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Repositioning a country for global manufacturing competitiveness: A case of South Africa

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Gareth Earle Gates
25538617

Repositioning a country for global manufacturing competitiveness: A case of South Africa

by

Gareth Earle Gates

Supervisor: Dr. Olufemi Adetunji

University: University of Pretoria

Department: Industrial Engineering

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Foreword

I want to thank my Lord and Saviour Jesus Christ for giving me the mind of Christ.

I would like to thank my supervisor Dr. Olufemi Adetunji for his support and continual encouragement throughout my studies and for introducing me to the various concepts and research methodologies.

I want to thank my two children Slowen Gates and Elianna Gates for making me understand how important flexibility in learning are and my mother Ursela Gates for laying the foundations of academic inquisitiveness.

Abstract

Manufacturing competitiveness is imperative for many economies because of the importance of the sector in job creation and economic growth. Manufacturing Competitiveness Index (MCI) has been used to measure this construct, but there is a need to include the relevant variables in such index. In addition, there is the need to interpret such measure in a relevant context so that actionable programme for strategic transition would be planned.

The relevant MCI was expanded to accommodate proxy variables that capture the levels of both the development and the adoption of cutting edge manufacturing technology within an economy appropriately. This is further supplemented by the use of the Ward's clustering algorithm to provide a relevant context of competitiveness grouping of countries so that a reference nation can develop an actionable plan to move from a level of global competitiveness to another.

Gap analysis, Pareto analysis and value analysis were used as integrated mechanisms with the national strategy plan in order to determine the best path of shift that the nation can adopt in order to transition across levels of competitiveness. The integrated methodology was illustrated using a case of South Africa and was found relevant.

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List of Abbreviations

ACI	Asia Competitiveness Index
AHP	Analytical Hierarchy Process
BCG	Boston Consulting Group
CNC	Computer Numerically Controlled
CMM	Capability Maturity Model
CCPR	Composite Country Performance Rating
CPI	Consumer Price Index
CWUR	Center for World University Rankings
EMI	Electronics Manufacturing Industry
GMCI	Global Manufacturing Composite Index
GWP	Galop World Poll
ICT	Information and Communication Technology
ISO	International Organization for Standardization
IMD	Institute of Management Development
IMF	International Monetary Fund
ISCI	Intelligent Synthetic Composite Indicator
ITT	Information Technology transfer
MCI	Manufacturing Composite Index
MICMAC	Cross-impact matrix multiplication applied to classification
MRL	Manufacturing Readiness Levels
NASA	National Aeronautics and Space Administration
NN	Neural Networks
NRI	Networked Readiness Index
OECD	Organization for Economic Co-operation and Development
PCA	Principal Component Analysis
PPI	Producer Price Index
PWC	PricewaterhouseCoopers
R&D	Research and Development
REER	Real Effective Exchange Rate
SEI	Software Engineering Institute
SIPRI	Stockholm International Peace Research Institute
TRL	Technical Readiness Level
UN	United Nations
UNDP	United Nations Development Program
WEF	World Economic Forum
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
USPTO	United States Patent and Trademark Office
WIFO	Austrian Institute of Economic Research

1. Introduction

1.1 Background to Research

The harsh global economic environment has made economic growth and national development a challenge for many countries and this has affected the quality of life that is affordable by the citizens of such countries. In this same global environment are countries whose economies are growing rapidly, driven by elevated levels of innovation, technological development and expanding manufacturing activity, thereby creating global competitiveness, which translates into expanding trade relations with other nations. It is, therefore, important to understand what makes a nation more competitive than others, especially in terms of global manufacturing capability. An understanding of factors and variables that bequeath global competitiveness on a nation can help others to make strategic and informed choices about areas for improvement, find relevant national projects that can enhance capability shifts, prioritise such areas and distribute national budgets and expenditure with such national priorities and strategies in mind.

