Gordon Institute
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Diffusion of additive manufacturing in Gauteng, South Africa

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Abstract

This study aimed to determine the status of additive manufacturing within the Gauteng province of South Africa and identify factors that are motivating or prohibiting its uptake.

The existing problem is that the South African manufacturing sector has experienced poor growth resulting in a contribution of 12 percent of GDP for the year 2014 (down from 19% in 1993). The comparatively poor performance of the manufacturing sector indicates its potential fragility and that some sort of intervention may be required. Experts are anticipating the global impact of additive manufacturing to be $550 billion by 2025 and as such, this could provide a solution. However, there is little information available about the adoption of additive manufacturing within South Africa.

A concurrent procedure mixed-method design intent on converging cross-sectional data was applied throughout this research. This enabled a comprehensive analysis of the possible constructs that affected the diffusion of additive manufacturing. A random-cluster sampling technique was applied which made use of a survey to sample reality.

The current state was evaluated based current theories of diffusion of innovation. It was evident that diffusion of additive manufacturing is occurring within the sample cluster however, a significant shortage of accurate information and knowledge is influencing the rate of diffusion. The research also found advertising to affect respondent's view of machine cost, opinion over machine brand and machine capability however, no dominant technology was found in the within the cluster. Information obtained from the survey was compiled with existing data to produce a Bass Model for the adoption of additive manufacturing machines within South Africa. The model predicts that the market will reach its full potential by 2040 with a peak in annual grow in 2023. The report concludes with a model incorporates existing theoretical frameworks and factors that are motivating or prohibiting the adoption of additive manufacturing.

Keywords

Additive manufacturing, Adoption, Diffusion, Innovation.

Declaration

I declare that this research project is my own work. It is submitted in partial fulfilment of the requirements for the degree of Masters of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination in any other University. I further declare that I have obtained the necessary authorization and consent to carry out this research.

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(Signature of Candidate)

…9…day of…November...year…2015…

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1 Introduction to research problem

1.1 Introduction

Additive manufacturing more commonly known as 3-D printing has been publicized as a potentially disruptive technology that if adopted could see rapid diffusion among consumers and manufacturers. Besides it ability to produce items previously impossible to manufacture, it enables on-demand production which has large implications for supply chains and stock warehousing which are both significant cost drivers of consumables (Manyika, Chui, Bughin, Dobbs, Bisson and Marrs, 2013).

The additive manufacturing market had an estimated value of $3.07 billion worldwide in 2013, up 34.9 percent from 2012 (Thilmany, 2014). According to Geelhoed (2014), key patents expired in February of 2014 and further patents on the technology are expiring in the near future, thus the market is set for potential rapid expansion. So much so, that Canalys (2014), a market research firm, has predicted the market to grow to a value of $16.2 billion in 2018. Cohen, Sargeant, & Somers (2014) state that McKinsey Global Institute research suggested that additive manufacturing could have a global impact of $550 billion a year by 2025. In 2014, President Obama announced two new manufacturing innovation institutes supported by a $140 million federal commitment combined with more that $140 million in non-federal resources. This is just two of the envisioned 45 manufacturing innovation institutes that will help ensure America’s future inclusion in the advanced manufacturing sector (The White House, 2014).

While the additive manufacturing market is showing growth, the Small Enterprise Development Agency (2012) indicated that the South African manufacturing sector has reduced from 19 percent of Gross Domestic Profit in 1993 to 17 percent in 2010. Statistics South Africa (2015b); consistent with the figures of the Small Enterprise Development Agencies historic statistics; indicated that the manufacturing industry has experienced poor growth resulting in a contribution of 12 percent of Gross Domestic Profit for the year 2014 (R379 billion at 2010 prices). Thus, the comparatively poor performance of the manufacturing sector indicated it potential fragility and that some sort of intervention may be required. However, there is potential scope for improvement. According to Statistics South Africa (2015a), South Africa has been a net importer since August 2013 indicating that demand for products has exceeded local supply or that South Africa’s manufacturing sector has lost its ability to be competitive. One example of this is the motor industry, which imports 70% more than what they do export (Small Enterprise Development Agency, 2012). Thus, it is critical to ensure South Africa has both the capability to manufacture demanded products as well as manufacture at internationally competitive rates if we are to see a revival of the manufacturing sector.

“Technology change is one of the principal drivers of competition. It plays a major role in industry structural change, as well as in creating new industries. It is also a great equalizer, eroding the competitive advantage of even well-entrenched firms and propelling other to the forefront” (Porter, 2007, p.60). With the additive manufacturing sector set for rapid growth South Africa has the opportunity to reinvent its manufacturing industry through the adoption of additive manufacturing. Additive manufacturing could provide South African manufacturers with the ability to become competitive in the global manufacturing market through new, more advanced manufacturing capability.

1.2 Context: Manufacturing in Gauteng

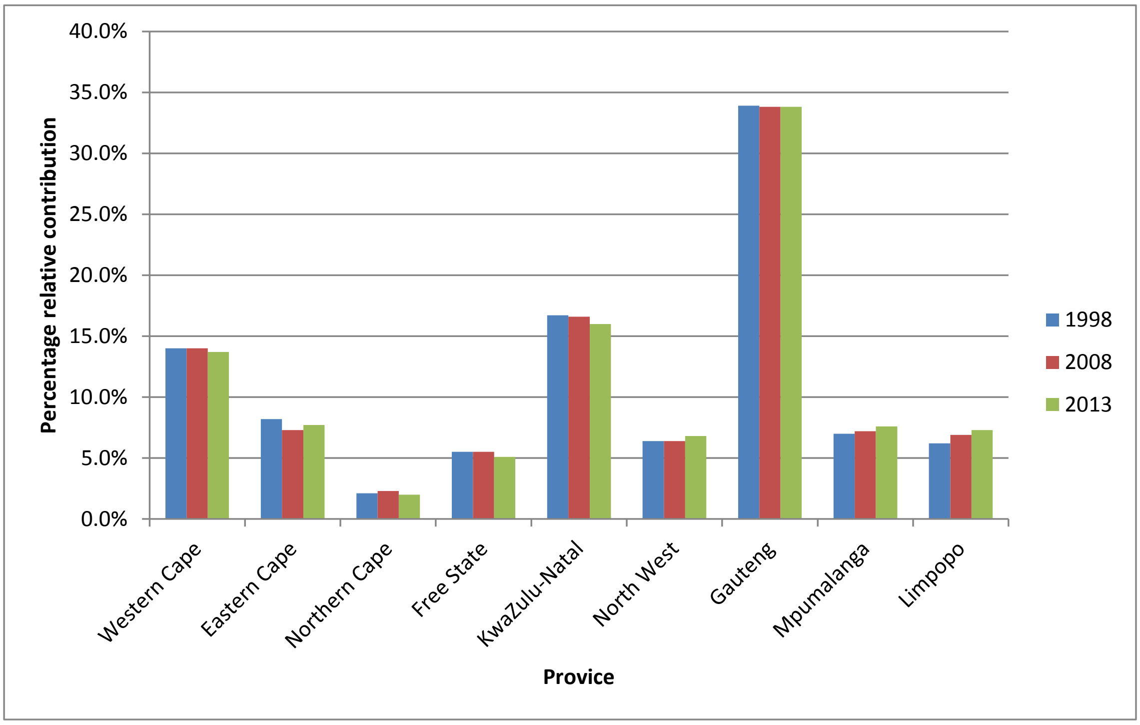
South Africa is divided into nine provinces of which 1.2% by land area makes up the province of Gauteng. By population, with 12.3 million people, it is the largest, most densely populated and fastest growing province. Table 1. 1 provides details on provincial population.

Table 1. 1: Total population by province, Census 1996, 2001, 2011, Statistics South Africa (2012).

Province	**Census 1996**	**Census 2001**	**Census 2011**	**Percentage growth 1996-2011**
Western Cape	3 956 875	4 524 335	5 822 734	47%
Eastern Cape	6 147 244	6 278 651	6 562 053	7%
Northern Cape	1 011 864	991 919	1 145 861	13%
Free State	2 633 504	2 706 775	2 745 590	4%
KwaZulu-Natal	8 572 302	9 584 129	10 267 300	20%
North West	2 727 223	2 984 098	3 509 953	29%
Gauteng	7 834 125	9 388 854	12 272 263	57%
Mpumalanga	3 123 869	3 365 554	4 039 939	29%
Limpopo	4 576 566	4 995 462	5 404 868	18%
South Africa	**40 583 572**	**44 819 777**	**51 770 561**	28%

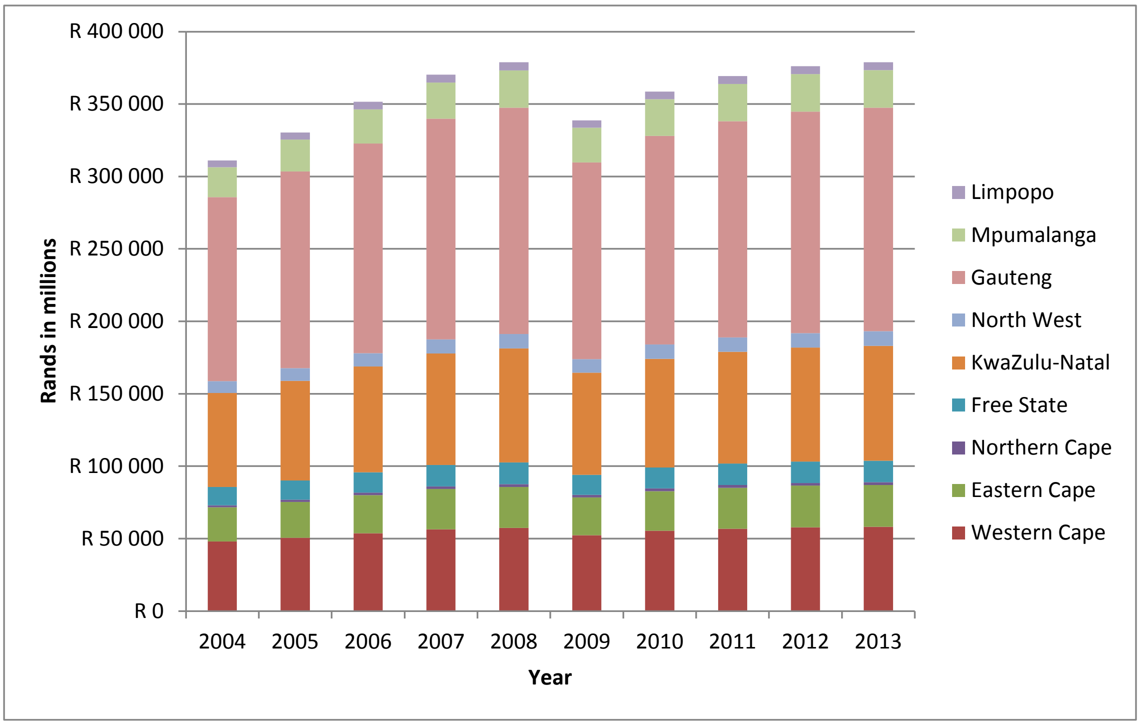
Gauteng is South Africa’s biggest contributor to the Gross Domestic Product with a contribution averaging 33.8 percent between 1998 and 2013 (Statistics South Africa, 2014). Comparative provincial contributions are shown in Figure 1. 1.

Figure 1. 1: Relative provincial contribution to South African Gross Domestic Product, Statistics South Africa (2014).



Gauteng is also home to South Africa's largest manufacturing sector, which contributed R154 billion in 2013 to the national GDP (Statistics South Africa 2014). The contributions of other provinces can be seen in Figure 1. 2.

Figure 1. 2: Provincial manufacturing activity at 2010 prices Statistics South Africa (2014).



However, the South African manufacturing sector is under threat. Mavuso (2014) indicated that local manufacturing firms have to deal with substantial cost pressures because of increased wages, input costs and administrative prices. He continued to advise that reductions in competitiveness because of electricity shortages, currency volatility, skills constraints and poor productivity further aggravate the situation.

Statistics South Africa (2015c) estimates that the manufacturing sector employs 1.138 million people with a total working population of 8.942 million when excluding the agricultural and informal sectors. This number is down from its peak in 2006 when the industry employed 1.33 million people (Small Enterprise Development Agency, 2012). The economic, industrial and political landscape has seen employer employee relationships stretched to breaking point. Linked to this was a five-month platinum mine strike and a four-week strike at steel and engineering firms in 2014, following a breakdown in wage negotiations.

South Africa’s industrial work force is heavily unionised however, current stress in the labour market are not limited to employer employee relations. Mbatha and Cohen (2014) stated “Divisions in the 2.2 million-member Congress of South African trade Unions came to a head on November 8 when the federation expelled the 350 000 member National Union of Metalworkers of South Africa for its decision last year not to back the ANC in elections.” They further indicated that this would be concerning to South Africa’s ruling African National Congress as these unions have underpinned its dominance since the end of apartheid.

The South African government has not been oblivious to the problems in the manufacturing sector and has intervened. Mavuso (2014) explained that the state introduced *The Preferential Procurement Policy Framework Act* in 2011, which empowered the Department of Trade and Industry to designate products that should be sourced locally. He further indicated that the *Industrial Policy Action Plan* was built on the vision of the *National industrial Policy Framework* by the Department of Trade and Industry and it is the overarching plan for dealing with the deindustrialisation threat.

1.3 Research Problem

The existing problem is that there is little information available about the adoption of additive manufacturing within South Africa and even less at provincial level. If South Africa is to benefit from the potential market growth this technology could bring, they need to understand whether individuals and organisations within South Africa are adopting additive manufacturing and what are the driving and prohibiting factors.

Struab (2009, p.625) with reference to product adoption indicated that “This decision of whether an individual will adopt a particular technology and the time frame involved with that decision has been a long source of research across multiple disciplines, and it influences business, school and everyday life”. If adoption is occurring, it could dramatically change the competitive landscape of the South African manufacturing sector. Individuals with little or no knowledge of traditional manufacturing techniques that take years to master could manufacture advanced products in a short period. High barriers to entry in some manufacturing markets could be eroded and logistics of products from factories to point of sale may no longer be relevant. The effect of this adoption could stretch far beyond the manufacturing sector.

There are many articles discussing the benefits of adopting additive manufacturing like that of Cohen, Sargeant, & Somers (2014). There are manufacturing comparisons between additive and traditional techniques (Gill and Kaplas, 2009) as well as articles on new developments in the field of additive manufacturing (Savage, 2014). However, this research will address the issue of whether additive manufacturing is being adopted within the South African manufacturing sector and what is driving or hindering that adoption.

1.4 Research Objectives

The aim of this research is to determine whether additive manufacturing is being adopted in industry and what factors are motivating or prohibiting this technologies uptake.

The proposed research will provide a cross-sectional view of the state of additive manufacturing in Gauteng thus providing insight for the business community. It can also be used as an initiating point for future longitudinal studies into the diffusion of additive manufacturing. The current state will be evaluated based current theories of diffusion of innovation. These theories will be used to determine the extent to which adoption is occurring, preferable technologies being adopted and factors that are driving or prohibiting the adoption of additive manufacturing. In addition, this work will also provide future insight into additive manufacturing by applying the Bass model of innovation diffusion using insights gained by the developed knowledge pertaining to the current state of additive manufacturing in Gauteng.

To follow will be a literature review documenting current theories of diffusion of innovation followed by a review of additive manufacturing.

2 Theory and literature review

2.1 Introduction

Straub (2009) in review of various adoption and diffusion theories stated that adoption theories assess an individual and their decision making to accept or reject a particular innovation. By contrast, diffusion theory seeks to examine the movement of an innovation through a social system. He provided the useful analogy of adoption theory being the micro-perspective focused on change in specific contexts while diffusion is the macro-perspective of the spread of innovation over time. Straub (2009, p.626) stated, “There is no one model for understanding the processes in which an individual engages before adopting a new innovation”. Thus, a range of models that have been applied in industry will be covered in this literature review. Before reviewing various models of innovation diffusion, it would be appropriate to define innovation.

2.2 Definition of Innovation

Rogers (2003, p.38) defines an innovation as “an idea, practice, or object that is perceived as new by an individual or other unit of adoption”. In the context of this research it is important to note that Rogers further stated that whether or not the idea is objectively new as measured by the amount of time past from the first use or invention, is irrelevant as far as human behaviour is concerned. However, the perceived newness of the idea determines the individual reaction to it.

2.3 Diffusion of Innovation

Straub (2009) suggested that Everett Rogers (1962 cited in Straub, 2009) and subsequent works had become the most influential work in the area of understanding how an innovation infiltrates a population. It provided the foundation for understanding adoption theory. He stated that Rogers theory had not always been easy to apply however, it has still been used across many disciplines with the intention of understanding and predicting. His theory had influenced many subsequent theories of adoption and diffusion.

Rogers (2003, p.31) defined diffusion of innovation as “the process in which innovation is communicated through channels over time among members of a social system”. Straub (2009) added that the adoption process was inseparable from the diffusion process as diffusion described the adoption process across a social system over a period of time. Rogers (2003) referred to the adoption process as the innovation-decision process. He explained that the innovation-decision process was a five steps process:

1. Knowledge.
2. Persuasion.
3. Decision.
4. Implementation.
5. Confirmation.

This model described the process of how an individual accepted or rejected an innovation. Rogers (2003) continued to explain that the fundamental elements of diffusion of innovation were:

1. An innovation (in the proposed research this would be additive manufacturing).
2. Communication through certain channels.
3. Time.
4. Member of a social system.

Rogers (2003, p.37) “These elements are identifiable in every diffusion research study and in every diffusion campaign or program”. Straub (2009) explained that these elements described the interaction and combination of individual adoptions, which result in diffusion. The innovation-decision process affected the time element of the diffusion model as the five steps usually occur in a time-ordered sequence. Rogers (2003) noted an exception to this and provided the example of an authority figure ordering an adoption in which circumstance the decision and implementation preceded the persuasion.

Rogers (2003) segregated innovation adopters based on the time taken to adopt a technology. He categorized them as follows:

1. Innovators
2. Early adopters
3. Early majority
4. Late majority
5. Laggards

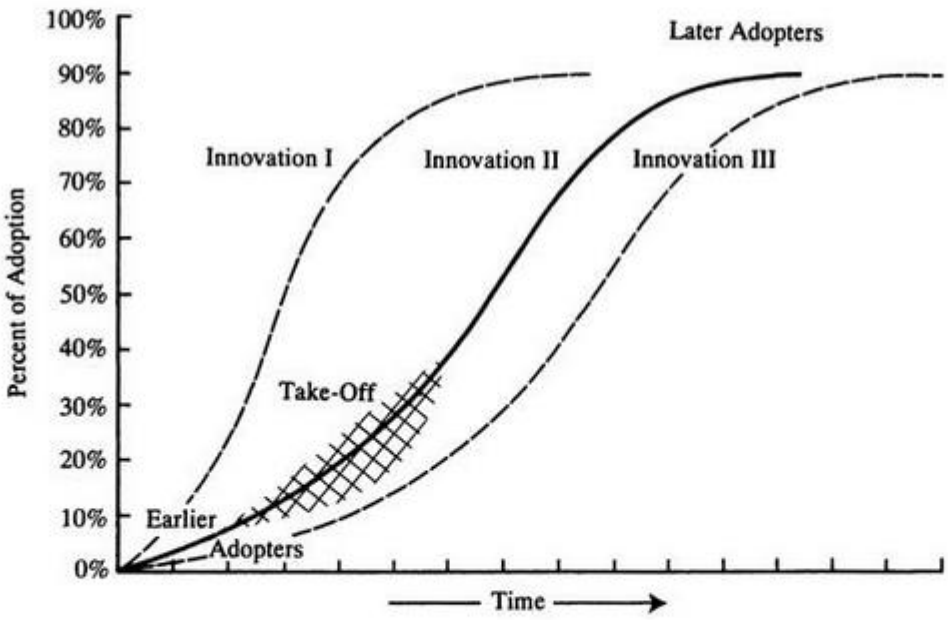
While discussing the various rates of adoption, Rogers (2003) stated that the number of individuals adopting a new idea resulted in an S-shaped curve when plotted on a cumulative frequency basis over time. An example of such curve is presented in Figure 2.1. The general form of the S-shaped curve is referred to as the logistic function, which is defined by the following mathematical equation:

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}} \tag{2-1}$$

Where:

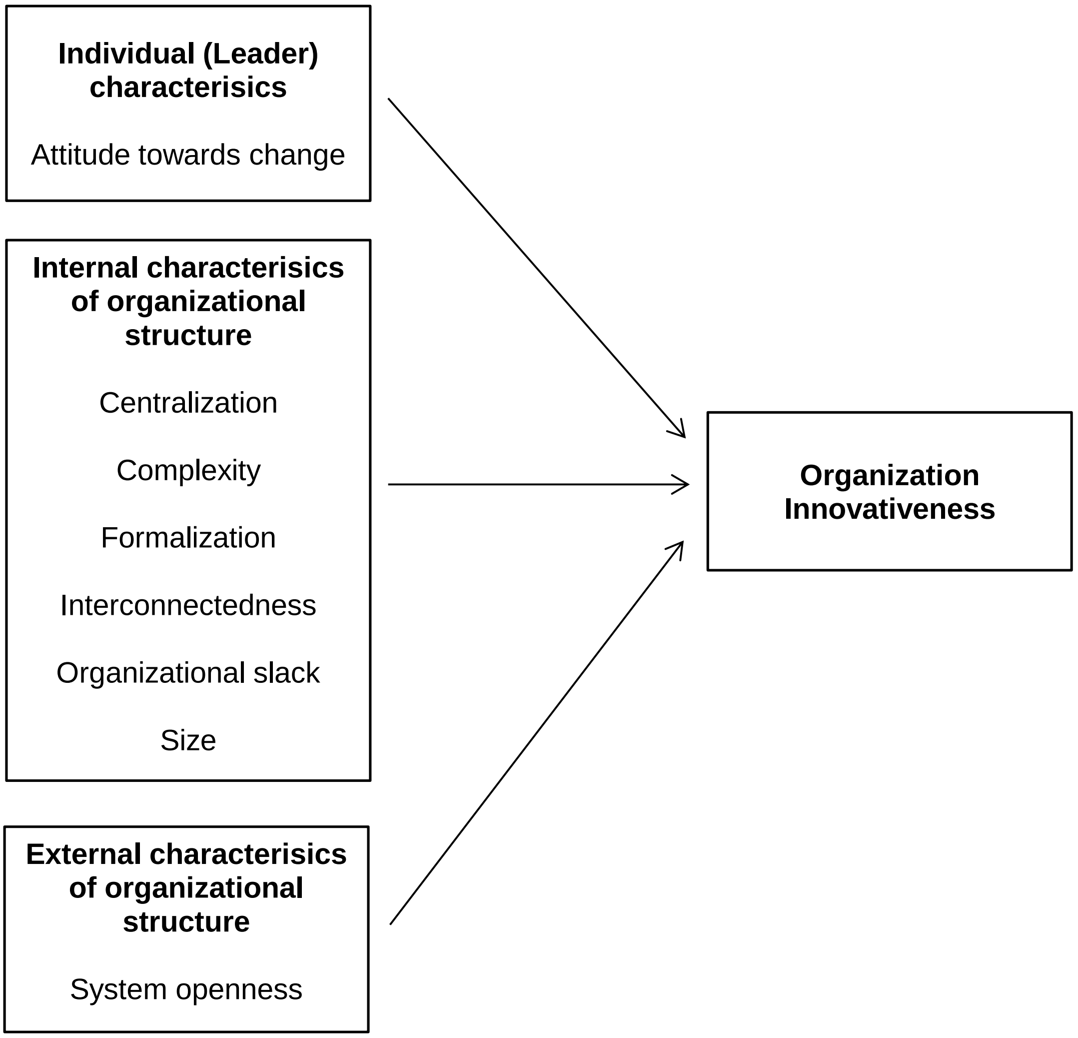
- $f(x)$ is the y-values making up the logistic function.
- x_0 is the x-value of the sigmoid midpoint.
- x is the x values in the real number domain.
- L is the maximum value the curve will achieve.
- e is the natural logarithm.
- k is the slope of the curve.

