four key elements that DOI provides which are influential in innovation diffusion. The elements are mentioned in section 2.4.2 as innovation, communication channels, time and social system. MAM technology in this instance is the innovation; communication channels which are used in connecting entities that are knowledge holders of the technology to those that are no knowlageble are to be interrogated by the knowledge dissemination variable (Rogers, 2003). Thus, the knowledge dissemination variable intends to measure the effectiveness of current communication channels used to create industry awareness about the technology. The time aspect is involved in the innovation-decision process, the time taken to adopt an innovation/technology by the adopter and the adoption rate across the social system (Rogers, 2003, p. 20). However, time of adoption will not be explicitly measured in this study. The social system element in this study will be linked to SA's manufacturing industry with sectors that are manufacturers and/or refurbishers of metal-based components (innovation adopters) using conventional ways of manufacturing.

2.6.2 Proposed research strategy, design, procedure, and methods arising from the literature reviewed.

As mentioned above in section 1.2.2 the objectives of the study are, i) to measure the extent which metal based additive manufacturing occurs in South Africa, and under which manufacturing sector; ii) to determine if knowledge generated about the technology in the country to be disseminated effectively; and iii) to examine factors that may be driving or constraining the adoption of the technology within SA's manufacturing industry. Thus, the researcher proposes a quantitative research strategy which seeks to clarify current conditions, establish relationships between variables, and possibly explain their causality through experimental methods and numerical measures (Creswell, 2014). The design that is found to suit this study is cross-sectional (survey) design, which will be in a form of an online questionnaire for collection of data from the metal-based manufacturing industry, to answer the study's research questions and test the hypothesis posed.

3 RESEARCH STRATEGY, DESIGN, PROCEDURE AND METHODS

In Section 1.2.3, three questions were posed that this research report intends to answer— that is, 'To what extent has the South African manufacturing industry adopted MAM technology?', 'Is knowledge of MAM technology effectively disseminated in South Africa, particularly in the manufacturing industry?', and 'What impact does cost, organisational capability, and potential job loss have on MAM technology adoption in SA's manufacturing industry?' The researcher has since reviewed literature and developed an interpretative as well as conceptual framework that guided the choices of techniques that were used. This chapter identifies and describes research approach, design as well as procedure and methods that were employed in this research to collect, process, and analyse empirical evidence. Broadly, it has three objectives; namely, to identify and describe the research strategy (Section 3.1), the research design (Section 3.2), as well as the procedure and methods (Section 3.3). The chapter also describes the reliability and validity measures (Section 3.4) that this research applies to make it credible as well as the technical and administrative limitations of the choices we make (Section 3.5).

3.1 Research strategy

Creswell, (2014) describes research strategy as "plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation" (p.3). Several decisions are involved in these plans which lead to the overall approach that would be applied in the research study. The approach is underpinned by the philosophical assumptions that the reseacher presents to the study, which is also informed by the resarch design, as well as research methods (Saunders, Lewis, & Lewis, 2007); (Creswell, 2014). These assumptions can either be epistemological or ontological in nature, however, the philosophical choice depends on the type of inquiry being presented by the study. Epistemology is concerned with the nature of knowledge, its limitations, its sources, validity and the potential gain that it presents to a reseacher to expand an understanding in a field of study, while ontology is more concerned with concepts of exisitence, and reality (Kivunja & Kuyini, 2017). The underpinning research paradigms for epistemological study can vary between positivism, pragmatism, realism, and interpretivism particularly in business research studies (Kivunja & Kuyini, 2017). This study was epistemological in nature and the three research approach choices that could

be used to guide the inquiry were qualitative, quantitative or mixed-method research strategies. (Creswell, 2014).

A positivism stance was taken for this research, as an understanding of factors contributing to poor adoption of MAM in a South African manufacturing context required to be expanded empirically in order to determine the industry's readiness. Kunniger's, (2015) study was at an abstract level and did not intend to prove any hypothesis or proposition with regard to these factors. According to Saunders, Lewis, & Lewis, (2007) citing Remenyi et al., (1998:32) a posivitist prefers "working with an observable social reality and that the end product of such research can be law-like generalisations similar to those produced by the physical and natural scientists"(p.103). The hypothetico-deductive method is often used in the positivism perspective for verification of "priori hypothesis" commonly stated in a quantitative manner, "where functional relationships can be derived between causal and explanatory factors (independent variables) and outcomes (dependent variables)" (Park, Konge, & Artino Jr, 2020, p. 690). Subsequent to the above uptake of positivism position, the study employed a quantitative research strategy to address the three inquiries in Section 1.2.3 and test the accompanying hypothesis. Quantitative research approach sought to clarify current conditions, establish relationships between variables and occasionally explain their causality through experimental methods and numerical measures (Creswell, 2014).

Schniederjans, (2017) employed the quantitative research strategy with the intension to "provide an empirical assessment from the standpoint of actual manufacturing practitioners to understand what impacts adoption"(p.287). The objective of the study was to establish the relationship between top manager adopter category and the rate of adoption of AM technology, and to determine factors that drive their intention to adopt the technology. Although, the reason for selecting this strategy are not explicitly stated in the study, however, it can be established from the objectives that the author seeked to establish a relationship between variables and explain their causality. The relationship between the variables were able to be measured and described, while, the factors that positively drive the intention to adopt were determined.

3.2 Research design

Research design is described as a plan that outlines the process in which research questions will be answered (Saunders, Lewis, & Lewis, 2007). It involves provision of

clearly defined objective that stem from the questions posed in the inquiry; defining the processes and sources for data collection, its analysis and interpretation, as well as identification and consideration of limitations that are inevitable in the study (Saunders, Lewis, & Lewis, 2007); (Bryman, 2012). According to Bryman, (2012) "A choice of research design reflects decisions about the priority being given to a range of dimensions of the research process" (p.46). The prioritised dimensions involved include, explaining of causal relationships amongst variables; sample generalisation to a larger population; developing behavioural understanding in varying social context; and appreciation of social phenomena and their mutual connections over time (Bryman, 2012). Brotherton, (2015) suggests that the purpose of a research study determined is also imperative in establishing its design. The author alludes to three types of research purposes, which are described as exploratory, descriptive, and explanatory (this section will not provide description of all the purposes, but that relevant to the research design this study commits to). Bryman, (2012) provides a list of prominent research designs used in inquiry studies; and these are experimental, cross-sectional (or survey), longitudinal, case study, and comparative design.

The purpose of this study was explanatory and descriptive in nature, nevertheless cross-sectional design was adopted, the research sought to establish relationships between variables at a particular point in time and infer their causality (Bryman, 2012). However, it was noted that cross-sectional design does not provide the opportunity to manipulate these variables like in experimental design, this is due to the single point in time that data is collected (Bryman, 2012). Also, there are time constrains attached to this study, as it is part of an academic course (Saunders, Lewis, & Lewis, 2007). Explanatory research attempts to find the causal connections between variables, "explaining the patterns and trends associated with the observed phenomena" (Bambale, 2014, p. 866). While descriptive research seeks to either provide a snapshot of a situation as it occurs or identifies variables of a particular phenomenon based on their observation or examine relationships between variables (Williams C. , 2007). As indicated above the study employed a cross-sectional research design, meaning that a survey was sent out to various organisations within the manufacturing industry of South Africa for data collection and its eventual analysis (Saunders, Lewis, & Lewis, 2007).

Kianian, Tavassoli, Larsson T, & Diegel, (2016) employed a survey research design with the aim of providing an elaborate perspective on the status of AM adoption and

utilization in Sweden. The objective of the study was to determine the application of AM amongst user in the country, and to examine factors that lead to the choice of these application. The study is both descriptive and explanatory in nature, hence their selection of survey design. The authors were able to establish that a growing number of users were using AM beyond rapid prototyping, exploiting its potential to gain benefits of the technology. They also managed to find the causality of the choices of these application. With regards to this study, the design selected will help determine the relationship between variables listed in Section 1.2.3 with the adoption of MAM in SA's manufacturing industry at a single point in time.

3.3 Research procedure and methods

This section documents the actual procedure and the methods employed in this research to collect, collate, process, and analyse empirical evidence. Broadly, details the data and information collection instruments (Section 3.3.1), the target population and sampling of respondents (Section 3.3.2), the ethical considerations during the research process (Section 3.3.3), data and information collection process and storage (Section 3.3.4), data and information processing and analysis (Section 3.3.5) as well as the background description of the respondents who provided empirical evidence for this research study (Section 3.3.6).

3.3.1 Research data and information collection instrument

A research data collection instrument is a tool designed for gathering relevant data required in a study, that can be analysed to provide credible answers to the established research question/s (Bryman, 2012). The instrument needs to align with the research strategy that has been employed in the study, this should be through consideration of a variety of possible data collection techniques (Creswell, 2014). The data collection instrument for a research study can either be in the form of self-administered questionnaire or interview schedule or both.

In this study, a self-administered questionnaire was adopted as a collection instrument, it aligned with the quantitative research strategy and the cross-sectional design employed which is also known as a survey design. The questionnaire was relevant in this instance because of its nature, as it was designed precisely for completion by a respondent without the involvement of the researcher collecting data (Lavrakas, 2008). The questions in the

survey were closed ended at most and did not bare much thinking load on the respondent, also the feedback can all be compared across.

Cohen, George, & Shaw, (2014) undertook a study surveying a global sample of 100 manufacturing executives and experts to evaluate industry readiness to adopt AM technology. The authors needed to determine the global manufacturing industry readiness in adopting AM manufacturing technology. The study was split across 30 organisations from North America; 26 from Europe; 19 from Asia; and the remainder were between Middle East, Africa, and South America. Usage of the self administered questionnaire provided the opportunity to "collect a large amount of data from a sizeable population in an economical way" (Saunders, Lewis, & Lewis, 2007, p. 138), thus, managing to determine the variables that impact AM adoption.

Questions that were operationalized from the first and second research questions were developed by the researcher, while some in relation to the 3rd research question are guided by Cohen's, (2014) study due to the relevance to this research (see Appendix 1.1).

3.3.2 Research target population and selection of respondents

3.3.2.1 Research target population

Target population is a total group of entities in which a sample can be extracted from, in order to draw information that will be examined, and the findings be inferred (Lavrakas, 2008). Specific delineation of the target population is important in a survey study as this will help determine the eligibility of the sample to be selected (Lavrakas, 2008).

The target population for this study consisted of organisations in the South African manufacturing industry represented by individuals with attributes similar to that of Rogers', (2003) early adopters' category. These organisations are those producing metal-based components through traditional manufacturing. The geographical location of the population was confined to all nine provinces of the country and the size of the organisations ranged between SME's and large enterprises.

Otettmeier & Hofmann, (2017) seeked to identify factors that determine the industry's decision to adopt AM technology for manufacturing of parts in Switzerland. The objective was to particularly examine the impact supply chain related factors, however, technology related, organisation related, as well as market related factors were also assessed. The

target population comprised of manufacturing organisations that were represented by individuals that are in influencial positions with regards to adoption of new innovative technologies. The authors found significant variences between up-takers and non uptakers of the technology in terms of the interdsciplinary determinants. Factors such as technology compatability and demand-side benefits are highlighted as distinguishers of users from non-users. This is due to the strong opinion that users have of AM having a fit within their structures and processes. These factors found to be having an impact on the decision to adopt AM or not, are relateble to the influence that the representetive of the organistions have.

3.3.2.2 Sampling or selecting respondents from the target population.

According to Taherdoost, (2016) sampling is concerned with the reduction of a population that is intended to be studied, by extracting a smaller representation called a sample. From this sample, relevant data can be collect, analysed and inferred into findings, therefore, these results are then taken to represent that of the entire population. The author attributes the inability to evaluate the entire population to lack of time and resources. The are various sampling techniques that can be used under quantitative research strategy, these are classified into probability techniques category, while, non-probability category are employed in qualititative strategy. For the purpose of this study only probability techniques are listed, these are, simple random, stratified random, cluster sampling, systematic sampling, and multi stage sampling.

Stratified random sampling technique was used in this research. The technique splits the population into homogeneous subgroups selecting a random sample from each of them, in order to provide more reliable and elaborate details about the sample (Taherdoost, 2016). Ding, Hsieh, Wu, & Pedram, (1996) lists the advantages of stratified sampling stating that "1) It performs sampling directly on the population and the estimation results are unbiased, 2) It, is more efficient, and 3) The sample distributions are more likely to be a normal distribution" (p.577). The selection of this sampling technique was based on the need to stratify the organisations based on their size and core industry serviced as Schniederjans, (2017) argued that biasness may occur as many respondents may be from large enterprises with resources that incline them to adopt AM.

3.3.3 Ethical considerations when collecting research data.

Ethics is a subset of philosophy concerned with the moral standards required for society to coexist whether in local or global terms, commonly provided by external sources (Stiglitz, 2014). Conversely, morals refer to the individual's own values that relates to the "standards of good or bad behaviour, fairness, honesty, dignity, diversity and individual rights, that each person believes in, rather than to laws", as defined by Cambridge-Dictionary, (2019). From the definitions above values are particularly important when it comes to ethical behaviour in a societal environment. Therefore, values associated with diversity and individual rights are critical for a researcher especially when their study involves other human beings (without undermining other values). Bryman, (2012) suggest that issues of ethics in social research has become a topic of concern, as this arose discussions around treatment of people whom the studies are conducted around. The other aspect being activities that reseachers should engage on or not during their association with the people in the study. Therefore, ethical consideration is extremely critical in the success of a research study that involves human, also gaining access to study them is important as well (Saunders, Lewis, & Lewis, 2007). The five important considerations were addressed below:

3.3.3.1 Researcher's profile and interest

The profile and interest in the research are attached in Appendix 2.1.

3.3.3.2 Assurance in not deceiving respondents.

Participation of the respondents in this study was completely voluntary, and there were no direct benefits in taking part. There was no discrimination, disadvantage, or penalties for non-participation. Withdrawing from the study was possible at any moment and choosing not to answer any question as wished was also possible.

3.3.3.3 Assurance in not causing harm or stress to respondents.

The study did not involve any physical experiments on any human or animal. The only involvement of the respondent was in answering the self-administered questionnaire. The questions asked did not pose any form of harm, cause any discomfort or stress.

3.3.3.4 Consent issues

Survey research design was adopted for this study no interviews or recording of respondents will happen. A self-administered questionnaire was sent out and attached to

it, was an invitation for participation in the study, as highlighted above partaking will be voluntary.

3.3.3.5 Anonymity and protection of data

The survey was completely confidential and anonymous as no names of respondents and any identifying information was requested. The data obtained will be secured by the researcher only, and it will not be disclosed to anyone else. No names of respondents will be used in the final report.

3.3.4 Research data and information collection process

The study employed an online based self-administered questionnaire that was distributed to the respondents for collection of data. The online based questionnaire was created on a cloud-based platform called Qualtrics (https://www.qualtrics.com). The respondents were required to answer the same set of questions that are close ended within a single point in time, with the intension to reach a large sample size. However, confusion towards the respondents may have arisen from the questions as they might have misinterpreted them, which may have a negative impact.

3.3.5 Research data and information processing and analysis

3.3.5.1 Research data and information processing

Data processing involves translation of raw data collected into usable information. This is done following a series of activities performed in order to verify quality, arrange, transform, incorporate, and draw the data accordingly so it can be used (sisu, n.d.).

Data coding is a process that involves transforming of data collected into information that can be used. The questions in this study are close ended, therefore, the coding scheme was directly integrated into the questionnaire, with the data numerically entered. As indicated the questionnaire was online based, meaning that the process was automated such that the response and its code were instantly recorded in the cloud-based platform during data collection. The researcher easily accessed the data and was able to load it on their computer as a data file. This addressed the aspect of **Data entry onto computer**, which is described as the loading of data into a computer. **Data cleaning** is a process concerned with the repairing or elimination of data that is corrupt, incomplete, duplicated or incorrectly formatted.

3.3.5.2 Research data and information analysis

According to (sisu, n.d.) "data analysis involves actions and methods performed on data that help describe facts, detect patterns, develop explanations and test hypotheses. This includes data quality assurance, statistical data analysis, modelling, and interpretation of results". Various methods are available to analyse data, for example, regressions analysis, cluster analysis, content analysis.

The nature of the study was explanatory and descriptive as previously mentioned; therefore, regressions analysis was applied in order to determine the relationships between the independent variables and a dependent variable. While descriptive analysis was used for describing the state of adoption. Kianian, Tavassoli, Larsson T, & Diegel, (2016) used both methods to describe the user application of AM in Sweden (descriptive) and to explain the factors that led to the choice of application (regression).

3.3.6 Description of the research respondents

The respondents to this study were representatives from organisations within the South African manufacturing industry, those producing metal-based and or refurbishing components through traditional manufacturing. The only thing that was specific about the respondents is, having influential characteristics with regards to decision making on AM technology uptake or rejection, and they will range between manufacturing industry executives, directors, managers, and non-managerial (technical) experts.

3.4 Research strengthens - reliability and validity measures applied.

Reliability and validity in research are concerned with evaluating the degree to which work was done to enhance the quality of the study (Heale & Twycross, 2015). Quantitative research studies require approval and validation, and it is important that the validity and reliability of the data collection instruments be ensured (Heale & Twycross, 2015); (Mohajan, 2017).

3.4.1 Reliability

Reliability relates to the level of constancy that an instrument can achieve similar results over time when utilised repeatedly in conditions that are the same (Golafshani, 2003). An exact calculation of reliability cannot be provided, however, there are three measures that it can be estimated through, such as homogeneity, stability, and equivalence (Heale &

Twycross, 2015). Homogeneity provided by the data collection instrument is commonly tested using the Cronbach α which seeks to accurately examine the average of all split-half connections between items in the scale (Heale & Twycross, 2015). The Cronbach α of 0.65 or higher is an acceptable reliability test score. The stability is measured by conducting the test twice to the same respondents at different times in order to assess their response to be the same, while equivalence evaluates the extent to which consistency is found from judgements of different observers (Price, Jhangiani, & Chiang, 2015)

Schniederjans, (2017) in her empirical study of determining the factors that impact the adoption of AM in the USA, ensured reliability through measuring the homogeinety the instrument provides, in which a Cronbach α greater than 0.7 was achieved for each of the variables.

3.4.2 Validity

Validity is concerned with the degree to which the collection instrument measures what it is intended to measure, is it able to accurately reflect the results of the measured construct as supposed to (Golafshani, 2003). There are four primary methods of validating a quantitative research study which are measurement, internal, external, and ecological validity.

3.4.2.1 Measurement validity

Measurement validity otherwise known as construct validity refers to the extent which a test measures what it supposed to measure as it claims. In this study the collection instrument is intended to solicit data from the manufacturing industry in order to determine its readiness to adopt MAM technology. However, what will be measured by the instrument are factors that impact the adoption, which will lead to the determination of the industry readiness.

3.4.2.2 Internal validity

Bleijenbergh, Korzilius, & Verschuren, (2011) states that "internal validity is mostly used for the validity of causal reasoning or causal conclusions and for the validity of the measurement procedure" (p.6). It concerns the level to which the results observed are representative of the truth in the population being studied and not by errors of the methodology applied (Patino & Ferreira, 2018). Therefore, in this study the instrument should be able to measure the independent variables, meaning that, the self-administered questionnaire will measure the factors that impact the adoption of MAM technology and

industry readiness through multiscale items to improve the rigour of the study. Validation of the self-administered questionnaire will be done through conducting of a pilot survey involving a group of approximately 10 organisations that matches the population sample characteristics. This is done to determine if it can measure what it is intended to measure, as well as to find out if the questions are understood as intended.

3.4.2.3 External validity

External validity pertains to relevance of generalising findings of a study, "either from a sample to a larger population or to settings and populations other than those studied" (Lucas, 2003, p. 236). The testing of the outcomes of this study is only within the context of the South African manufacturing industry with only organisations producing metal-based components.

3.5 Research weaknesses - technical and administrative limitations

The sample size response was found to be constraining the study, as it is too small compared to the anticipated responses of the online questionnaire from the industry, thus, creating difficulty in finding significant relationships of variables from the data. Low responses may also have been attributed to time limitation of the study, the type of respondents (as mostly were on higher hierarchy levels e.g., executives), and COVID 19 pandemic having impact on the dynamics of work i.e., working from home. The other aspect is with regards to the questionnaire due to the to the direction that it has been structured, as the respondent only provides answers according to the way the enquiry is made, therefore, no further insights can be given to the researcher.

4 PRESENTATION OF RESEARCH RESULTS

The previous chapter details the research strategy, design, procedures, and methods employed in this study. Therefore, in this chapter, results from the collected and analysed data using the online self-administered questionnaire (see Appendix 1.1) and SPSS Statistics software respectively are presented. These findings are pertinent in establishing an understanding on the readiness to adopt MAM technology by SA's manufacturing industry. Hence, these attempt to answer or provide insight to the research questions as well as the accompanying hypothesis posed in section 1.2.3.

The initial data set from the online self-administered questionnaire comprised of 36 of the 200 targeted respondents, however, 15 of them did not start the survey, as a result they were eliminated. This meant that only 21 respondents completed the online survey. However, 4 (19.1 %) of the respondents did not finish the survey, therefore, missing fields were identified, leading to core variable fields such as items 2.1 to 4.3 in the questionnaire, being populated using the mode for the 4 respondents.