1.2 Definition of competitiveness

Competitiveness has been defined by different researchers including Scott (1985), Porter (1990), Dollar and Wolff (1993) , Singh et al. (2018), World Economic Forum (2018), Krugmann (1994), Hannigan et el. (2015), Dechezleprêtre and Sato (2017) , Aiginger and Vogel (2018), Sharpe (1995). Dollar and Wolff (1993) indicates that a competitive nation is one that can succeed in international trade via high technology and productivity, with accompanying high wages and income. Sharpe (1995) indicates that all economists agrees that productivity and efficiency is the key to international competitiveness. For this study the definition of Scott was chosen. Refer to section 2.2 of literature study for review of definitions. National competitiveness refers to a nation`s ability to produce, distribute, and service goods in the international economy in competition with goods and services produced in other countries, and to do so in a way that earns a rising standard of living (Scott,1985). Given this definition, the best overall measure of competitiveness is one that has long been used in international comparisons, which is productivity.

Competitiveness at country, company and industry level

Competitiveness occurs at a company level, industry level and country level. At a company level competitiveness looks at how successful the companies are within a nation with a focus on their ability to achieve success against their competitors within their country and in other countries. Industry level competitiveness compares competitors relating to the same types of goods or services. In this research we focus on competitiveness at country level in terms of their manufacturing activities, the objective being to determine what factors make a country to be more successful globally compared to other countries that could be manufacturing destination for the same items.

Currently, there is a growing interest in the establishment of advanced manufacturing centres of excellence in countries to help them to remain competitive. Governments in most countries are realizing more and more that the emerging technologies require a mixture of manufacturing, economic and innovation growth in order to deliver the quality of life they desire for their citizens (World Economic Forum, 2018).

Historical shifts in global powers due to revolution in technology

The development of novel technology or technique has been responsible for the global repositioning of many countries. The introduction of the steam engine shifted the global power balance to Britain during the 18th century. Britain became the leading world economy due to the invention of the steam engine during the first industrial revolution. Companies shared information with each other during this period which allowed Britain to become dominant. This proliferated the use of steam engines in mills and the mining industry. The steam engine made Britain highly competitive due to improved productivity and technology.

The establishment of cotton mills in the USA caused a global shift in the balance of power to the USA. The embargo act of 1807 forced the USA to start making its own products and not rely on imports from Europe. The establishment of large scale industrial textile mills led to industrialisation especially in the New England area. The establishment of railroads, abundant labour force and new inventions like electricity assisted the USA to industrialise heavily during the 19th century and become the dominant economic power. The rise of mass production after the turn of the 20th century e.g. Henry Ford's assembly line also spurred industrialisation. As a result, the total manufacturing output of the United States was 28 times higher in 1929 than it was in 1859 (History of Massachusetts, 2018).

The application of lean management principles in Japan especially in the automotive industry made Japan a dominant figure in automotive production from the 1970's (Cusumano, 1994). Historical records have shown, therefore, that technological advancements have caused global shifts in economic dominance of nations.

The role of Technology in Competitiveness

Countries can gain (or lose) their competitiveness by investing (or not investing) at the right time into acquiring new manufacturing technologies like additive manufacturing machines, industrial robotics, CNC machining etc.(Abramovitz, 1986). A country can also lose its competitiveness by not investing into Research and Development (R&D) of new technologies which can unlock new manufacturing processes and accelerate the economic development of the country. This risk can be mitigated by countries that do not own such technologies by the acquisition of such through procurement and transfer of the relevant machineries and capabilities.

Technological innovation is regarded as an important component of the competitiveness of a country. In recent years as the fourth industrial revolution gains momentum, the competitiveness of countries are becoming more important as can be seen from the emergence of countries like South Korea that used technological innovation to make them more competitive on the global scale, thereby increasing the size of their economy ultimately. The World Economic Forum (2018) defines the fourth industrial revolution as the implementation of cyber-physical systems. This involves entirely new capabilities for people and machines and how they interact. Professor Klaus Schwab (World Economic Forum ,2018) believe that humankind are at the beginning of a revolution that is fundamentally going to change all aspects of human society. This involves how we live, work and engage with each other.