Figure 2.1: The diffusion process (Rogers 2003, p.37)



Oliveira & Martins (2011) described the innovation and adoption process within an organization as more complex than an individual adoption. It typically involved a number of individuals that would normally be categorized into differing categories (according to Rogers categories) of the five rates of adoption. Oliveira & Martins (2011) also presented Figure 2. 2 as a diffusion of innovation model at an organizational level. However, the originator (Rogers, 2003) of this model presented it as the independent variables related to organizational innovativeness. It is possible that this was done due to this framework's similarity to the Technology, Organization and Environment framework as discussed in Chapter 2.7. The similarities do provide motivation that the model be applied as an organizational innovation model however; it would require empirical evidence to prove its accuracy.

Figure 2. 2: Diffusion of innovation by Oliveira & Martins (2011, p.111).



Straub (2009) indicated that the Diffusion of Innovation model was still used in research either directly or indirectly through its influence. He further indicated that although his research could not find anything directly contradicting the model, he did have some concerns. Those concerns were as follows:

1. The depth and breadth of the Innovation of Diffusion theory framework made it difficult to frame a single case within the structure.
2. The theory was descriptive and not prescriptive thus it did not explain why adoption occurred but rather how to facilitate it.
3. The Diffusion of Innovation theories applicability to any field may necessitate that it be customization to suite specific situations.

Straub (2009) stated that this theories ability to be applied to the formal and informal adoption environments provided it with distinct advantage.

2.4 Technology Acceptance Model

Straub (2009) tells us that Davis's (1989) research was some of the first research to study how an individual's perception of technology innovation affected the eventual use of that technology. Davis (1989) identified two perceived characteristics that he believed to be predictors of a technologies adoption. The first was the perceived ease of use of the technology and the second was the perceived usefulness of the technology. Straub (2009) believed that Davis's (1989) work was important as it started the conversation about the importance of individual perceptions in the adoption of technology.

2.5 United Theory of Acceptance and Use of Technology

Venkatesh, Morris, Davis & Davis (2003) conducted a study of the eight most common theoretical frameworks and models used to understand the adoption of technology. They then compiled the most noticeable characteristics of all the models to create the United Theory of Acceptance and Use of Technology. Straub (2009) explained that the framework consisted of four key determinants of use and four moderators of individual user behaviour. Key determinants were performance expectancy, effort expectancy, social influence and facilitating conditions. The individual moderators used were gender, age, experience and voluntariness.

Straub (2009) questioned the models accuracy, as it was a relatively new model.

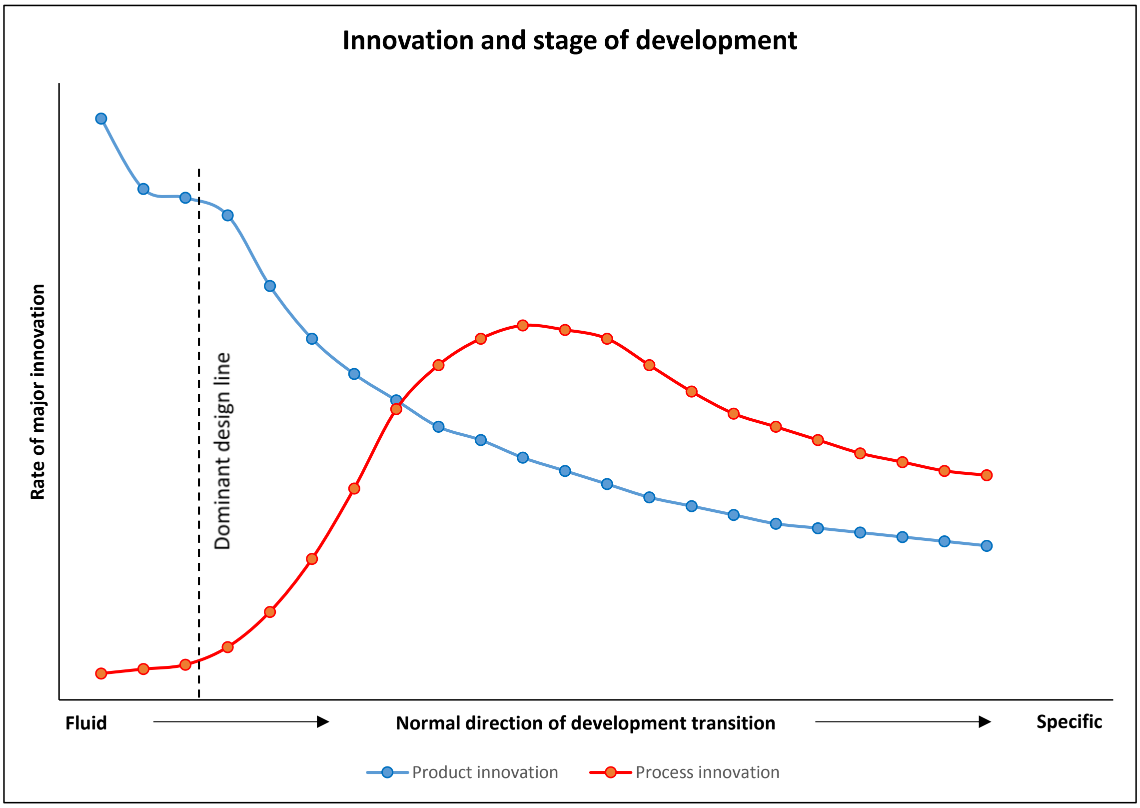
2.6 Abernathy-Utterback Model

According to Akiike (2013) innovation was seen as an extremely important element in corporate competition and considerable attention had been paid to it in existing research. "The Abernathy-Utterback model is a representative model in the field. The Abernathy-Utterback model shows that many product innovations occur from the initial stage of an industry to the advent of a dominant design. After the advent of dominant design, a shift toward process innovations and incremental innovation related to products and processes takes place" (Akiike, 2013, p.226).

According to Akiike (2013) the Abernathy-Utterback model was formulated through three separate pieces of work, Utterback and Abernathy (1975), Abernathy and Utterback

(1978) and Abernathy (1978). The Abernathy-Utterback model reached completion in Abernathy (1978) however subsequent references to the Abernathy-Utterback (1978) model by Teece (1986 cited in Akiike, 2013) and Utterback (1994) let many too believe that Abernathy and Utterback (1979) article was the final model.

Figure 2.3: Abernathy-Utterback model Abernathy (1978), Reproduced as depicted by Akiike (2013) as the completed model.

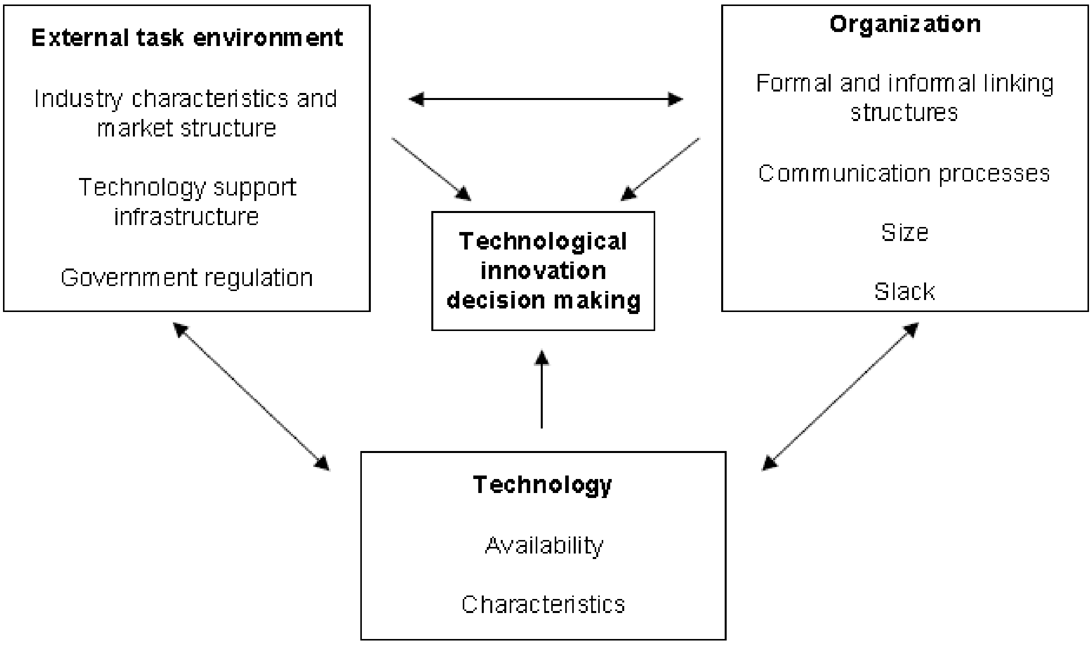


The model presented in Abernathy and Utterback (1978) described the process of innovation as moving from a fluid to a focused or specific direction of development. At the same time, the model showed how product innovation preceded process innovation. Abernathy (1978) expanded on that concept by including a point where a dominant design became evident. This point suggested the initiation of the process innovation cycle.

2.7 Technology, Organization and Environment Framework

Oliveira & Martins (2011) indicated that the Technology, Organization and Environment framework was originally developed by Tornatzky and Fleischer in 1990 and published in there book *The Process of Technology Innovation*. Oliveira & Martins (2011) described the framework as consisting of three elements that influenced the technological innovation adoption by enterprises. These elements are presented in Figure 2.4

Figure 2.4: The Technology, Organization and Environment Framework as presented by Oliveira & Martins (2011, p.112).



Oliveira & Martins (2011) stated that the Technology, Organization and Environment framework provided a useful analytical framework that could be used for studying the adoption of different types of Information technology innovations. They motivated this by stating that the framework had a solid theoretical base and consistent empirical support. Oliveira & Martins (2011) provided proof of empirical support of the framework by providing a list of 16 studies that made use of the Technology, Organization and Environment framework from 1997 to 2010.

2.8 Bass Model

The Bass Model Principle article documented the development of a theory regarding the timing of an initial purchase for new consumer products (Bass, 2004a). Subsequently it has become a highly influential paper. So much so, INFORMS members voted it as one of the top ten most influential papers published in the 50-year history of Management Science (Bass, 2004b).

After having read Everret Rogers book (1962, cited in Bass, 2004b), Frank Bass decided to express Rogers ideas using mathematical formula. Bass used Rogers idea of five categories of adopters (1. Innovators, 2. Early Adopters, 3. Early Majority, 4. Late Majority and 5. Laggards). He then decided to re-categorize the five classes as innovators (Rogers category 1) and imitators (Rogers category 2 through 5). Bass (2004a, p.1825) argues: “Apart from innovators, adopters are influenced in timing of adoption by the pressures of the social system, the pressure increasing for later adopters with the number of previous adopters”. Beyond the differing categorization, Bass (2004a) did not contradict Rogers Diffusion of Innovation model.

The growth model developed by Bass founded on the assumption that the probability of a purchase was linearly proportional to the number of previous buyers (Bass 2004a). With regard to initial purchases, Bass (2004a, p.1831) stated, “The model implied exponential growth of initial purchases to a peak and then exponential decay”. Following the development of the Bass Model, Frank Bass produced growth models for 11 consumer durable products. He validated his results using a Regression test and found that the data from the durable consumer goods was in good agreement with the respective models. Bass (2004b) stated that the model was intended for application to consumer durables. However, application of the model has shown applicability to a much wider class of products and services and it has become significant in forecasting Business-to-Business products and services of many categories including telecom services and equipment, component products such as semiconductor chips, medical products, and many other technology-based products and services.

Since the original development of the Bass model, subsequent extensions have been developed (Bass, 2004b). The first extension focused on the diffusion of successive generations of technology and was developed by Norton and Bass (1987). The second extension incorporated decision variables into the diffusion model. According to Bass (2004b), one of the first works to document the extension of a pricing variable was that of Robinson and Lakhani (1975, Cited in Bass, 2004b). This work was later extended by Bass & Krishnan (1994) to produce the Generalized Bass Model which incorporated the shifting of the curve concept. Bass, Gordon, Ferguson & Githens (2001) documented the planning of DIRECTV, as an example of the Generalised Bass Models application.

2.8.1 The Bass Model principle

Following Bass s’ review of Rogers work, he attempted to develop a mathematical equation to describe the diffusion of durable products. According to Bass (2004a), this led to the development of the conditional likelihood of adoption equation (hazard function). This equation described the likelihood of an adoption at time t as a linear function of the number of previous adoptions. The conditional likelihood equation as developed by Bass (2004a, p.1826) is presented as equation 2-2:

$$\boldsymbol{P(t) = p + (q/M)A(t)} \qquad \textbf{2-2}$$

Where:

- $P(t)$ is the probability that an initial purchase will be made at T given that no purchase has yet been made.
- p is the probability of an initial purchase at T=0.
- $(q/M)A(t)$ is the pressure operating on imitators as the number of previous buyer's increases.

Manipulation of the conditional likelihood function led to the development of the unconditional likelihood equation as presented in equation 2-3 (Bass 2004a, p.1826). This equation is in the form of a non-linear differential equation.

$$\boldsymbol{\frac{f(t)}{1 - F(t)} = p + q.A(t)} \qquad \textbf{2-3}$$

Where:

- p became known as the coefficient of innovation.
- q became known as the coefficient of imitation.
- t represented time from the product launch.
- $f(t)$ is the portion of M that adopts at time t.
- M is the potential market (the ultimate number of adopters).
- $F(t)$ is the portion of M that have adopted by time t.
- $A(t)$ is the cumulative adopters (or adoptions) at t.

Later Bass manipulated equation 2-3 with the intent of finding a solution to the non-linear differential equation. The manipulation led to the expression of an equation commonly referred to as the Bass Model Principle. It is presented in equation 2-4:

$$\boldsymbol{\frac{f(t)}{1 - F(t)} = p + \frac{q}{M}[A(t)]} \qquad \textbf{2-4}$$

Bass (2004b, p.1834) provided the following motivation for his model over existing models: "As sales of a new product begin to grow exponentially the industry becomes unrealistically optimistic and extrapolates sales growth into the hereafter, failing to take into account saturation effects. My point here is that the Bass Model provides a useful framework for viewing the diffusion of new products and technologies so as to permit realistic guesses about the pattern of sales growth and the timing of the peak in sales".

It is important to note that the derived equation 2-4 has its limitations. This model does not include replacement purchases and only focuses on initial purchases.

The Bass Model Principle has the ability to provide valuable insight into the possible diffusion of products however; it is a function of a set of input parameter. Thus to make effective use of the model, these parameters need to be clearly understood. The following section will discuss these input variables and suggested methods for their selection.

2.8.2 **Bass Model parameters**

The principle input variables to the Bass Model are:

- p the coefficient of innovation.
- q the coefficient of imitation.
- M the potential market (the ultimate number of adopters).

Lilien & Rangaswamy (2007) stated that there are several methods of determining the input parameters to the Bass model. These methods could be categorised based on the reliance of historic data or judgement for calibrating the model. Examples of this would be the use of linear or non-linear regression if historic sales data is available or analogues and survey data to determine customer purchase intentions (Judgement method).

Bass presents a method of determining the three input parameters in the original paper in which he presents his model (Bass 2004a). The method makes use of a discrete analogue. Bass begins with equation 2-5, which is a manipulated version of the Bass Model Principle:

$$\boldsymbol{a(t) = Mp + [q - p]A(t) - \frac{q}{M}A(t)^2} \qquad \textbf{2-5}$$

Where:

$a(t)$ is the adopters at time t.

The analogue is presented as equation 2-6:

$$\boldsymbol{a_t = a + bA_{t-1} + cA_{t-1}^2} \qquad \textbf{2-6}$$

Thus, a estimates Mp, b estimates $q - p$ and c estimates $-q/m$. Therefore:

$$\boldsymbol{-Mc = q, \qquad \frac{a}{M} = p} \qquad \textbf{2-7}$$

Then

$$\boldsymbol{q - p = -Mc - \frac{a}{M} = b, and\ M = \left(-b \pm \sqrt{\frac{b^2 - 4ca}{2c}}\right)} \qquad \textbf{2-8}$$

Therefore, parameters p, q and M can be solved. However, this method assumes initial sales data is available for at least three observations. Bass (2004a, p.1828) provided the parameters to eleven durable goods he used to evaluate the model. These parameters are given in Appendix C: Bass Model Parameters for eleven consumer durable products for comparison purposes.

The Bass Model Principle has been applied substantially since its introduction in1967. As such, large parameter estimate databases have been created. Bass (2004b, p.1835) provides an alternative method of parameter estimation in his statement: “the existence of data of sales histories of previously introduced products and services suggests the approach of ‘guessing by analogue’ by which the p and q parameters for the new product are determined by a guess as to which product or products in the database are likely to be most similar to the new product in diffusion pattern features”. He continued to suggest that the market potential parameter should be estimated based on known market characteristics that could be supplemented with intentions data from a survey. Appendix D: Bass Model Parameters for various consumer durable products provides a substantial list of short and long data series derived Bass Model parameters used by Lilien, Rangaswamy and Van den Bulte (1999).

Messiani and Gohs (2015) critically review the selection of Bass Model parameters applied to new automotive technologies. They reviewed previously applied parameters as well as the method in which they were determine compared with the models performance. They had significant conclusions that could be applicable to this work:

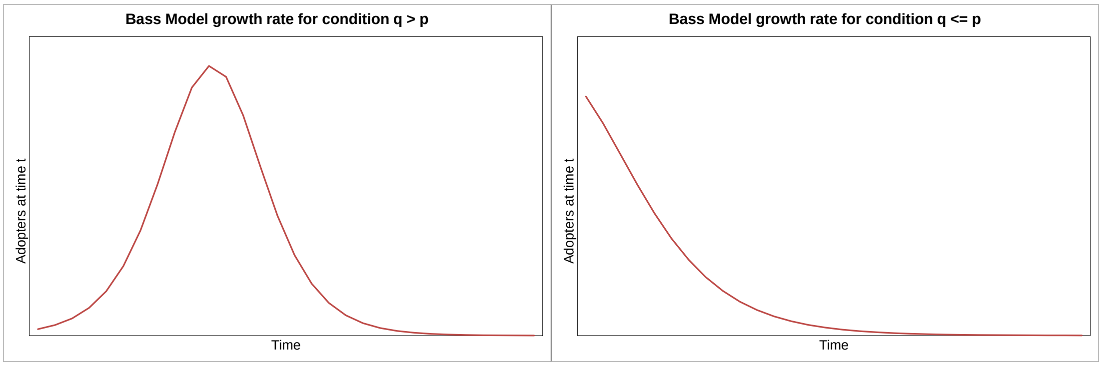
1. There was a large discrepancy/ range among ad-hoc parameter estimates.

2. Where ad-hoc estimates have been made, the Bass p parameter appears unstable and is sensitive to the assumed market potential M.
3. When the proposed potential market is not certain, their results show a variation in results by a factor of up to 100.
4. The Bass p parameter was highly influenced by proposed market potentials (when the market potential was exogenous), while the q parameter was only marginally affected.

Messiani and Gohs (2015) also suggested a two-step parameter selection process. Firstly, select a Bass q parameter value from the Bass Model with exogenous determined market potential. Secondly, determine the Bass p parameter value given M and q. If there is insecurity regarding the market potential, determine the p and M values given the q value simultaneously.

When considering the effects of the Bass parameters, Bass (2004b, p.1827) stated, "Since for successful new products the coefficient of imitation will ordinarily be much larger than the coefficient of innovation, sales will attain its maximum value at about the time that cumulative sales is approximately one-half M". Users of the Bass model should also be aware that should q be larger than p, the solution will rise to a peak and the decline while in the case of q smaller or equal to p, a decline will initiate immediately. These two instances can be seen in Figure 2. 5.