The characteristics of the sample (questionnaire item 1.1 to 1.4) were observed through measuring variables such as the region of operation, the core industry serviced, organisation size (number of employees), and years in operation of organisations represented by the respondents. With regards to the region of operation, 17 (81 %) of the 21 respondents were from Gauteng province while 1 (4.8 %) was from KwaZulu-Natal, and 3 did not specify, while none of the other provinces were stated. The core industry serviced variable observed 28.6 % of respondents being in the manufacturing of mining and mineral processing equipment, 23.8 % in aerospace, 9.5 % in medical devices; 4.8 % in automotive, tooling, defence, railway systems, and power generation, respectively. On the number of employees variable, 47.6 % of the respondents observed represented large enterprises, while 38.1 % were SMEs. The years in operation variable observed 76.2 % being in operation for more than 10 years, as well as 9.5 % being between 5 and 10 years. 14.3 % of respondents on all four variables did not specify their characteristics, respectively.

Table 2 below shows the computed measures of central tendency and dispersion of the observed characteristics of the sample in which the trend was almost similar with all the variables measured. Core industry serviced having a higher mean (M) at 4.17 and a

standard deviation (σ) of 2.503, while organisation size (M = 3.22 and σ = 1.06), region (M = 3.06 and σ = 0.236), and No. of years (M = 2.89 and σ = 0.323).

Table 2. Descriptive statistics - Characteristics of Sample

Variable	N (Valid)	N (Missing)	Mean	Median	Mode	SD(σ)	Min.	Max.
1.1 Region	18	3	3.06	3.00	3	0.236	3	4
1.2 Core industry	18	3	4.17	5	5	2.503	1	8
1.3 Org. Capability	18	3	3.22	4	4	1.06	1	4
1.4 No. of years	18	3	2.89	3	3	0.323	2	3

Reliability of the questionnaire was tested through survey items (category of variables) 4.1 Cost, 4.2 Organisational Capability, and 4.3 potential Job loss (see appendix 1.1 for items), using a 7-point Likert Scale in which respondents were asked to indicate the extent they agreed or disagreed with the 12 statements (4 for each variable category) to examine the impact they have on MAM adoption by industry. The Cronbach alpha was used for assessing the reliability of this data and with all 3 categories of variables testing at coefficients of 0.8, 0.832, and 0.722, respectively, which are higher than 0.65 standard minimum.

This study is descriptive and explanatory in nature, therefore, research question 1 and 2 responses were analysed using descriptive analysis, while research question 3, regression analysis was used as the accompanying hypotheses required testing. The link between the research questions and the operationalised questions on the questionnaire are indicated in Table 3. The results are presented in the order displayed in the table below except for items 1.1 to 1.4 as they have been presented above (characteristics of sample).

Table 3. Survey questions linked to research questions.

Research Questions	Survey questions Item Numbers	Sub-questions
1. To what extent has the South African manufacturing industry adopted MAM technology?	1.1, 1.2, 1.3, and 1.4 2.1, 2.2, and 2.3	2.1.1 to 2.1.4, 2.2.1 to 2.2.4
2. Is knowledge of MAM technology effectively disseminated in South Africa, particularly in the manufacturing industry?	3.1, 3.2, and 3.3	3.1.1, 3.2.1, 3.3.1 to 3.3.2
3. What impact does cost, organisational capability, and job loss have on MAM technology adoption in SA's manufacturing industry?	4.1, 4.2, and 4.3	

4.1 The level of MAM adoption in the South African manufacturing industry.

The research question was operationalised into three ways: 4.1.1 ownership/leasing, 4.1.2 consideration of ownership, and 4.1.3 reasons for non-consideration of ownership. This was aimed at determining the current state of adoption of MAM technology within the manufacturing industry, which sectors, and their application of the technology. In addition, to identify potential adopters or non-adopters, as well as their reasons for the uptake or non-uptake.

4.1.1 Ownership/leasing of MAM machine

In order to determine how many organisations owned/leased MAM machines, the respondents were asked to respond to a Yes/No question. Fourteen-point three % (N=3) of the 21 respondents said yes to owning/leasing a MAM machine, while 85.7 % (N=18) said no (see Table 4). Those owning/leasing the machines, 2 of them indicated the type of machines they owned/leased, whereas 1 did not. However, there was also an indication of the use of the machine from the group of respondents owning/leasing the machines, with 1 respondent using it for both rapid-prototyping and low-volume part production. While the other two respondents stating that they use the machine only for rapid prototyping, and low-volume part production, respectively. This group of respondents owning the machines also revealed that the machine brought value to their organisations. However, one respondent from the group that did not own/lease the machines had responded to "use of machine" and "value bringing" sub-questions, their responses were eliminated. This group was not supposed to respond to the sub-questions of item 2.1 in the questionnaire.

Table 4. Ownership/Leasing

	Frequency	Percent
Yes	3	14.3
No	18	85.7
Total	21	100.0

4.1.2 Consideration of owning a MAM machine.

Consideration of owning a MAM machine by non-adopters is vital in this study as it can also assist in giving a better indication on the readiness of industry to adopt. The question posed required a Yes/No response in which 66.7 % (N=14) of the 21 respondents agreed that their company would consider owning a MAM machine, while 19 % (N=4) said they would not, and 14.3 % (N=3) did not respond to the question (see Table 5). From the 14 respondents that claimed to consider owning a MAM machine, 71,43 % (N=10) indicated the type of machine they would like to own, while 28,57 % (N=4) did not respond. Then 11 respondents from the 14 further indicated their intended use of the machine, in which 19 % (N=4) stated rapid prototyping and low volume part production, 9.5 % (N=2) for R&D, 9.5 % for rapid prototyping, 9.5 % for low volume part production, and 4.8 % for high volume part production. In addition, the 11 claimed that they believed that MAM technology can bring value to their organisation, while 4.8 % (N=1) stated the opposite. Overall, 52.4 % (N=11) (with 3 of them being owners of the machines already) of the total sample 21 did not respond to the "type of machine", "machine usage", "value bringing" sub-questions.

Table 5. Consideration of owning MAM machines.

	Frequency	Percent
Yes	14	66.7
No	4	19.0
No response	3	14.3
Total	21	100.0

4.1.3 Reason/s for non-consideration of owning a MAM machine.

Table 6 below provides feedback from 11 of the 21 respondents with regards to reasons that they believed were influencing them not to consider owning a MAM machine. The response revealed that 9.5 % had no knowledge of the technology, and a further 9.5 % thought the technology was at its infancy and did not suit their processes. In addition,

14.3 % believed that the technology was expensive and can only be used for low volume production of overly complex and customised parts, while another 14.3 % indicating that the technology was not cost effective. However, only 4.8 % believed that the parts produced from MAM technology had quality assurance issues, while 47.6 % did not respond.

Table 6. Reason for non-consideration of owning a MAM machine.

Variable	Frequency	Percent
No response	10	47.6
No knowledge	2	9.5
Infancy stage and not suitable	2	9.5
Expensive and it is for low volume production of overly complex/custom parts	3	14.3
Not cost effective e.g., speed of production, high marginal costs	3	14.3
Quality assurance issues e.g., problematic surface finish, tolerances of parts produced	1	4.8
Total	21	100.0

4.2 Effective dissemination of MAM knowledge to the manufacturing industry.

On research question 2, the intension was to examine whether the knowledge that has been developed in South Africa about MAM technology was effectively disseminated by the knowledge holders to the industry. This was done by operationalising the question into three ways: 4.2.1. industry awareness of MAM technology knowledge, 4.2.2. industry awareness of the RAPDASA initiative, 4.2.3. industry awareness of other government initiatives. Therefore, the operationalised questions were intended to interrogate the 21 respondents about their familiarity with MAM initiatives developed in SA, and trade media available to create awareness and disseminate knowledge.

4.2.1 Industry awareness of the knowledge developed about MAM technology in South Africa.

In determining the level of industry awareness of the knowledge that has been developed, a Yes/No question was asked, in which 57.1 % (N=12) response from the 21 respondents was yes, whereas 19 % (N=4) stated no, and 23.8 % (N=5) did not respond. The 15 respondents from the 21 further replied to another Yes/No question linked to the previous one which determined trade publications they subscribed to. Nine (42.9 %) of the respondents had subscriptions, and 6 (28.6 %) did not have. For those who had

subscriptions they provided the names of the publications (see Appendix 4.1 Table 1), and 5 of them indicated that there was regular publishing of MAM technology in the publications subscribed to, while 4 said the opposite. Further, 4 of the 5 respondents said that the publications were effective in creating MAM technology awareness, however 1 indicated that it was not case (as displayed in Table 7).

Table 7. Effectiveness of trade publications in creating awareness.

	Frequency	Percent
Yes	4	19.0
No	1	4.8
No response	16	76.2
Total	21	100.0

4.2.2 Industry awareness of the RAPDASA initiative

In assessing the industry awareness about the RAPDASA initiative, a Yes/No question was posed and feedback from the respondents revealed that, 42.9 % (N=9) agreed to know the initiative, and 38.1 % (N=8) did not, while 19 % did not specify. However, 6 of the respondents that agreed to know the initiative believed that it was effective in creating awareness, while 4 believed the opposite, with 11 not responding (see Table 8).

Table 8. Effectiveness of RAPDASA in creating awareness.

	Frequency	Percent
Yes	6	28.6
No	4	19.0
No response	11	52.4
Total	21	100.0

4.2.3 Industry awareness of other government initiatives

Yes/No question was asked in order to establish the industry's familiarity with other government initiatives creating awareness of MAM technology. The response was from 16 (76.2 %) of the 21 respondents, in which 3 (14.3 %) were aware, and 13 (61.9 %) were not (see Table 9). The 3 respondents provided the names of the initiatives which are shown in Appendix 4.1 Table 2. The latter respondents further stated that the initiatives contributed to their understanding of the technology.

Table 9. Industry awareness of other government initiative

	Frequency	Percent
Yes	3	14.3
No	13	61.9
No response	5	23.8
Total	21	100.0

Table 10 below displays the measures of central tendency and dispersion computed to summarise the data, and to understand the variability scores of the three variables measured under knowledge dissemination. Other government initiatives showed a higher mean (M=1.81) and standard deviation of $\sigma = 0.403$; RAPDASA awareness: M=1.47, $\sigma = 0.514$; knowledge awareness: M=1.25, $\sigma = 0.447$.

Table 10. Descriptive statistics for variables of knowledge dissemination

Variable	N (Valid)	N (Missing)	Mean	Median	Mode	SD(σ)	Min.	Max.
3.1 Knowledge	18	3	3.06	3.00	3	0.236	3	4
3.2 RAPDASA	18	3	4.17	5	5	2.503	1	8
3.3 Other gov. initiatives	18	3	3.22	4	4	1.06	1	4

4.3 Impact of cost, organisational capability, and potential job loss on South Africa's manufacturing industry's adoption of MAM technology.

In determining the influence that variables of cost, organisational capability, and potential job loss may have on the adoption of MAM technology within the manufacturing industry, a 7-point Likert Scale was used. Respondents were asked to indicate the extent they agreed or disagreed with the 12 statements operationalised, 4 for each variable category. The forward multiple regression model was built first, with ownership/leasing as the dependent variable (DV) and the three-variable category's operationalised statements as the independent variables (IV), to explain their functional relationship through testing of the three hypotheses. The means, standard deviations and intercorrelation are displayed in Table 11. The regressed DV resulted in only one IV (flexibility of staff) under organisational capability category, explaining the impact on MAM adoption, $F(1,13) = 5.219$, $p<0.05$ ($P=0.040$), adjusted $R^2=0.286$ (see Table 12).

However, a second computation was conducted in which a backward multiple regression equation was used to examine if more explanatory variables wont feature to test the three hypotheses. The beta weights and significance values of Model 4 ($F(6,8) = 10.143$, $p<0.1$

(p=0.1), adjusted R^2=0.855) which explained the utmost is shown in Table 13. The independent variables comprise of:

- cost of material, and cost of substitution under the cost variable,
- flexible skills of staff, technology fit, and management processes, under the organisational capability variable, and
- introduction of MAM technology, skills level, labour action, and meeting the bottom-line, under the potential job loss variable.

Table 11. Means, Standard Deviations and intercorrelation for ownership/leasing and the independent variables (cost, organisational capability, potential job loss)

Variable	Mean	SD		1	2	3	4	5	6	7	8	9	10	11	12
Dependent															
Ownership/leasing	1.80	0.414	1	0.025	-0.027	-0.178	0.325	*-0.527	*-0.535	-0.301	0.106	-0.234	0.234	-0.056	-0.109
Independent															
Cost															
1. Equipment	5.40	1.404		1	*0.612	0.269	0.390	-0.108	0.147	0.118	0.125	0.109	-0.006	-0.050	0.256
2. Material	4.93	1.280			1	*0.616	***0.748	0.106	-0.271	0.314	0.330	-0.204	-0.330	-0.359	-0.059
3. Substitution	4.13	1.552				1	0.561	0.283	-0.046	0.339	*0.441	-0.288	**-0.418	-0.331	-0.309
4. Training	3.93	1.486					1	0.347	0.050	*0.466	0.314	-0.257	-0.149	-.283	-0.353
Org. Capability															
5. Flexible skills	2.87	1.506						1	*0.479	*0.699	***0.823	*-0.481	**-0.616	*-0.481	-0.070
6. Fit	3.933	1.8696							1	*0.504	0.226	-0.032	-0.075	0.210	0.273
7. Champions	3.67	1.718								1	***0.747	-0.125	**-0.431	-0.255	-0.035
8. Management processes	3.67	1.633									1	-0.330	*-0.553	**-0.624	-0.064
Potential job loss															
9. MAM technology	4.533	1.7674										1	**0.657	***0.765	0.136
10. Skills level	4.53	1.767											1	*0.568	-0.093
11. Labour action	4.133	1.8465												1	0.203
12. Bottom line	4.33	1.589													1

*p<0.05; **p<0.01; ***p<0.001

Table 12. Forward multiple regression results

Variable	B	β	Sig.	90 % CI		R^2	Adjusted R^2	F
Model			0.04*			0.286	0.323	5219
(Constant)	2,282		0.00	1.783	2.781			
Flexibility	-0.119	-0.535	0.04*	-0.231	-0.006			

*p<0.05; **p<0.001

Table 13. Backward multiple regression results

Variable	B	β	Sig.	90 % CI		R^2	Adjusted R^2	F
Model 4			0.1			0.948	0.855	10.143
(Constant)	2.877		0.001	2.147	3.608			
Cost								
2. Material	0.179	0.554*	0.012	0.085	0.274			
3. Substitution	-0.123	-0.463*	0.040	-0.213	-0.033			
Org, Capability								
5. Flexible skills	-0.377	-1.372*	0.006	-0.545	-0.209			
6. Fit	-0.147	-0.665*	0.011	-0.223	-0.072			
8. Management	0.415	1.638*	0.005	0.239	0.591			
Potential job loss								
9. MAM tech.	0.195	0.832*	0.032	0.062	0.327			
10. Skills level	-0.079	-0.338	0.126	-0.166	0.008			
11. Labour act.	-0.197	-0.879*	0.037	-0.338	-0.056			
12. Bottom line	-0.098	-0.376*	0.040	-0.170	-0.027			

*p<0.1, **p<0.05; ***p<0.01, ***p<0.00; **Note:** Ownership/leasing is the dependent variable.

A non-parametric Mann-Whitney U test was also conducted as the forward and backward regression results drastically differed in explaining the impacts of MAM adoption. The test rejected the same null hypothesis as the forward regression model with $p<0.05$ ($p=0.040$) for two sub-variables (flexible skills and fit) under the organisational capability variable. Both sub-variables had $U = 6.500$, $Z = -2.157$ (flexible skills), and $Z = -2.030$ (fit). These results are shown in Appendix 4.1 Table 3 and Table 4, respectively.

5 DISCUSSION OF RESEARCH FINDINGS

5.1 Introduction

This section analyses and discusses findings presented in chapter 4 by linking them to AM adoption literature reviewed in chapter 2, and comparing them to the theoretical concepts, models, and frameworks identified. It establishes a link between the existing body of work and the new information obtained from this study to advance the knowledge base of MAM. The presentation of this chapter follows the order used in the previous chapter.

5.2 State of MAM adoption in South Africa's manufacturing industry

As indicated in the previous chapter, the first research question aimed at determining the current state of adoption of MAM technology within the manufacturing industry, which sectors were adopting, and their application of the technology. In addition, to identify potential or non-adopters, intended usage, as well as reasons for the uptake or non-uptake.

5.2.1 Ownership/leasing of MAM adoption (Innovation adopters)

Metal additive manufacturing in South Africa has been having traction within the research and development area through higher education and research institutions, supported by government initiatives (du Preez & de Beer, 2015). However, with much of the developments made, the adoption rate is extremely low within the manufacturing industry. Vermuelen, (2020) quantified the number of machines in the country, in which he stated that a total of 18 MAM system were available, with only 5 based in the manufacturing industry.

However, from this research study, 14,3 % of the respondents indicated that their organisation owned/leased MAM machines. The percentage number translates into 3 systems being available in the industry. Nevertheless, this number does not necessarily dispute the one quantified by Vermeulen (2020), as the number of respondents that completed the survey was not representative of the entire targeted population. Only 81% of the 21 respondents were from Gauteng and 4.8% from KwaZulu-Natal, with other provinces not represented. The 3 machines within the industry are based in Gauteng which is known as an economic hub of South Africa. The machines are owned/leased by a medium enterprise (no. of

employees = 50 to 249), and two large enterprises (no. of employees = 250+). Although the number of industry adopters of this technology was not substantial, the sizes of these organisations seem to concur with Schniederjans' (2017) argument from her study that large enterprises with resources were inclined to adopt MAM. However, Kianian, Tavassoli, Larsson T, & Diegel, (2016) may counter the previous argument, according to their study in Sweden, SME's seem to be the main driver of AM adoption. Nevertheless, it is noted that the latter authors do not specify the type of AM technology their study focused on, hence, this argument may not suffice if it were to be put up.

Rogers, (2003) described innovators as entities that adopt innovations independent from the influence of a social system and are neither risk seeking nor risk averse. The three organisations that owned/leased the MAM machines are within the aerospace, medical device, railway systems manufacturing sectors, respectively. The first two sectors are known to be leading in the uptake of MAM technology globally, hence, it was not a surprise for the appearance of companies from these manufacturing divisions, as most of their components produced are complex and bespoke. These entities (large enterprises) use their machines for rapid prototyping, while the medium enterprise's application is for both rapid prototyping and low-volume production. The three adopters seemed to understand the benefits of the technology that Cohen, (2014) mentioned in his study, as they indicated that MAM has brought added value to their respective organisations.

5.2.2 Potential adoption of MAM technology

The perceived benefits that actual and potential adopters believe they can exploit to maximise their competitiveness was presented as the driver of AM adoption by authors such as Cohen, (2014); Kunniger, (2015) and Schniederjans, (2017), among others. Therefore, the answers received have revealed that there may be some form of undestanding or familiarity amongst the 21 respondents about the benefits associated with the technology. Hence, 66,7 % of the respondents indicated that their organisation would consider owning a MAM machine. However, 78.86 % of the 66.7 % responded to the follow up questions linked to the adoption consideration question. These questions were technically related to the technology and could only be answered by respondents familiar with the technology, as they inquired about the type of MAM machine, material to be processed, as well as the its application. This meant

that there were 52.4 % potential uptakers of MAM technology in the manufacturing industry who believed that it can bring value to their organisations.

The potential uptakers of MAM technology were from different manufacturing subsectors, as well as from a common region (Gauteng), except for only one respondent from KwaZulu-Natal (see Table 14). The number one seeker of the technology was the mining and mineral processing equipment manufacturer subsector (new trend), with aerospace following behind.

Table 14. Potential adopters' industry sector and region (N=11).

Subsector	Percentage	Region
Aerospace	27.3	Gauteng
Automotive	9.1	KwaZulu-Natal
Mining and mineral processing	45.4	Gauteng
Power generation	9.1	Gauteng
Tooling	9.1	Gauteng
Total	100	

5.2.3 Factors constraining MAM adoption.

The previous section gave a picture of potential adopters of MAM technology, nonetheless, identifying factors constraining the adoption of MAM was a vital part of this study. From the results in section 4.2.1 it can be observed that at least 19 % of the 21 respondents would not consider adopting the technology. Even so, provision of reasons why they would not consider adopting was not only open to the non-adopters, but to all respondents. As a result, only 52.38 % of the 21 respondents provided reasons they believed had influence in deciding not to adopt MAM as indicated in Table 6. Several authors such as Cohen, (2014); Kunniger, (2015); Thomas, (2016); Savolainen & Collan, (2020) among others, suggested constrains that were key enablers to non adoption. These were lack of awareness, cost, organisational readiness, to mention a few. Lack of awareness was seen as the leading factor in deciding not to adopt by Cohen, (2014). However, in this study lack of awareness/no knowledge did not feature as the leading constrain, factors associated with cost and capability were seen as the main drivers. This meant that the cost of investment, material, operations, as well as substitution, and alignment of technology with business process were significant drivers of non-adoption of MAM in the South African manufacturing industry. This was consistent with assertions made by authors such as Fried, (2019) and Huckstepp, (2019).

5.3 MAM knowledge in South Africa's manufacturing industry

Although the previous section highlighted cost as a notable enabler of non-adoption of MAM, it can be argued that if the industry has no knowledge of the technology, then it would not know about the cost associated with the technology. The findings from the previous section gave the impression that most of industry organisations have knowledge of MAM technology. Well, this cannot be considered as conclusive, due to the small sample size which may have created biases. It is likely that most of the respondents that completed the survey may have prior knowledge about MAM technology.