Emerging technologies include additive manufacturing, Nano-technology, synthetic technology, cyber physical systems and other related technologies. As these technologies evolve and scale up with adoption, their impact on countries and current systems becomes more prominent. Countries that do not invest in the necessary skilled workers and that also do not change their current training programs might find that in the future they are less competitive.

As the emerging technology matures it also changes the nature of the manufacturing worker who is now more specialized in nature and not a general worker. Therefore, a country will remain competitive by investing in a more upskilled labour force. Workers must also be multidisciplinary in nature; e.g. combing knowledge of mechanics, electronics and software.

Technology also makes the practice of doing business to change over time. Some countries that do not adopt the necessary technological driven changes in business practice, also start lagging. As technologies change, the practices used in the countries need to change. Since the evolution of technologies affects competitiveness of nations and shifts the competitive balance among countries and consequently the standard of living of such countries, it becomes imperative for every country to continue to check the evolution of modern technologies and its effects on their competitiveness. It also becomes important to have a measure of preparedness of countries as modern technologies begin to emerge so that countries can position or reposition themselves. This has led to the developments of many techniques or approaches for countries to evaluate how ready they are considering the emerging technologies. The techniques include Composite Indexes (CI), Capability Maturity Models (CMM), Technology Readiness Level Assessments (TRL) and Manufacturing Readiness Levels (MRL). Many countries, however, do not seem to have veritable means of evaluating how prepared they are for possible disruption because of shifts in the efficiency frontier and productivity of industries due to the emergence of new technologies.

Disruptive technologies and national competitiveness

The term disruptive technology was defined and first analysed by the American scholar Clayton Christensen, also known as disruptive innovation. It is the process in which a new technology is developed that displaces an established technology (Clayton , 2018).This then upsets the established industry, or creates a completely new industry. Jameson (2014) noted that history is replete with examples of disruptive innovation, dating back to ancient times. Examples include the compass, the printing press, currency and gunpowder.

The evolution of new technologies like additive manufacturing and robotics has been considered disruptive in the manufacturing industry and may change the global manufacturing terrain and the destiny of many countries involved in the manufacturing space. It becomes pertinent for countries to be able to determine how they measure relative to others, and how to shift their standing in terms of relative competitiveness. This is important because manufacturing is a big employer of labor in most countries, especially in the developing world. As a result, any shift in such balance could lead to the loss of manufacturing competitiveness for such countries and by extension the quality of life of their citizens and the level of employment in their economy.

Many models and frameworks like maturity models, readiness models and composite indexes have been developed to measure the manufacturing capacity and competitiveness of organizations and nations and some of these would be reviewed briefly at the literature section; but the focus in this work is on the use of the Manufacturing Composite Index. Coates et al (2001) argues that "…every scientist working towards eventual innovation: each design engineer, production manager, product developer and technology marketing professional; should become informed on where the related technologies are likely heading…". A Manufacturing Composite Index (MCI) is one means of acquiring such insight. Composite Indices offer a benchmarking approach to gather information on the current state of the manufacturing environment within an industry which can equip the leadership of a country with the best possible knowledge to make informed decisions.

1.3 Summary of Problem Statement

The manufacturing sector in today`s world are going through a challenging period (Zagloel and Jandhana , 2016). Knowledge of what makes a country competitive provides a direction for improving the country`s preference as an investment destination. Every nation faces a similar challenge of improving the life of its citizens, which means competitiveness has to be improved. It is evident that the manufacturing industry is becoming more technology intensive and that new forms of technology are emerging all the time (Coates et al., 2001). Country examples of national shift in manufacturing competitiveness are South Korea and Germany who have become leaders in manufacturing. Vishnevskiy et al. (2015) stated that there is a need for specialized tools that enable corporations to identify concrete steps to achieve the desired results in the future.