Figure 2. 5: The effect on modelled adopters at time t when considering the Bass model parameter p relative to q.



Users of the Bass model should have an understanding of the models limitations. Linked to this would be limitations on the selected Bass parameters. Bass (2004a) stated that even though it is possible to estimate the three Bass model parameters using only three observations, any estimate made on such basis should be viewed with scepticism, as the Bass parameters would be sensitive to small variations in the three observations. Bass (2004b) also provided a warning regarding the guessing by analogue method and suggests that users of this method keep in mind that even though the method has been applied with success, it is still based on a best guess. He further warns that the growth of the global economy may affect the nature of factors related to multicultural and international diffusion of new technologies and as such, the model may need revision.

To define the current state of diffusion of additive manufacturing in Gauteng, it was critical to understand the various diffusion models that have been proposed and applied in various field but more specifically in the technology. Having reviewed some of the more relevant models, it was important to understand what is already know about the additive manufacturing market and how the technology has been diffusing. The following section will review the available literature on this topic.

2.9 Additive Manufacturing

Additive manufacturing is a comparatively new manufacturing technique that has been possible due to technological developments in the manufacturing industry. Balinski (2014) indicated that the additive manufacturing industry is actually not a new industry. It has existed for approximately 25 years. Roth (2014) indicated that the fundamental principles of additive manufacturing were first demonstrated in 1801 with the invention of the Jacquard weaving machine (weaved in two planes but built a fabric in a third).

Additive manufacturing has often been associated with Rapid prototyping and was previously considered a method of producing rapid prototypes. A more recent push toward production type additive manufacturing equipment has seen these roles reverse. Rapid prototyping is now considered one application for additive manufacturing techniques. “Additive manufacturing, also referred to as 3-D printing, involves manufacturing a part by depositing material layer-by-layer. This differs from conventional processes such as subtractive processes (i.e., milling or drilling), formative processes (i.e., casting or forging), and joining processes (i.e., welding or fastening)” (Conner et al., 2014, p.64).

Balinski (2014) explained that the medical and aerospace industries were the primary uptakes of the technology for actual production purposes. He further stated that consolidated parts were driving investment by aerospace companies. Conner et al. (2014) quoted General Electric’s CEO, Jeff Immelt as having viewed additive manufacturing as a game changer and that he anticipated GE to be producing over 100,000 additive parts for its LEAP engines by 2020. Adoption of the technology has extended to the point where Loff (2014) told us that in 2014, the National Aeronautics and Space Administration sent a 3-D printer to the International Space Station and comparative samples of items made on earth were produced with the intent of paving the way for future long-term space expeditions.

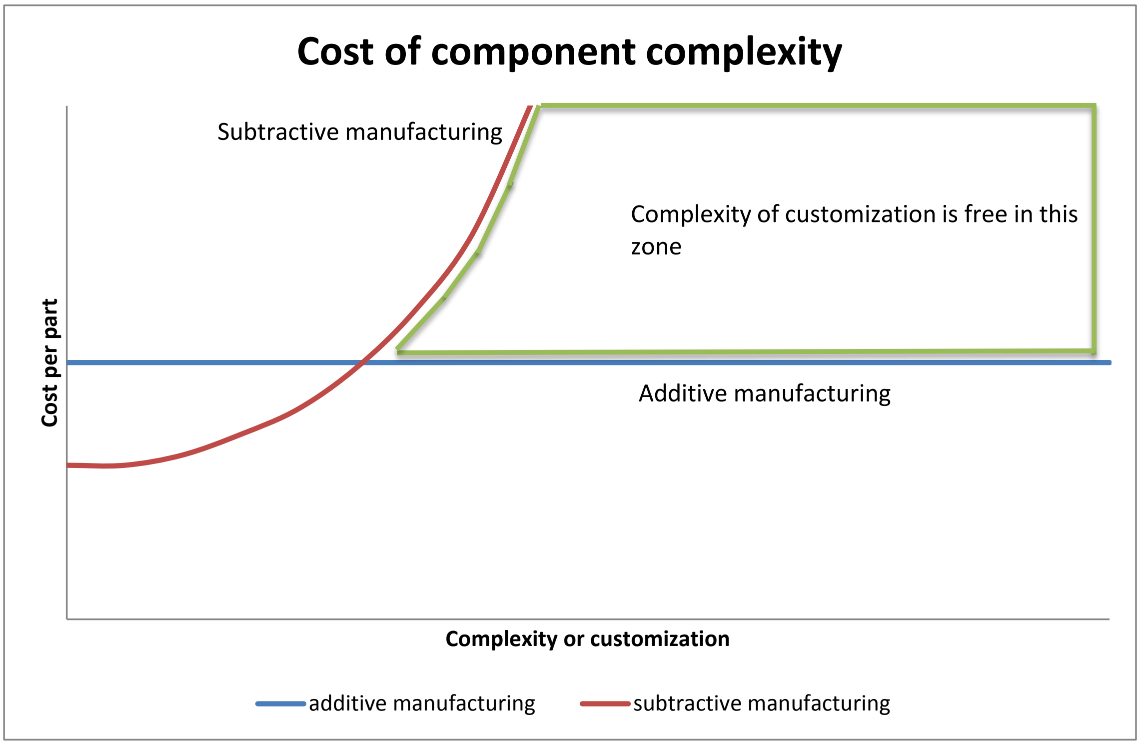
To follow will be a brief overview of the various technologies that comprise additive manufacturing as well as a look at the comparative advantages and disadvantages of this type of manufacturing. Following that will be a review of the adoption of additive manufacturing at the international and domestic levels.

2.9.1 **Additive manufacturing technology**

Since its initial invention, additive manufacturing machines have taken many shapes. Geo & Leu (2013) indicated that since the 1980's many methods of advanced manufacturing had been attempted with some having been commercialised. These include Stereolithography, Fused Deposition Modelling, Selective Laser Sintering, Laminated Object Manufacturing, 3-D printing and Laser Metal Deposition. Due to the diversified fabrication methods, a range of materials such as photo-curable resin, polyamide, wax, acrylonitrile-butadiene-styrene, polycarbonate, metal powders, ceramic powders and polymer powders have be used. Geo & Leu (2013) provided a few advantages of additive manufacturing "AM technology allows free form fabrication of geometrically complex parts without special fixtures as required in material removal processes. AM processes significantly shorten the lead-time, are cost-effective for single parts and small batches and can build parts not possible with subtractive manufacturing techniques".

Earls and Baya (2014) suggested that the biggest challenge additive manufacturing faces is in the reduction of manufactured components cost. They stated that additive manufacturing is still not cost effective for most end-product or high-volume commercial manufacturing. Conner, et al. (2014) stated that additive manufacture provides high levels of value when high cost components are being manufactured. They suggest that a threshold exist after which additional complexity comes at no additional cost when using additive methods relative to subtractive manufacturing. Figure 2. 6 illustrate this concept.

Figure 2. 6: Manufactured component cost comparison between additive and subtractive manufacturing. Reproduced from Conner, et al (2014).



Conner, et al. (2014) continued to state that additive manufacturing also provides the relative advantage of reduced product lead-times and enables product agility. Cohan (2014) extended on this by suggesting reduced tooling and assembly costs as well as the potential to reduce inventory of raw materials and work-in-progress. Weller, Kleer and Piller (2015) provided a list of technological and economic advantages and disadvantages. This list is given in Appendix B.

Earls and Baya (2014) suggested that additive manufacturing needs to improve in three areas if it is to capture opportunities beyond today's predominant case of rapid prototyping. These areas are:

1. **Performance:** Improved key performance characteristic such as speed, resolution, autonomous operation, ease of use, reliability and repeatability.
2. **Multi-material capability and diversity:** Incorporate multiple types of materials including the ability to mix materials while printing a single object.
3. **Finished products:** Provide the ability to print fully functional and active systems that incorporate many modules such as embedded sensors, batteries, electronics, microelectromechanical systems and others.

Earls and Baya (2014) described the existing additive manufacturing machine industry as segregated into high-cost high-capability and low-cost low-capability. They stated that high-end machines targeted enterprises while low-end machines targeted consumers and hobbyists. However, they continued to state that a new middle class of machines had started to emerge over the past year. They offered high-end features at low-end costs. They believed that additive manufacturing products would continue to improve at a rapid pace over the next few years although the degree and nature of the improvements would vary across technologies and vendors.

Earls and Baya (2014) ultimately recommended that additive manufacturing be used to supplement existing methods of manufacturing components and should be used when items cannot be manufactured any other way.

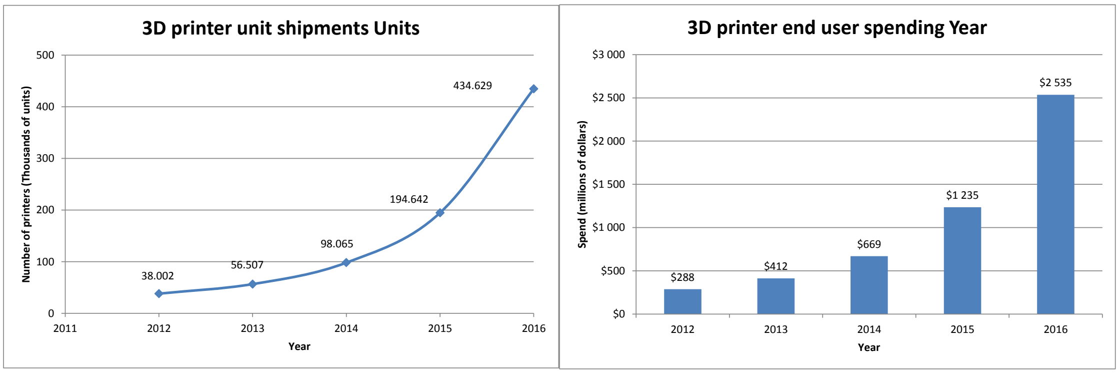
Many comparative studies have and are being conducted to determine the feasibility of 3-D printing for manufacturing applications. The comparative research by Gill and Kaplas (2009) concluding that the “proposed RC technologies based on 3-D printing, proved to be effective for the production of cast technological prototypes, in very short times, avoiding any tooling phase and with dimensional tolerances that are completely consistent with metal casting process” was just one of many such studies. Many of these studies are aiding in the construction of business models that can be used to motivate adoption of the technology as well as to continue its diffusion.

2.9.2 **International adoption of additive manufacturing**

Conner et al. (2014) stated that 3-D printing had seen unprecedented attention from the investment community. This attention reached its pinnacle when President Barack Obama mentioned 3-D printing in his State of the Union Address in February.

Thilmany (2014) advised that revenue from worldwide additive manufacturing products and services had increased from $2.3 billion in 2012 to $3.07 billion in 2013, thus showing an exponential rate of growth. De Jong and de Bruijn (2013) stated that the additive manufacturing industry had an annual compound growth rate of 26.4% over its 24-year history and that double-digit growth was expected to continue until at least 2019. Cohen (2014, p.62) stated that additive manufacturing had just started to penetrate the market with current estimations of market penetration ranging between 1% and 10%. He continued to put context to the growth by stating that “compared with traditional manufacturing however, additive manufacturing production volumes are diminutive, and the technology remains far from gaining mass adoption, especially in direct-part production”. He stated that global 3-D printer sales were around $0.6 billion while conventional machines tools were around $90 billion and plastic processing equipment at $25 billion.

Figure 2.7: Worldwide growth for 3-D printers under $100 000 (Gartner 2013, Cited in Brown, 2014)



Brown (2014) quoting Pete Basiliere, a research director at Gartner, indicated that as prices for industrial quality printers had then fallen below $10,000, many managers could afford to buy such a unit on their own authority to learn how the technology may aid there organization. On the low-cost side of additive manufacturing, Brown (2014) indicated that markets were being driven by growth of low-cost printers for schools and hobbyists. De Jong and de Bruijn (2013) expected 3-D printing to become part of the mass market. Cohen (2014) suggested technology, awareness and organisational readiness as key contributors to the adoption rate. He also cited McKinsey and Company research showing a general lack in additive manufacturing applications and value. They suggested that this was fuelled by a lack in familiarity of the technology beyond the cover press and that potential adopters needed to learn more about the technology.

Besides purchased machines, the DIY community also appeared to be adopting additive manufacturing. According to de Jong and de Bruijn (2013), Adrian Bowyer created the RepRap in 2005. He shared his design under the GNU license and since then, the design has spawned entire communities. In early 2012, it was estimated that 29,745 RepRap replicas had been constructed thus presenting the existence of a peer-to-peer network involved in the diffusion of the technology at a grass roots level. In 2012, user-found companies started selling and shipping thousands of these machines annually.

Roth (2014) provided some difficulties to the diffusion of additive manufacturing. He suggested that it was exceptionally difficult to separate the machine and the raw material from the final product and as such, it was difficult to build a business case to substantiate the machine. He further suggests that buyers and suppliers of additive manufacturing machines had different views of 3D printing resulting in difficulty in diffusing the technology. Roth (2014) suggested suppliers viewed the sale of a machine as a means of making money, thus resulting in constant technical benchmarking of machines against one another. Buyers on the other hand were not interested in the machine but rather "How they can use 3D printing as a medium in which to realize their needs and desires" (Roth 2014, p.8).

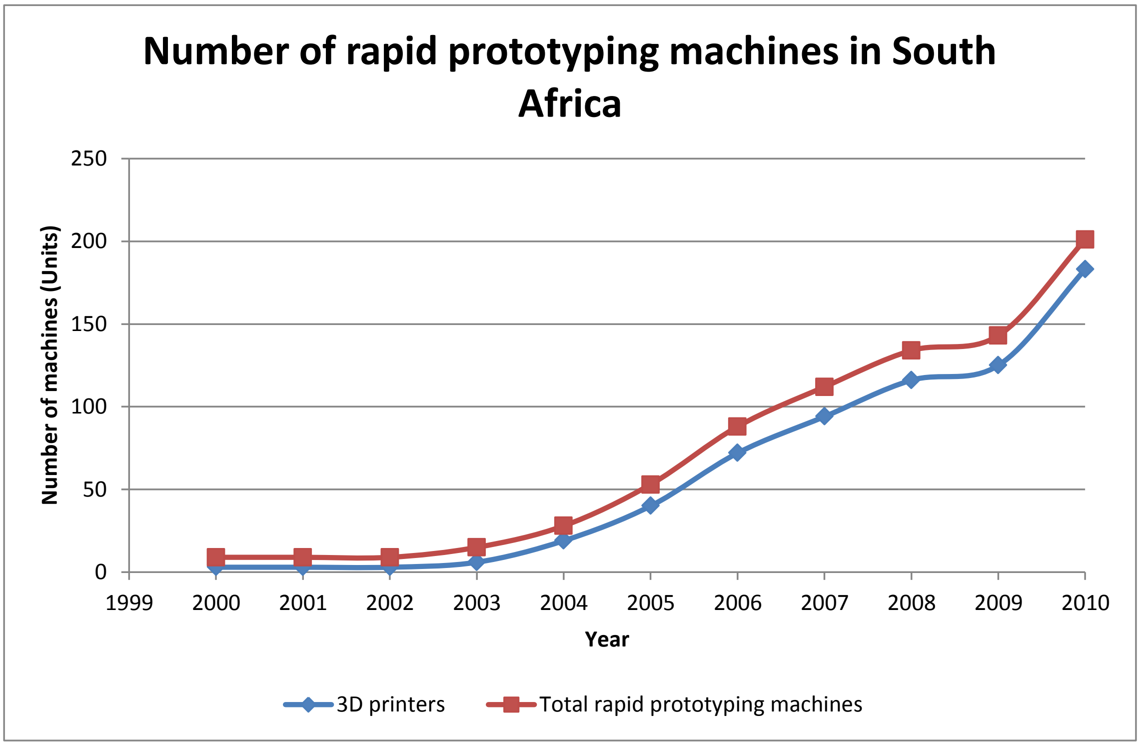
Cohen (2014) indicated that many executives were having difficulty deciding on the technology due to second-order effects on operations and economics. Weller, et al. (2015) supported this and stated that even with all the hype around the topic, little research exists on the economic and business effects of additive manufacturing technology. They believe most academic literature is still focuses on the technological aspects in the fields of engineering, material science, and computer science.

2.9.3 Adoption of additive manufacturing within South Africa

According to du Preez and de Beer (2006), the first rapid prototyping machines in South Africa were imported in 1994. Since then, The Rapid Product Development Association of South Africa (RAPDASA) was formed and has played a critical role in raising awareness through an annual conference and international ties such as the Global Alliance of Rapid Prototyping Associations. DefenceWeb (2015) stated that South Africa no longer only imported rapid prototyping and additive manufacturing machines but also developed them. They indicated that Boeing and the Council for Scientific and Industrial Research were developing a large-scale titanium additive manufacturing machine intent for use in the aviation industry. A titanium beneficiation program funded by the South African government backed this.

According to de Beer (2008), in 1998 only one privately owned South African company owned a rapid prototyping machine however, significate adoption was experienced during 2004 as can be seen in Figure 2.8. Campbell, de Beer and Pei (2011) stated that by the end of 2005, 74 percent of the rapid prototyping machines in South Africa were privately owned. By the end of 2008, 88 percent of them were of 3-D printer type. Campbell et al. (2011) only acknowledged the low-cost low-capability and the high-cost high-capability market segments. They estimated that the market was 54% (by machine cost) high-cost high-capability machines and the remainder of low-cost low-capability type. Wild (2014) stated that recent RAPDASA estimates place the number of low-end machines in South Africa at approximately 1400 and high-end machines at approximately 300.

Figure 2.8: Number of rapid prototyping machines in South Africa (du Preez et al., 2011).



Wild (2014) stated that the Department of Science and Technology had begun to develop an additive manufacturing technology road map to set the direction for South African manufacturing companies. The road map was to be developed in conjunction with the Council for Scientific and Industrial Research, academia and industry, however she indicated that no clear indication of a completion date had been made available. In addition to the lack in clarity surrounding this plan, Campbell et al. (2011) identified the following weaknesses and threats:

1. The available systems (machines) and raw materials for these systems is limited.
2. Fabrication times could be long.
3. Major South African industries were not embracing additive manufacturing. They suggest this could be due to dependence on product designs from companies outside of the country.
4. Lack in fundamental research in higher institutions that made peer-reviewed publications hard to achieve.
5. Growing competition in the tooling industry from foreign nations.

With the South African economy being dependent on the manufacturing sector for a significant portion of its revenue generation, it is important to understand the potential effects and implications of disruptive technologies such as additive manufacturing. To follow will be the presentation of the research question derived from the research problem with the aid of additional insight gained from the literature study.

3 Research Questions

3.1 Introduction

This study sets out to further the understanding of the diffusion of additive manufacturing in Gauteng. Existing literature such as Campbell et al. (2011) suggests the initiation of diffusion of additive manufacturing in South Africa however he does not suggest to what extent it has penetrated the manufacturing sector nor does he put forward possible constructs that may result in or hinder diffusion of additive manufacturing.

This research initiates at the abstract level and intends to develop these constructs thus allowing further future research to be conducted at the empirical level. Zikmund, Babin, Carr and Griffin (2013) advised that research questions are used to establish constructs; propositions are intended to develop the understanding between constructs and hypotheses are formal statements that explain an outcome and are empirically testable. This research intends to establish which constructs are relevant and as such, research questions are presented.

3.2 Research Questions

This research aims to answer the following questions:

3.2.1 **Question one**

To what extent has additive manufacturing been adopted in the Gauteng manufacturing sector?

Campbell et al. (2011) provided insight into the adoption of the technology across South Africa, however this adoption was inclusive of learning institutions that are involved in the technologies development and not industry related manufacturing. This question aims to define manufacturing related diffusion and discover the depth of penetration.

3.2.2 **Question two**

Has a dominant design of additive manufacturing machinery emerged?

This question draws from the Abernathy-Utterback model of innovation development and is design to evaluate whether the test population believes that a dominant technology design has set in. If so, this speaks to the 'what', of the current state of additive manufacturing. Whether or not a dominant design existing, this question will implicitly answer whether the dominant design line from the Abernathy-Utterback model has been crossed or not and as such will also suggest at what stage additive manufacturing has developed relative to this model.

3.2.3 Question three

What factors are driving or hindering the adoption of additive manufacturing?

The aim of this question is to establish the driving and hindering factors of the diffusion process thus providing insight into 'why' diffusion of additive manufacturing is occurring. This question stems from Rogers (2003) work where he viewed diffusion through a sociology lens.

3.2.4 Question four

What is the predicted rate of diffusion of additive manufacturing?

This question will be developed with the aid of the Bass Model which has been shown to be effective in estimating product adoption. This model will be used to establish the time period in which diffusion can be expected to occur. It is also appropriate to determine 'when' diffusion of this technology will reach its maximum potential.

4 Research Methodology and Design

4.1 Introduction

This research was intent on exploring and describing the current state of diffusion of additive manufacturing and establishing key constructs that drove or prohibited its diffusion. This chapter will detail various aspect of the research methodology that was selected and motives its use.

4.2 Research Design

To understand diffusion of innovation it was necessary to observe and understand what was happening in the real world. The literature study had shown that although models attempted to simulate reality, certain assumptions are made to obtain the desired result. As assumptions are made, it was important for the researcher to acknowledge the research paradigms. Sobh and Perry (2005) suggested that the research paradigm consists of three elements, ontology which is reality, epistemology which is the relationship between the reality, the researcher and the methodology which is the technique the researcher applies to discover the reality. These paradigms suggest the nature of the knowledge and as such should be provided by the researcher.

Saunders and Lewis (2012, p.105) defined the realism paradigm as “a research philosophy which stresses that objects exist independently of our knowledge of their existence”. Sobh and Perry (2005, p.1199) stated that “its (realism) philosophical position is that reality exists independently of the researchers mind, that is, there is an external reality”. They continued to explain that “realism refers to this external reality as consisting of structures that are themselves sets of interrelated objects, and of mechanisms through which those objects interact”.