5.3.1 Awareness of the knowledge developed.

Understanding the degree to which the industry was aware of the knowledge that has been developed about MAM technology in South Africa was also key to the determination of the industry's readiness. Rogers', (2003) DOI theory introduced a process comprised with five stages following a sequence which decision-makers go through after recognizing existence of a need and searching for an applicable solution. This is known as the innovation-decision process. Scholars such as Straub, (2009); Wisdom, Chor, Hoagwood, & Horwitz, (2014); Taherdoost, (2017) emphasised on the importance of this process and how the first stage (knowledge) was essential in starting up a process of innovation adoption.

The South African government have invested substantially into additive manufacturing, in particular the department of science and innovation which publicly funded the RD&I programmes and infrastructure developments (de Beer, et al., 2016). In order to develop a sound knowledge base and capability in AM processes, especially MAM. Considerable advancements have been made on the subject of MAM through these R&D programmes and proven capability of technology building, yet these developments seemed not to be reflecting in the manufacturing industry. Hence, examining the industry's awareness of the developments.

The presented results in section 4.2.1, highlights a different industry position (than assumed) in terms of the observed awareness of knowledge developments within MAM. Just a little over half (57 %) of the respondents claimed to be aware of these developments, and trade publications may have played a role in creating this awareness. However, only 42.9 % stated

that they subscribed to trade publication, and 55.5% of these subscribers believed that there was regular publication of MAM, yet others claiming the opposite. In reviewing Table 7 in section 4.2.1, it can be observed that trade publications were not the most effective method of creating awareness. Nonetheless, this could be counter argued, because the size of respondents that completed the survey was too small.

An assumption can be made from these results that, those respondents that indicated not to be subscribers to trade publications, and those with trade publications that do not publish MAM developments, may have become aware of the technology through other means. These other means could be from conferences held by initiatives such as RAPDASA or from other government programmes.

5.3.2 Rapid Product Development Association of South Africa (RAPDASA) Initiative

The RAPDASA initiative was formed to spearhead AM campaigns, fostering its awareness and importance for the benefit of the South African manufacturing industry to become globally relevant and competitive (de Beer, et al., 2016). This initiative was created by a network of entities from academia, research and development (R&D) institutions, as well as industry partners with interest in the technology, supported by DSI (Oyesola, Mathe, Mpofu, & Fatoba, 2018). It was important to develop an understanding of the breadth to which this initiative was creating awareness about MAM in the manufacturing industry. In finding that, 42.9 % of the 21 respondents knew about the initiative, while 38.1 % did not know, it meant that 4.8 % more organizations were familiar with RAPDASA. This variance shows that one organisation more knew about MAM technology in the industry. Can this be considered as effective? Indeed RAPDASA may be effective, that was according to the 66,7 % of the respondents (42,9 %) familiar with the initiative as seen in Table 8 of the results section. However, there was room for improvement, as RAPDASA could start conducting industry surveys in order to increase their visibility. Interest for better understanding of the knowledge product might be engendered by awareness, which can result in providing a foundation for action (Ordoñez & Serrat, 2009)

5.3.3 Other government initiatives

Although RAPDASA emanated from literature as the first initiative to drive the awareness of MAM (and AM in its entirety) in South Africa, the government had other progammes developed with some of its agencies to support the advancement of knowledge about the technology. Similarly with RAPDASA, It was important to establish the extent to which these initiatives were effective in creating awareness about MAM in the manufacturing industry. As the results presented in Table 9 of section 4.2.3, only 14.3 % of the 21 respondents knew of other goverments initiatives and provided their names, while 61.9% did not know of any(with 5 not responding). From this, an assumption could be made that other government initiatives are not as effective in creating awareness, however, this may not be a true reflection of reality due to the number of respondents who completed the survey.

5.4 Cost, organisational capability, and potential job loss' influence on MAM adoption.

Section 5.2.3 discussed the reasons that respondents in this study believed to be constraining the adoption of MAM technology in the industry. These factors coincided with some variables in the category of cost, and organisational capability posited in this study. This is indicative that determining the impact that these variables and the job loss have on MAM adoption was a step in the right direction in advancing knowledge in this field of study. Two multiple regression models were built, the forward and backward multiple regression models. Independent variables were categorised into cost, organisational capability, and fear of job loss. Each category of variables comprised of 4 operationalised statements which respondents had to agree or disagree with. This was in the form of a 7-point Likert scale, and the reliability of the data was tested as mentioned in the introduction of section 4, with Cronbach alpha coefficient testing at of 0.8, 0.832, and 0.722, respectively, which are higher than 0.65 standard minimum.

The forward multistage regression model was the first to be built, and the results are shown in Table 12, only tested hypothesis 2. These results indicated that the model did not test the other hypotheses, and they were not satisfactory. They suggested that the "technology to fit business processes" variable from the organizational capability category was the only IV that could explain ownership/leasing of MAM between machines. Hence, the backward

multistage regression model was built to examine if more explanatory variables would test all three hypotheses. The correlation test was included in this model. Therefore, Table 11 in section 4.3 shows the means, standard deviations and intercorrelation of ownership/leasing and the independent variables categories (cost, organisational capability, potential Job loss). It can be noted that there was a negative correlation between ownership/leasing and two IVs from the category of organisational capability, flexible skills of staff $p<0.05$ ($p=0.022$), $r = -0.527$; and technology fit to business processes $p<0.05$ ($p=0.02$), $r = -0.535$. However, all the other variables did not correlate with the DV. This correlation test results seem to agree with the forward regression outcomes.

The backward multiple regression model led to the selection of the most suitable model from the 7 iterations computed, which was Model 4 shown in Table 13 in section 4.3. The independent variables have significant causal relationship with the dependent variable, $F(9,5) = 10.143$, $p<0.1$ ($p=0.1$), which indicated the three categories of factors (cost, organisational capability, and potential job loss) having a significant impact on ownership/leasing of MAM machines. In addition, the model explained 94.8 % of the variance on ownership/leasing. The ownership/leasing variable translates to MAM technology adoption. Therefore, this infers that causal relationship between cost, organisational capability, and potential job loss with MAM adoption exists, and these factors have a significant impact on the uptake or non-uptake of the technology.

5.4.1 Impact of cost – Hypothesis 1

H o: Evidence indicate that cost does not have any impact on the adoption of MAM technology.

H a: There is clear evidence that cost has a significant impact on the adoption of MAM technology.

The cost category variable comprised of 4 statements which tested hypothesis 1. From the 4 variables, only two rejected the null hypothesis, cost of material, $B=0.179$, $p<0.05$ ($p=0.012$), as well as cost of substitution, $B=-0.123$, $p<0.05$ ($P=0.04$) as presented in Table 13. The most influential variable in this category was cost of material with a beta (β) of 0.554. This suggests that cost has a significant impact on the adoption of MAM technology in the manufacturing

industry, particularly the material cost. Huckstepp, (2019) had alluded that one of the major cost drivers of MAM technology was the material cost as most technologies require sole source purchasing of feedstock from their developers at high margins due to the intellectual property attached to the equipment.

The cost of subtitution, though not highly influential as the material cost, but it had impact in this regard. Thomas & Gilbert, (2014); Huckstepp, (2019) mentioned that investments made by organisations to fully develop their current functions made it difficult to adopt MAM technology, as they may not want to lose their return on investment. Most respondents in this study agreed with the statement relating to this issue of cost of substitution. However, understanding the application of MAM technology, its benefits, and how it would fit business processes will highlight its relevance to the potential adopter. Therefore, this will assist in making an informed decision on whether to adopt or not.

5.4.2 Impact of organisational capability – Hypothesis 2

H o: Organisational capability negatively impact the adoption of MAM technology.

H a: Organisational capability does not negatively impact the adoption of MAM technology.

Similarly, to the cost variable category, organisational capability variable had 4 statements to test hypothesis 2, in which three of them rejected the null hypothesis and the alternative was true. These were flexible skills of staff, B=-0.377, $p<0.05$ ($p=0.006$); technology fit to business processes B=-0.147, $p<0.05$ ($p=0.011$); and management processes B=0.415, $p<0.05$ ($p=0.005$) as shown in Table 13. This variable category's impact is highly significant in explaining the causal relationship between its variables and MAM adoption, in which management processes was the most influential among the three. Cohen, (2014) had stated that MAM technology will bring new challenges to organisations that will require new management processes (among others) should there be consideration to adopt.

Organisational capability is somewhat related to the compatibility variable from DOI theory and facilitating conditions from UTAUT theory. It is so because organisational capability is the uniqueness of skills, processes, human abilities, and technologies that differentiate an entity. Compatibility as Rogers, (2003) defined it, is "the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential

adopters" (p.16). When considering this definition and fusing it to organizational capability, it then becomes the extent to which organisations perceive MAM technology to be consistent with the uniquely flexible skills of staff, its alignment to fit business processes, as well as the agility of management processes for its adoption.

5.4.3 Impact of potential job loss – Hypothesis 3

H o: There is no relationship between potential job loss and the adoption of MAM technology.

H a: There is a clear relationship between potential job loss and the adoption of MAM technology.

According to Hlatshwayo, (2017) technological advancement has been identified to have led to job loss in the past. With Sutherland, (2020) stating that the adoption impact will heighten the unemployment rate in countries such as South Africa, diminishing the demand for low level skills, while escalating the level of inequality.

Three of the 4 statements from the potential job loss variable category rejected the null hypothesis. These were, introduction of new technology, B= 0.195, $p<0.05$ ($p=0.032$); fear of labour actions B= -0.197, $p<0.05$ ($p=0.374$); and achieving the bottom-line, B=-0.098, $p<0.05$ ($p=0.040$) as indicated in Table 13. Introduction of new technology came out as the most influential variable in this category with $\beta = 0.832$. This variable assessed if respondents agreed that "it was a known fact that introduction of MAM technology would lead to job loss in their organisations". Most of the responses disagreed with the statement, this revealed that, although introduction of MAM technology had significant impact on its adoption, they did not believe that it will lead to job loss.

The fear of labour action statement in this variable category measured if organizations would base their decision to adopt or not adopt on this aspect as the technology is known to be less labour-intensive. Numerous responses alluded that fear of labour action was not necessarily a deciding factor, though it had an impact. However, the same argument as Hlatshwayo (2017) that South Africa was a highly unionised country and labour organizations treat technology innovation as contested terrain can be placed. Therefore, this assertion needs to

be hugely considered by potential adopters, as the realization of what adopting MAM would mean to other stakeholders may create friction.

The bottom-line statement sought to measure that if pursuing profits was the most vital factor in organisations, to the extent that MAM technology could be adopted, and jobs are lost. The response disagreed with the statement, thus, indicating that the bottom-line was critical but not to the degree that it can perpetuate the already high unemployment rate in the country.

6 CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

This section of the study summarises and concludes the research study, as well as provides existing limitations, and recommendations for continuation of the research.

6.1 Conclusions

The study's purpose was to help gain an understanding of the South African manufacturing industry's readiness to adopt locally developed MAM technology, as the industry holds a very crucial role in commercialisation of the technology. Three research questions were posed that this study intended to answer—that is, 1. 'To what extent has the South African manufacturing industry adopted MAM technology?', 2. 'Is knowledge of MAM technology effectively disseminated in South Africa, particularly in the manufacturing industry?', and 3. 'What impact does cost, organisational capability, and potential job loss have on MAM technology adoption in SA's manufacturing industry?

The researcher employed a quantitative research approach, in which cross-sectional design survey was adopted to conduct the interrogation, guided by innovation diffusion theories, particularly DOI. The study was descriptive and explanatory in nature, therefore, descriptive analysis was applied to the former to determine the current state of MAM adoption and if the knowledge about the technology was effectively disseminated. Backward multiple regression was used for the explanatory part as the study sought to determine if cost, organisational capability, and potential job loss had impact on the adoption of the technology within the industry. The focus was on organisations that produce metal-based components using traditional manufacturing processes.

The findings for the first research question suggests that the state of MAM adoption within the South African manufacturing industry is still low, with only three machines owned/leased contrary to the five mentioned in the literature review (section 2.1). However, this variation cannot be conclusive due to the number of responses received in this study. Organisations owning these machines are classified as medium and large enterprises and are within the aerospace, medical device, railway systems manufacturing sectors, respectively, all based in Gauteng province. Nonetheless, there is 52.4 % of potential adopters (from the sample) that

are likely to uptake the technology, who believe it can bring value-add to their organisations. The potential uptakers of MAM technology are from different manufacturing subsectors, as well as from a common region (Gauteng), except for only one respondent from KwaZulu-Natal. The number one sector seeking the technology is the mining and mineral processing equipment manufacturer (new trend), with the aerospace sector following behind.

The non-uptakers of the machine provided reason they believed would lead or led them to non consideration of MAM adoption, other respondents as well gave their view. Therefore, 52.38 % of the sample respondents providing reasons such as, cost of investment, material, operations, as well as substitution, and alignment of technology with business process to be significant drivers of non-adoption of MAM in the South African manufacturing industry.

The second research question's findings indicated that there was some headway in how effectively knowledge is disseminated, as 57% of the sample had some knowledge about MAM technology and this was through subscriptions of trade publications, RAPDASA, and other government initiatives in South Africa. However, drilling down to awareness of how they became aware, not all organisations subscribed to trade publications relevant to MAM, not all were aware of RAPDASA, and other government initiatives. The sample was spread with a combination of organisation who knew either through all or one of the means of dissemination available in the country.

On the last research question, the findings infer that causal relationship between cost, organisational capability, and potential job loss with MAM adoption exists, and these factors have a significant impact on the uptake or non-uptake of the technology. This indicates that organisations decisions to adopt or not adopt MAM are influenced by these factors. With organisational capability significantly having impact on these decisions in comparison to cost and potential job loss.

In conclusion the findings above give the impression that the South African manufacturing industry may be ready for adoption of MAM technology, however, this cannot be a conclusive position due to limitations indicated below, since the results would be difficult to generalise.

6.2 Limitations

The first limitation of this study is with regards to limited information available about industry adoption of MAM technology in South Africa, however, this is not only specific to this country. It seems to be a global phenomenon, the information available is of the wider AM technology platform, which include all types of AM technologies, hence, the use of literature on AM not MAM technology for the literature review.

The second limitation was the response rate, which was found to have constrained the study, as it was too low than expected. It led to an analysis of responses from a small sample size that participated in the survey, creating results credibility issues. Most responses were from the Gauteng province and only one from KwaZulu-Natal. Hence, the study could not be adjusted to the former province, as a similar investigation was done by Kunniger, (2015) and was limited to Gauteng. This study required coverage of all the nine provinces in South Africa.

Although, significant relationships could be inferred among the variables in this study, two regression methods of data analysis were tested to get to the results. These analysis methods were built for the explanatory section of the study to get the most suited model that tested the three hypotheses. These were forward multiple regression with results that were unsatisfactory, and backward multiple regression analysis which produced a model that could test all three hypotheses. The findings of this study should be viewed within the context of the data analysed.

This study's required higher hierarchy levels respondents representing their organisations e.g., manufacturing industry executives, directors, managers and non-managerial (technical) experts. Therefore, most of the sent requests for participation of the survey were to company chief executive officers (CEO's), managing directors (MDs). This may have contributed to the low response rate, coupled with the COVID 19 pandemic.

6.3 Recommendations for future research

In this study, limited understanding of the readiness of the South African manufacturing industry was established. This was due to the low industry response rate that led to the analysis of a small sample size, which was attributed to by the listed limitations in the previous section. The researcher recommends that this study be conducted for a longer period than the prescribed dissertation time of the MBA, perhaps it could become a study for either a Master of Science degree (MSc) or Doctor of Philosophy (PHD). It will require support of stakeholders involved with MAM technology in South Africa i.e., DSI, HEIs, CSIR, RAPDASA, and the manufacturing industry.

Further studies that can be conducted within the context of MAM technology adoption in SA's manufacturing industry, is the impact that the technology may have in the development of SMEs. The technology value-chain provides an opportunity in areas such as hardware (machine building), software development, material supply, and service provision. Adoption of the technology in Asia, Americas, and Europe is growing at a rapid pace as many SMEs are entering the market and having significant support from their governments and large enterprises. Therefore, other aspect that will require to be considered in relation to the above is the available policies and funding models from the South African government to support these SMEs.

REFERENCES

Ajzen, I. (1991, December). The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processe, 50*(2), 179-211. doi:10.1016/0749-5978(91)90020-T

Akinsowon, V. (2019). *The Additive Manufacturing Landscape 2019: Essential Insights into the Additive Manufacturing Market, Key Trends and Analyses.* London: AMFG. Retrieved September 14, 2021, from https://amfg.ai/wp-content/uploads/2019/08/The-Additive-Manufacturing-Landscape-2019_Whitepaper.pdf

Alabi, M. O., de Beer, D., & Wichers, H. (2019). Applications of additive manufacturing at selected South African universities: promoting additive manufacturing education. *Rapid Prototyping Journal, 25*(4), 752-764.

AMFG. (2019, October 08). *10 of the Biggest Challenges in Scaling Additive Manufacturing for Production [Expert Roundup]*. Retrieved September 22, 2020, from amfg.ai: https://amfg.ai/2019/10/08/10-of-the-biggest-challenges-in-scaling-additive-manufacturing-for-production-expert-roundup/

Bambale, A. J. (2014). Research Methodological Techniques as a Model for Quantitative Studies in Social Sciences. *British Journal of Economics, Management & Trade, 4*(6), 862-879.

Bandura, A. (1986). *Social foundations of thought and action: a social cognitive theory.* Englewood Cliffs, NJ: Prentice-Hall.

Bass, F. (2004). A new product growth for model consumer durables. *Management Science, 50*(12), 1825-1832. doi:10.1287/mnsc.1040.0264

Bhattacharjya, J., Tripathi, S., Taylor, A., Taylor, M., & Walters, D. (2014). Additive Manufacturing: Current Status and Future Prospects. *IFIP International Federation for Information Processing*, 365-372.

Bizzconnect. (n.d.). *SWOT analysis of the manufacturing industry*. Retrieved August 09, 2020, from Standard Bank Bizzconnect: https://bizconnect.standardbank.co.za/sector-news/manufacturing/guides/swot-analysis-of-the-manufacturing-industry.aspx

Bleijenbergh, I., Korzilius, H., & Verschuren, P. (2011). Methodological criteria for the internal validity and utility of practice oriented research. *Quality and Quantity International Journal of Methodology, 45*, 145-156. doi: 10.1007/s11135-010-9361-5

Brotherton, B. (2015). *Researching Hospitality and Tourism* (2 ed.). London: SAGE.

Brownson, R. C., Eyler, A. A., Harris, J. K., Moore, J. B., & Tabak, R. G. (2018). Getting theWord Out: New Approaches for Disseminating Public Health Science. *Journal of Public Health Management and Practice*, 102-111. doi:10.1097/PHH.0000000000000673

Bryman, A. (2012). *Social Research Methods* (4 ed.). Oxford: Oxford University Press.

Cambridge-Dictionary. (2019, October 16). *Meaning of moral in English*. Retrieved October 22, 2019, from https://dictionary.cambridge.org/dictionary/english/moral: https://dictionary.cambridge.org/dictionary/english/moral

Campbell, T. A., & Ivanova, O. S. (2013). Additive Manufacturing as a Disruptive Technology: Implications of Three-Dimensional Printing. *Technology and Innovation, 15*, 67-79. doi:10.3727/194982413X13608676060655

Cohen, D. L. (2014). Fostering Mainstream Adoption of Industrial 3D Printing: Understanding the Benefits and Promoting Organizational Readiness. *Mary Ann Liebert, Inc., 1*(2), 62-69. doi:10.1089/3dp.2014.0007

Cohen, D. L., George, K., & Shaw, C. (2014). Are you ready for 3D printing? *Mckinsey Quartely*(4), pp. 20-23. Retrieved from https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/mckinsey-quarterly-2014-number-4-overview-and-full-issue

Creswell, J. W. (2014). *Research Design: Qualitative, Quantitative, And Mixed Methods Approaches* (4 ed.). Los Angeles: SAGE.

Davis, F. D. (1985). *A TECHNOLOGY ACCEPTANCE MODEL FOR EMPIRICALLY TESTING NEW END-USER INFORMATION SYSTEMS: THEORY AND RESULTS.* Sloan School of Management. Cambridge: Massachusetts Institute of Technology. Retrieved from https://www.researchgate.net/publication/35465050

de Beer, D. J. (2011). Establishment of rapid prototyping/additive manufacturing in South Africa. *Journal of South African Institute of mining and metallurgy, 111*(3), 211-215.

de Beer, D., Dupreez, W., Greyling, H., Prinsloo, F., Sciammarella, F., Trollip, N., & Vermuelen, M. W. (2016). *A South African Additive Manufacturing Strategy*. Tshwane: Department of Science and Technology. Retrieved from https://nipmo.dst.gov.za/impact/3d-printing

Ding, C.-S., Hsieh, C.-T., Wu, Q., & Pedram, M. (1996). Stratified Random Sampling for Power Estimation*. *Proceedings of International Conference on Computer Aided Design* (pp. 576-582). San Jose: IEEE. doi:10.1109/ICCAD.1996.569913.

du Preez, W., & de Beer, D. (2015). Implementing The South African Additive Manufacturing Technology Roadmap - The Role of an Additive Manufacturing Centre of Competence. *South African Journal of Industrial Engineering August, 26*(2), 85-92.