A key challenge of the current measurement indexes is the lack of the inclusion of some relevant manufacturing technology data to assist in benchmarking countries. From literature review, the following studies excludes manufacturing technologies as proxy variables: Tan and Tan (2014), Shami et al (2013), Shaker and Zubalsky (2015), Milenkovic (2016), Terzić (2017), Fisher et al (2018), Delgado-Márquez and García-Velasco (2018), Abramovitz (1986), Singh et al (2018), Alginger and Vogel (2018), Sharpe (1995), Wenzel and Wolf (2016), Kharub and Sharma (2017), Postelnicu and Ban (2010), World Economic Forum (2018), Boston Consulting Group (2018), Khayyat and Lee (2015), Alard (2015), Filippetti and Peyrache (2011) .The manufacturing technologies are CNC machining equipment, additive manufacturing machinery, plastic injection moulding machinery, lathes,milling machines and industrial robots. There is a need to expand the current measurement indexes to include manufacturing machinery technologies as part of an enhanced manufacturing composite index. A possible contextual interpretation here is a methodology that can be used for clustering countries into groups for relevant gap determination. The proposed methodology then makes use of value and gap analysis to determine a pathway for a country to follow for a country to migrate from one cluster to the next cluster in order to improve its relative competitiveness.

1.4 The aim of this study

The research will focus on the development of a Manufacturing Composite Index (MCI) to benchmark different countries against each other. A composite index (CI) consists of individual indicators compiled into a single index.(Handbook on constructing composite indicators, 2008). This definition will be adopted in this study. The composite index should ideally measure multidimensional concepts which cannot be captured by a single indicator. This will enable the measurement of the manufacturing competitiveness. By benchmarking different countries on key parameters we can then determine the current areas of improvement in the manufacturing environment in a particular country. South Africa (ZAF) is used as a case study.

Composite Indexes (CI) offer a benchmarking approach to gather information on the current state of the manufacturing environment within a country that can equip the leadership of a country with the best possible knowledge to make the correct decisions.

An enhanced quantitative MCI will be developed to benchmark different countries in terms of key manufacturing parameters. The main artefact is an MCI that makes use of variables that act as a proxy for manufacturing capability. This includes the level of country's internal innovation and the level of importation of machine tools like CNC machines, Plastic Injection Moulding machines, Additive Manufacturing machines, Industrial Robotics and Vacuum Injection Moulding Machines. These measures are going to be used in conjunction with other economic and development data to create an index to benchmark different countries against each other through a Clustering Algorithm. This procedure is illustrated using South Africa as a case and recommendations will be made for future research.

1.5 The sub-objectives of the study

The research objectives will focus on the following main aspects:

a) The development of a quantitative Manufacturing Composite Index (MCI) to benchmark different countries in terms of key indicator variables that is inclusive of measurement of both home grown manufacturing capability as well as imported capability that can contribute to the global competitiveness of such countries once acquired
b) Providing a contextual interpretation of benchmark countries in a more meaningful way such that gaps are determined on a parsimonious number of categories as opposed to using all countries involved in the benchmarking process. The Ward Clustering Algorithm is used to logically group the countries and visually display the categories
c) Determination of the gaps that the country needs to close in order to transition from a cluster to another. The gap analysis makes use of the cluster identification from the previous step and the normalisation procedure such that the differences of metrics of

measurements of the various variable items in the composite index are eliminated and all items rendered dimensionless for the gap prioritisation analysis.

d) Seek out the sequence of projects to improve the positioning of the country in a reasonable order to minimise the cost of achieving a target transition or to maximise the level of transition attainable given a level of resource available. To achieve this, value analysis is done to rank the actions identified to close the gaps for the case of South Africa considered in this work. Figure 1 summarises the steps graphically. As a last case study the developed MCI will be compared with an existing Composite Index to highlight differences and similarities and make refences to Porter's Diamond framework and comments on qualitative variables.