This research made use of a survey to sample reality and in so doing aimed to define constructs that could one day be used to develop theory that simulated reality. As such, a philosophical approach of realism was adopted for this research. This selection was consistent with the definitions of realism by Saunders and Lewis (2012) as well as Sobh and Perry (2005) and as such was suitable.

Within the realism paradigm, a deductive reasoning process is used for this research. Zikmund et al. (2013, p.43) defined deductive reasoning as “the logical process of deriving a conclusion about a specific instance based on a known general premise or something known to be true”. He continued to explain that a theory may be developed by progressing from a general statement to a specific assertion using deductive reasoning and that this occurred at the abstract or constructs level. Further, he stated that inductive reasoning should be used to develop theories at an empirical level. Sanders and Lewis (2012) defined a deductive approach as having five sequential stages:

1. Defining research question from general theory that exists.
2. Operationalizing these questions.
3. Seeking answers to the questions defining stage one.
4. Analysing the results of the inquiry to determine whether it supports the theory or suggests the need for its modification.
5. Confirming the initial general theory or modifying it in the light of the findings.

This research was conducted at the abstract level and made use of existing related theories to develop questions or general premise that were used to explore and define specific constructs supporting additive manufacturing. Thus, the applied process aligned with Zikmund et al.’s (2013) definition of deductive reasoning and as such, is motivated by this definition. Further, the questions developed from theory reviewed in Chapter 2 and proposed in Chapter 3 fulfilled the requirements of Sanders and Lewis’s first stage. The actions required to complete the subsequent four stages will be present from Chapter 5 through Chapter 7. Thus, the applied process also complied with Sanders and Lewis’s (2012) defined deductive approach.

The research questions put forward are of exploratory type. They are intent on discovering constructs based on related theory on a topic not well defined by previous literature. This is consistent with Saunders and Lewis (2012) definition of exploratory research: “research that aims to seek new insights, ask new questions and to assess topics in a new light”.

A survey strategy was select for the research. Zikmund et al. (2013) suggested that exploratory research is typically associated with qualitative data, as ideas that lead to research hypotheses need to be developed. This is consistent with Sanders and Lewis (2012) who suggested that the most common ways in which exploratory research is conducted are:

1. Literature review

2. Interviewing ‘experts’ in the subject
3. Conducting interviews.

This created a possible argument against the use of a survey strategy for this research. However, Sanders and Lewis (2012) advocated a survey strategy to be particularly suitable for asking questions such as ‘Who?’ ‘What?’ ‘Where’ ‘how much?’ and ‘how many’. They continued to state that their ability to generate answers to such questions makes them useful for exploratory and descriptive studies. These questions can be closely tied to the research questions which were principally attempting to establish ‘who?’ ‘what?’ ‘where?’ and ‘how much?’, relative to the diffusion of additive manufacturing. Further, the diversity of the manufacturing sector with in Gauteng required a relatively large sample for it to be representative of the population and be relevant to the industry. As an example, a case-study strategy may have been suitable in answering the research questions but would be limited to a single instance of adoption. The intent was to identify constructs that were applicable to all adoptions of additive manufacturing at the manufacturing industry level and as such, a survey strategy was selected.

Creswell (2003) provided a comprehensive look at qualitative, quantitative and mixed-method research. He advocated that any single method is subject to the researcher’s bias, however combining methods many neutralise or cancel this effect. He continued to explain that based on the original concept of triangulation, results from one method may be seen to aid in the development of the results of the other. Creswell (2003) suggests three possible formats of mixed-method research:

1. Sequential procedure. This is when a researcher seeks to elaborate on the finding of one method with those from another.
2. Concurrent procedure. When a researcher converges qualitative and quantitative data to provide a comprehensive analysis of a problem.
3. Transformative procedure. When a research applies a theoretical lens as the principle perspective within a design that contains both quantitative and qualitative data.

This research applied a concurrent procedure mixed-method design intent on converging the data there by providing a comprehensive analysis of the possible constructs that affected the diffusion of additive manufacturing. Quantitative questions were used to probe a large spread of possibilities in the field of additive manufacturing. Answers to those questions were intent on evaluating possible abstract constructs. Those questions were simultaneously supported by qualitative questions which were intended to seeking out any constructs that were not detected using the quantitative questions. Further, the qualitative questions may have suggested possible relations between the constructs that could be tested in future research at an empirical level. Sanders and Lewis (2012) also advocated this method and provide the following four reasons supporting a mixed-method design:

1. Some data collection methods are more suited to particular tasks than others are.
2. Focusing on different aspects of the study.
3. Corroborating your research findings with a study using two or more independent sources of data or data collection methods.
4. Using qualitative methods to explain relationships between quantitative variables.

The research was constructed using a cross-sectional time-horizon however; the researcher acknowledges that question four did progress into the longitudinal time horizon. This was deemed acceptable as the longitudinal time horizon used in question four was based on the current state and was intent on providing further insight into the field in which this research was being conducted. Further, it was of predictive nature and not historic which would therefore require future evaluation to determine it validity. This was still consistent will exploratory research.

4.3 Population and Unit of Analysis

Zikmund et al. (2013, p.385) defined a population as “any complete group that shares some common set of characteristics”. Drawing from this definition, the population was selected as any individual currently employed within the formal manufacturing sector and located within the Gauteng provincial boundaries. Previously employed or retired members were not included in the population.

For the purpose of this study, manufacturing was defined as the process of converting a raw material into a finished product. Thus, a manufacturing company was an organisation responsible for arranging manufacturing. Individuals that were defined as part of the population had the following characteristics:

1. Any individual responsible for the selection or promotion of new or alternative manufacturing processes and equipment.
2. Any key stakeholder that had a direct affect on the adoption of new technology. Example of these would have been company owners, directors, engineers, plant managers and procurement officers.

Zikmund et al. (2013, p.118) defined a unit of analysis for a study as “what or who should provide the data and at what level of aggregation”. The selected unit of analysis was at the individual level of the selected population. The individual level was closely associated with those individuals within a company whose perspective or opinion about the adoption of additive manufacturing could have had an influence on the company’s decision to adopt or reject the technology.

4.4 Sample Method and Size

Marshall, Cardon, Poddar and Fontenot (2013) stated, “Other than selecting a research topic and appropriate design, no other research task is more fundamental to creating credible research than obtaining an adequate sample”. The sampling technique selected for this research was cluster sampling which had the characteristics of a probability sample. A list of the selected population could not be defined however; it was possible to determine the population in a specific geographical location. Thus, the selected sample frame was that of a single industrial area randomly selected with in the Gauteng province. Zikmund et al. (2013, p.398) confirmed this as a probability sampling technique based on the principle of cluster samples either having a random selection of the cluster or a random selection of elements within the cluster. He also added that this type of sampling was commonly used when lists of the entire population were unavailable.

It was decided that a census of the entire sample frame would be conducted. All elements within the sample frame were determined by the researcher conducting an internet based search for manufacturing firms within the cluster. This was supported by the researcher traversing all the streets in the cluster searching out manufacturing organisations. It is acknowledged that a sample frame error did exist using this technique but it was believe that the combination of the internet search as well as the traversing of the cluster would minimise this error.

Zikmund et al.(2013) did warn of samples not being representative of a population should the sample not be heterogeneous of the population itself. He also warned of problems arising when elements within a cluster exhibited characteristics and attitudes that were similar. As an example, this method would have been a poor selection for evaluate the Gauteng police force by sampling one cluster. However many of the manufacturing clusters within Gauteng were built-up of companies competing in differing subsectors within the manufacturing sector, as such, a homogeneously distributed sample across the subsectors would be obtained. This would result in the difficulties described by Zikmund et al. being avoided.

4.5 Data Collection Instrument

The applied instrument of measurement was an online questionnaire. The online research tool Survey Monkey was used to generate the questionnaire and collect data. It was assumed that all people with the means to adopt additive manufacturing would have access to the internet thus; this selection would not affect the population. Sanders and Lewis (2012) advocate the use of a questionnaire when the same set of standardised questions are posed to a large sample. They also provide some generic guidelines when distributing an online survey. They were complied with.

A pilot study was conducted using readily available respondents that matched the required characteristics of the population. However, these respondents did not fall within the industrial cluster of Sebenza and as such were not included in the research survey. There responses as well as a secondary feedback session were used to confirm both content and construct validity.

4.6 Research Process

The research was broken down into two fundamental components. The first was the literature review that was presented in Chapter 2. This presented details of the existing body of knowledge and was aimed at developing a deeper understanding of the possible constructs affecting additive manufacturing. This provided a foundation for the second component of the research, which was intent on establishing a set of constructs that affect the adoption of additive manufacturing.

The industrial cluster of Sebenza (Edenvale) was randomly selected for the second component of the research. To obtain the contact details of the population, two processes were followed. The first was an online search of various business indexes. All listed manufacturing and potential manufacturing companies contact details were extracted from the indexes and a list was formed. The second process was the traversing of all the streets in the industrial cluster seeking out potential manufacturing companies. Their contact details were also collected and added to the list. A total of 121 companies within the cluster were suspected of being manufacturing companies.

Each of these potential manufacturing companies was then contacted and a member of the organisation with characteristics of those previously described, identified. The activities of the organisation were checked against the definition of manufacturing as provided above. Companies that comply with the definition from the view-point of the employee and not the researcher were included in the study.

From the 121 companies originally suspected of been manufacturing companies, only 95 were in the opinion of the potential respondent, actually manufacturing companies. These remaining respondents were then requested to complete the survey. An e-mail with a link to the survey was provided and receipt thereof was confirmed. Only a single respondent from each organisation was targeted there by neutralize a bias effect of multiple respondents from a single organisation. Fifteen respondents immediately declined to take part, sighting lack in relevance and knowledge of the subject. The remained volunteered to complete the survey however; a total of 31 respondents actually completed the online questionnaire.

4.7 Data Analysis

The conducted research was of mixed-method design. As such, both qualitative and quantitative results were obtained and needed to be analysed. The research was conducted at the abstract level and was of explorative nature, thus no hypothesises or propositions were put forward, only research question which were sub-categorised into construct level questions. These construct level questions were further deconstructed into operationalized questions that formed the questionnaire. The data types of the operationalized questions can be seen in Table E. 1.

Due to the fact that no hypothesises or propositions were being tested, descriptive statistics were used to present information. This was achieved by converting data obtained using the questionnaire in to coded data which was then used to determine the descriptive statistics. To generate further insight, binary logic (and, or operators) were regularly applied to multiple categories of the quantitative data to obtain focused answers. An example of this would be a respondent that made use of additive manufacturing and researched additive manufacturing.

Qualitative data was processed using the Key-Words-In-Context method to identify themes. These themes were later assessed as possible constructs. Alternatively they provided insight into the construct level questions. Ryan and Bernard (2003, p97) support this method and state the following “Word-based techniques are typically fast and efficiency ways to start looking for themes. We find that they are particularly useful at the early stages of theme identification”.

Following the processing of both quantitative and qualitative data into information, this information was then consolidated and used to evaluate constructs, which were used to answer the research questions.

4.8 Potential Research Constraints and limitations

All research has limitations and constraints. The following is a list of fundamental constraints and limitations of this research.

Components of the research that may have been better quantified using a longitudinal study were limited to a cross-sectional study where a current state is analysed, opposed to a time-dependant data series. This is because of the allocated time restrictions.

The study is primarily focused on the Sebenza industrial business district within Gauteng. The relatively small sample size achieved brings in to question the ability to generalise the results to as large an area as Gauteng even though the adopted method of a random cluster samples permits such generalisation (Zikmund et al, 2013).

The research was confined to Gauteng due to limited access of suitable respondents outside of the defined area.

With respect to diffusion theory, an implicit bias of preadoption exists (Straub, 2009). Thus, the questionnaire questions will have to be carefully constructed with the intent of creating equal adoption or rejection conditions.

Many of the models reviewed and to be applied are influenced by social cognitive theory (Straub, 2009). Social cognitive theory is one of the most influential theories in psychology and it should be acknowledged that theories of adoption and diffusion do not include many of these aspects.

5 Results

5.1 Introduction

This chapter presents the results of the online questionnaire that was completed by 31 of the 121-targeted (80 of which the respondents believed they represented a manufacturing company) respondents. The questionnaire incorporated results that were of quantitative and qualitative type and as such, both statistical and Key-Word-In-Context analysis of results are presented.

The research was conducted at an abstract level and as such, relevant statistics will be presented at a descriptive level, as there was no intent on proving a hypothesis or proposition. The intention was to discover or establish possible constructs that are relevant to the research questions.

Table 5. 1 presents the connection between research questions and the operationalized survey questions. This allows the reader to obtain insight into the generation of the operationalized survey questions through the constructural-linking questions derived from the literature and research question. The questionnaire can be seen in Appendix A.

The results will be present in the order of the research questions. Information relevant to each research questions will be sub-divided and discussed at the conceptual question level in this chapter (operationalize level data will be processed and presented at conceptual level) however discussion in Chapter 6 will take a holistic view of the conceptual level information presented in this chapter and will discuss the results in term of the research question.

Table 5. 1: Research question to operationalized question linking.

	Conceptual level questions (Sub questions were operationalised questions)		Linked questionnaire numbers (operationalized questions), yellow are qualitative questions			
Question 1	1	**How much adoption is occurring?**				
			1			
				2		
					3	
						4
	2	**At what level of penetration is the adoption occurring?**				
			5			
				6		
					7	
	3	**When are companies adopting additive manufacturing?**				
			8			
				9		
	4	**Which manufacturing sub-sectors are adopting additive manufacturing?**				
			10			
				11		
					12	
	5	**How interested are companies in additive manufacturing?**				
			13			
				14		
	6	**Are companies aware of different technologies and do they have sufficient knowledge of them?**				
			15			
Question 2	7	**Is there a perceived dominant technology?**				
			16			
				17		
	8	**Is there a reason for a technology to be seen as dominant**				
			18			
Question 3	9	**Is there a preferred technology for the respondents operating domain?**				
			19			
				20		
	10	**What are the financial implications of additive manufacturing?**				
			21			
				22		
					23	
	11	**Are companies sufficiently exposed to allow for an adoption decision to be made?**				
			24			
				25		
	12	**Are there sufficient equipment providers in the industry to create confidence in adopting?**				
			26			
	13	**Are the required materials available in the additive manufacturing industry?**				
			27			
				28		
	14	**Is additive manufacturing capable of manufacturing companies existing products?**				
			29			
	15	**Do all stakeholders have the same opinion of additive manufacturing?**				
			30			
				31		
Question 4	16	**Does advertising impact the adoption of additive manufacturing?**				
			32			
	17	**Does advertising affect the price sensitivity of companies entering the additive manufacturing industry?**				
			33			
				34		
	18	**Are additive manufacturing machines seen as durable purchases?**				
			35			
	19	**Do you see the company as an innovator or an imitator?**				
			36			

5.2 Question 1

This question was aimed at defining the current state of adoption within the industrial sector. Although quantification of the current state of adoption is included in this section, it is only a part thereof. Understanding the depth of the adoption and what the adopted technology is used for was also the focus. The knowledge of respondents relative to the additive manufacturing industry was also reviewed as this could affect adoption rates.

5.2.1 How much adoption is occurring?

With the intent of understand the constructs supporting additive manufacturing, it is highly relevant that the extent to which adoption is occurring is understood. The extent of adoption was not confined to market penetration but was also focused on the respondent’s type of application of the technology (e.g. Prototyping, production).

When considering the market penetration of the 31 respondents in the cluster, only 16 percent claimed that their employer leased or owned an additive manufacturing machine. However, 45 percent of respondents did acknowledge that they personally knew of a manufacturing company that leased or owned an additive manufacturing machine. This resulted in 48 percent of respondents being aware of additive manufacturing technology. Some respondents owned a machine and were aware of another company with a machine, hence the 48 percent opposed to 61 percent, should there not have been common respondents.

Following knowledge of someone that owned an additive manufacturing machine, respondents were asked if they believe additive manufacturing would add value to their business. Sixty percent of the respondents believed that additive manufacturing would add value to their business. The definition of ‘value-add’ was left to the respondent interpretation as it was believed that the decision to adopt the technology would be based on the respondents definition.

When reviewing respondents that had exposure to additive manufacturing, 19 thought it would not add value to their business. Concurrently, 19 percent of the respondents with no direct contact to additive manufacturing believe that the technology would add value to their business if adopted.

The most common key-word-in-context used by respondents when asked to motivate their response to additive manufacturing as a business value-add was ‘prototyping’.

When put in context, 42 percent of respondents believe that additive manufacturing added value as a prototyping tool. Other supporting factors included speed (23 percent) and ability to manufacture complex components. The most prominent negative factor was material capability (13 percent) while industry requirement was used by 6 percent of respondents. A full list of prominent motivating factors can be seen in Table 5. 2.

Table 5. 2: Respondents hindering and motivating factors for additive manufacturing as a value-add.

Key word in context	Number of occurrences	As a percentage of respondents
Prototyping (in term of applicability)	13	42%
Speed (positive factor)	7	23%
Incorrect material capability (negative factor)	4	13%
Complex components (positive factor)	3	10%
Space claim (Positive application)	3	10%
Geometrically not suitable (negative factor)	2	6%
Lower cost than existing method (positive factor)	2	6%
Higher cost than existing method (negative factor)	2	6%
Component quantity (negative factor)	2	6%
Not an industry requirement (negative factor)	2	6%
Development at alternative location (negative factor)	1	3%
Track-record of technology not established (negative factor)	1	3%
Not good for bespoke components (negative factor)	1	3%

5.2.2 At what level of penetration is the adoption occurring?

Some companies choose to experiment with a technology before committing to it. When asked, 68 percent of respondents stated that their company was not actively involved in experimentation with additive manufacturing.

Approximately one third of respondents (39 percent) believed that there company would use additive manufacturing to extend existing capabilities; one third (29 percent) believed that there company would use additive manufacturing to replace older manufacturing techniques and one third (32 percent) did not respond to this question. Possible cause for no response may have been that respondents were uncertain as to how there company would apply the technology. This was not provided as a possible option for respondents. When reviewing respondents that owned or leased an additive manufacturing machine, 60 percent of respondents stated that they used the technology to extend existing capabilities. The remaining 40 percent used it to replace existing manufacturing techniques. When asked what quantities of items they would make using an additive method, 68% of all respondents indicated either one-off or small batch quantities while 100 percent of respondents with machines indicated one-off items.

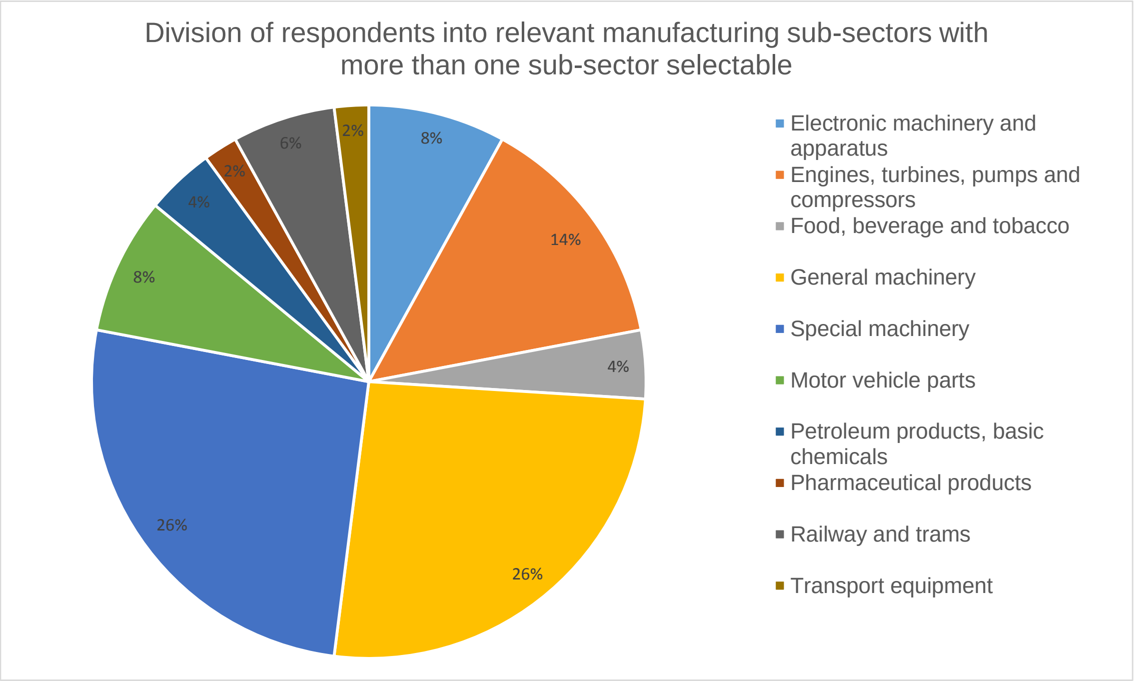
5.2.3 When are companies adopting additive manufacturing?

The earliest reported case of adoption of additive manufacturing by one of the respondents was in 2010. Looking forward, 77 percent of respondents indicated that they believed their company would never purchase an additive manufacturing machine. However, 10 percent of respondents indicated that they believed their employing company would purchase an additive manufacturing machine in 2017. This was the peak year for intended machine procurements but, 2016 and 2020 equally split the remaining 12 percent (6 percent each) of planned machine procurements.