Dustman, E., Elwakil, K., & Smart, M. (2019). *Metals 3D Printing: Closing the gap and getting to value.* New York: PwC. Retrieved September 14, 2021, from https://www.strategyand.pwc.com/gx/en/insights/2019/metals-3D-printing/metals-3d-printing.pdf

Duvenage, B. J. (2019). *Towards a Conceptual Framework for the Identification & Implementation of Additive Manufacturing Standards.* Cape Town: Stellenbosch University. Retrieved September 24, 2020, from http://scholar.sun.ac.za/handle/10019.1/106104

Dwivedi, Y. K., Rana, N. P., Jeyaraj, A., Clement, M., & Williams, M. D. (2019). Re-examining the Unified Theory of Acceptance and Use of Technology (UTAUT): Towards a Revised Theoretical Model. *Information Systems Frontiers, 21*, 719-734. doi:10.1007/s10796-017-9774-y

Flor, C. R., & Hansen, S. L. (2013). Technological advances and the decision to invest. *Annals of finance, 9*, 383-420. doi:10.1007/s10436-012-0191-4

Frazier, E. W. (2014). Metal Additive Manufacturing: A Review. *Journal of Materials Engineering and Performance, 23*(6), 1917-1928.

Fried, S. (2019, April 25). *Additive Manufacturing Cost Drivers: 4 Key Considerations*. Retrieved September 13, 2020, from nano-di.com: https://www.nano-di.com/blog/2019-additive-manufacturing-cost-drivers-4-key-considerations#:~:text=The%20cost%20drivers%20associated%20with,three%20of%20these%20critical%20areas.

Gagnon, M. L. (2011). Moving knowledge to action through dissemination and exchang. *Journal of Clinical Epidemiology, 64*, 25-31. doi:10.1016/j.jclinepi.2009.08.013

Gibson, I., Rosen, D., & Stucker, B. (2015). Directed Energy Deposition Processes. In *Additive Manufacturing Technologies* (pp. 245-268). New York: Springer.

Godina, R., Ferreira, I. A., Brás, I., Espadinha-Cruz, P., & Matos, F. (2019). Knowledge Management and Additive Manufacturing Technology: A literature review. *ECKM 2019 20th European Conference on Knowledge Management* (pp. 398-404). Lisbon, Portugal: Academic Conferences Limited.

Godina, R., Ribeiro, I., Matos, F., Ferreira, B. T., Carvalho, H., & Peças, P. (2020). Impact Assessment of Additive Manufacturing on Sustainable Business Models in Industry 4.0 Context. *Sustainability, 12*(17), 7066. doi:10.3390/su12177066

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report, 8*(4), 597-607. Retrieved from http://www.nova.edu/ssss/QR/QR8-4/golafshani.pdf

Green, L. W., Ottoson, J. M., García, C., & Hiatt, R. A. (2009). Diffusion theory and knowledge dissemination, utilization, and integration in public health. *Annual Review of public health, 30*, 151-174. doi:10.1146/annurev.publhealth.031308.100049

Hase, S. (2000). Measuring organisational capability. *AVETRA conference*, (pp. 1-6). Rydges. Retrieved from Http://www.avetra.org.au/Conference_Archives/2000/abstracts.shtml.

Hassinger, E. (1959). Stages in the adoption process. *Rural Sociology, 24*, 52-53.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-Based Nursing, 18*, 66-67. doi:10.1136/eb-2015-102129

Hlatshwayo, M. (2017, May 31). Technological Changes and Manufacturing Unions in South Africa: Failure to Formulate a Robust Response. *Global Labour Journal, 8*(2), 100-119. doi:https://doi.org/10.15173/glj.v8i2.2896

Hollenstein, H. (2004). Determinants of the adoption of Information and Communication Technologies (ICT) An empirical analysis based on firm-level data for the Swiss business sector. *Structural Change and Economic Dynamics, 15*, 315-342. doi:10.1016/j.strueco.2004.01.003

Huckstepp, A. (2019, January 31). *Economics of Metal Additive Manufacturing*. Retrieved September 24, 2020, from digitalalloys.com: https://www.digitalalloys.com/blog/economics-metal-additive-manufacturing/#:~:text=Material%20costs%20can%20be%20subdivided,%2C%20waste%20material%2C%20and%20consumables.&text=The%20metals%20used%20by%203D,kg%20for%20high%2Dquality%20powder.

Johnson, G., Whittington, R., Scholes, K., Angwin, D., & Regnér, P. (2017). *Exploring Strategy: Text and Cases* (11 ed.). Harlow: Pearson.

Karevska, S., Steinberg, G., Müller, A., Wienken, R., Kilger, C., & Krauss. (2019). *3D Printing: Hype or game changer*. London: EY. Retrieved September 14, 2021, from https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/advisory/ey-3d-printing-game-changer.pdf

Kianian, B., Tavassoli, S., Larsson T, C., & Diegel, O. (2016). The Adoption of Additive Manufacturing Technology in Sweden. *13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource* (pp. 7-12). Binh Duong New City: Elsevier B.V. doi:10.1016/j.procir.2016.01.036

Kivunja, C., & Kuyini, A. B. (2017). Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education, 6*(5), 26-41. doi:10.5430/ijhe.v6n5p26

Kunniger, D. (2015). *Diffussion of additive manufacturing in Gauteng, South Africa.* Gordons Institute of Business Science. Tshwane: University of Pretoria. Retrieved from http://hdl.handle.net/2263/52427

Kunniger, D., & Walwyn, D. (2017, January). Weaknesses in policy to support technology diffusion: a study of additive manufacturing in South Africa. *International Journal*

of Technological Learning, Innovation and Development, 9(2). doi:10.1504/IJTLID.2017.10005918

Larsen, G. D. (2011). Unsderstanding the early stages of innovation diffussion process: awareness, influence and communication networks. *Construction Management and Economics, 29*(10), 987-1002. doi: 10.1080/01446193.2011.619994

Lavrakas, P. J. (2008). *The SAGE Encyclopedia of Survey Research Methods.* Thousand Oaks, CA: SAGE Publications Inc. doi:10.4135/9781412963947

Leedy, P. D., & Ormrod, J. E. (2015). *Practical Research Planning and Design* (11 ed.). London: Pearson Education Limited.

Lucas, J. W. (2003, September). Theory-Testing, Generalization, and the Problem of External Validity. *Sociological Theory, 21*(3), 236-253.

Mellor, S., Hao, L., & Zhang, D. (2014). Additive manufacturing: A framework for implementation. *International Journal of Production Economics, 149*(1), 194-201. doi:10.1016/j.ijpe.2013.07.008

Mohajan, H. K. (2017). Two Criteria for Good Measurements in Research: Validity and Reliability. *Annals of Spiru Haret University, 17*(3), 58-82.

Niaki, M. K., & Nonino, F. (2017). Impact of additive manufacturing on business competitiveness: a multiple case study. *Journal of Manufacturing Technology Management, 28*(1), 56-74. doi:0.1108/JMTM-01-2016-0001

Nussbaum, M. C. (2011). *Creating Capabilities: The Human Development Approach.* Massachusetts: Harvard University Press.

Ordoñez, M., & Serrat, O. (2009). *Disseminating knowledge products.* Manila: Asian Development Bank. Retrieved September 19, 2020, from https://www.adb.org/sites/default/files/publication/27581/disseminating-knowledge-products.pdf

Otettmeier, K., & Hofmann, E. (2017). Additive manufacturing technology adoption: an empirical analysis of general and supply chain-related determinants. *Journal for Business Economics*, 97-124. doi:DOI 10.1007/s11573-016-0806-8

Oyesola, M., Mathe, N., Mpofu, K., & Fatoba, S. (2018). Sustainability of Additive Manufacturing for the South African aerospaceindustry: A business model for laser technology production, commercialization and market prospects. *Procedia*

CIRP. *72*, pp. 1530-1535. Stockholm: Elsevier B.V. doi:10.1016/j.procir.2018.03.072

Park, Y. S., Konge, L., & Artino Jr, A. R. (2020, May). The Positivism Paradigm of Research. *Academic Medicine*, *95*(5), 690-694.

Patino, C. M., & Ferreira, J. C. (2018). Internal and external validity: can you apply research study results to your patients? *Jornal Brasileiro de Pneumologia*, 183. doi: 10.1590/S1806-37562018000000164

Price, P. C., Jhangiani, R. S., & Chiang, I.-C. A. (2015). *Research Methods in Psychology* (2 Canadian ed.). Creative Commons Attribution NonCommercial ShareAlike. Retrieved from https://opentextbc.ca/researchmethods/

Proff, H., & Staffen, A. (2019). *Challenges of additive manufacturing: Why companies don't use additive manufacturing in serial production.* Deloitte. Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/de/Documents/operations/Deloitte_Challenges_of_Additive_Manufacturing.pdf

Project Aeroswift. (2020). Retrieved 09 20, 2020, from www.csir.co.za: https://www.csir.co.za/project-aeroswift

RAPDASA. (2019, November 5). *RAPDASA AM TECHNOLOGY DEVELOPMENT*. Retrieved September 18, 2020, from site.rapdasa.org: https://site.rapdasa.org/rapdasa-am-technology-development/

Roberti, G., & Spasova, G. (2019). *3D Printing: Top 5 Trends in 2019.* London: IDC. Retrieved September 14, 2021, from https://www.uk.idc.com/idc-ebooks/RESOURCES/ATTACHMENTS/ebooks/3d_printing_-_ebook_-_5_trends_in_2019.pdf

Rogers, E. (2003). *Diffusion of innovations* (5 ed.). New York: Free Press.

Saunders, M., Lewis, P., & Lewis, P. (2007). *Research Methods for Business Students* (4 ed.). Harlow: Prentice Hall.

Savolainen, J., & Collan, M. (2020). How Additive Manufacturing Technology Changes Business Models? – Review of Literature. *Additive Manufacturing*, 1-13. doi:10.1016/j.addma.2020.101070

Schniederjans, D. G. (2017). Adoption of 3D-printing technologies in manufacturing: A survey analysis. *International Journal of Production Economics, 183*(1), 278-298.

Sheppard, B. H., Hartwick, J., & Warshaw, P. R. (1988). The Theory of Reasoned Action: A Meta-Analysis of Past Research with Recommendations for Modifications and Future Research. *Journal of Consumer Research, 15*(3), 325-343. Retrieved from https://doi.org/10.1086/209170

sisu. (n.d.). *Research data management*. Retrieved Nov 5, 2020, from https://sisu.ut.ee/: https://sisu.ut.ee/rdm_course1/data-collection-processing-and-analysis#:~:text=Data%20processing%3A%20A%20series%20of,output%20form%20for%20subsequent%20use.&text=Data%20Analys

Smallwood, N., & Ulrich, D. (2004). Capitalizing on Capabilities. *Havard Business Review -Accounting*. Retrieved from https://hbr.org/2004/06/capitalizing-on-capabilities

statssa.(a). (2019, February 12). *Manufacturing: winners and losers of 2018*. Retrieved August 09, 2020, from Statistics South Africa: http://www.statssa.gov.za/?p=11890

statssa.(b). (2020). *Quarterly Labour Force Survey.* Statistics South Africa. Pretoria: Statistics South Africa. Retrieved August 30, 2020, from http://www.statssa.gov.za/publications/P0211/P02111stQuarter2020.pdf

Stiglitz, J. E. (2014). Ethics, Economic Advice, and Economic Policy. In G. F. DeMartino, & D. McCloskey, *The Oxford Handbook of Professional Economic Ethics* (pp. 495-519).

Straub, E. T. (2009). Understanding Technology Adoption: Theory and Future Directions for Informal Learning. *Review of Educational Research, 79*(2), 625-649. doi:10.3102/0034654308325896

Sutherland, E. (2020). The Fourth Industrial Revolution – The Case of South Africa. *Politikon, 47*(2), 233-252. doi: 10.1080/02589346.2019.1696003

Taherdoost, H. (2016). Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. *International Journal of Academic Research in Management, 5*(2), 18-27.

Taherdoost, H. (2017). A review of technology acceptance and adoption models and theories. *Procedia Manufacturing. 22,* pp. 960-967. Tirgu-Mures: Elsevier B.V. doi:10.1016/j.promfg.2018.03.137

Tavassoli, S., Brandt, M., Qian, M., Arenius, P., Kianian, B., Diegel, O., . . . Pope, L. (2020). Adoption and Diffusion of Disruptive Technologies: The Case of Additive Manufacturing in Medical Technology Industry in Australia. *17th Global Conference on Sustainable Manufacturing* (pp. 18-24). Shanghai: Procedia Manufacturing. doi:10.1016/j.promfg.2020.02.103

Taylor, S., & Todd, P. A. (1995). Understanding Information Technology Usage: A Test of Competing Models. *Information Systems Research, 6*(2), 144-176. Retrieved from https://doi.org/10.1287/isre.6.2.144

Thomas, D. (2016). Costs, benefits, and adoption of additive manufacturing: a supply chain perspective. *International Journal of Advanced Manufacturing Technology, 85*, 1857–1876. doi:10.1007/s00170-015-7973-6

Thomas, D., & Gilbert, S. W. (2014). *Costs and Cost Effectiveness of Additive Manufacturing.* NIST, Commerce. NIST. doi:10.6028/NIST.SP.1176

Thompson, R. L., Higgins, C. A., & Howell, J. M. (1991, March). Personal Computing: Toward a Conceptual Model of Utilization. *MIS Quarterly, 15*(1), 125-143. doi:10.2307/249443

Titanium Pilot Plant. (2020). Retrieved 09 20, 2020, from csir.co.za: https://www.csir.co.za/titanium-pilot-plant

Tuli, F. (2010). The Basis of Distinction Between Qualitative and Quantitative Research in Social Science: Reflection on Ontological, Epistemological and Methodological Perspectives. *Ethopian Journal of Education Sciences, 6*(1), 97-108. doi: 10.4314/ejesc.v6i1.65384

Vallerand, R. J. (1997). Towards a hierarchical model of intrinsic and extrinsic motivation. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology* (Vol. 29, pp. 271–360). San Diego: Academic Press. doi:10.1016/s0065-2601(08)60019-2

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003, September). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly, 27*(3), 425-478. doi:10.2307/30036540

Venkatesh, V., Thong, J. Y., & Xu, X. (2016). Unified Theory of Acceptance and Use of Technology: A Synthesis and the Road Ahead. *Journal Association for Information Systems, 17*(5), 328-376. Retrieved from http://www.vvenkatesh.com/wp-content/uploads/dlm_uploads/2016/01/2016_JAIS_Venkatesh-et-al.-UTAUT.pdf

Vermuelen, M. W. (2020, 09 22). How many metal additive manufacturing systems are available currently in South Africa? (O. Sono, Interviewer)

Watt, P. (1998). *Foresight Manufacturing Report.* https://www.dst.gov.za/images/pdfs/FORESIGHT%20MANUFACTURING%20REPORT.pdf: Department of Science and Technology. Retrieved March 6, 2020

Wei, C., Sun, Z., Huang, Y., & Li, L. (2018). Embedding anti-counterfeiting features in metallic components via multiple material additive manufacturing. *Additive Manufacturing, 24*, 1-12. doi:10.1016/j.addma.2018.09.003

Weller, C., Kleer, R., & Piller, F. (2015). Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. *International Journal for Production Economics, 164*, 43-56. doi:10.1016/j.ijpe.2015.02.020

Williams, C. (2007). Research Methods. *Journal of Business & Economic Research, 5*(3), 65-72.

Williams, G., Cunningham, S., & de Beer, D. (2014). Advanced Manufacturing and Jobs in South Africa: An Examination of Perceptions and Trends. *International Conference on Manufacturing-Led Growth for Employment and Equality*, (pp. 1-36). Johannesburg. Retrieved September 24, 2020, from http://www.tips.org.za/files/advanced_manufacturing_and_jobs_in_south_africa_140301_williams_cunninham_de_beer_0.pdf

Williams, M. D., Rana, N. P., Dwivedi, Y. K., & Lal, B. (2011). Is UTAUT really used or just cited for the sake of it? A systematic review of citations of UTAUT's article. *ECIS 2011. 231.* Helsinki: Association for information systems. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1230&context=ecis2011

Wisdom, J. P., Chor, K. H., Hoagwood, K. E., & Horwitz, S. M. (2014). Innovation Adoption: A Review of Theories and Constructs. *Administration and Policy in Mental Health, 41*, 480-502. doi:10.1007/s10488-013-0486-4

Wohlers, T. (2015, November 08). *Wohlers Talk: Progress in South Africa*. Retrieved September 22, 2020, from wohlersassociates.com: https://wohlersassociates.com/blog/2015/11/progress-in-south-africa/

Word-Bank. (2017). *Innovation for Productivity and Inclusiveness.* Washngton DC: The World Bank.

Zanello, G., Fu, X., Mohnen, P., & Ventresca, M. (2016). The creation and diffusion of innovation in developing countries: A Systematic literature review. *Journal of Economic Surveys, 30*(5), 884-912. doi: 10.1111/joes.12126

APPENDICES

Appendix 1.1: Data collection instrument(s)

Start of Block: Default Question Block

Dear participant

My name is Oscar Sono, and I am a master's student at Wits Business School, registered for a Master of Business Administration (MBA). I am currently conducting a survey study for my master's dissertation titled "Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness". The purpose of this study is to evaluate the readiness of the South African manufacturing industry to adopt metal based additive manufacturing technology developed locally. The objective of the study is to measure the extent to which metal based additive manufacturing occurs in South Africa and under which manufacturing clusters that produce and/or refurbish metal components or products. Further, the study seeks to determine if knowledge generated about the technology in the country is disseminated effectively. In addition, examine factors that may be driving or constraining the adoption of the technology within the SA's manufacturing industry. The focus is on organizations that produce and refurbish metal-based components using traditional manufacturing processes.

The study has received ethical clearance from the University of Witwatersrand ethics committee in terms of meeting the research ethics requirements. Thus:

- Participation in this study is completely voluntary, and there will not be any direct benefit in taking part.
- There will be no discrimination, disadvantage, or penalties for non-participation.
- Withdrawing from the study is possible at any time and choosing not to answer any question as wished is also possible.
- The survey is completely confidential and anonymous, no personal details are required.
- The information obtained will be secured by the researcher only, and it will not be disclosed to anyone else.

If you would like more information on the study or have any queries, please feel free to contact me (1133278@students.wits.ac.za) or my supervisors Dr K Wotela (kambidima.wotela@wits.ac.za) and Mr J George (934478@students.wits.ac.za). Your participation is greatly appreciated.

Kind Regards

Oscar Sono: MBA candidate

1 General Information

1.1 Please indicate the province your organization is based.

- ☐ EC (1)
- ☐ FS (2)
- ☐ GP (3)
- ☐ KZN (4)
- ☐ LP (5)
- ☐ MP (6)
- ☐ NC (7)
- ☐ NW (8)
- ☐ WC (9)

1.2 Please indicate which industry is core to your organisation.

- ☐ Aerospace (1)
- ☐ Automotive (2)
- ☐ Electronic devices (3)
- ☐ Medical devices (4)
- ☐ Mining & mineral processing equipment (5)
- ☐ Tooling (6)
- ☐ Jewellery (7)
- ☐ Other (8)

1.2.1 If other in 1.2, please add below.

_____

1.3 Please indicate size of your organization.

- ☐ 2 to 10 employees (1)
- ☐ 11 to 49 employees (2)
- ☐ 50 to 250 employees (3)
- ☐ 251+ employees (4)

1.4 Please indicate years of operation.

- [ ] 1 to 5 yrs (1)
- [ ] 5 to 10 yrs (2)
- [ ] 10 yrs + (3)

End of Block: Default Question Block

Start of Block: Block 1

2 This section is for testing the extent to which MAM adoption occurs in South Africa's manufacturing industry.

2.1 Does your company own or lease a metal based additive machine (3D Printing machine)

- [ ] Yes (1)
- [ ] No (2)

2.1.1 If yes above, what type of machine is it? (if no, please proceed to 2.2)

- [ ] Direct energy deposition (1)
- [ ] Powder bed fusion (2)
- [ ] Sheet lamination (3)

2.1.2 What type of material do you process on the machine?

- [ ] Aluminium (1)
- [ ] Aluminium alloys (2)
- [ ] Cobalt chrome alloys (3)
- [ ] Nickel-based Alloys (4)
- [ ] Precious metals (5)
- [ ] Stainless Steel (6)
- [ ] Titanium (7)
- [ ] Titanium alloys (8)

2.1.3 What application is the machine used for?

- [ ] Rapid prototyping (1)
- [ ] Research & development (2)
- [ ] Low volume part production (3)
- [ ] Rapid prototyping and low volume part production (4)
- [ ] High volume part production (5)
- [ ] Refurbishment of metal parts (6)

2.1.4 Has the technology brought added value in your company?

- [ ] Yes (1)
- [ ] No (2)

End of Block: Block 1

Start of Block: Block 2

2.2 Would your company consider owning a metal based additive manufacturing machine in the near future?

- [ ] Yes (1)
- [ ] No (2)

2.2.1 If yes above, what type of machine will you consider? (if no, please proceed to section 2.3)

- [ ] Direct energy deposition (1)
- [ ] Powder bed fusion (2)
- [ ] Sheet lamination (3)

2.2.2 What type of material should the machine process?

- [ ] Aluminium (1)
- [ ] Aluminium alloys (2)
- [ ] Cobalt chrome alloys (3)
- [ ] Nickel based alloys (4)
- [ ] Precious metals (5)
- [ ] Stainless steel (6)
- [ ] Titanium (7)
- [ ] Titanium alloys (8)

2.2.3 What application will your company use the machine?

- [ ] Rapid prototyping (1)
- [ ] Research & development (2)
- [ ] Low volume part production (3)
- [ ] Rapid prototyping & low volume part production (4)
- [ ] High volume part production (5)
- [ ] Refurbishment of metal parts (6)

2.2.4 Do you believe that the technology can bring value to your company?

- ☐ Yes (1)
- ☐ No (2)

2.3 Please select the best suitable reason/s for non-consideration of owning metal additive manufacturing machine.

- ☐ **Not knowledgeable about the technology (1)**
- ☐ **The technology is still in its infancy and it does not suit our processes (2)**
- ☐ **It is very expensive and only suitable for low volume production of highly complex or customized parts (4)**
- ☐ **It is not cost effective compared to traditional methods e.g., speed of production, high marginal cost (5)**
- ☐ **Quality assurance issues e.g. problematic surface finish and tolerances of parts produced (6)**

End of Block: Block 2

Start of Block: Block 3

3 This section is intended to test if knowledge about MAM technology has been disseminated effectively to the industry.

3.1 Is your company aware of the knowledge that has been developed about metal additive manufacturing in South Africa?

- ☐ Yes (1)
- ☐ No (2)

3.1.1 If yes above, does your organization subscribe to trade publications such as journals, manufacturing magazines etc. relevant to your type of business?