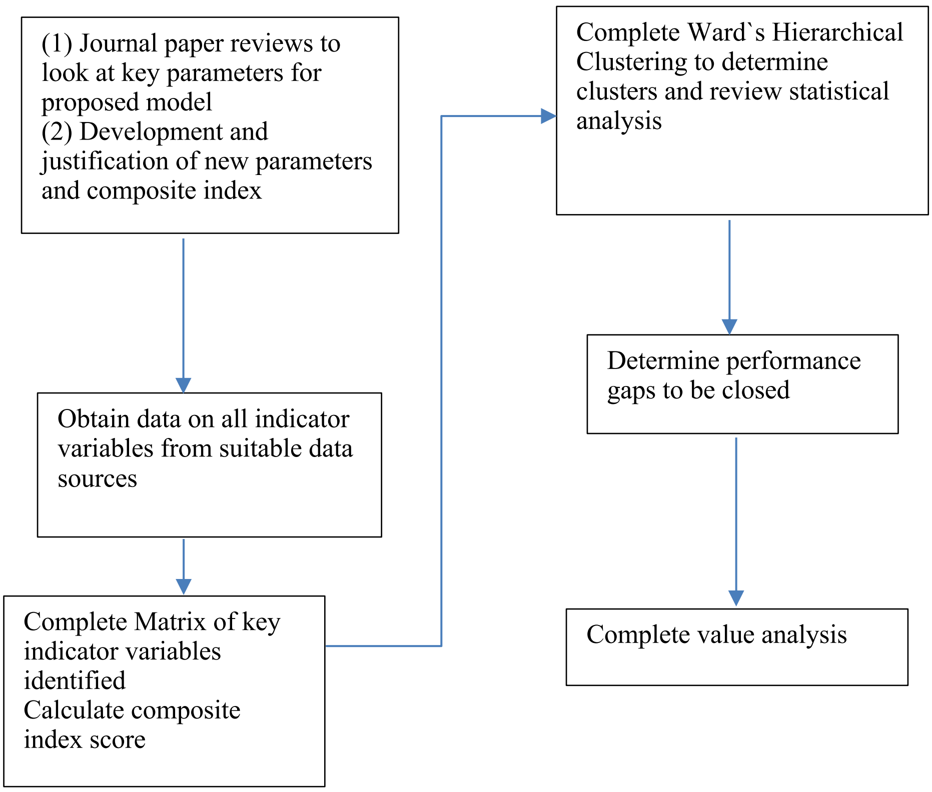

Figure 1. Flow diagram indicating research objectives

1.6 Scope and limitation of study

The scope of the study is to analyse quantitative data on 27 countries from open reliable data sources to rank countries, cluster them, complete gap analysis and value analysis. The study is also limited to data for the year 2016 from January to December. In addition, the study is limited to quantitative data from national and international databases that are openly available or can be acquired from the relevant agencies. The research does not consider opinions and other qualitative data and no survey data is incorporated into the study.

1.7 Justification of research

Research into manufacturing competitiveness is important because it affects the capacity of a nation to raise the standard of living of its people and create decent jobs. While the composite index is a popular metric for such competitiveness, most CI's designed, do not include proxy variables for manufacturing competencies (Tan and Tan, 2014; Shami et al (2013); Shaker and Zubalsky, 2015; Milenkovic, 2016 ; World Economic Forum, 2018; Boston Consulting Group, 2018; Khayyat and Lee, 2015; Alard, 2015 ; Filippetti and Peyrache, 2011) that could complement the indicators measuring local conditions, in order to have a holistic view of the manufacturing capacity of a nation, and this is included in this study. In addition, while many CI studies seek to measure many countries of many parameters and rank them, such do not usually provide appropriate references for improvement ,because there are usually too many factors to consider; moreover, the preference of a nation is usually dependent on a number of related variables that have to be interpreted together. This was done in this study.