5.2.4 Which manufacturing sub-sectors are adopting additive manufacturing?

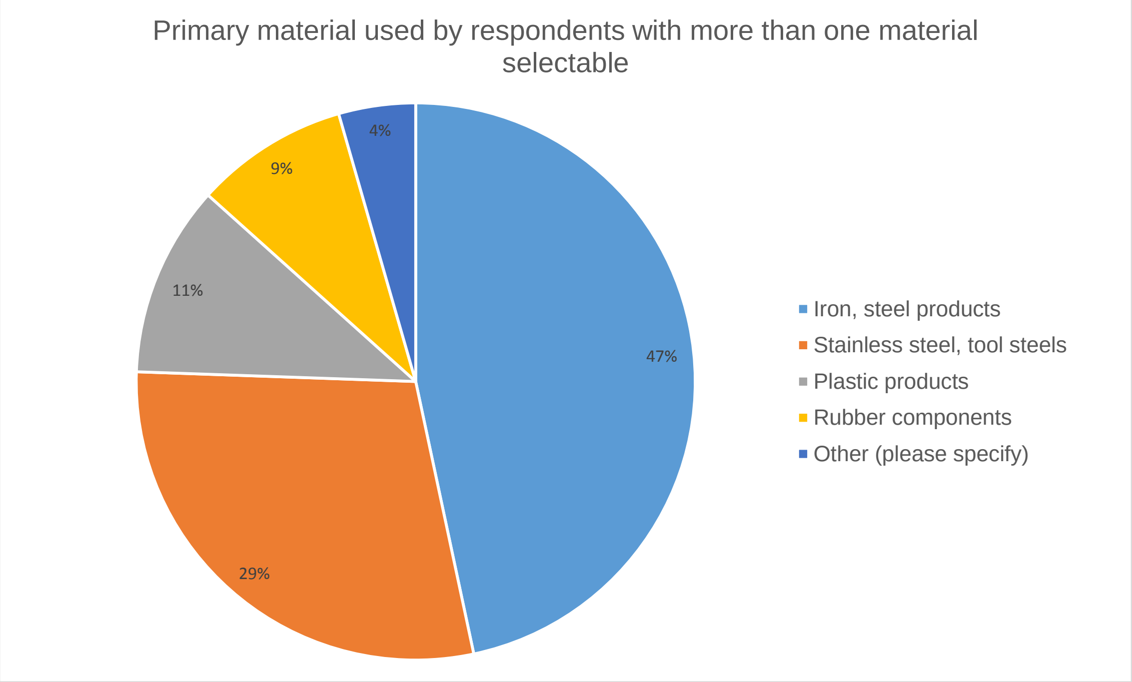
Having asked respondents about their companies' interaction with additive manufacturing, respondents were then questioned about the sub-sector of manufacturing their company fell into. Sixty-six responses were obtained from the 31 respondents (multiple selections by respondents). Sixteen of these were the 'other' criteria, however in all cases examples of the items their company manufactured were provided opposed to sub-sectors. Nine of the 16 selected sub-sectors as well as the 'other' option. For the remaining, based on the product examples provided, these companies were segmented. The result of this segmentation can been seen in Figure 5. 1.

Figure 5. 1: Division of respondents into relevant manufacturing sub-sectors.



The primary material used by the respondents were steels (76 percent). Rubber and plastic material were the next most common materials used. This is graphically presented in Figure 5. 2. When asked if they believed and equivalent printable raw material by comparison to their currently use material was available, only 32 percent of respondents answered yes.

Figure 5. 2: Primary material used by manufacturing companies according to their respective representatives.



5.2.5 **How interested are companies in additive manufacturing?**

As a component of evaluating a company's interest in additive manufacturing, respondents were asked if they had previously research additive manufacturing. Fifty-five percent of respondents advised that they had research additive manufacturing. Under further scrutiny, it was found that 80 percent of respondents whose employing company either leased or owned an additive manufacturing machine or knew of a company with one, had research the technology. Thirty one percent of respondents that worked for companies that did not lease or own an additive manufacturing machine admitted to having research the technology. When asked if they found what they were looking for, 45 percent of all respondents answer yes. This equated to 82 percent of the respondents that had researched the technology, stating that they found the information they were looking for.

5.2.6 **Are companies aware of different technologies and do they have sufficient knowledge of them?**

Following respondents admissions on whether or not they had research additive manufacturing, they were asked which of seven common additive manufacturing terms they could explain. This question was intent on evaluating the quality of research conducted as well as basic knowledge of additive manufacturing. Only 25% of the possible seven terms each of the 31 respondents were asked to explain, could be explained by the respondents. Further, of the 31 respondents, only two believed they could explain more than two of the terms provided.

5.3 Question 2

Question two was motivated by the Abernathy-Utterback model. The intention was to determine how far along the product development and process development curves additive manufacturing technology had progressed and if the dominant design line had been passed.

5.3.1 **Is there a perceived dominant technology?**

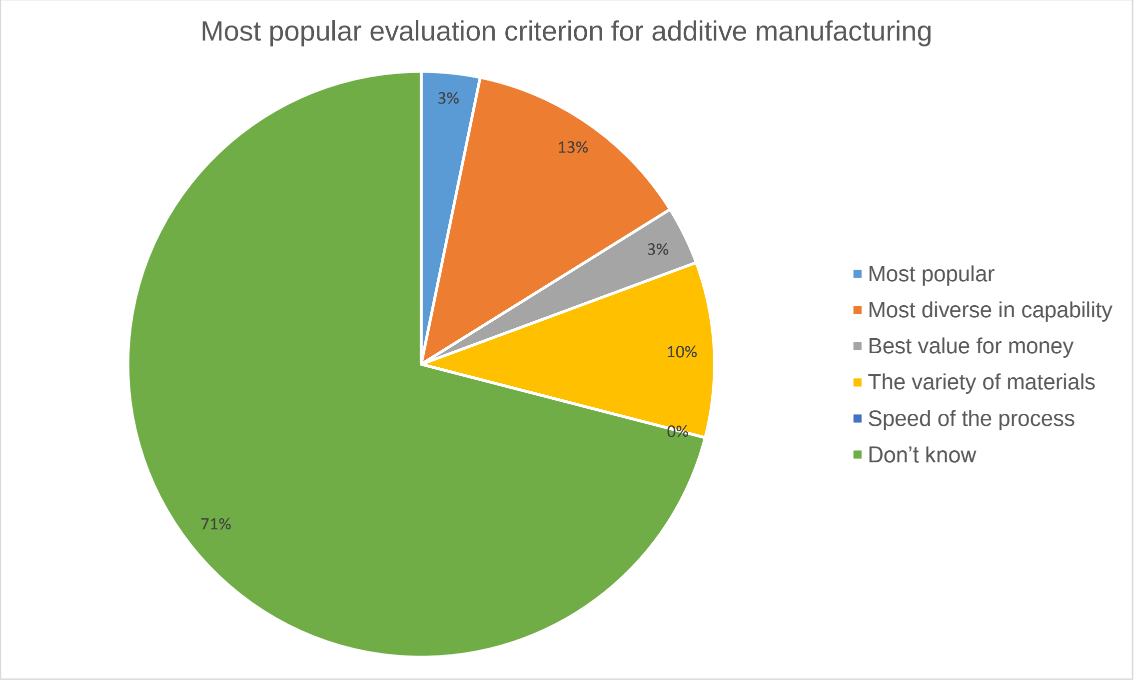
When asked about a dominant design or technology in the industry, 81 percent of respondents stated that they did not believe one existed yet. Out of the 19 percent of respondents that believed a dominant design or technology existed, 50 percent could motivate their answer however, each respondent motivated a differing technology as being dominant. When reviewing all respondents, 77 percent acknowledged that they did not know enough about additive manufacturing to comment.

It was observed that all respondents that believe a dominant technology existed, had research the technology. However, this group only surmounted to 35 percent of those that had claimed to have researched additive manufacturing.

5.3.2 **Is there a reason for a technology to be seen as dominant?**

Having established whether respondents believe a dominant technology existed, they were asked to provide a criterion on which they though would result in a technology being dominant. Seventy-one percent advised that they did not know. Thirteen percent selected diversity in capability and 10 percent diversity in material selection. Complete results to the evaluation criterion can be seen in Figure 5. 3.

Figure 5. 3: Most popular evaluation criterion for additive manufacturing, Single selection per respondent.



5.4 Question 3

The literature review has shown that many factors drive or hinder the product adoption process. Question 3 was intent on establishing what some of the possible factors could be.

5.4.1 **Is there a preferred technology for the respondents operating domain?**

Following from question two where we tried to establish whether there was a dominant technology, as a sub-section for research question 3, we tried to determine if there was a dominant technology per industrial sub-sector. The large majority (74 percent) of the respondents once again advised that they did not know the technology sufficiently well to decide which was best suited to their organisation. An example of one such response was as follows “Our products are exposed to intense high pressure, I am therefore not sure which process would be able to give a suitable replacement to steel or aluminium”.

Thirteen percent of the respondents did select material extrusion as the most preferable however only 25 percent of those respondents selected a technology that would function with the raw material they previously selected as there companies primary raw material. This respondent motivated his selection by stating that it was a technology that they were already using.

Powder bed fusion with 6 percent of respondents was motivated by its ability to print metallic based components. Further, all 6 percent of these respondents used metallic based materials as raw materials. Fifty percent of these respondents were actively involved in the engines, turbines, pumps and compressors sub-sector while the remaining 50 percent were involved in both the general machinery and specialised machinery industries.

5.4.2 What are the financial implications of additive manufacturing?

Cost implications of any new adoptions are always considered within the manufacturing sector. This is due to the fact that the cost of the manufacturing equipment directly impacts the cost of the product being manufactured. Thus, when asked about the costs linked to additive manufacturing, 52 percent of respondents believed that components manufactured using additive manufacturing cost more than existing manufacturing techniques. The key-words-in-context with regard to motivating both for and against additive manufacturing being more cost effective can be seen in Table 5. 3. The most prominent finding was that respondents sighted the technology as being new and as such, there was a focus on capability rather than production cost by machine developers.

Table 5. 3: Key words in context with respect to respondent's motivation for cost associated with components manufactured using additive manufacturing versus traditional methods.

Key words in context (number of occurrences in responses)	**Additive manufacturing cheaper than traditional methods**	**Traditional methods cheaper than additive manufacturing**
Previous experience		2
No scale benefit		2
New process (focus on capability not production cost)		4
Slower process		3
Additional processing of components will be required (like a cast component opposed to a machined item)		1
Limited accessibility		1
New technology thus cheaper	1	
Less components need due to increase complexity capability	1	
Reduced operating cost	2	
Total occurrences	**4**	**13**

Respondents were asked what they believed an additive manufacturing machine that could manufacturing a component equivalent to that which they already manufacture would cost. The distribution of these estimates relative to the raw material the respondents company used is provided in Table 5. 4.

Table 5. 4: Respondents estimated additive manufacturing machine cost relative to the primary raw material used by the company.

	Across all raw materials	Composite , glass, cement	Iron, steel products	Stainless steel, tool steels	Plastic products	Rubber components	Exotic steels (gold, silver)	Other (please specify)
R1 - R100 000	2%	0%	0%	0%	0%	0%	0%	50%
R100 001 - R250 000	9%	0%	10%	8%	20%	0%	0%	0%
R250 001 - R750 000	24%	0%	29%	31%	20%	0%	0%	0%
R750 001 - R2 000 000	33%	0%	38%	31%	0%	75%	0%	0%
R2 000 001 and higher	16%	0%	14%	15%	20%	25%	0%	0%
No answered selected	16%	0%	10%	15%	40%	0%	0%	50%

From Table 5. 4 we can see that 57 percent of the respondents believe that they could obtain a suitable additive manufacturing machine for between R250 001 and R2 000 000. It is also evident that respondents expect to pay less for an additive manufacturing machine that processes plastic opposed to steel.

5.4.3 Are companies sufficiently exposed to allow an adoption decision to be made?

With respondents having answered 23 operationalized questions by this stage, they were asked whether they believed they would be able to motivate either for or against the adoption of additive manufacturing at their employing company. Only 6 percent believed they would be able to motivate either way. The 6 percent that could motivate there answer both motivated for the adoption of additive manufacturing. Key-words-in-context used during the explanation of their ability to motivate for or against the adoption of additive manufacturing can be seen in Table 5. 5.

Table 5. 5: Number of occurrences of key words in context with respect to respondents reasoning for their ability to motivate for or against adoption of additive manufacturing.

Key words in context (number of occurrences in responses)	Could motivate adoption of additive manufacturing	Couldn't motivate adoption of additive manufacturing
Have not done sufficient researched		24
Have not researched, not relevant to the company		1
Don't understand the cost structure relative to traditional methods		1
Previous experience shows it expensive, thus more research needed		1
Not sure of capability		4
Only exposed to it at university, thud don't know enough		1
Own a 3D printer at home, thus understand costs involved.	1	
Technology of the future	1	
Total occurrences	**2**	**32**

One of the respondents that believed he would not be able to motivate an argument stated the following “We can’t work out what our costs for such a machine will be as we have little experience. We understand the costs involved in our lathes and mills”. Opposed to this, a respondent that could motivate for the adoption of additive manufacturing stated the following “I own a 3D printer at home. Know how it works and costs involved”.

5.4.4 Are there sufficient equipment providers in the industry to create confidence in adopting?

One of the respondents suggested that limited access to additive manufacturing technology has elevated its cost above traditional manufacturing (Table 5. 3). Following this trend of thought, respondents were asked if they believe sufficient additive manufacturing suppliers with the required support structures were present in the Gauteng market. Only 3 percent of respondents believed there were and 23 percent believing there were not. The remaining 74 percent were uncertain.

5.4.5 Are the required materials available in the additive manufacturing industry?

Raw material is critical to all manufacturing as it is the process of converting raw material to finished goods. The focus of this this construct revolved around potential difficulties in the material supply chain should a company change to additive manufacturing. Respondents were divided on whether a change to additive manufacturing technology would generate additions difficulties or problems to the material supply chain. Thirty-five percent believe it would result in challenges, 35 percent believed it would not result in challenges and 30 percent refrained from answering the question. Respondents were asked to motivate their answer. The key-words-in-context from their motivation can be seen in Table 5. 6. Responses from all respondents are not highlighted, only key findings. As such, the total occurrences do not reflect the total number respondents.

Table 5. 6: Key word in context related to anticipated material supply chain challenges when shifting to additive manufacturing.

Key words in context (number of occurrences in responses)	**Procurement of additive manufacturing raw material more problematic that traditional raw material**	**Procurement of additive manufacturing raw material less or equally problematic that traditional raw material**
Additive material expensive	3	
Need alternative material suppliers (not only machine suppliers providing material)	2	
Will have to change current material suppliers	1	
Uncertain who can supply material	1	
Material imported	4	
Not many suppliers	2	
Difficult to obtain good information	1	
Fewer raw materials for additive manufacturing than for traditional methods (only steel powder, not different size bars, etc.)		2
Don't know enough		1
Additional processing	1	
Special formats	1	
Machines are available, as such material will be available		1
Very new thus specialized	2	
Procurement should be the same as current		2
Total occurrences	**7**	**6**

It is important to note that many of the issues identified with additive manufacturing materials had to do with the source and cost associated with the beneficiation of this material e.g. the material being powdered. However, it was important to note that two respondents did identify the fact that they would require fewer raw materials if adopting additive manufacturing. e.g. In traditional methods, a manufacturer would have to keep different size bar stock for different size turned parts while with additive manufacturing a single stockpile of powdered metal would suffice.

5.4.6 Is additive manufacturing capable of manufacturing companies existing products?

As respondents progressed through the questionnaire, their limited knowledge about the additive manufacturing industry became more apparent. More respondents became reluctant to respond and not all concepts raised by respondents were applicable. Looking at capabilities, 26 percent of the respondents felt that additive manufacturing could produce equivalent products to those which they currently made. Thirty-five percent believed that additive manufacturing techniques would not produce an equivalent product and 39 percent elected not to answer. Strong belief that additive manufacturing is limited in capability to prototypes, space claims and R&D products may have affected the response rate of this question. Table 5. 7 shows key motivating factors supporting additive manufacturing's capability or inability to manufacture equivalent components to existing products.

Table 5. 7: Key concepts derived from respondents believes regarding additive manufacturing's capabilities relative to traditional methods.

Key words in context (number of occurrences in responses)	Machine is capable of required tolerance	Machine is not capable of required tolerance
Already make prototypes	2	
exceptional quality	1	
Surface finish might be a problem	1	
Manufacturing duration is currently to slow.	1	
Capable of tolerance	4	
Certain parts would probably have too tight a tolerance		2
Not good for large volumes		2
Equal to existing tolerances		1
Costs will be to high for large items		2
In the future yes		1
The components (steel) we manufacture are to large. 0.5m - 1m diameter or equivalent	1	4
The components (steel) we manufacture are to large. 1m - 2.5m diameter or equivalent	1	1
The components (steel) we manufacture are to large. > 2.5m diameter		2
Total occurrences	**6**	**15**

As can be seen from Table 5. 7, 46 percent of the motivation for additive manufacturing not being capable of manufacturing equivalent parts was due to the belief that additive machines could not manufacture large scale components. This was supported by concerns that the cost of large components would be uncompetitive due to high raw material costs of additive manufacturing.

5.4.7 **Do all stakeholders have the same opinion of additive manufacturing?**

Adoption of new technology can affect multiple stakeholder. This construct level question focused on stakeholders as a set of decision makers with the power to affect the decision to adopt additive manufacturing technology or not. More than half (55 percent) of the respondents felt that various stakeholders would have differing options to their own with regard to the adoption of additive manufacturing. Only 19 percent felt that relevant stakeholders in the decision process would have a unified opinion. This was not entirely unexpected as stakeholders involved in such a decision would have differing viewpoints. However, this question was intent on priming the respondent with a yes or no starting point from which they were asked if they believed this would prevent the adoption of additive manufacturing in their company. Table 5. 8 presents a list of critical statements regarding differing opinions of stakeholders affecting the adoption of additive manufacturing. This is presented relative to the respondents response to whether stakeholders would have differing opinions over the adoption and whether this would affect the adoption.

Table 5. 8: Key constructs produced by respondents relative to shared or differing stakeholder opinions and the respondents expectation of the stakeholder opinion unity affecting additive manufacturing technology adoption.

Key words in context (number of occurrences in responses)	Differing opinion	Same opinion	Won't prevent adoption	Will prevent adoption
As long as the cost can be motivate	2		2	
Engineering department to determine its value		1	1	
Engineering department to determine its value	1			1
Production teams don't like to adopt new types of machines they are not used to using	1			1
Won't be easy to convince other stakeholders	1			1
Older generation engineering personnel are set in their ways	1			1
Our research and product development if overseas	1			1
Management decision based upon commercial viability and optimization in works processes	1		1	
If stakeholders are not familiar with the technology	1			1
Total occurrences	**9**	**1**	**4**	**6**

Upon examination of Table 5. 8 it was noticed that the constructs presented by the respondents could be divided into two groups:

1. Constructs that can be analytically supported and financially motivated.
2. Constructs that are related to the human aspects of adoption such as persuasion and change management (Highlighted in yellow).

All the statements that were made and had a focused on the human element, had the same respondent believe that additive manufacturing would not be adopted. Another key finding was that of two differing respondents using contextually the same argument to motivate both will, and won't prevent the adoption of additive manufacturing arguments.

5.5 Question 4

The Bass Model was the principle motivator of this question. Principally it would have been better suited to a longitudinal study however; it was relevant to the cross-sectional study as conclusions about the current state could be drawn from the model. Specific constructs needed to be evaluated to enable the development of the Bass Model. This was done using the following constructural level questions.

5.5.1 **Does the brand affect the adoption of additive manufacturing?**

Chapter 2.8 refers to later revisions of the Bass Model having incorporated decision variables. One of these decision variables was related to the effects of consumer advertising and as such it was necessary to evaluate the potential effects of advertising relative to the adoption of additive manufacturing. Table 5. 9 presents information regarding respondents claims to having seen advertising for additive manufacturing. It also presents earlier findings with regard to respondents companies leasing/ owning an additive manufacturing machine or the respondent knowing a company that does. In Table 5. 9 this is termed a respondent that is involved.

Table 5. 9: Additive manufacturing advertising relative to involvement with additive manufacturing.

	Lease/ own an additive manufacturing machine or know a company with one.	Respondents that have seen advertising for additive manufacturing	Have seen advertising and have involvement in additive manufacturing	Have not seen advertising and have involvement in additive manufacturing	Have seen advertising and have no involvement in additive manufacturing	Have not seen advertising and have no involvement in additive manufacturing
Percentage yes	48%	39%	32%	13%	6%	26%
Percentage no	52%	39%	45%	65%	71%	52%
No response	0%	23%	23%	23%	23%	23%

Table 5. 9 shows that respondents that have seen advertising for additive manufacturing have a higher tendency to have some form of involvement with additive manufacturing. It does not prove causality or directionality and as such, it is possible that respondents that are involved with additive manufacturing may be more aware of advertising pertaining to additive manufacturing

The table also shows that 32 percent of respondents that have seen advertising for additive manufacturing are also involved (the counter argument is also possible). This is in contrast to 13 percent of respondents claiming that they have not seen advertising and have no involvement with additive manufacturing. This is further supported by the fact that there were less respondents not involved in additive manufacturing that had seen advertising (6 percent) than those that had not seen advertising (26 percent). The constant non-response rate of 23 percent was generated by respondents not having responded to the question regarding advertising and as such, it carries through to all conclusions involving this response.

5.5.2 Does advertising affect the price sensitivity of companies entering the additive manufacturing industry?

The manufacturing machine industry has numerous reputable and no-name (unknown) suppliers. Significance to the Gauteng market is the alternative of low cost Chinese machines opposed to the more traditional European and Western suppliers. This fact was recognised and as such, respondents were questioned to determine if this would have any immediate effect on consumer habits or adoption pertinent to additive manufacturing.

Table 5. 10: Additive manufacturing advertising relative to belief that additive manufacturing machine cost is more important than capability.