- ☐ Yes (1)
- ☐ No (2)

3.1.1.1 If yes, which publications does your company subscribe to? (Please list 1)

_____

3.1.1.2 Does the publication regularly write about metal based additive manufacturing to create awareness of technology to industry?

- ☐ Yes (1)
- ☐ No (2)

3.1.1.3 If yes, do you think this has been effective in creating awareness about metal based additive manufacturing?

- ☐ Yes (1)
- ☐ No (2)

3.2 Is your company aware of the initiative driving the awareness of additive manufacturing in South Africa called Rapid Product Development Association of South Africa (RAPDASA)?

- ☐ Yes (1)
- ☐ No (2)

3.2.1 If yes, do you think this initiative is effective in creating the awareness towards the industry?

- ☐ Yes (1)
- ☐ No (2)

3.3 Is your company aware of other government initiatives spearheading the awareness creation of the technology?

- ☐ Yes (1)
- ☐ No (2)

3.3.1 If yes, kindly list at least one that you are familiar with?

_____

3.3.2 Has this initiative mentioned in 3.3.1 been effective in contributing to your understanding about the technology?

- [ ] Yes (1)
- [ ] No (2)

End of Block: Block 3

Start of Block: Block 4

4 Testing factors that impact the adoption of MAM technology by the industry.

4.1 Please indicate to what extent do you agree with this statement regarding cost influencing MAM technology adoption in your company:

	Strongly disagree (1)	**Disagree (2)**	**Somewhat disagree (3)**	**Neither agree nor disagree (4)**	**Somewhat agree (5)**	**Agree (6)**	**Strongly Agree (7)**
Cost of the metal based additive manufacturing machines are too high. (1)	○	○	○	○	○	○	○
The raw material used in these machines are quite expensive. (2)	○	○	○	○	○	○	○
Our organization invested substantially in conventional manufacturing that we use, thus, we cannot afford to lose our investment for the sake of adapting to the current trend of MAM technology. (3)	○	○	○	○	○	○	○
The company will incur high training costs to align the staff with the use of the technology (4)	○	○	○	○	○	○	○

4.2 Please indicate to what extent do you agree with the statements regarding organizational capabilities influencing MAM technology adoption in your company:

	Strongly disagree (1)	Disagree (2)	Somewhat disagree (3)	Neither agree nor disagree (4)	Somewhat agree (5)	Agree (6)	Strongly agree (7)
Our staff's level of skills are flexible enough to adapt to the introduction of MAM technology in the company (1)	○	○	○	○	○	○	○
It is easy to align the technology to fit our business processes across all units. (2)	○	○	○	○	○	○	○
We have proactive executive champions that understand this innovation and can easily facilitate its adoption in our organization (3)	○	○	○	○	○	○	○
Our management processes are inclined to adjust to suite new innovations such as MAM technology (4)	○	○	○	○	○	○	○

4.3 Please indicate to what extent do you agree with the statements regarding fear of job losses influencing MAM technology adoption in your company:

	Strongly agree (1)	Agree (2)	Somewhat agree (3)	Neither agree nor disagree (4)	Somewhat disagree (5)	Disagree (6)	Strongly disagree (7)
It is a known fact that introduction of MAM technology in organizations will lead to job losses. (1)	○	○	○	○	○	○	○
Our workforce is largely comprised of low-level skilled personnel performing routine work, thus, adoption of this technology in our company means that we will have to shed these jobs. (2)	○	○	○	○	○	○	○
AM technology is less labour intensive in comparison to traditional manufacturing methods and its adoption may well cause labour action against our organization (3)	○	○	○	○	○	○	○
Advanced manufacturing technologies are required in our organization to achieve the bottom line, even if the consequence is shedding of jobs. (4)	○	○	○	○	○	○	○

End of Block: Block 4

Appendix 2.1: One-page bio of the researcher including declaration of interest in the research and funders, if any

Oscar JH. Sono

I am currently working as a project manager at the National Laser Centre within CSIR providing leadership and strategic direction for the Laser-Enabled Manufacturing (LEM) research group that conducts laser-based research on additive manufacturing and laser-based refurbishment. My experience branches from working in various industries such as automotive manufacturing, mineral processing equipment manufacturing, and laser material processing.

My career started as a trainee technician at J & G Support Engineering in 2001. I have a total of 18 years work experience. My highest qualification is Master of Engineering degree from Wits university, and I am currently doing my final year for an MBA degree at Wits Business School.

My education qualifications are as follows: NDip. (Mechanical) and B-Tech (Mechanical) from Tshwane University of Technology, M.Eng. Degree (with a specific focus in Engineering Management) from University of Witwatersrand. I also have a Project Management Diploma from Varsity College.

Appendix 2.2: Ethic documentation

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

SCHOOL OF GRADUATE SCHOOL OF BUSINESS ADMINISTRATION ETHICS COMMITTEE
CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE **PROTOCOL NUMBER: WBS/BA1133278/708**

PROJECT TITLE	Adoption of locally developed Metal Additive Manufacturing Technology: Evaluation of South Africa's manufacturing industry's readiness.
INVESTIGATOR	Mr Oscar Sono
SCHOOL/DEPARTMENT OF INVESTIGATOR	MBA (Research Article)
DATE CONSIDERED	24 November 2020
DECISION OF THE COMMITTEE	Approved unconditionally
RISK LEVEL	MINIMAL RISK
EXPIRY DATE	30 JUNE 2021

ISSUE DATE OF CERTIFICATE 7 December 2020 **CHAIRPERSON** _____

(Dr MDJ Matshabaphala)

cc: Supervisor: Mr George

DECLARATION OF INVESTIGATOR

To be completed in duplicate and ONE COPY returned to the Chairperson of the School/Department ethics committee.

I fully understand the conditions under which I am are authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

_____ 07 , 12 , 2020

Signature **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

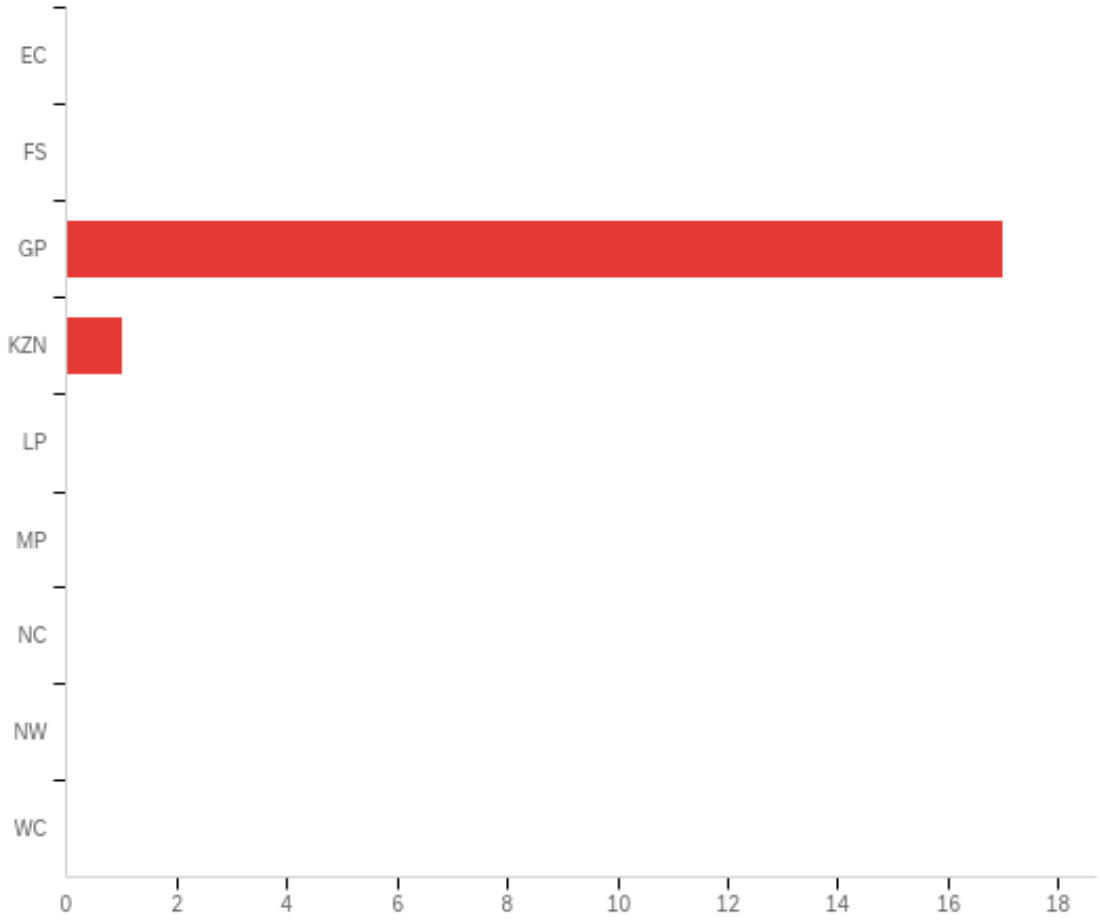
Appendix 3.1: Dully filled in data collection instrument(s)

Default Report

Adoption of locally developed Metal Additive Manufacturing Technology (MAM)

March 12th, 2021, 4:16 pm MDT

1.1 - Please indicate the province your organization is based

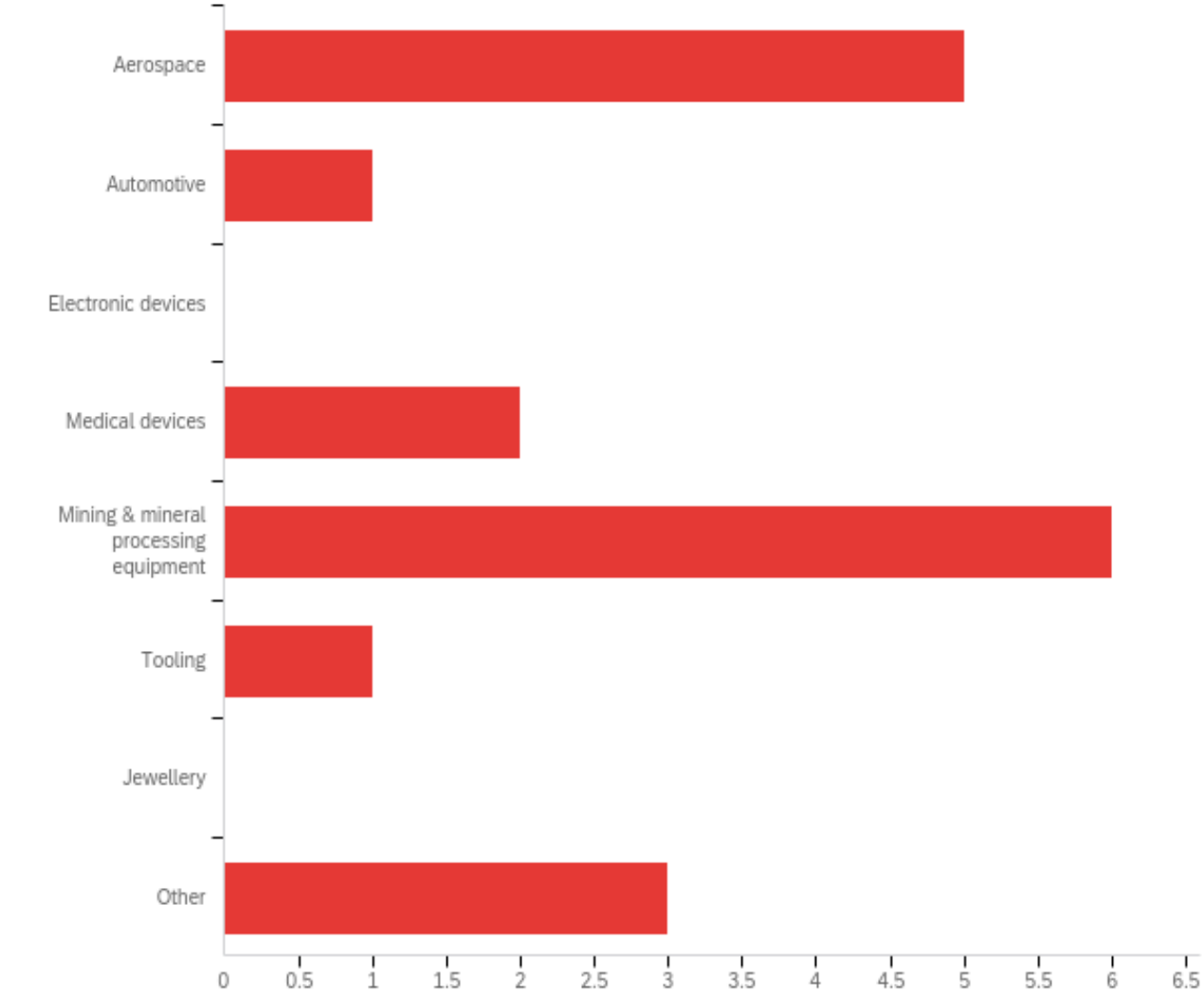


Data source misconfigured for this visualization.

#	Answer	%	Count
1	EC	0.00%	0
2	FS	0.00%	0
3	GP	94.44%	17
4	KZN	5.56%	1

5	LP	0.00%	0
6	MP	0.00%	0
7	NC	0.00%	0
8	NW	0.00%	0
9	WC	0.00%	0
	Total	100%	18

1.2 - Please indicate which industry is core to your organization



Data source misconfigured for this visualization.

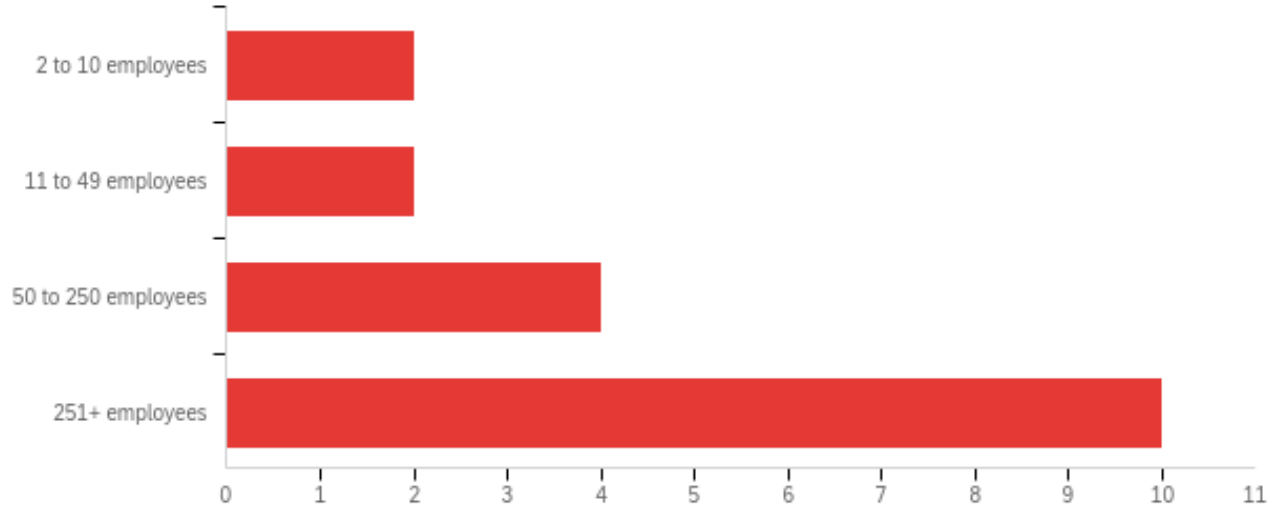
#	Answer	%	Count
1	Aerospace	27.78%	5
2	Automotive	5.56%	1
3	Electronic devices	0.00%	0
4	Medical devices	11.11%	2
5	Mining & mineral processing equipment	33.33%	6
6	Tooling	5.56%	1
7	Jewellery	0.00%	0

8	Other	16.67%	3
	Total	100%	18

1.2.1 - If other in 1.2, please add

If other in 1.2, please add
Manufacturing
Power Industry
Railway systems
Other

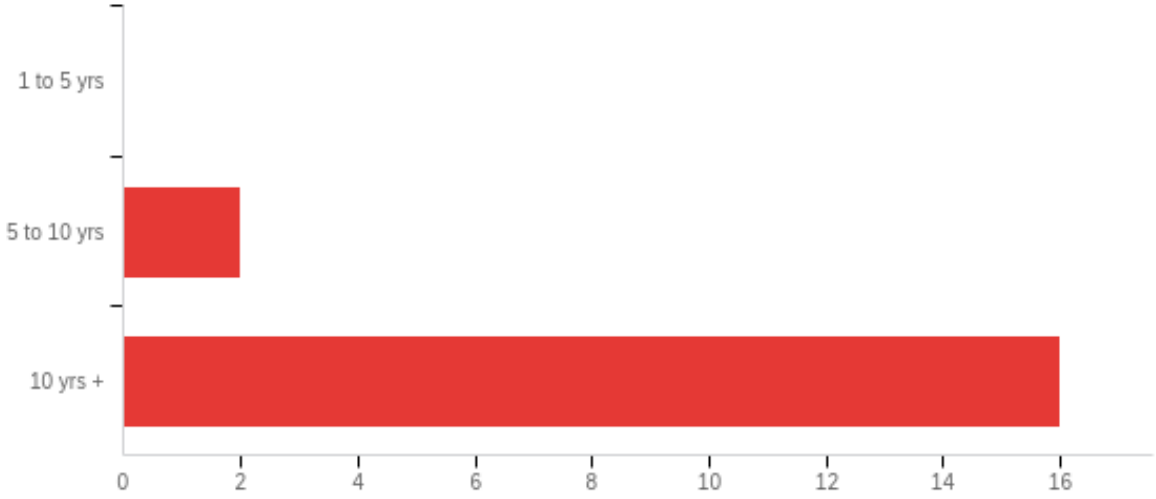
1.3 - Please indicate size of your organization



Data source misconfigured for this visualization.

#	Answer	%	Count
1	2 to 10 employees	11.11%	2
2	11 to 49 employees	11.11%	2
3	50 to 250 employees	22.22%	4
4	251+ employees	55.56%	10
	Total	100%	18

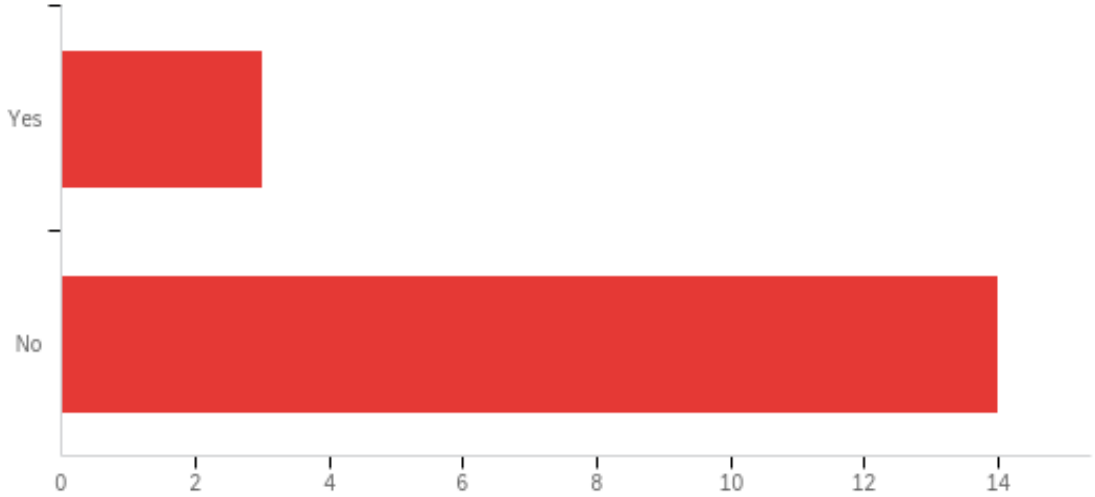
1.4 - Please indicate years of operation



Data source misconfigured for this visualization.