The MCI in this research will also provide an integrated solution to take a country from diagnosis up unto an improvement map. In this work, a complete framework from diagnosis to improvement plan was provided by integrating the expanded MCI index with cluster analysis, gap analysis, Pareto analysis and value analysis to determine the pathway a country may follow in order to become more competitive. The combination of all these techniques in a logical and integrated manner, offers a novel method which can be applied to benchmark and reposition a country at the same time.

1.8 Summary of sections of study

The summary of the sections of this document is now discussed. Section 1 provides clarity on the research objectives and rational of the study. It also introduces the concept of manufacturing competitiveness. The literature review is discussed in section 2, starting from broad areas of capability measurement and dovetailing into the manufacturing index review. The research method is discussed in section 3. In section 4, the case study is presented showing South Africa in the context of the other nations included in the benchmark; following which the results of the research are discussed. In section 5 the MCI is compared to the Global Manufacturing Composite Index(GMCI).This is then followed by the conclusion and recommendations in section 6. Section 7 contains the references and Appendix A discusses South Africa in the manufacturing context. Appendix B and C contains the actual data used in the study. Appendix D describes the proposed alignment of the MCI framework used with Porter's Diamond Model Framework.

2. Literature Review and Theoretical background

In this section the different definitions of competitiveness are reviewed. An overview of competitiveness including Porter's 'Diamond Framework are provided to create the theoretical background for the study. Composite indexes, Capability Maturity Models (CMM), Technology Readiness Level (TRL) Assessments, Manufacturing Readiness Levels (MRL) are reviewed. While they are not exactly the same, they are related as a method to measure competitiveness. From their review, it becomes evident that the Composite Index is the most appropriate method to achieve the research objectives of this study.

2.1 Overview

The importance of competitiveness of nations in global context has been widely discussed in literature, and so also is the methodology for measuring competitiveness or evaluating readiness for competition. In this section, the emphasis is to further review competitiveness, to discuss some of the measurement frameworks and related artefacts that have been developed for its measurement or evaluation, and to discuss the framework of choice for this study. Different definitions of competitiveness are referenced and competitiveness is then linked to composite indexes and a review of selected composite indexes is completed. Composite indexes is further expanded into manufacturing composite indexes to build the framework for the MCI and the procedure for clustering of composite indexes and its relevance to the research is finally summarised as part of the literature review process.

The review is topical and comparative. Topical in the sense that each of the sub-sections of the literature review is presented sequentially, and comparative in the sense that within the two main sections, the work of the authors follow a similar format of presentation which is done using tabular form. The first section is a review of the concept and relevance of competitiveness. This section is followed by a section discussing the popular measurement and related evaluation models including capability maturity model, technology readiness model, performance indexes and the Manufacturing Composite Index (MCI). The last section is a comparative review of select articles on the MCI, which is the framework that has been adopted and adapted for this work. Figure 2 summarises the literature review process graphically.