	Respondents that have seen advertising for additive manufacturing	Machine cost more important than capability	Have seen advertising and cost more important than capability	Have not seen advertising and cost more important than capability	Have seen advertising and capability more important than cost	Have not seen advertising and capability more important than cost
Percentage yes	39%	23%	6%	16%	26%	0%
Percentage no	39%	45%	61%	52%	42%	68%
No response	23%	32%	32%	32%	32%	32%

Table 5. 10 presents the respondents results when responding whether machine cost was more important than its capability. Twenty three percent of respondents felt cost was more important with 45 percent believing capability was more important. However, advertising does seem to have some relation to cost and capability. The table also shows that respondents that have seen advertising for additive manufacturing machines value cost over capability (6 percent) less than those that have not seen advertising (16 percent). Extending on this, respondents that have seen advertising for additive manufacturing value capability over cost more than those that had not seen advertising. Thus, simply put (simple version for clarity only, not implying causality or direction of relation), advertising reduced respondents willingness to pay more for a machine and increased their belief that capability was more important.

Table 5. 11: Additive manufacturing advertising relative to respondent willingness to pay more for a brand name machine over a no-name machine.

	Respondents that have seen advertising for additive manufacturing	Prepared to pay more for a brand name machine over no-name machine	Have seen advertising and pay more for brand name machine	Have not seen advertising and pay more for brand name machine	Have seen advertising and prefer cheaper no-name machine	didn't see advertising and prefer cheaper no-name machine
Percentage yes	39%	42%	26%	0%	19%	26%
Percentage no	39%	29%	45%	71%	52%	45%
No response	23%	29%	29%	29%	29%	29%

Table 5. 11 presents the respondents results when responding to their willingness to pay more for a brand machine over a no-name machine. Forty two percent of respondents were willing to pay more for a brand name with 29 percent preferring an equivalent no-name brand machine. However, advertising did seem to have a relation to willingness to pay for a well know additive manufacturing machine brand. This table also shows that respondents that have seen advertising were prepared to pay more for a brand name machine (26 percent) than those that had not seen advertising for an additive manufacturing machine (0 percent). Extending on this, respondents that did prefer a cheaper no-name machine reduced from 26 percent to 19 percent relative to having seen advertising for an additive manufacturing machine.

The values presented in the comparisons are not absolute values but rather relative measures obtained by applying binary logic. As such, they are solely intended to aid in the identification of possible relations between factors but not make absolute measurement of the relation.

5.5.3 Are additive manufacturing machines seen as durable purchases?

Frank Bass origionally proposed the Bass Model for durable products. In such circumstance durable refers to items that are not purchased frequently. As such it was important to evaluate whether respondents believe the product was durable. Table 5. 12 presents key constructs provided by respondents with respect to the determination of when to replace an additive manufacturing machine.

Table 5. 12: Key constructs proposed by respondents with regard to the determination of when to replace an additive manufacturing machine.

Key words in context (number of occurrences in responses)	Occurrences	As a percentage of respondents
When the machine cannot meet customer requirements	6	19%
When the machine requires maintenance that is not cost effective	2	6%
When newer models can generate products sufficiently faster	4	13%
Usually a machine won't be replaced but an additional machine will be bought to increase production output	1	3%
Replace when costs of materials become less for modern machines	1	3%
When the machine has covered its cost	3	10%
Not sure	9	29%
Chose not to comment	5	16%

With exception of the respondents that chose not to respond and those that were uncertain, all respondents provided constructs that have a time dependence. One of the constructs refers to new generation machines that can produce components sufficiently faster. Others refer to the machine having covered its cost. This type of evaluation criteria would be expected for durable products where value of investment would be of importance.

5.5.4 Do you see the company as an innovator or an imitator?

The Bass Model categorises adopters of a durable product as innovators or imitators based on when they adopt the product. Innovators lead to imitators adopting a product according to the model. Thus it was felt that respondents opinion of their company showing traits of an innovator or an imitator would be of interest when developing the applying the Bass Model to additive manufacturing. Thirty five percent of respondents believed that their employing company was innovative, 55 percent believed their company showed traits of an imitator and 10 percent chose not to respond.

6 Discussion of Results

6.1 Introduction

This chapter discuss the findings from Chapter 5 and consolidate these findings into results. Construct level questions under each of the research questions will be consolidated to produce results to the research questions.

Having produced results to the research questions, existing literature will be drawn on to create a link between the existing work and the additional contribution this work makes to further the knowledge base of the relevant fields of study. The chapter will be ordered according to the research questions.

6.2 Question 1

Campbell et al. (2011) and du Preez et al. (2011) provide insight into the existing adoption of additive manufacturing in South Africa with the quantification of the number of additive manufacturing machines. This question however primarily focused on defining the existing adoption within the research cluster.

Sixteen percent of the respondents claimed that their employing organisation owned or leased an additive manufacturing machine and 48 percent claimed to be aware of a company that owned or leased an additive manufacturing machine. Although the ownership of additive manufacturing equipment seemed low, by Cohen's (2014) estimation of additive manufacturing penetration of the market ranging between 1% and 10%, the current level of machine ownership appears to be ahead of the international trend.

The current level of adoption is also set for further growth when considering 60 percent of the respondents believed that additive manufacturing would add value to their business. This is further supported by the fact that only 19 percent of respondents that claim to have been exposed to additive manufacturing believe that it does not add value to their business. Thus, beyond new adopters, there is a potential for 80 percent of the already adopting additive manufacturers repurchasing a replacement machine in the future or extending their current capacity.

Figure 6. 1: Number of rapid prototyping machines in South Africa (du Preez et al., 2011).

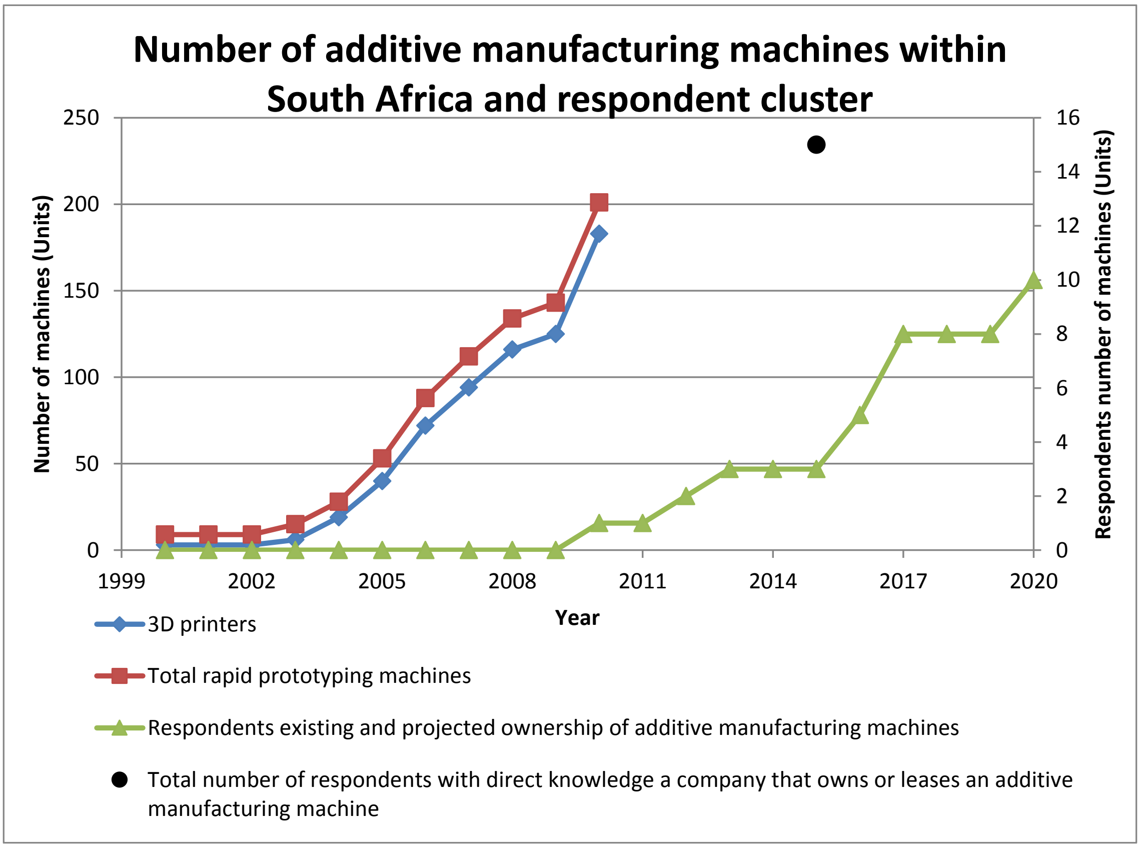


Figure 6. 1 presents du Preez et al. (2011) data showing the present number of machines within South Africa. Their data has been extended to include adoption data from the sampled cluster. By visual inspection it is clear that adoption is been occurring however this adoption appears linear and slower than the national cumulative adoption numbers presented by du Preez et al. (2011). However when the future expected adoption is included (survey data), the form appears to progress to exponential. This may be due to the examination period being very early in the adoption cycle, alternatively it may be evidence that imitators can be expected to be joining innovators in the adoption of additive manufacturing in the near future. Bass (2004a) like Rogers (2003) define innovators as the first 2.5% of all adopters. Thus, should imitators only begin adopting additive technology now (already 19% adoption within the sample), they will be late by definition.

Adoption is occurring in the target cluster; however, it is not for production items but rather prototyping. Sixty eight percent of respondents that owned a machine indicated that they only produced one-off items while 100 percent of all respondents indicated that they did or intended on using the machine for one-off or small batch production. This is typical of prototypes, jigs and fixtures or specialised items. When respondents provided reasons for additive manufacturing adding value to their business, prototyping (42 percent of respondents) was the key word used by respondents when taken in the context in which it was used. Thus, it is suggested that prototyping, jigs and fixtures and specialist items may be motivating the adoption of additive manufacturing at this stage.

Figure 5. 1 showed that 52 percent of respondents categorised themselves as participants in the general machinery and specialist machinery (26 percent) sub-sectors. The engines, turbines, pumps and compressors subsector had the second largest contribution with 14 percent. Thus with a large percentage of respondents taking part in the special machinery sector, this further motivates the use of additive manufacturing with in the cluster for the production of prototypes and equivalent one-off items. Further, engines, turbines, pumps and compressors are often customised to meet application specific duty-points and as such may further drive the use of additive manufacturing for one-off items. Seventy-six percent of respondents also claimed that their primary raw material was a type of steel followed by 11 percent claiming a type of plastic as their primary material (Figure 5. 2). Additive manufacturing techniques can be used to process both of these materials to produce final products however; metallic additive manufacturing machines lie within the high-cost, high-capability division which only comprises 21 percent of the machines within South Africa (Wild, 2014). When considering this in combination with the key factor of incorrect material availability (Table 5. 2) being a key hindrance to additive manufacturing adding value to a business, this once again supports additive manufacturing primarily being used for one-off prototype application opposed to mass production type manufacturing.

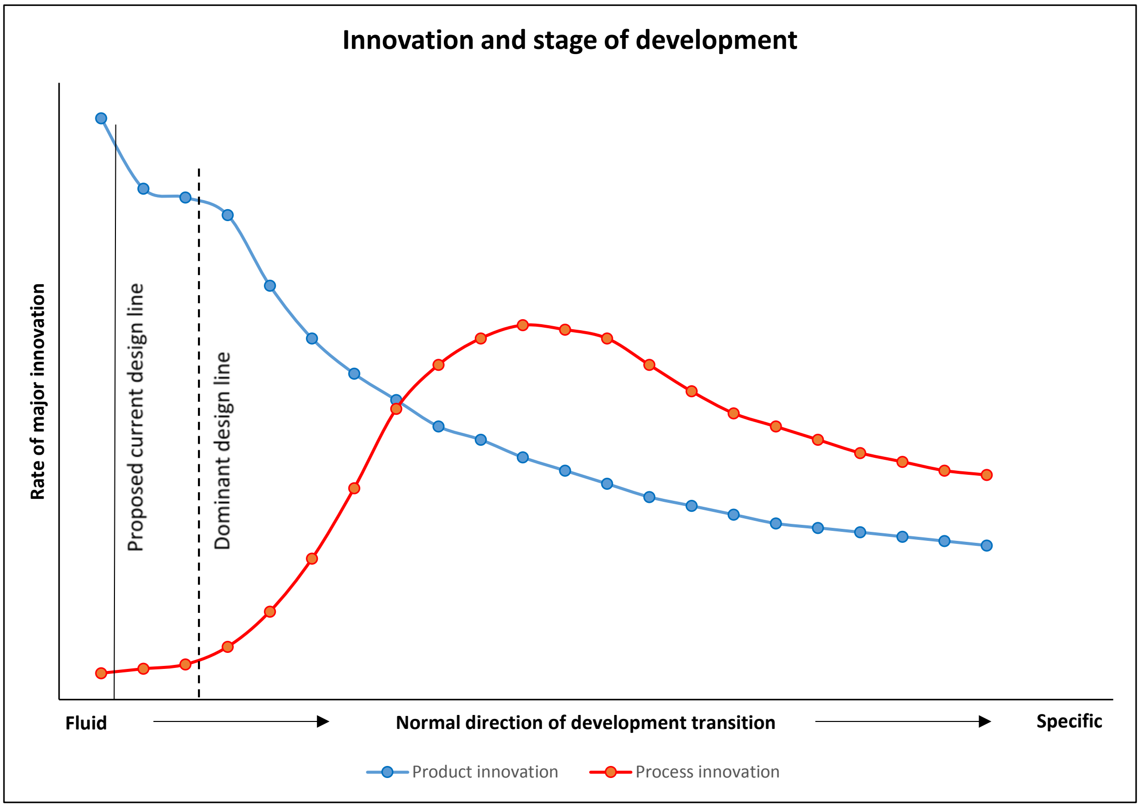
When quantifying the adoption within the cluster, it was suspected that knowledge was key component to the adoption of additive manufacturing. Rogers (2003) who referred to the adoption process as the innovation-decision process with knowledge being the first step in the process supported this statement (p.8). Fifty-five percent of respondents stated they had research the additive manufacturing and 45 percent of respondents claimed to have found the information they were looking for. This was substantially higher than the 16 percent that had already adopted the technology thus showing considerable interest by respondents that had not yet adopted. The result was 2.8 times as many people have research the topic and found the information they seek by comparison to existing adopters. Thus suggesting a pool of adopters large enough to support exponential growth of adoptions. However, when considering only 25% of respondents could explain common additive manufacturing terminology, it is improbable that the level of research conducted was sufficient to support the persuasion stage of Rogers (2003) innovation-decision process. This suggests that there are a sufficient number of respondents interested in additive manufacturing to support exponential growth; however, it is questionable whether the research being conducted or the information currently available is sufficient to persuade potential adopters to adopt.

6.3 Question 2

The Abernathy-Utterback model (Abernathy, 1978) is a classic model describing the link between product development and process development. It plays an important part in the explanation of diffusion of production type equipment as it can explain the shift in focus from the product to the product integration into existing manufacturing environments. The model proposes that following the establishment of a dominant technology, design focus shifts from product to process.

Eighty-one percent of respondents believed that a dominant technology does not exist and of the remaining 19 percent, none selected the same technology as dominant. This is therefore viewed as 100 percent of respondents not agreeing on a dominant technology. The presented literature (p.20) can be interpreted to support this because multiple additive manufacturing technologies are currently available in the local market (Guo & Leu, 2013). Further, the development of a middle-class of machines (Earls & Baya, 2014) has the potential to challenge any existing technologies that seems to be developing a dominant position. Figure 6. 2 presents the Abernathy-Utterback model as presented in Chapter 2. However, it includes a proposed current design line based on respondents lack in belief of a dominant design as well as findings from literature.

Figure 6. 2: Abernathy-Utterback model Abernathy (1978), including the proposed current design line for additive manufacturing relative to cluster respondents opinion.



The research results show a general belief that a dominant technology does not exist and as such, the proposed current design line is to the left of the dominant design line in Figure 6. 2. Although the greater majority of respondents (71 percent) could not provide insight into suitable criterion with which to determine a dominant technology, the most common were diversity in capability and diversity in material selection. However, these two factors were both presented as negative attributes of additive manufacturing when considered as a value proposition (Table 5. 2). Both factors are product limitations, not process which further supports the belief that a dominant technology has not yet been reached. The inability of the majority of the respondents to motivate their answers supports the findings of Chapter 6.2, which proposes inadequate knowledge among potential adopters to ensure persuasion to adopt.

6.4 Question 3

Question 3 posed many challenges to the respondents, as many of the questions in this sector required some knowledge of additive manufacturing and its implications. The primary finding was once again that the majority of the respondents did not know enough about the technology to make firm decisions that could be substantiated. Of the seven constructural level questions put forward, respondent uncertainty was a major factor in five. This equates to 71 percent of all questions asked. As part of this discussion, information suggesting weaker and stronger areas of respondent knowledge will be presented.

When reviewing preferable sub-technologies within the additive manufacturing industry, it was found that a significant lack in understanding of the technology existed. This was supported by 74 percent of respondents admitting so. It was also found that a substantial portion of the respondents that believed they understood the technology actually did not. This can be motivated by the fact that only 25 percent of respondents that selected material extrusion technique could actually apply this technique with their selected primary raw material. Further, of the 76 percent of respondents that chose a type of steel as their primary raw material, only 6 percent selected an additive manufacturing method that supported construction with this material.

Understanding the cost implications of additive manufacturing is exceptional complex with companies unable to grasp the implications. So much so that this has spawned an industry of specialist consultants assisting companies in determining such implications. One such example would be Senvol.

Respondents were split on whether additive manufacturing was more cost effective than other existing manufacturing techniques. This was a perfectly acceptable answer as there are many highly complex factors that contribute to the cost of item production. So much so that computer simulation of the manufacturing process is often used to determine the cost effectiveness. This is linked to Conner et al. (2014) model showing possible areas of advantage to additive manufacturing (p.21).

Table 5. 4 presented the anticipated costs that respondents expected to pay for an additive manufacturing machine. The first observation was the normal distribution of the cost estimates about the R750 001 – R2 000 000 amount. When broken down into material categories, the distribution remained normal in both the iron, steel products and the Stainless steel, tool steel market sub-segments. However, the distributions in the plastic products and rubber components industries were not normal. These distributions supported the fact that the majority of the respondents were from the steel industry (76 percent) and suggested that conclusions draw from this research would be applicable to the steel additive manufacturing industry however caution should be exercised should conclusions be drawn about the plastic or rubber additive manufacturing markets.

Rogers (2003) referred to the adoption process as the innovation-decision process. He explained that the innovation-decision process was a five steps process:

1. Knowledge
2. Persuasion
3. Decision
4. Implementation
5. Confirmation

When asked if respondents believed they could motivate either for or against the adoption of additive manufacturing, only 6 percent believed they could. The remaining used the key-words-in-context “Have not done sufficient research” which suggests insufficient knowledge. According to Rogers innovation-decision model, knowledge is the first step which supports the second, persuasion. Without knowledge, persuasion cannot occur. This is consistent with the research findings.

When reviewing other-key-words-in-context with respect to the motivation for or against additive manufacturing, support for key constructs emerged. Uncertainty regarding machine capability and lack in understanding of manufactured item cost structures using additive manufacturing were both highlighted. Both these constructs had appeared in previous areas of the research. Of interest was one of the respondents that stated he understood the cost structures involved as he had a simple 3-D printer at home.

The earlier literature review presented The Technology, Organisation and Environment framework (p.13). This model consisted of three primary constructs each with multiple sub-constructs. The sub-constructs of availability and technology support infrastructure were believe to be of importance should additive manufacturing intend on gaining traction in Gauteng and as such were tested. Seventy-four percent of respondents felt they were uncertain if there were sufficient equipment suppliers within the Gauteng area, 23 percent believed there were an insufficient number of suppliers and only 3 percent believed there were sufficient suppliers. Thus, based on The Technology, Organisation and Environment framework, a technological innovation decision would be exceptionally difficult as neither the external task environment nor the technology construct could support a decision due to failure of sub-constructs.

Manufacturing is the process of converting a raw material into a finished product. However, beyond just the raw material is the second order affect surrounding availability and the ease of procurement. Respondents were split with regards to the second order effects of additive manufacturing on material procurement (35 percent believed it would result in additional challenges, 35 percent believed it would not and 30 percent chose to refrain from answering. This was consistent with Cohen (2014) who stated that executives do not understand the second order effects of additive manufacturing on their organisations.

Primary problems sighted by respondents were not of second order nature but rather primary. Additional material expense, difficulties importing materials and insufficient material suppliers were sighted. These problems are not uncommon for manufacturing companies using traditional methods. However, one valuable insight obtained was from a respondent who stated, “Need alternative material suppliers”. This respondent was making reference to the fact that within the additive manufacturing industry raw material is supplied by machine manufacturers (much like a conventional paper printer). However, in the traditional manufacturing industry, material come from one supplier while manufacturing equipment comes from another. This potential second order affect could have substantial effects on companies’ procurement policy (companies being tied to single suppliers).

If additive manufacturing is to continue being adopted, it needs to demonstrate its ability to produce finished goods and in so doing build confidence in its capability. Only 26 percent of respondents believed that additive manufacturing could manufacture an equivalent finished product to that which they currently make. When looking at the key-words-used-in-context as motivation for their argument, just under 50 percent of the respondents that did not think additive manufacturing could produce an equivalent product, believe size was an issue. The cost of large components was also raised. This was consistent with Cohen (2014) who stated that additive manufacturing is still not cost effective for most end-product or high-volume commercial manufacturers.

The last construct evaluated was that of shared opinions of the various stakeholders. This was somewhat present in both the Diffusion of Innovation Model (Oliveira & Martins, 2011) and The Technology, Organization and Environment Framework (Oliveira ^ Martins, 2011). A little over half (55 percent) of the respondents believed that the various stakeholders would have a shared opinion over the adoption of additive manufacturing. However, as shown in chapter five, the motivation for their thoughts could clearly be divided into two categories:

1. Analytically supported and financially motivated.
2. Human aspects of adoption.

This division was not present in any of the adoption models reviewed and it is felt that this is one of the key finding of the research. For adoption to occur within an organisational context, not only does analytical motivation for adoption need to be provided but the human aspects also need to be addressed from preadoption stages.