#	Answer	%	Count
1	1 to 5 yrs	0.00%	0
2	5 to 10 yrs	11.11%	2
3	10 yrs +	88.89%	16
	Total	100%	18

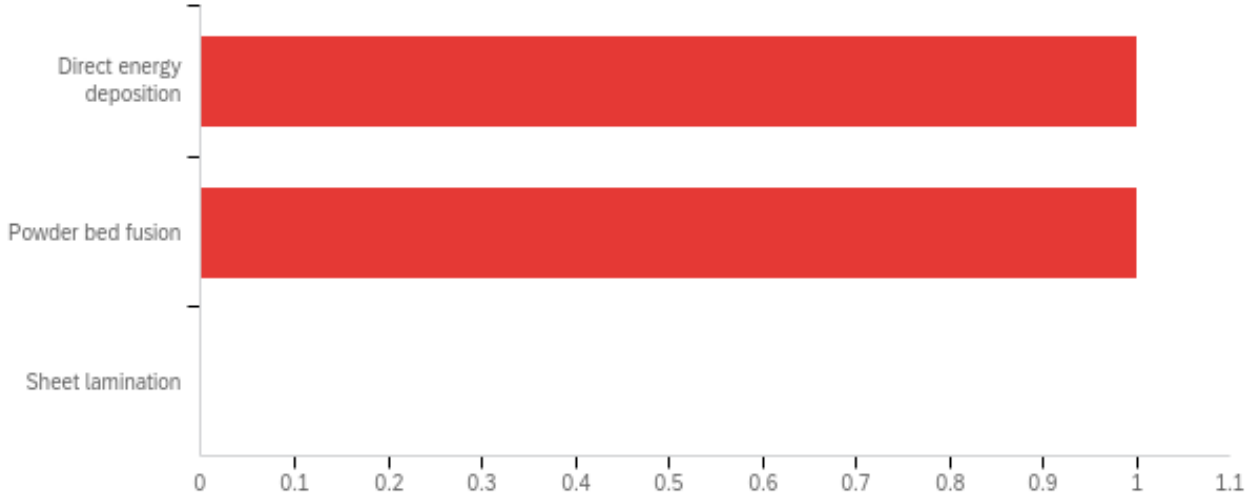
2.1 - Does your company own or lease a metal based additive machine (3D Printing machine)



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	17.65%	3
2	No	82.35%	14
	Total	100%	17

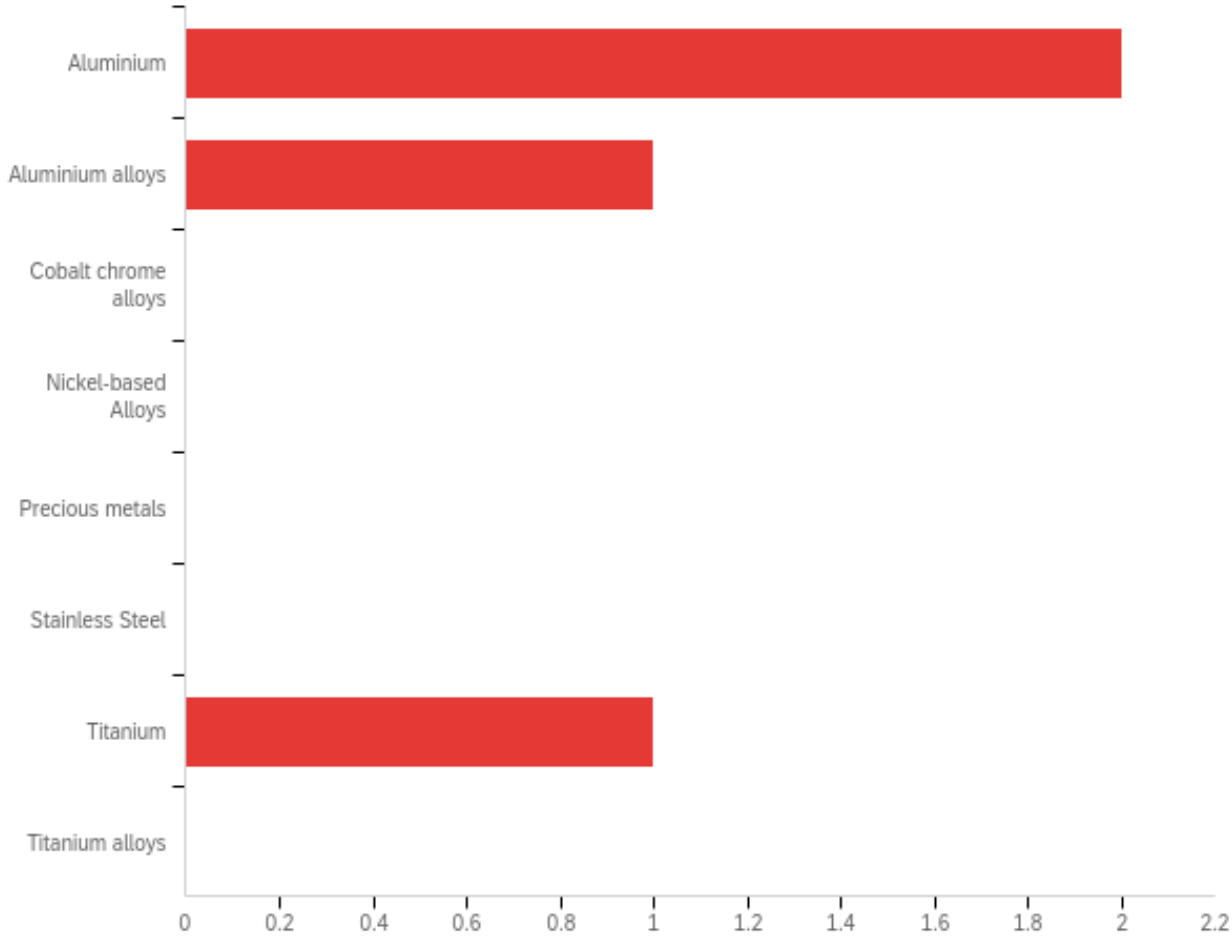
2.1.1 - If yes above, what type of machine is it? (if no, please proceed to 2.2)



Data source misconfigured for this visualization.

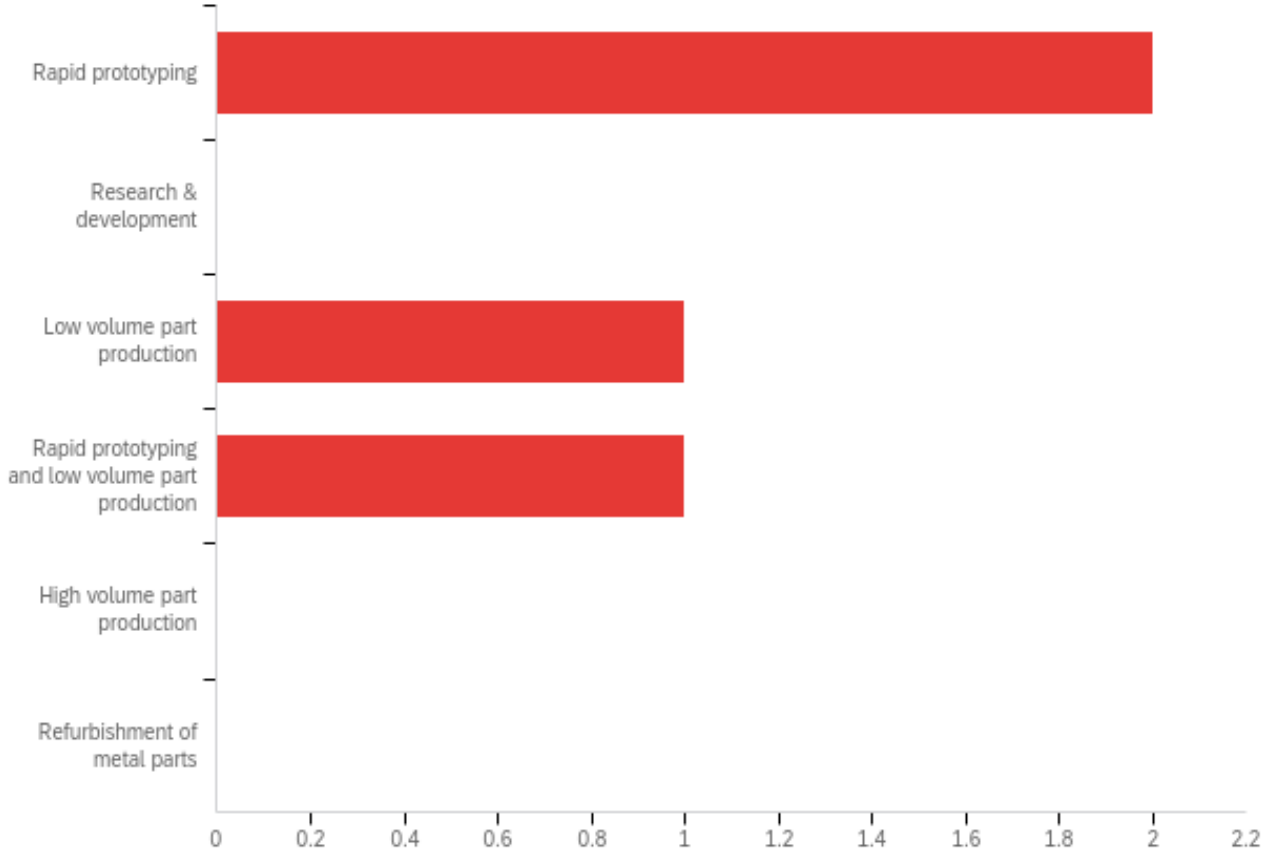
#	Answer	%	Count
1	Direct energy deposition	50.00%	1
2	Powder bed fusion	50.00%	1
3	Sheet lamination	0.00%	0
	Total	100%	2

2.1.2 - What type of material do you process on the machine?



#	Answer	%	Count
1	Aluminium	50.00%	2
2	Aluminium alloys	25.00%	1
3	Cobalt chrome alloys	0.00%	0
4	Nickel-based Alloys	0.00%	0
5	Precious metals	0.00%	0
6	Stainless Steel	0.00%	0
7	Titanium	25.00%	1
8	Titanium alloys	0.00%	0
	Total	100%	4

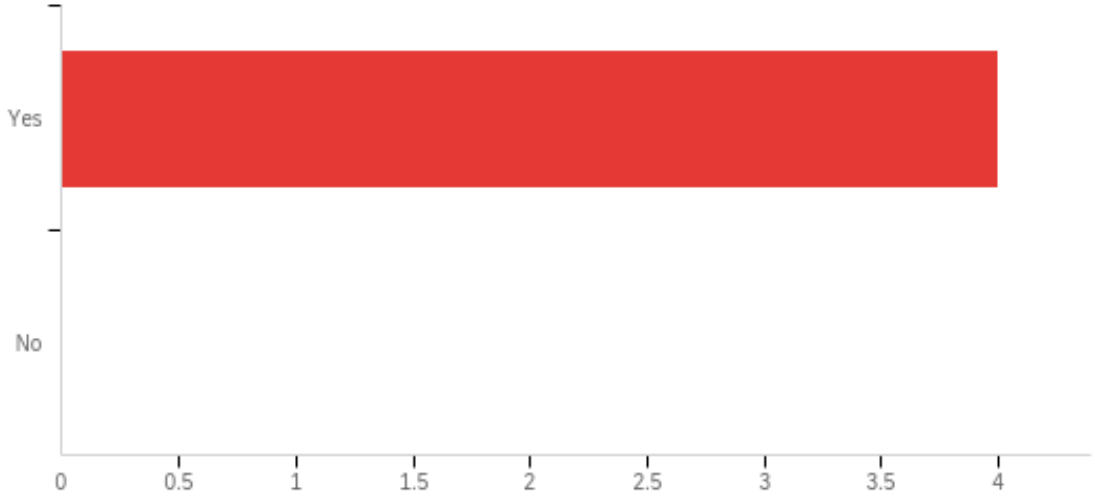
2.1.3 - What application is the machine used for?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Rapid prototyping	50.00%	2
2	Research & development	0.00%	0
3	Low volume part production	25.00%	1
4	Rapid prototyping and low volume part production	25.00%	1
5	High volume part production	0.00%	0
6	Refurbishment of metal parts	0.00%	0
	Total	100%	4

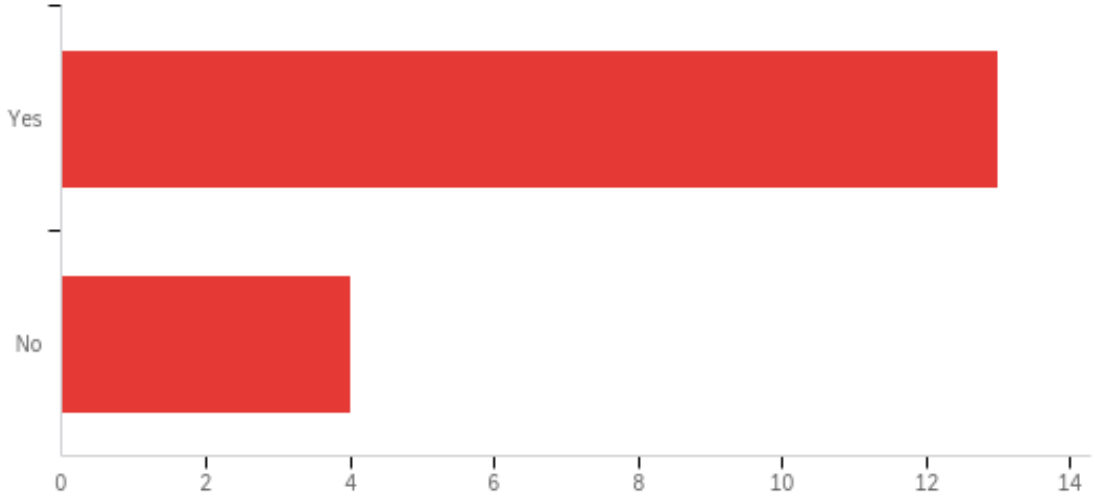
2.1.4 - Has the technology brought added value in your company?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	100.00%	4
2	No	0.00%	0
	Total	100%	4

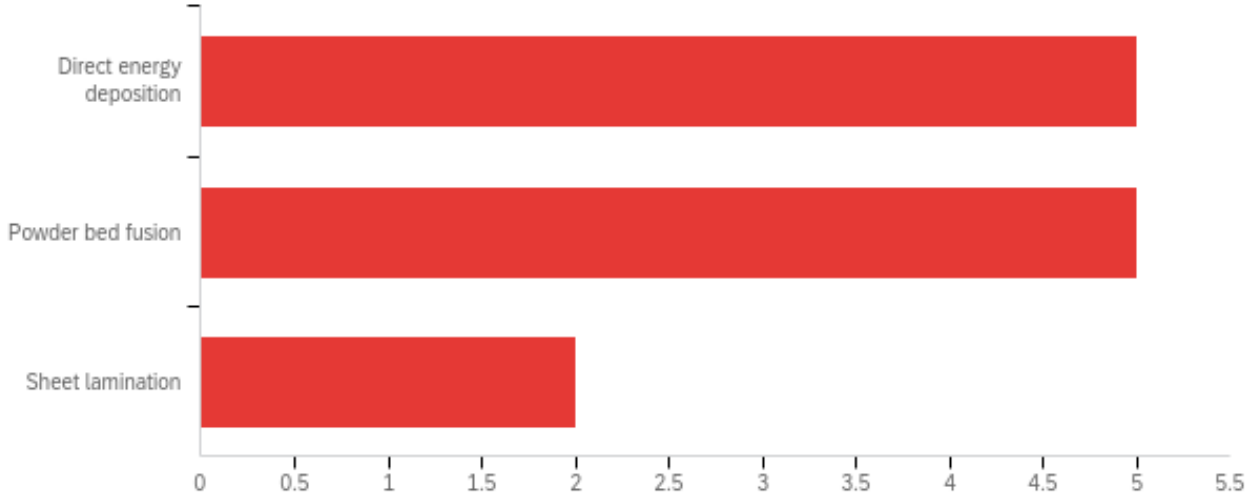
2.2 - Would your company consider owning a metal based additive manufacturing machine in the near future?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	76.47%	13
2	No	23.53%	4
	Total	100%	17

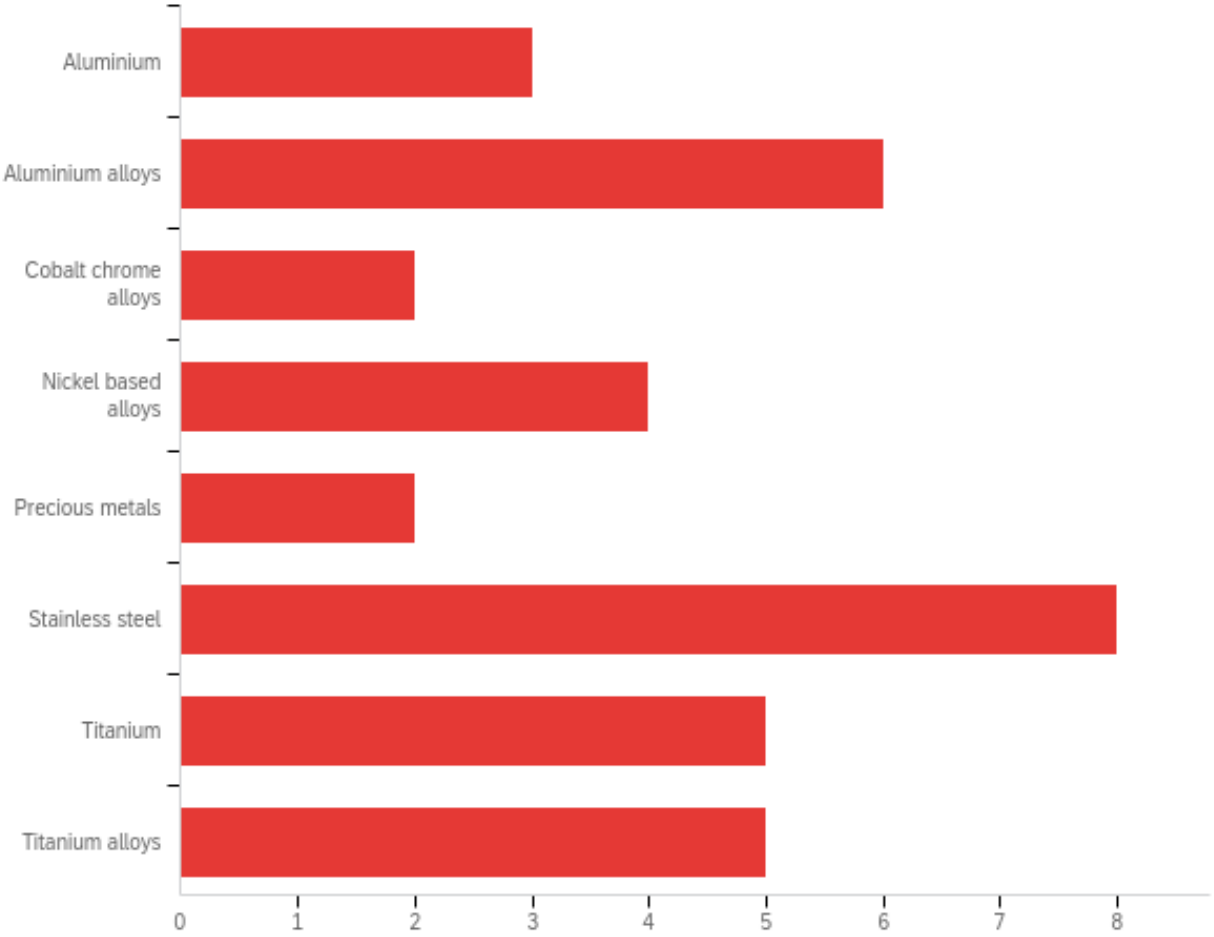
2.2.1 - If yes above, what type of machine will you consider? (if no, please proceed to section 2.3)



Data source misconfigured for this visualization.