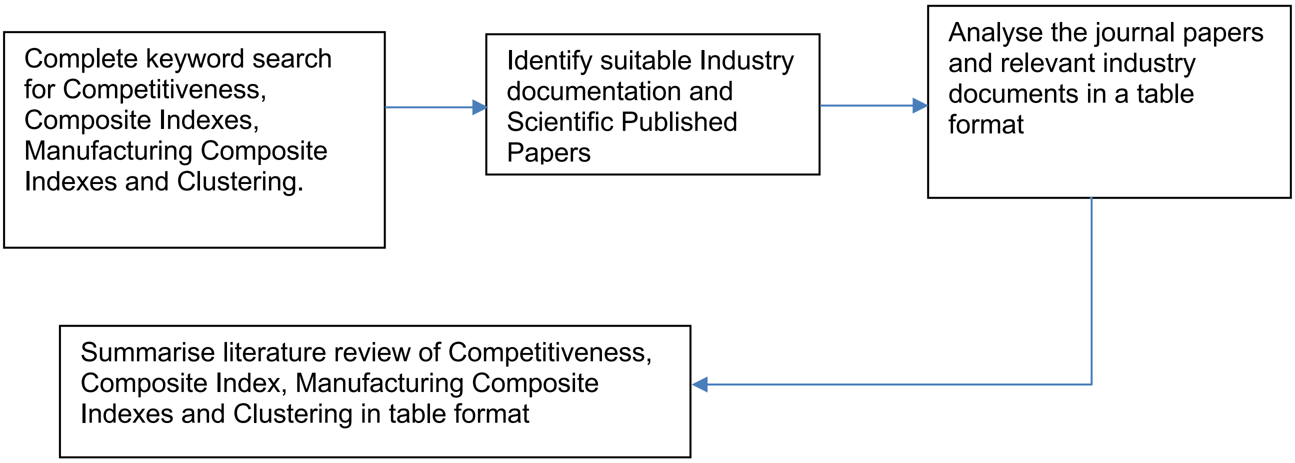

Figure 2. Literature review process in graphical format

2.1.1 Structure of the table for comparison of studies

As mentioned, some sections of the review were done comparatively in order to implicitly and succinctly compare and contrast the opinions of the different authors where such is considered insightful. The tabular structure for the review of articles on competitiveness is shown in Table 1. This format provides an easy way to highlight and summarise the objectives, techniques, main findings and list the data sources of the papers where necessary.

Title and author	Objectives and methods	Findings	Data Source

Table 1. Tabular format of journal paper review on competitiveness

2.2 Definitions of competitiveness

Competitiveness has been defined by different researchers including Scott (1985), Porter (1990), Dollar and Wolff (1993) , Singh et al. (2018), World Economic Forum(2018), Krugmann (1994), Hannigan et el. (2015), Dechezleprêtre and Sato (2017) , Aiginger and Vogel (2018), Sharpe (1995). Dollar and Wolff (1993) indicates that a competitive nation is one that can succeed in international trade via high technology and productivity, with accompanying high wages and income. Therefore international competitiveness is a function of relative productivity and income levels. National competitiveness refers to a nation`s ability to produce, distribute, and service goods in the international economy in competition with goods and services produced in other countries, and to do so in a way that earns a rising standard of living (Scott,1985). Kruggman (1994) argues that competitiveness is an elusive concept which cannot be extrapolated from a national firm to a country level since "…they have not a well-defined bottom line".

The World Economic Forum (WEF,2018) defines competitiveness as “the set of institutions, policies and factors that determine the level of productivity of a country. Singh et al. (2018) defines competitiveness as “… free and fair market conditions, which profitably produces goods and services to customers, while maintaining sustainable economic growth.”. Competitiveness is defined as the pooling of knowledge and capabilities of an organization to give it the edge through strengthening core competencies (Hannigan et el., 2015). Dechezleprêtre and Sato (2017) indicates that environmental regulations has an impact on a firm’s competitiveness “as measured by trade, industry, location, employment, productivity and innovation”. Sharpe (1995) indicates that all economist agrees that productivity and efficiency is the key to international competitiveness. The effect is to increase living standards.

The definition of competitiveness varies across the different articles reviewed. Competitiveness has been defined from different dimensions (products, companies, industries, subnational economies, national economies, and regional blocks) Larossi (2013). The definition of competitiveness should be extended beyond costs and also look at the general welfare of the country (Aiginger and Vogel, 2018). For the purpose of this study, the definition of Scott (1985) was chosen.

Competitiveness has been linked to measurement frameworks. These measurement frameworks may be quantitative, qualitative or a combination of both. Various techniques have been used diversely for competitive analysis including composite index, clustering and regression analysis. Feurer and Chaharbaghi (1995) states that although the notion of competitiveness lies at the heart of business strategy development, its definition is often vague and does not lend itself to a measurement process. In this research the aim is to develop a framework from which the indicator variables for a composite index will be developed since it is the most widely used method.