6.5 Question 4

Having evaluated the state of additive manufacturing in questions one through three, it was felt that addition insight could be gained through the application of the Bass Model Principle and examination of the outcome. Relative to this application were a set of constructural questions that will first be discussed.

Sections 5.5.1 and 5.5.2 motivate the construct of advertising affecting respondent involvement (respondent owns a machine or is aware of someone that does) in additive manufacturing, respondents opinion on the importance of capability versus cost and the selection of brand opposed to no-name brand machines. This also suggests that both advertising and cost impact additive manufacturing and as such, the Generalised Bass Model should be applied. This extension to the Bass Model includes a current market effort function. However, Bass, Krishan and Jain (1994) stated that the Generalised Bass Model is beneficial should the decision variables vary with time. Thus, if the market effort function is constant, the Generalised Bass Model provides approximately the same fit as the Bass Model, which should then rather be applied. Although we are aware of an advertising effect, the cross-sectional nature of the study has meant that we are uninformed as to the possibility of the time dependent change in this variable. As such, for this study, it was assumed the affect was constant and the Bass Model was applied. This does not imply that no advertising affect exists, only that its affect was constant over the period of observation.

The Bass Model was constructed using the historic machines count data presented in Figure 2.8. Following the suggestion by Bass, Gordon, Ferguson and Githens (2001), first estimates for the coefficient of innovation an imitation were selected by finding a similar new product that was previously introduced and had historical data fitted to estimate coefficients. Coefficients from the diffusion of stores with retails scanners (FRG) during 1980-1993 was selected from Table D. 1 at the discretion of the researcher. The selection was base similarities in five areas as per Lilien et al's (1999) suggestion:

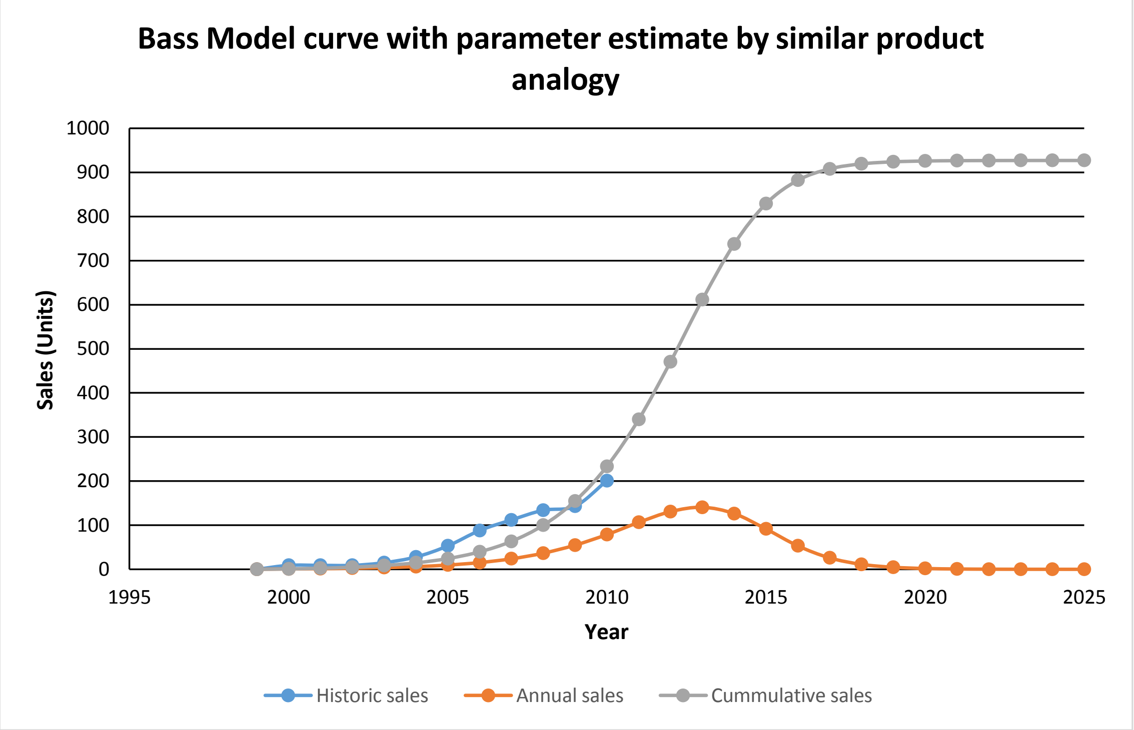
1. Environmental context.
2. Market structure.
3. Buyer behaviour.
4. Marketing mix strategies of firms.
5. Characteristic of the innovation.

The coefficients selected were as follows:

- $p = 0.001$
- $q = 0.605$

As the market potential M was unknown, the value was iteratively adjusted until the historic machine count was best represented. Bass (2004a) stated that the R^2 value of a regression analysis was an indication of how well the model described the growth rate behaviour. A market potential of 927 units and an R^2 of 0.914 was found to be the best fit. This is visually depicted in Figure 6. 3.

Figure 6. 3: Bass model based on parameter estimate by similar product (Stores with retail scanners).



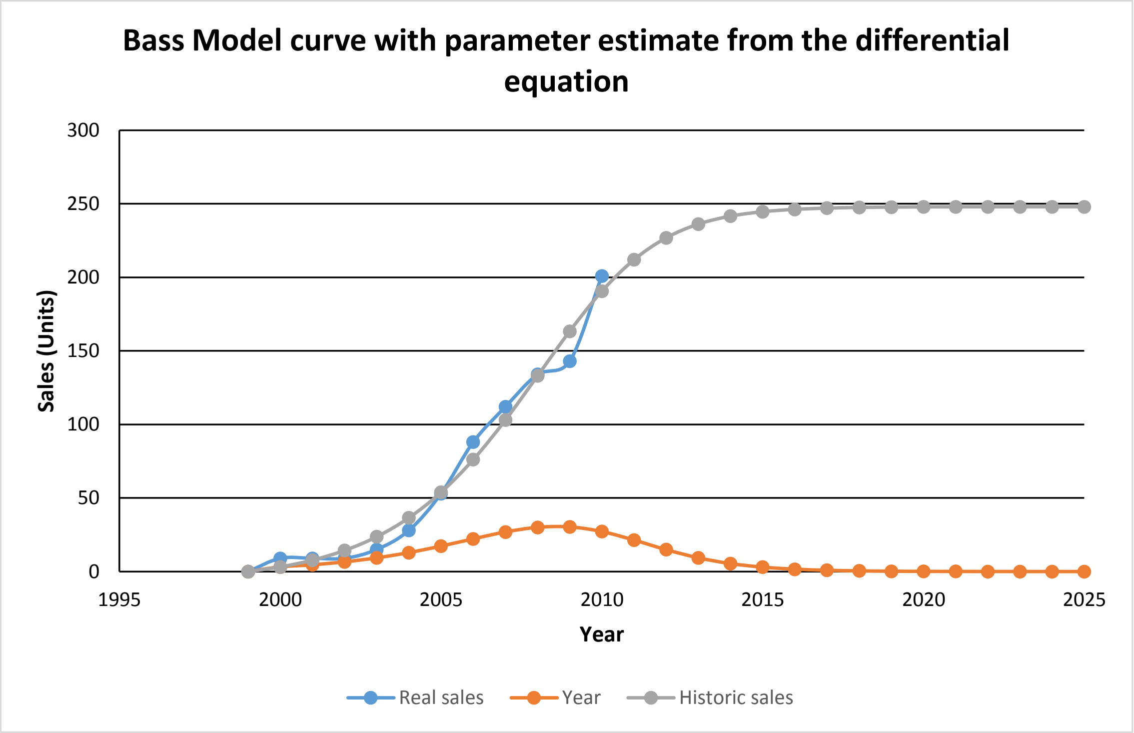
However, this first estimate was influence by the researcher's opinion and as such it was important to produce a model free of researchers bias. As described in section 2.8.2, Bass (2004a) provided a method of obtaining all three of the required parameters by applying the discrete analogue (equation 2-6) to the Bass Model Principle (equation 2-5). However, when applying this method, two negative solutions for the coefficient of imitation were obtained. These resulted in negative solutions for both the coefficient of innovation as well as the potential market. Thus, the obtained solution could not be real and the diffusion could not be modelled using Bass's discrete analogue method. Massiani and Gohs (2015) reported having encountering the same problem with this method.

They continue to advise that other authors have recommended estimation of the Bass coefficients directly from the differential equation (2-5) as a solution. However, Masiani and Gohs (2015) do advise that the superiority of estimating the Bass parameters directly from the differential equation (2-5) rather than its discrete analogue (2-6) is not established. When solving for the parameters directly, the following values were obtained:

- $p = 0.012$
- $q = 0.468$
- $M = 927$ units

The calculation of these values was followed by a regression analysis that resulted in an $R^2 = 0.98$. This model is shown in Figure 6. 4.

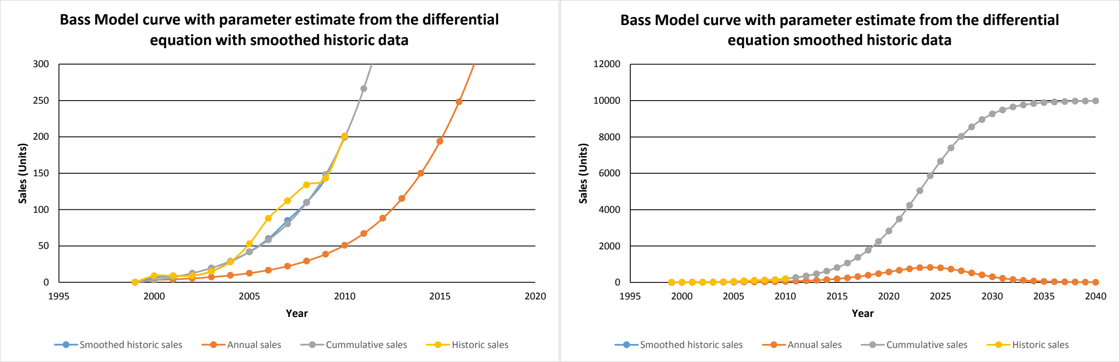
Figure 6. 4: Bass model based on parameter estimate from the differential equation.



Bass Model curve with parameter estimate from the differential equation

By visual inspection, it was apparent that the historic sales curve was not smooth and as such could have been influencing the model performance. As such, a moving average produced by averaging three moving periods (one period back, current value and one period forward) was used to smooth the historic sales curve. The Bass Model was then recreated using these values. This can be seen in Figure 6. 5.

Figure 6. 5: Bass model based on parameter estimate from the differential equation with smoothed historic data.



Bass Model curve with parameter estimate from the differential equation with smoothed historic data

Bass Model curve with parameter estimate from the differential equation smoothed historic data

The smoothed historic data curve resulted in the following Bass parameters creating the best representation:

- $p = 0.0003$
- $q = 0.3284$

- $M = 10000$ units

The regression analysis relative to the smoothed historic data and the subsequent Bass Model yielded a $R^2 = 0.997$ while the actual historic data to the Bass Model (created using the smoothed curve) $R^2 = 0.96$.

The three model have a significant variation in outcome with the market potential estimate ranging from 248 units peak by 2018 through 10000 units by 2045. However, Massiani and Gohs (2015) suggest that coefficient of innovation values should lie between 0.00007 and 0.03 while coefficient of imitation values should range between 0.38 and 0.53. Should this be applied, the curve created by analogue to a similar product and displayed in Figure 6. 3 becomes invalid (this brings in to question the values of the initial estimate). However, this removes the nominal estimate leaving the two extremes.

When reviewing the historic sales data, there is a clear reduction in growth of sales in 2009 which was the time of the global financial crisis. Thus if we remove the effects of this, we effectively obtain the results show in Figure 6. 5 which would be the recommended Bass Model for additive manufacturing machine diffusion in South Africa.

Figure 1. 1 shows that the Gauteng province contributes 34 percent to the national Grows Domestic Product. As such, if we assume that 34 percent of all additive manufacturing machine projected are located in Gauteng, it is estimated that approximately 26 additive manufacturing machine should currently be located within the Gauteng province.

7 Conclusion

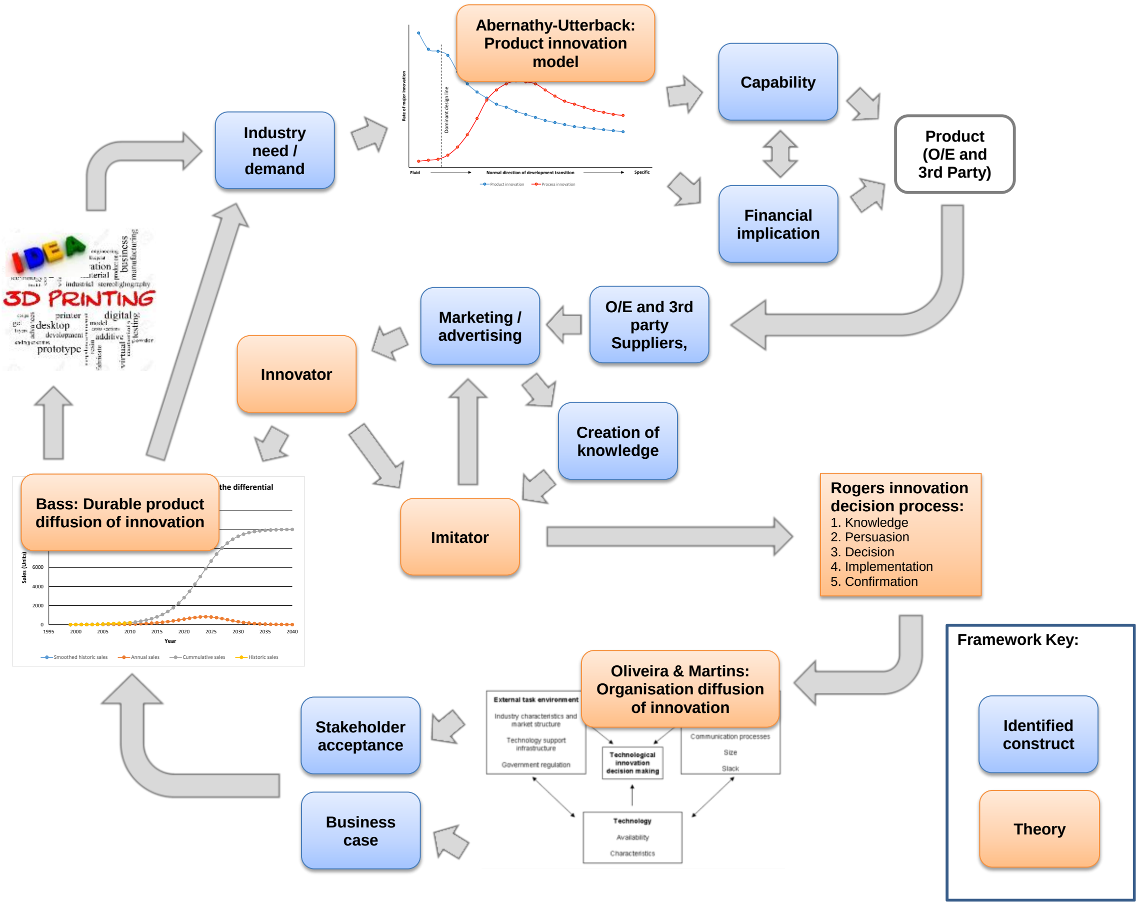
7.1 Introduction

This study aimed to determine the status of additive manufacturing within the Gauteng province of South Africa and identify factors that are motivating or prohibiting this technologies uptake. Following the discussion of the results in the previous chapter, a model connecting the various theories and the key research finding will now be presented. The relevance of this research to company manager will then be presented as well as the limitations of this research and recommendations for future for research within the adoption of additive manufacturing field.

7.2 Principle Findings

This research was conducted at the abstract level and as such, in defining the status of additive manufacturing, constructs that affect the adoption of additive manufacturing were identified and composed with existing theoretical models to create Figure 7. 1. The arrows in this figure do not indicate directionality of constructs or their implications but rather suggest a direction of process flow for clarity purposes.

Figure 7. 1: Integration of innovation and adoption theory with the research findings.



The driving factor for adoption of additive manufacturing is industrial demand. At current, additive manufacturing is not perceived as providing a cost benefit but does offer the potential to expand capability into new areas. However, this will require a demand for such products if additive manufacturing technology in its current form is to continue.

The Abernathy-Utterback model of product innovation states that there is a pivotal change in development focus once a dominant technology has been established. The diversity of technologies commercially available supports the respondents view that this point has not yet been reached. As such, it is perceived that most of the product development effort is still going into the products innovation and not its processes.

Machine capability is a significant motivator and prohibitor for the adoption of additive manufacturing. However, there are many misperceptions and a general lack of knowledge in this area. This has resulted in the primary application of additive technologies being prototype manufacture. Although instances of small batch production have been identifies this was minimal. Concerns over machine capability were primarily based on large component size and material capability. Most of the sampled cluster used steels as the primary raw material and as such, introduction of cost effective additive manufacturing machines may start a shift into product manufacturing and not just prototypes.

The research found that the cost structure of additive manufacturing is not well understood. Direct product costs (raw materials) are assumed to be expensive as they are imported and have additional beneficiation as a raw material (e.g. powderized, plastic extrusion). Further, machine overheads and secondary costs are also not understood. Extension of the titanium beneficiation program (DefenceWeb, 2015) to include other raw materials required by manufacturers may prove to be advantageous to the adoption of the technology in the local context.

Roth (2014) proposed that seller and purchasers of additive manufacture equipment have differing views about the value of these machines. Consistent with this, it is evident that machine suppliers and purchases have a differing viewpoints on the supply of material. Respondents expect to purchase material from third party material suppliers and not the machine supplier, as is currently thhe norm for materials used by traditional manufacturing equipment. However, it appears that local machine suppliers are following the same model as paper printer manufacturers, which supply both machine and material. This may result in unsettled executives as this model effectively ties manufacturers to suppliers.

Marketing in the form of advertisements has had an effect on the opinion of respondents. It was found that it affected the clusters respondents machine cost versus performance as well as their brand versus no-name brand perception. As we were only intending on identifying influential constructs, neither causality nor directionality was tested or proven however evidence of its affect was found.

Rogers (2003) originally categorised adopters into five categories. Bass (2004) later simplified this categorisation into innovators and imitators. Innovators are akin to impulse buyers that have to be the first to own a product. Imitators are slower and adopt a product later in the cycle. Critical to this is that the innovators influence imitators. Bass (2004) defines the increasing influence or pressure on an imitator to purchase as a linear association. Imitators are also more dependent on information and product knowledge to motivate an adoption. The research found a complete lack in subject knowledge beyond cover press. This is in support of Cohen’s (2014) findings. Based on Rogers

(2003) innovation decision process, knowledge and persuasion are the first two steps. Thus if the individual does not have sufficient knowledge of the field, it is unsightly that they will be able to persuade themselves that adoption of the technology is the correct option. Thus, the quantity, quality and relevance of the additive manufacturing related media is critical at this stage in the Gauteng industry based on results from the cluster.

Should an imitator be able to persuade himself that adoption is the correct option, in many settings within Gauteng, he will have to persuade relevant stakeholders of the value in the adoption. This connects to Oliveira & Martins (2011) Technology, Organisation and Environment Framework as well as their Diffusion of innovation model (more than one stakeholder). Beyond the constructs already discussed, the research highlighted the need for technology support, which could be connected to the models. The research showed that the greater majority of the respondents felt that there were insufficient machine supplier and inadequate support.

Critical to the adoption was the alignment in opinions of stakeholders. The research found that there were two constructs that needed to be addressed in relation to the adoption of additive manufacturing. The first was the financial justification (business case) while the other was the human aspect. Many respondents believed individuals would resist the change. Some suggestions were provided to why this could be however insufficient evidence was available to motivate the presentation of sup-constructs in this field. Cohen (2014) found that a lack of knowledge surrounding additive manufacturing was a major problem and as such, suggest the identification of champions within upper management to promote technologies such as additive manufacturing within the organisation before attempting adoption.

The result of this flow present in Figure 7. 1 was technology adoption. This was modelled using The Bass Model Principle and historic sales data compiled by du Preez et al. (2011). The model showed an increase in the rate of diffusion of the additive manufacturing machines until 2023 at which time the rate of diffusion will slow until the maximum market penetration is achieved in 2045. However, a constant market effort was assumed due to the available information produced by the cross-sectional research. Should the market effort (e.g. increase advertising and diffusion of accurate information) deviate from its current, it is expected that the Bass Model produced for this research will become inaccurate.

7.3 Implications for Management

This research is academic in nature however; it has far-reaching implication for management of both additive manufacturing equipment companies as well as product manufacturing companies. Based on the insights gained from the research, the following implications for managers are put forward.

There is an immense hype currently surrounding additive manufacturing however, this research shows that there are exceptionally few people competent in making an argument for or against the adoption of the technology. It is recommended that time be invested in obtaining the required knowledge prior to make any decision for or against the adoption of the technology.

Marketing for additive manufacturing equipment is having an effect on both the perception of cost versus capability as well as brand name versus no-brand name machine adoption. Thus, it is recommended that machine manufacturers be cautious of the message being portrait in the current press the technology is receiving. Should machine manufacturers wish to increase the market potential, or rate of diffusion, a significant increase in the market effort will be required.

Additive manufacturing's primary area of deployment is currently in prototype manufacture. However, based on the fact that a dominant technology has not yet been achieved, this signals that substantial development to additive manufacturing equipment is yet to come. This may lead to solutions to factors currently limiting the technology. As such, it is recommended that executives keep track of the technology until it reaches a dominant design, which should signal a stabilisation in the technology. Further, many executives are having difficulty understanding the second order effects of the technology. This will be clarified once the technology development stabilises and efforts are invested in process development.

There is a clear gap between the perceptions of those selling additive manufacturing machines and those purchasing them. This gap extends from the motivation of the initial capital outlay of the machine to material supplier conflict. It is suggested that manager seeking to adopt additive manufacturing technology understand the material supply chain prior to adoption.