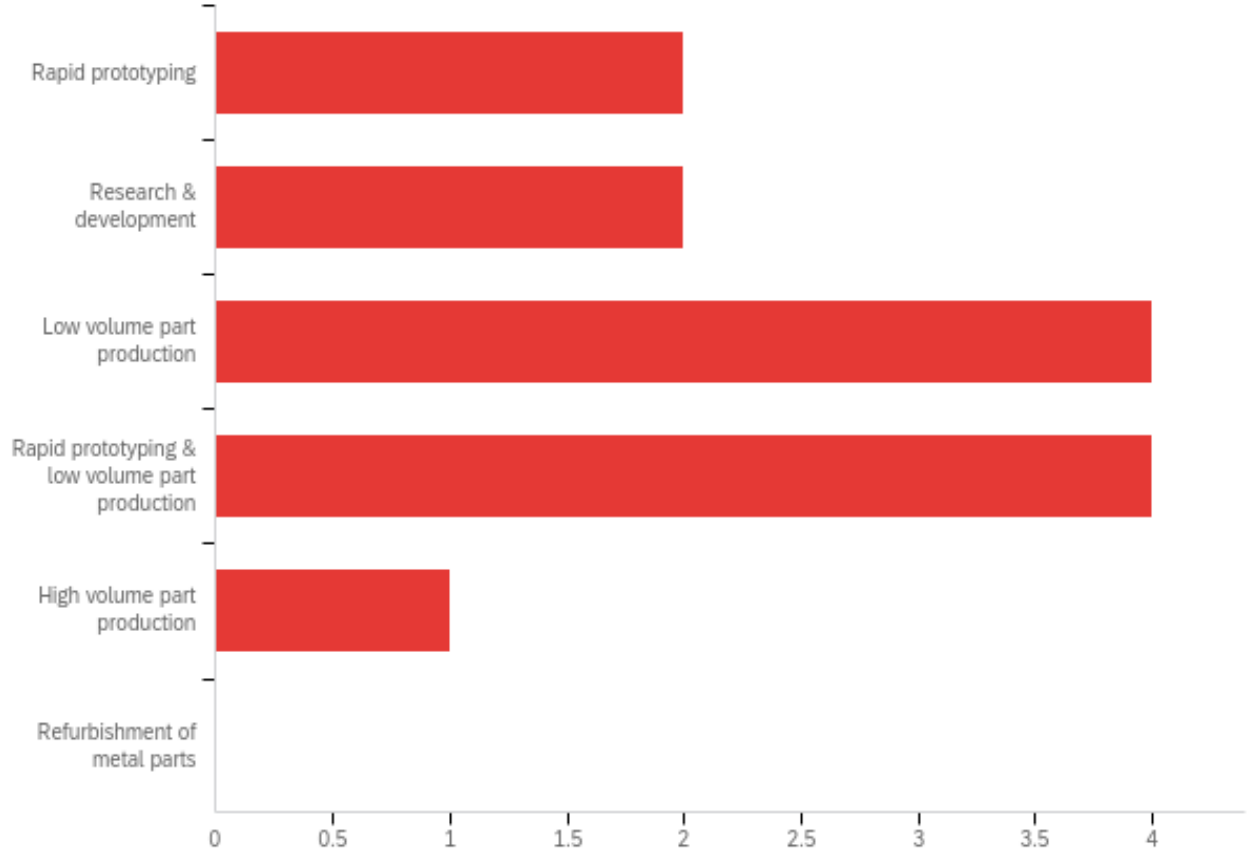
#	Answer	%	Count
1	Direct energy deposition	41.67%	5
2	Powder bed fusion	41.67%	5
3	Sheet lamination	16.67%	2
	Total	100%	12

2.2.2 - What type of material should the machine process?



#	Answer	%	Count
1	Aluminium	8.57%	3
2	Aluminium alloys	17.14%	6
3	Cobalt chrome alloys	5.71%	2
4	Nickel based alloys	11.43%	4
5	Precious metals	5.71%	2
6	Stainless steel	22.86%	8
7	Titanium	14.29%	5
8	Titanium alloys	14.29%	5
	Total	100%	35

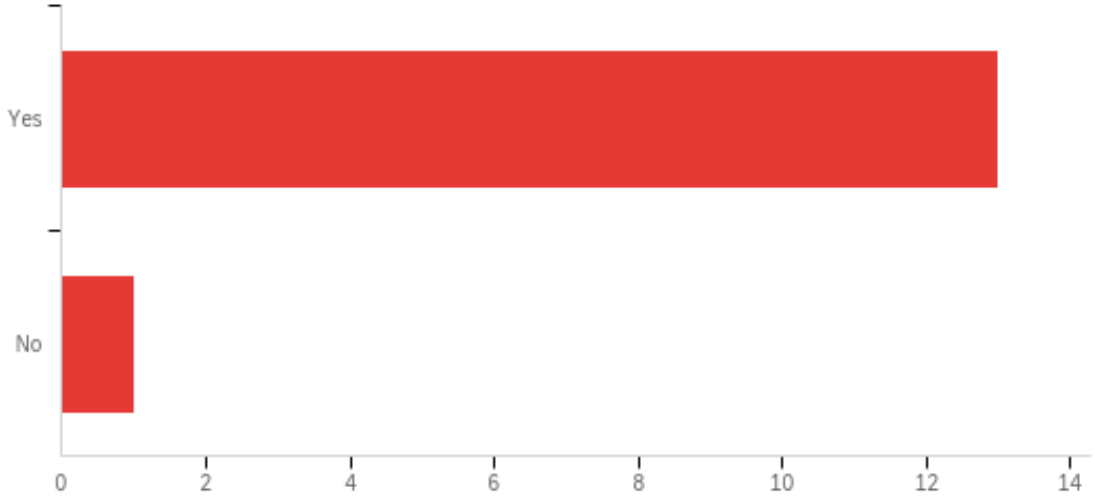
2.2.3 - What application will your company use the machine?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Rapid prototyping	15.38%	2
2	Research & development	15.38%	2
3	Low volume part production	30.77%	4
4	Rapid prototyping & low volume part production	30.77%	4
5	High volume part production	7.69%	1
6	Refurbishment of metal parts	0.00%	0
	Total	100%	13

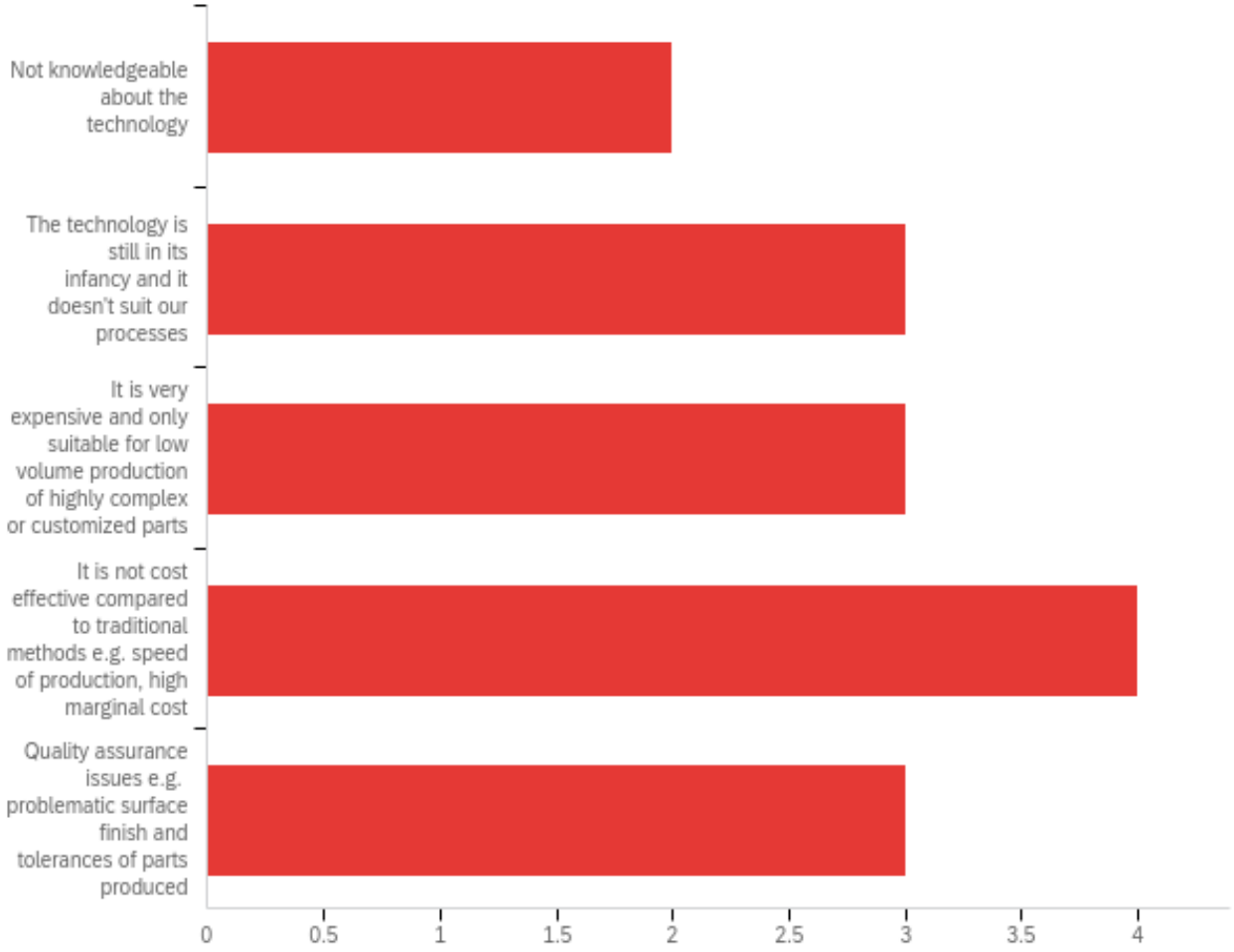
2.2.4 - Do you believe that the technology can bring value to your company?



Data source misconfigured for this visualization.

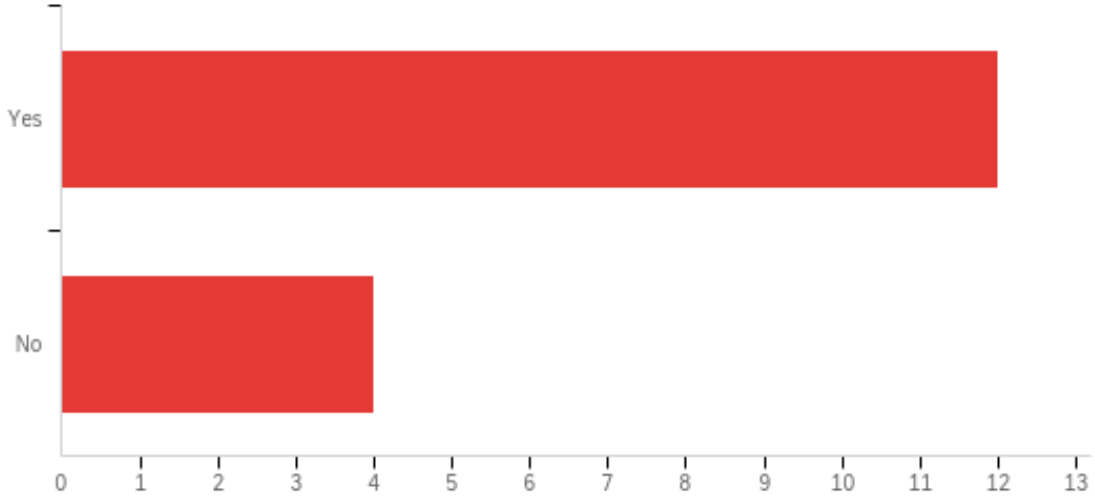
#	Answer	%	Count
1	Yes	92.86%	13
2	No	7.14%	1
	Total	100%	14

2.3 - Please select the best suitable reason/s for non-consideration of owning metal additive manufacturing machine.



#	Answer	%	Count
1	Not knowledgeable about the technology	13.33%	2
2	The technology is still in its infancy and it does not suit our processes	20.00%	3
4	It is expensive and only suitable for low volume production of highly complex or customized parts	20.00%	3
5	It is not cost effective compared to traditional methods e.g., speed of production, high marginal cost	26.67%	4
6	Quality assurance issues e.g. problematic surface finish and tolerances of parts produced	20.00%	3
	Total	100%	15

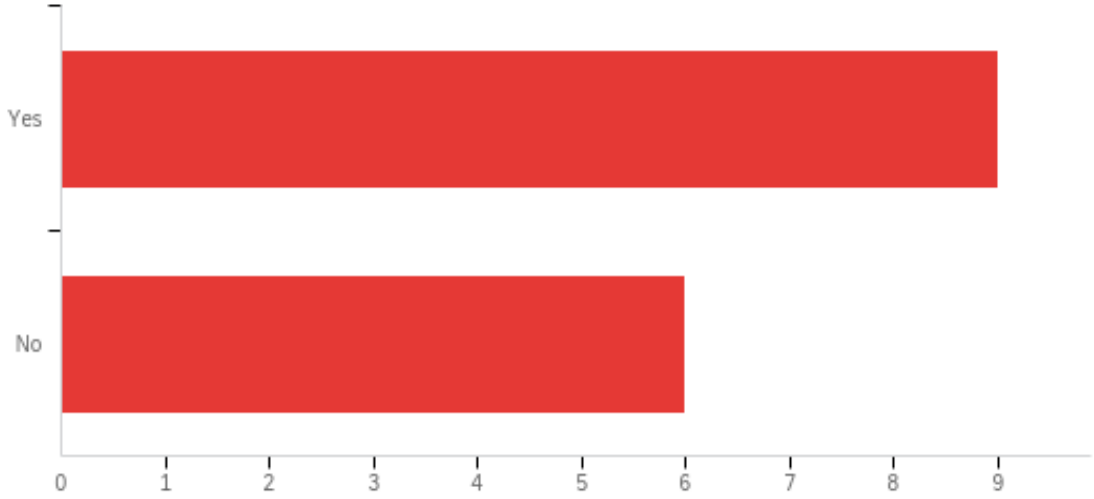
3.1 - Is your company aware of the knowledge that has been developed about metal additive manufacturing in South Africa?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	75.00%	12
2	No	25.00%	4
	Total	100%	16

3.1.1 - If yes above, does your organization subscribe to trade publications such as journals, manufacturing magazines etc. relevant to your type of business?



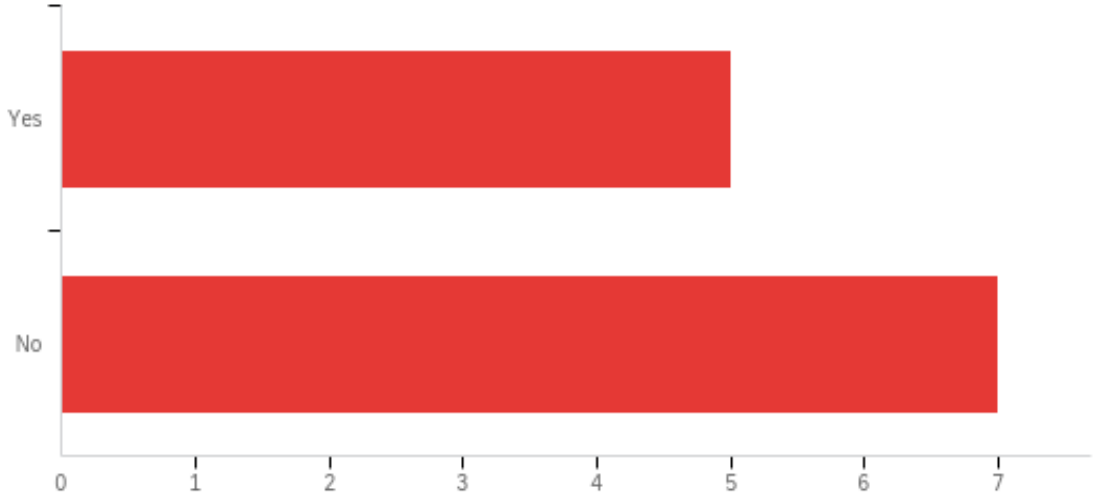
Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	60.00%	9
2	No	40.00%	6
	Total	100%	15

3.1.1.1 - If yes, which publications does your company subscribe to? (Please list 1)

If yes, which publications does your company subscribe to? (Please list 1)
Engineering News
MIT XPRO
Engineering News
N/A
MTM South Africa
CSIR Newsletter
Railway Africa
Metal AM.com
Plant Engineering and Construction Equipment
Metal Engineering News and various other publications

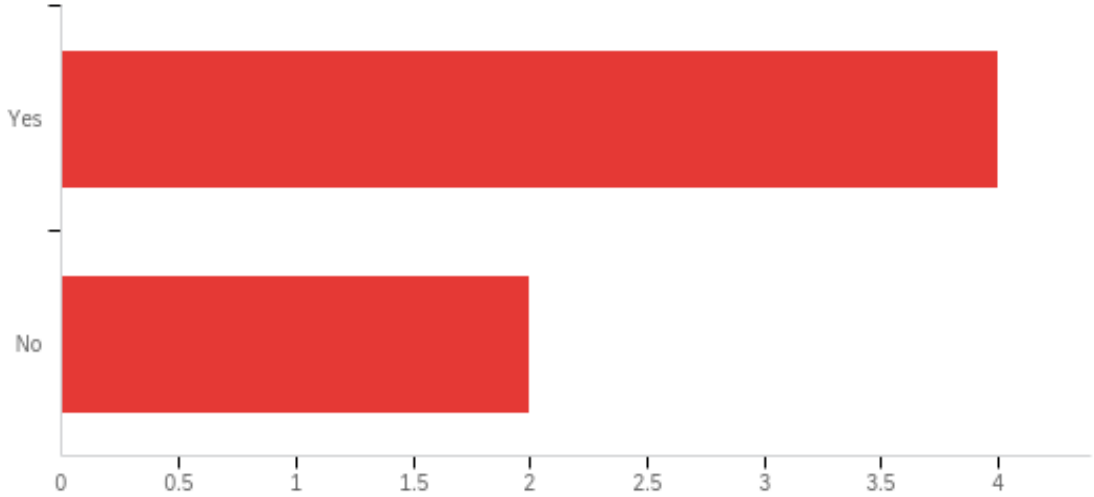
3.1.1.2 - Does the publication regularly write about metal based additive manufacturing to create awareness of technology to industry?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	41.67%	5
2	No	58.33%	7
	Total	100%	12

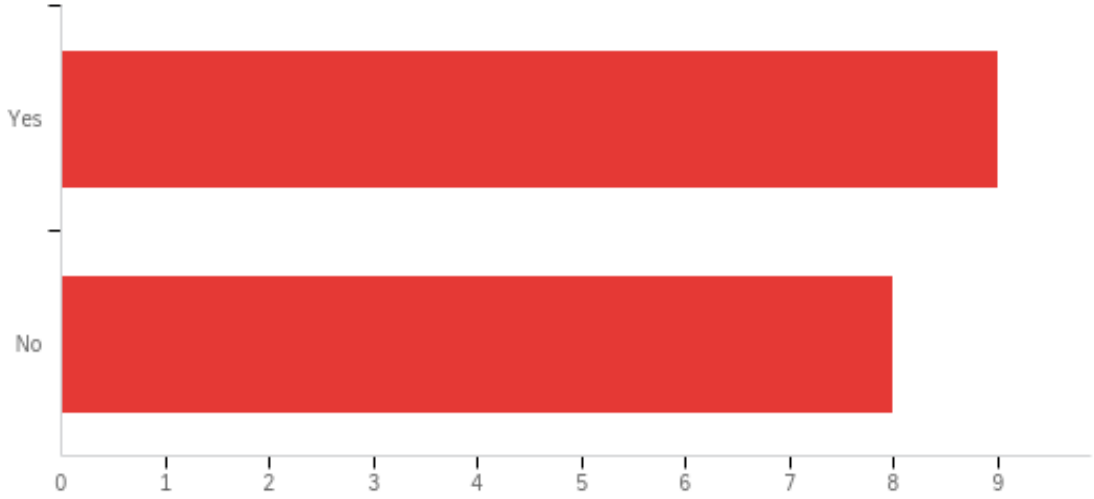
3.1.1.3 - If yes, do you think this has been effective in creating awareness about metal based additive manufacturing?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	66.67%	4
2	No	33.33%	2
	Total	100%	6

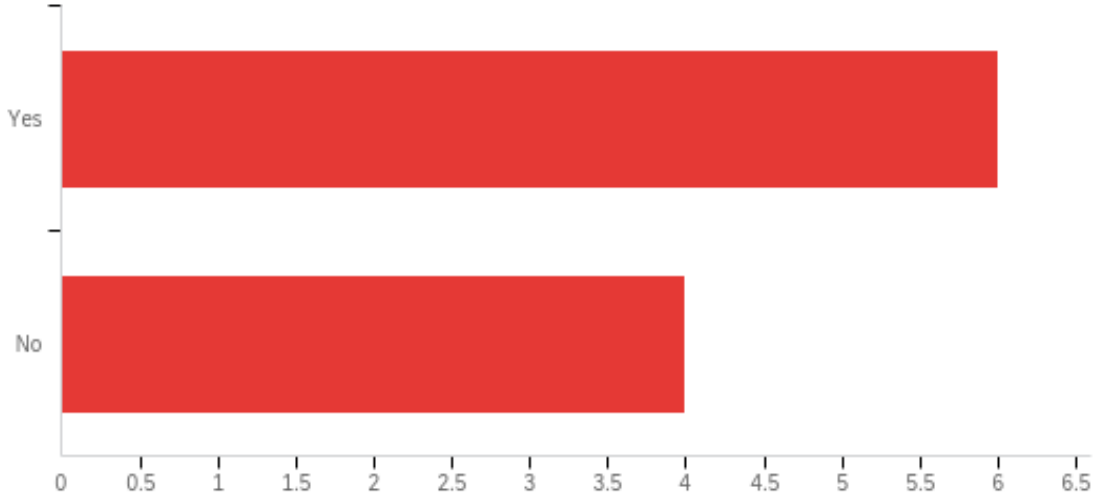
3.2 - Is your company aware of the initiative driving the awareness of additive manufacturing in South Africa called Rapid Product Development Association of South Africa (RAPDASA)?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	52.94%	9
2	No	47.06%	8
	Total	100%	17