7.4 Limitations of the Research

The research findings have been presented and discussed however it is important to understand the limitations and constraints of the research so as to avoid misinterpretation. To follow will be a discussion on some of the limitations of this research.

The research design was one of abstract level research and not empirical level. Thus, constructs that have a high probability of affect the adoption of additive manufacturing were identified. The level of construct correlation was not determined and causality was not proven.

The findings of this research were established on survey data obtained from respondents located in the Sebenza industrial business district within Gauteng. The relatively small sample size realized may limit the credibility of results when generalised to large areas even though the adopted method of a random cluster samples permits such generalisation (Zikmund et al., 2013).

The sub–sector of manufacturing in which respondents conduct their business as well as the type of primary material they use would have an effect on their perspective and as such the research data. The majority of the respondents were orientated towards the metallic item trade and as such, the influencing factors on these respondents needs to be considered when generalising the results presented in this report to all forms of additive manufacturing.

With respect to diffusion theory, an implicit bias of preadoption exists (Straub, 2009). Thus, the questionnaire questions were carefully constructed with the intent of creating equal adoption or rejection conditions. However, this bias may still be evident.

Many of the models reviewed and applied are influenced by social cognitive theory (Straub, 2009). Social cognitive theory is one of the most influential theories in psychology and it should be acknowledged that theories of adoption and diffusion do not include many of these aspects.

7.5 Suggestions for the Future

Following this research, the following suggestion for future research is made:

Many constructs have been identified at an abstract level. Extending on this work and verifying the presented findings at an empirical level would extend the knowledge and understanding of adoption in South African industrial markets.

The generation of Bass Models from data collected in other industrial clusters within South Africa's major hubs would provide valuable comparison data and could provide insight into South African industrial technology appetite within South Africa.

Extending on the application of the Bass model, it would be of interest to study the marketing of additive manufacturing in South Africa. This knowledge could then be used to derive conclusions with regard to the current market effort and recreate a Bass model using the Generalised Bass Model thus showing the effects of marketing on the adoption of additive manufacturing.

The research suggested that adopters are uncomfortable with machine manufacturers supplying machines and raw materials. With traditional manufacturing methods, machines and raw materials were procured from different suppliers thus reducing the dependability of product manufacturers on machine manufacturers. It further encouraged competition among material suppliers as product differentiation was not possible. Thus, the relationship between suppliers and adopters should be studied and compared to that of existing manufacturers and material suppliers relations.

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Appendices

Appendix A: Research questionnaire

(Reproduced using Survey Monkey tool)

Dear Participant

You are here with invited to participate in an academic research project. Given the recent press additive manufacturing (the formal name for 3D printing) has recent received; this research aims to evaluate the adoption of the additive manufacturing technology in the manufacturing industry in the Gauteng province.

Please note that your participation in this survey is completely voluntary and you can withdraw at any time without penalty. Your responses will be treated with the highest confidentiality and is to be used solely for the purpose of research. The research findings will be available on request from Daniel Kunniger (442917@mygibs.co.za).

By completing this research questionnaire, it is accepted that you give full consent to the researcher to make use of your responses for the described research. It is acknowledged that the provided information will be used for academic research purposes ONLY and that your responses will be treated in an anonymous and confidential manner.

There are a total of 19 fundamental questions that need to be completed. Please answer all questions. The questionnaire should take approximately 15 minutes of your time.

I truly appreciate your willingness to participate in this important research project and the valuable time you are willing to commit in completing this research questionnaire.

Kind Regards

Researcher:

Daniel Kunniger
442917@mygibs.com

How much adoption is occurring?

1. Does your company own or lease an additive manufacturing machine? (Yes/ No)

2. Do you know any manufacturing companies that own an additive manufacturing machine? (Yes/ No)

3. Do you believe additive manufacturing does/ could add value to your business? (Yes/No)
4. Why? (Explanation)

At what level of penetration is the adoption occurring?

5. Does/ would your company use additive manufacturing machine for technology experimentation (learning about additive manufacturing)? (Yes/ No)

6. Does/ would your company your company use additive manufacturing to replace older manufacturing techniques or extend current capabilities? (Tick-box to select one of the two options)

7. Would/ are the majority of the items you manufacture using an additive manufacturing machine: one-off/ small batch/ mass production items? (Tick-box to select one of the three)

When are companies adopting additive manufacturing?

8. If you company owns an additive machine, when did you procure it? (Year or N/a)

9. If your company is considering procuring an additive machine, when do you anticipate this acquisition to happen? (Year or N/a)

In what industries is additive manufacturing being adopted?

10. Would you consider your company to be a general manufacturing company (will manufacture anything for anyone) or would it be specific to an industry? (Tick-boxes with pre-selected fields including other)

11. What is the primary raw material your company works with (e.g. Mild steel, tool steel, ABS plastic)? (Tick-boxes with pre-selected fields including other)

12. Do you believe additive manufacturing machines can “print” an equivalent raw material to that which your company currently uses? (Yes/ No)

How interested are companies in additive manufacturing?

13. Have you researched additive manufacturing in any way? This includes reading magazine articles, attending presentation, internet searches etc. (Yes/No)

14. Did you find the information you were looking for? (Yes/ No)

Are companies aware of different technologies and do they have sufficient knowledge of them?

15. Indicate which of the following additive manufacturing processes you believe you could explain in layman's terms (Tick-boxes with pre-selected fields including none):
    i. Binder jetting
    ii. Direct energy deposition
    iii. Material extrusion
    iv. Material jetting
    v. Powder bed fusion
    vi. Sheet lamination
    vii. Vat photopolymerization
    viii. None

Is there a perceived dominant technology?

16. Do you believe any one of the above process is preferable. (Yes/ No)
17. Please explain your answer?

Is there a reason for a technology to be seen as dominant?

18. Which of the following best describes the reason you believe the process you selected in question 6 is dominant? (Tick-box)
    i. Most popular.
    ii. Most diverse in capability.
    iii. Best value for money.
    iv. The variety of materials.
    v. Speed of the process.
    vi. Don't know.

Is there a preferred technology for the respondents operating domain?

19. Which technology do you believe is best suited to your company? (Tick-boxes with the same list as question 18)
20. Please explain your answer?

What are the financial implications of additive manufacturing?

21. Do you believe additive manufacturing costs more to manufacture an equivalent item than using traditional manufacturing techniques? Please motivate your answer. (Yes/ No)
22. Please explain your answer?

23. How much do you anticipate an additive manufacturing machine capable of manufacturing your company's products to cost? (Tick-box to select a price category: R0 – R100 000; R100 001 – R250 000; R250 001 - R750 000; R750 001 – R2 000 000; Over R 2 000 000)

Are companies sufficiently exposed to allow for an adoption decision to be made?

24. Do you believe you have sufficient knowledge on additive manufacturing to motivate a decision for or against the adoption of additive manufacturing? Why (Yes/ No)
25. Please explain your answer?

Are there sufficient equipment providers in the industry to create confidence in adopting?

26. Do you believe there are sufficient machine suppliers in Gauteng with the correct support structures available? (Yes/ No/ Not sure)

Are the required materials available in the additive manufacturing industry?

27. Do you believe raw material procurement for additive manufacturing equipment will require more effort or pose more problems than that of existing materials and if so, why? (Yes/ No)
28. Please explain you answer?

Is additive manufacturing capable of manufacturing companies existing products?

29. Do you believe additive manufacturing machines are geometrically capable of manufacturing your products (i.e. tolerance, size, etc.)? Please specify any units you do not believe will be possible. E.g., we manufacture item 1m in diameter that I believe is too big for additive manufacturing equipment that is available. (Unit and explanation)

Do all stakeholders have the same opinion of additive manufacturing?

30. Do you believe different departments/personal in your company will have differing opinions on whether to adopt or not to adopt additive manufacturing in the future?(Yes/No)

31. Do you believe this will prevent adoption of additive manufacturing in your company? (Explanation)

Does advertising impact the adoption of additive manufacturing?

32. Have you seen any advertising for additive manufacturing services or equipment? (Yes/ No)

Does advertising affect the price sensitivity of companies entering the additive manufacturing industry?

33. Would the cost of an additive manufacturing machine be more important to you then machines capabilities? (Yes/ No)

34. Would you be prepared to pay more for a reputable name brand machine opposed to a lesser known machine with an equivalent specification? (Yes/ No)

Are additive manufacturing machines seen as durable purchases?

35. How do you believe you should determine when to replace an additive manufacturing machine? I.e. get a newer model, discard, or replace with the same machine only newer. (Descriptive)

Do you see the company as an innovator or an imitator?

36. Do you consider your company to be an innovator or an imitator (more of a follower) in its product design and manufacture? (Tick-box, Innovator or imitator)

Appendix B: Advantages and disadvantages of additive manufacturing

Figure B. 1: Additive manufacturing technology's advantages and disadvantages from a technological perspective (Weller et al., 2015).

Technological characteristics of additive manufacturing	
Opportunities	**Limitations**
Direct digital manufacturing of 3-D product designs without the need for tools or moulds.	Solution space limited to 'printable 'materials (e.g. no combined materials) and by size of build space.
Change of product designs without cost penalty in manufacturing.	Quality issues of produced parts: limited reproducibility of parts, missing resistance to environmental influences.
Increased design complexity (e.g. lightweight designs or integrated cooling chambers) without cost penalty in manufacturing.	Significant efforts are still needed for surface finishing.
High manufacturing flexibility: objects can be produced in any random order without cost penalties.	Lacking design tools and guidelines to fully exploit possibilities of additive manufacturing.
Production of functionally integrated designs in one step.	Low production throughput speed.
Less scrap and fewer raw materials required.	Skilled labour and strong experience needed.

Figure B. 2: Additive manufacturing advantages and disadvantages from an economic perspective (Weller et al., 2015).

Economic characteristics of additive manufacturing	
Opportunities	**Limitations**
Accelerated and simplification of product innovation: iterations are not costly and end products are rapidly available.	High marginal cost of production (raw material costs and energy intensity).
Price premiums can be achieved through customization or functional improvement (e.g. lightweight) of products.	No economies of scale.
Customer co-design of products without incurring cost penalty in manufacturing.	Missing quality standards.
Resolving "Scale-scope dilemma": no cost penalties in manufacturing for higher product variety.	Product offering limited to technological feasibility (solution space, reproducibility, quality, speed).
Inventories can become obsolete when supported by make-to-order processes.	Intellectual property rights and warranty related limitations.
Reduction of assembly work with one-step production of functional products	Training efforts required.
Lowering barriers to market entry	Skilled labour and strong experience needed.
Local production enabled	
Cost advantages of low-wage counties might diminish in the long run	

Appendix C: Bass Model Parameters for eleven consumer durable products

Table C. 1: Bass Model input parameters for eleven consumer durable products (Bass 2004a, p.1828).

Product	Period covered	a (10^3)	b	c(10^{-7})	m(10^3)	p	q
electronic refrigerators	1920-1940	104,67	0,21350	-0,053913	40,001	0,0026167	0,21566
Home freezers	1946-1961	38,12	0,15298	-0,077868	21,973	0,018119	0,17110
Black and white television	1946-1961	2696,20	0,22317	-0,025957	96,717	0,027877	0,25105
Water softeners	1949-1961	0,10	0,27925	-512,59	5,793	0,017703	0,29695
Room air conditioners	1946-1961	175,69	0,40820	-0,24777	16,895	0,010399	0,41861
Clothes dryers	1948-1961	259,67	0,33968	-0,23647	15,092	0,017206	0,35688
Power lawnmowers	1948-1961	410,98	0,32871	-0,075506	44,751	0,0091837	0,33790
Electric bed coverings	1949-1961	450,04	0,23800	-0,031842	76,589	0,005876	0,24387
Automatic coffee makers	1948-1961	1008,20	0,28435	-0,051242	58,838	0,017135	0,30145
Steam irons	1949-1960	1594,70	0,29928	-0,058875	55,696	0,028632	0,32791
Recover players	1952-1961	543,94	0,62931	-0,29817	21,937	0,024796	0,65410

Appendix D: Bass Model Parameters for various consumer durable products

Table D. 1: Parameters of the Bass model in several product categories based on penetration data and long series data (Lilien et al, 1999).

Product/Technology	Period of analysis	p	q	m
Agricultural				
Tractors (thousands of units)	1921-1964	0	0,134	5201
Hybrid corn	1927-1941	0	0,797	100
Artificial insemination	1943-1959	0,028	0,307	73,2
Bale hay	1943-1959	0,013	0,455	92,2
Medical equipment				
Ultrasonic imaging	1965-1978	0	0,534	85,8
Mammography	1965-1978	0	0,729	57,1
CT scanner (50-99 beds)	1980-1993	0,044	0,35	57,9
CT scanner (>100 beds)	1974-1993	0,036	0,268	95
Production Technology				
Oxygen steel furnace (USA)	1955-1980	0,002	0,435	60,5
Oxygen steel furnace (France)	1961-1980	0,008	0,279	88,4
Oxygen steel furnace (Japan)	1959-1975	0,049	0,333	81,3
Steam (vs. sail) merchant ships (UK)	1815-1965	0,006	0,259	86,7
Plastic milk containers (1 gallon)	1964-1987	0,02	0,255	100
Plastic milk containers (half gallon)	1964-1987	0	0,234	28,8
Stores with retail scanners (FRG, units)	1980-1993	0,001	0,605	16702
Stores with retail scanners (Denmark, units)	1986-1993	0,076	0,54	2061
Electrical appliances				
Room air conditioner	1950-1979	0,006	0,185	60,5
Bed cover	1949-1979	0,008	0,13	72,2
Blender	1949-1979	0	0,26	54,5
Can opener	1961-1979	0,05	0,126	68
electric coffee maker	1955-1979	0,042	0,103	100
Clothes dryer	1950-1979	0,009	0,143	701
Clothes washer	1923-1971	0,016	0,049	100
Coffee maker ADC	1974-1979	0,077	1,106	32,2
Curling iron	1974-1979	0,101	0,762	29,9
Dishwasher	1949-1979	0	0,213	47,7
Disposer	1950-1979	0	0,179	50,4
Fondue	1972-1979	0,166	0,44	4,6
Freezer	1949-1979	0,019	0	94,2
Fry pan	1957-1979	0,142	0	65,6
Hair dryer	1972-1979	0,055	0,399	51,6
Hot plates	1932-1979	0,056	0	26,3
Microwave oven	1972-1990	0,002	0,357	91,6
Mixer	1949-1979	0	0,134	97,7
Power leaf blower (gas or electric)	1986-1996	0,013	0,315	26
Range	1925-1979	0,004	0,065	63,6
Range, built-in	1957-1979	0,048	0,086	21,7
Refrigerator	1926-1979	0,025	0,126	99,7
Slow cooker	1974-1979	0	1,152	34,4
Steam iron	1950-1979	0,031	0,128	100
Toaster	1923-1979	0,038	0	100
Consumer Electronics				
Cable television	1981-1994	0,1	0,06	68
calculators	1973-1979	0,143	0,52	100
Camcorder	1986-1996	0,044	0,304	3,5
CD player	1986-1996	0,055	0,378	29,6
Cellular telephone	1986-1996	0,008	0,421	45,1
Cordless telephone	1984-1996	0,004	0,338	67,6
electronic toothbrush	1991-1996	0,11	0,548	14,8
Home PC (millions of units)	1982-1988	0,121	0,281	258
Radio	1922-1933	0,027	0,435	100
Telephone answering device	1984-1996	0,025	0,406	69,6
Television, black and white	1949-1979	0,108	0,231	96,9
Television, colour	1965-1979	0,058	0,146	100
VCR	1981-1994	0,025	0,603	76,3
Average		0,37	0,327	
25th percentile; median; 75th percentile		0,004; 0,025; 0,054	0,134; 0,28; 0,435	
Unless indicated, the model was estimated on penetration data collected in the USA				

Table D. 2: Parameters of the Bass model in several product categories based on penetration data and short series data (Lilien et al, 1999).

Product/Technology	**Period of analysis**	**p**	**q**	**m**
Agricultural				
Tractors (thousands of units)	1921-1931	0	0,211	1324
Hybrid corn	1927-1939	0	0,798	100
Artificial insemination	1943-1953	0	0,567	56,9
Bale hay	1943-1955	0,006	0,583	80,3
0,51				
Ultrasonic imaging	1965-1977	0,001	0,51	89,2
Mammography	1965-1976	0	0,738	56,4
CT scanner (50-99 beds)	1980-1990	0,036	0,572	47,8
CT scanner (>100 beds)	1974-1985	0,034	0,254	100
0,477				
Oxygen steel furnace (USA)	1955-1970	0	0,477	56,2
Oxygen steel furnace (France)	1961-1974	0,003	0,384	58,2
Oxygen steel furnace (Japan)	1959-1968	0,048	0,324	83,9
Steam (vs. sail) merchant ships (UK)	1815-1900	0	0,311	77
Plastic milk containers (1 gallon)	1964-1975	0,024	0,331	73,6
Plastic milk containers (half gallon)	1964-1973	0,04	0,63	4,4
Stores with retail scanners (FRG, units)	1980-1993	0,001	0,605	16702
Stores with retail scanners (Denmark, units)	1986-1993	0,076	0,54	2061
Electrical appliances				
Room air conditioner	1950-1963	0,16	0,304	24,2
Bed cover	1949-1962	0,002	0,177	64,2
Blender	1949-1960	0,023	0,199	10,3
Can opener	1961-1971	0,027	0,341	51,8
electric coffee maker	1955-1965	0,001	0,302	72,8
Clothes dryer	1950-1960	0,009	0,514	18,2
Clothes washer	1923-1936	0,004	0,093	100
Coffee maker ADC	1974-1979	0,077	1,106	32,2
Curling iron	1974-1979	0,101	0,762	29,9
Dishwasher	1949-1974	0	0,189	57,4
Disposer	1950-1966	0,008	0,256	15,5
Fondue	1972-1979	0,166	0,44	4,6
Freezer	1949-1959	0,043	0,213	25,3
Fry pan	1957-1967	0,301	0	51
Hair dryer	1972-1979	0,55	0,399	51,6
Hot plates	1932-1942	0,95	0,143	18,2
Microwave oven	1972-1983	0,12	0,383	33,1
Mixer	1949-1959	0	0,145	83
Power leaf blower (gas or electric)	1986-1996	0,013	0,315	26
Range	1925-1935	0,071	0	10,2
Range, built-in	1957-1969	0,03	0	41,3
Refrigerator	1926-1940	0,015	0,29	69,5
Slow cooker	1974-1979	0	1,152	34,4
Steam iron	1950-1960	0	0,376	63,8
Toaster	1923-1933	0,039	0,262	46,2
Consumer Electronics				
Cable television	1981-1991	0,8	0,167	60,8
calculators	1973-1979	0,143	0,52	100
Camcorder	1986-1996	0,044	0,304	30,5
CD player	1986-1996	0,055	0,378	29,6
Cellular telephone	1986-1996	0,008	0,421	451
cordless telephone	1984-1994	0	0,438	54
electronic toothbrush	1991-1996	0,11	0,548	14,8
Home PC (millions of units)	1982-1988	0,121	0,281	25,8
Radio	1922-1933	0,028	0,42	100
Telephone answering device	1984-1994	0,019	0,481	63,4
Television, black and white	1949-1959	0,1	0,353	90,1
Television, colour	1965-1975	0,058	0,168	97,1
VCR	1981-1991	0,011	0,832	67,5
Average		0,37	0,327	
25th percentile; median; 75th percentile		0,004; 0,025; 0,054	0,134; 0,28; 0,435	
Unless indicated, the model was estimated on penetration data collected in the USA				

Appendix E: Operationalized question data types

Table E. 1: Data types of operationalized questions.

	Conceptual level questions (Sub questions were operationalised questions)	Number of outcome variables	Type of outcome	How many predictor variables	Type of predictor
Question 1	1				
	1	one	Binary	one	Binary
	2	one	Binary	one	Binary
	3	one	Binary	one	continuous
	4	qualitative analysis			Text
	2				
	5	one	Binary	one	Binary
	6	one	Binary	one	Binary
	7	one	Categorical	one	Categorical
	3				
	8	one	Continuous	One	Continuous (Date)
	9	one	Continuous	One	Continuous (Date)
	4				
	1	one	Categorical	one	Categorical
	11	one	Categorical	one	Categorical
	12	one	Categorical	one	Binary
	5				
	13	one	Binary	one	Binary
	14	one	Binary	one	Binary
	6				
	15	one	Binary / categorical	one	Categorical
Question 2	7				
	16	one	Binary	one	Binary
	17	qualitative analysis			Text
	8				
	18	one	Categorical	one	Categorical
Question 3	9				
	19	one	Binary	one	Categorical
	20	qualitative analysis			Text
	10				
	21	one	Binary	one	Binary
	22	qualitative analysis			
	23	one	Binary / categorical	one	Continuous
	11				
	24	one	Binary	one	Categorical
	25	qualitative analysis			Text
	12				
	26	one	Categorical	one	Categorical
	13				
	27	one	Binary / categorical	one	Binary
	28	qualitative analysis			Text
	14				
	29	qualitative analysis			Text
	15				
	3	one	Binary	one	Binary
	31	qualitative analysis			Text
Question 4	16				
	32	one	Binary	one	Binary
	17				
	33	one	Binary	two	Categorical
	34	one	Binary	two	Categorical
	18				
	35	qualitative analysis			Text
	19				
	36	one	Binary	one	Categorical

Appendix F: Ethical clearance approval

Gordon Institute of Business Science
University of Pretoria

Dear Mr Daniel Kunniger

Protocol Number: **Temp2015-01208**

Title: **Diffusion of additive manufacturing in Gauteng, South Africa**

Please be advised that your application for Ethical Clearance has been APPROVED.

You are therefore allowed to continue collecting your data.

We wish you everything of the best for the rest of the project.

Kind Regards,

GIBS Ethics Administrator