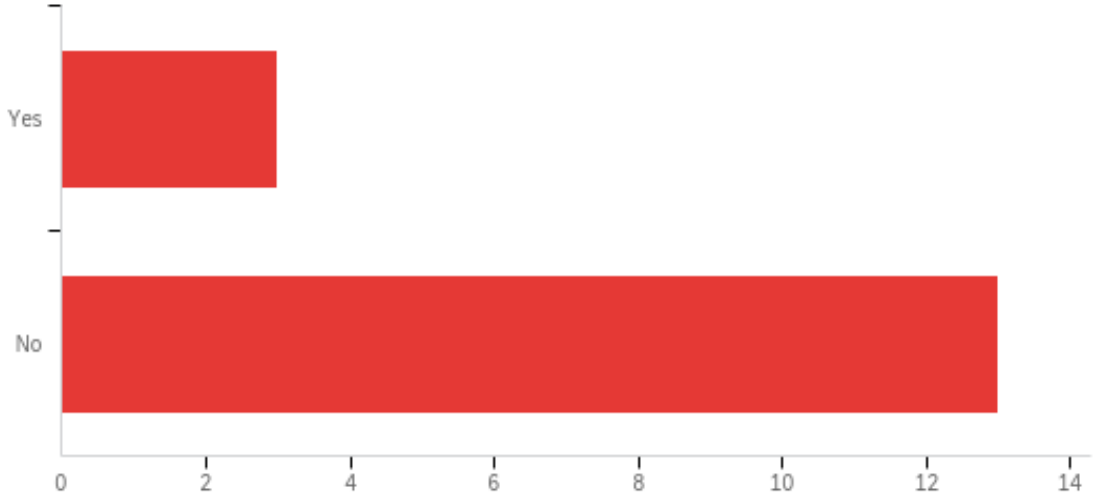
3.2.1 - If yes, do you think this initiative is effective in creating the awareness towards the industry?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	60.00%	6
2	No	40.00%	4
	Total	100%	10

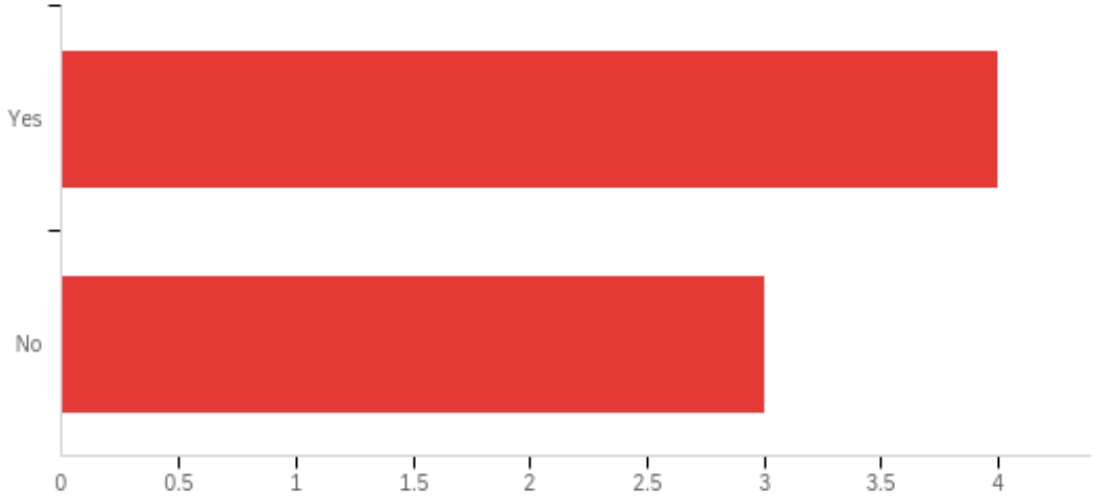
3.3 - Is your company aware of other government initiatives spearheading the awareness creation of the technology?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	18.75%	3
2	No	81.25%	13
	Total	100%	16

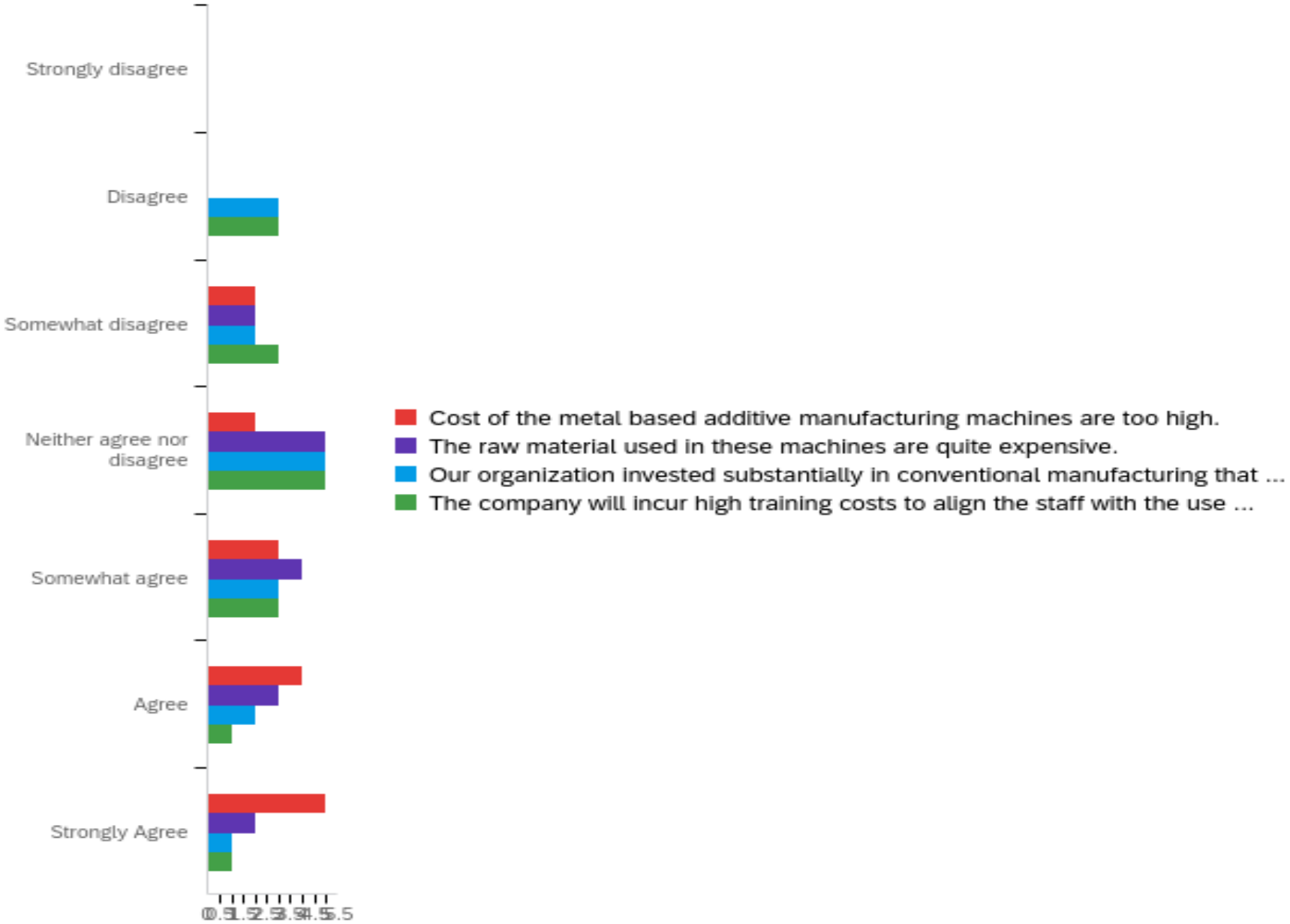
3.3.2 - Has this initiative mentioned in 3.3.1 been effective in contributing to your understanding about the technology?



Data source misconfigured for this visualization.

#	Answer	%	Count
1	Yes	57.14%	4
2	No	42.86%	3
	Total	100%	7

4.1 - Please indicate to what extent do you agree with this statement regarding cost influencing MAM technology adoption in your company:

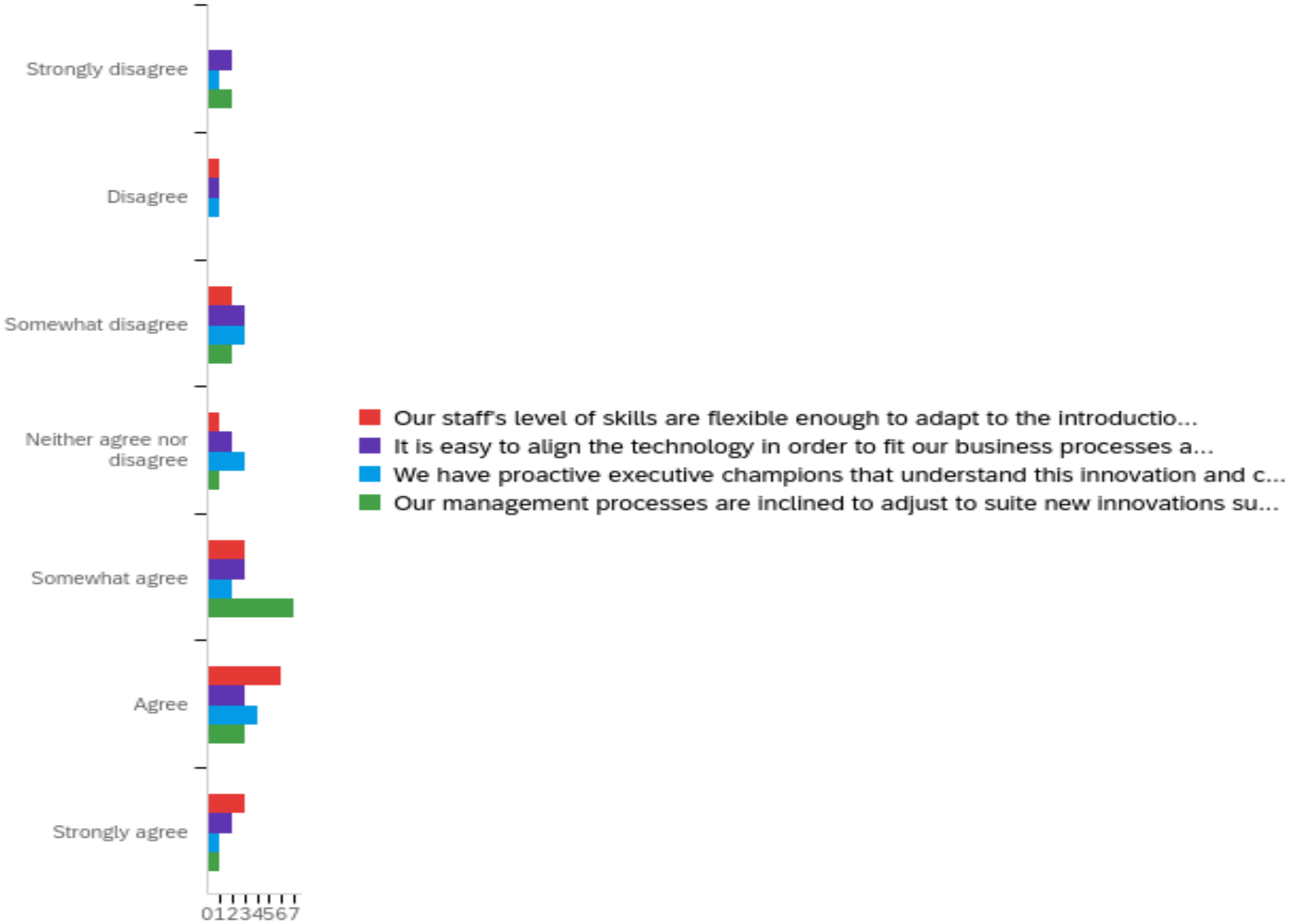


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Cost of the metal based additive manufacturing machines are too high.	3.00	7.00	5.50	1.37	1.88	16
2	The raw material used in these machines are quite expensive.	3.00	7.00	4.88	1.22	1.48	16
3	Our organization invested substantially in conventional manufacturing that we use, thus, we cannot afford to lose our investment for the sake of adapting to the current trend of MAM technology.	2.00	7.00	4.13	1.45	2.11	16
4	The company will incur high training costs to align the staff with the use of the technology	2.00	7.00	3.94	1.39	1.93	16

#	Question	Strongly disagree		Disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Agree		Strongly Agree		Total
1	Cost of the metal based additive manufacturing machines are too high.	0.00%	0	0.00%	0	12.50%	2	12.50%	2	18.75%	3	25.00%	4	31.25%	5	16
2	The raw material used in these machines are quite expensive.	0.00%	0	0.00%	0	12.50%	2	31.25%	5	25.00%	4	18.75%	3	12.50%	2	16
3	Our organization invested substantially in conventional manufacturing that we use, thus, we cannot afford to lose our investment for the sake of adapting to the current trend of MAM technology.	0.00%	0	18.75%	3	12.50%	2	31.25%	5	18.75%	3	12.50%	2	6.25%	1	16
4	The company will incur high training costs to	0.00%	0	18.75%	3	18.75%	3	31.25%	5	18.75%	3	6.25%	1	6.25%	1	16

| | | |

4.2 - Please indicate to what extent do you agree with the statements regarding organizational capabilities influencing MAM technology adoption in your company:

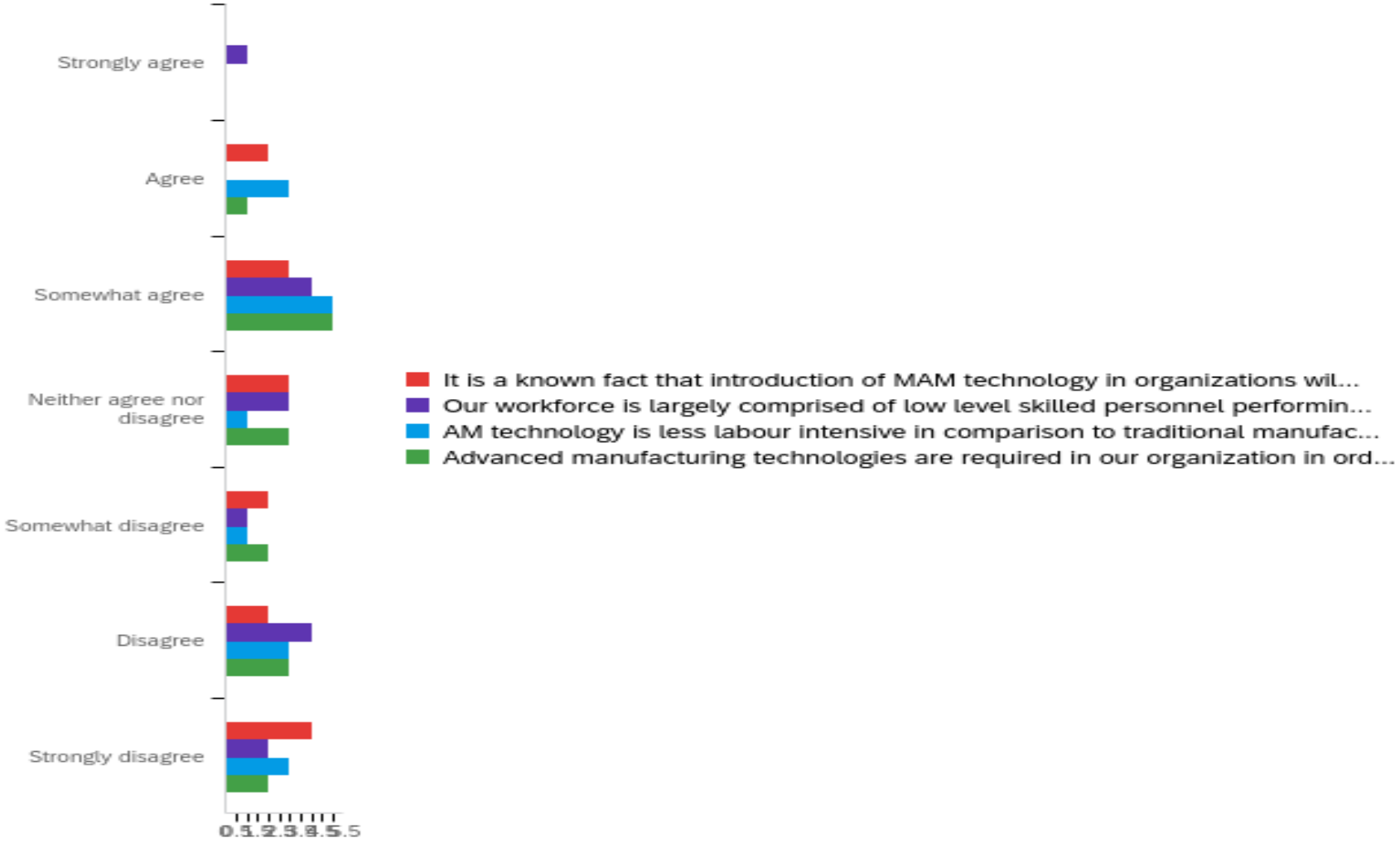


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Our staff's level of skills are flexible enough to adapt to the introduction of MAM technology in the company	2.00	7.00	5.25	1.48	2.19	16
2	It is easy to align the technology in order to fit our business processes across all units.	1.00	7.00	4.25	1.89	3.56	16
3	We have proactive executive champions that understand this innovation and can easily facilitate its adoption in our organization	1.00	7.00	4.33	1.66	2.76	15
4	Our management processes are inclined to adjust to suite new innovations such as MAM technology	1.00	7.00	4.50	1.66	2.75	16

#	Question	Strongly disagree		Disagree		Somewhat disagree		Neither agree nor disagree		Somewhat agree		Agree		Strongly agree		Total
1	Our staff's level of skills are flexible enough to adapt to the introduction of MAM technology in the company	0.00%	0	6.25%	1	12.50%	2	6.25%	1	18.75%	3	37.50%	6	18.75%	3	16
2	It is easy to align the technology in order to fit our business processes across all units.	12.50%	2	6.25%	1	18.75%	3	12.50%	2	18.75%	3	18.75%	3	12.50%	2	16
3	We have proactive executive champions that understand this innovation and can easily facilitate its adoption in our organization	6.67%	1	6.67%	1	20.00%	3	20.00%	3	13.33%	2	26.67%	4	6.67%	1	15
4	Our management processes are inclined to	12.50%	2	0.00%	0	12.50%	2	6.25%	1	43.75%	7	18.75%	3	6.25%	1	16

| | | |

4.3 - Please indicate to what extent do you agree with the statements regarding fear of job losses influencing MAM technology adoption in your company:


Strongly agree
Agree
Somewhat agree
Neither agree nor disagree
Somewhat disagree
Disagree
Strongly disagree
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
It is a known fact that introduction of MAM technology in organizations wil...
Our workforce is largely comprised of low level skilled personnel performin...
AM technology is less labour intensive in comparison to traditional manufac...
Advanced manufacturing technologies are required in our organization in ord...

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	It is a known fact that introduction of MAM technology in organizations will lead to job losses.	2.00	7.00	4.69	1.76	3.09	16
2	Our workforce is largely comprised of low-level skilled personnel performing routine work, thus, adoption of this technology in our company means that we will have to shed these jobs.	1.00	7.00	4.53	1.71	2.92	15
3	AM technology is less labour intensive in comparison to traditional manufacturing methods and its adoption may well cause labour action against our organization	2.00	7.00	4.31	1.86	3.46	16
4	Advanced manufacturing technologies are required in our organization in order to achieve the bottom line, even if the consequence is shedding of jobs.	2.00	7.00	4.44	1.54	2.37	16

#	Question	Strongly agree		Agree		Somewhat agree		Neither agree nor disagree		Somewhat disagree		Disagree		Strongly disagree		Total
1	It is a known fact that introduction of MAM technology in organizations will lead to job losses.	0.00%	0	12.50%	2	18.75%	3	18.75%	3	12.50%	2	12.50%	2	25.00%	4	16
2	Our workforce is largely comprised of low-level skilled personnel performing routine work, thus, adoption of this technology in our company means that we	6.67%	1	0.00%	0	26.67%	4	20.00%	3	6.67%	1	26.67%	4	13.33%	2	15

	will have to shed these jobs.															
3	AM technology is less labour intensive in comparison to traditional manufacturing methods and its adoption may well cause labour action against our organization	0.00%	0	18.75%	3	31.25%	5	6.25%	1	6.25%	1	18.75%	3	18.75%	3	16
4	Advanced manufacturing technologies are required in our organization in order to achieve the bottom line, even if the consequence is shedding of jobs.	0.00%	0	6.25%	1	31.25%	5	18.75%	3	12.50%	2	18.75%	3	12.50%	2	16

Appendix 4.1: Additional Results

Appendix Table 1. Trade publications subscriptions

	Frequency	Percent
No response	12	57.1
CSIR Newsletter	1	4.8
Engineering News	2	9.5
Metal AM.com	1	4.8
Metal Engineering News and various other publications	1	4.8
MIT XPRO	1	4.8
MTM South Africa	1	4.8
Plant Engineering and Construction Equipment	1	4.8
Railway Africa	1	4.8
Total	21	100.0

Appendix Table 2. Listed government initiatives (other)

	Frequency	Percent
No response	18	85.7
Advanced Manufacturing Initiatives by DST and TIA	1	4.8
Collective Programme for Additive Manufacturing (CPAM)	1	4.8
TIA (Technology Innovation Agency)	1	4.8
Total	21	100.0

Appendix 4.1: Additional Results

Appendix Table 3. Mann Whitney U Test - Flexible Skills

Mann-Whitney U	6.500
Wilcoxon W	12.500
Z	-2.157
Asymp. Sig. (2-tailed)	.031
Exact Sig. [2*(1-tailed Sig.)]	.040[b]

a. Grouping Variable: Ownership/leasing

b. Not corrected for ties.

Appendix Table 4. Mann Whitney U Test - Technology Fit

Mann-Whitney U	6.500
Wilcoxon W	12.500
Z	-2.030
Asymp. Sig. (2-tailed)	.042
Exact Sig. [2*(1-tailed Sig.)]	.040[b]

a. Grouping Variable: 2.1

b. Not corrected for ties.