2.2.1 Competitiveness, frameworks and benchmarking

The measurement of competitiveness makes use of frameworks and the framework is developed based on the perceptions and objectives of the applicable author. This also involves obtaining data on a pre-selected group of countries which is used for benchmarking. The calculation of a composite index score from qualitative or quantitative data is used to rank countries. From the foregoing, it can be inferred that the evaluation of competitiveness should be accompanied by the development of a measurement framework and the context of its interpretation.

Literature review indicates that most studies of competitiveness offer a benchmarking technique to compare countries with each other, but does not provide a method for grouping countries. This is achieved from clustering the MCI and subindexes. Cluster Analysis is used when we believe that the sample units come from an unknown number of distinct populations or sub-populations. It helps us to identify the groups from the data set. In this way we are able to group the countries. Our objective is to describe those populations with the observed data. Of the two most commonly accepted definitions of competitiveness at the macro level, one refers to the ability of an economy to export, and the other refers to its level of productivity Larossi (2013). As part of the definition in this study productivity levels will be analysed since it is in line with measuring manufacturing activities in a country (Sharpe, 1995). In this study, to measure manufacturing competitiveness will entail the creation of a quantitative framework consisting of indicator variables grouped into subindices (business infrastructure, economic environment, education, innovation, research and manufacturing activities) and further aggregated into the MCI to benchmark countries relative to each other. Next is a presentation of the table of comparative review studies on competitiveness.

Table 2: Comparative review of competitiveness studies			
Title and author	**Objectives and methods**	**Findings**	**Data Source**
(1) Assessing competitiveness of ASEAN-10 Economies **(Tan and Tan ,2014)**	Develops the **Asia Competitiveness Institute Index (ACI)** to measure competitiveness in Asian countries. The ACI defines competitiveness through **4 environments** (a) **Macroeconomic** Stability (b) **Government and Institutional setting** (c) **Financial**, business and **manpower** conditions and (d) **Quality of life** and **infrastructure development**. A "What if" simulation is completed,, by looking at the bottom 20% indicator scores for a country. The 20% lowest scored indicators increased to the mean value for that specific indicator. The ranking of the countries are recalculated to see what effect that has on the ranking. It is used as input into Policy decision making for that specific country. Therefore recommendations on structural reforms can be made to increase the competitiveness of that country.	Each component in the Index contributes equally in weight. The **4 subindexes that constitutes the ACI** are` weighted equally. Under each subindex are 3 sub-environments, which are also equally weighted. In total the 12 sub-environments consist of 128 indicators which are measured for each country. ACI=$\sum_i W_i X_i$ with the W_i equally weighted	Worldbank, IMF, WEF, Asian Development Bank
(2) Intelligent synthetic composite indicators with application **(Shami, Lotfi. and Coleman, 2013)**	A **fuzzy c-mean** clustering algorithm are used to group together the different countries. This then represent the Information and Communication Technology (ICT) Index score for that country. An **Intelligent Synthetic Composite Indicator(ISCI**) is developed by making use of Information and Technology variables. The fuzzy c-means clustering finds its origins in the K-means clustering.	**A web crawler are used** to mine the internet for specific keywords "technology" and " technological". The text based information obtained including definitions, keywords an variables are then analysed with a Fuzzy Proximity Knowledge Mining Techniques. The outcome is a qualitative taxonomy which is the analysed with a Fuzzy c-mean clustering algorithm to group and rank the countries.	Internet webpages, WEF, Worldbank
(3) Examining patterns of sustainability across Europe **(Shaker and Zubalsky, 2015)**	The study reviews **36 European nations**, with **25 composite indexes** of sustainability across the nations. The 25 indices of environmental competitiveness covers three major aspects of (a) **environmental** quality, (b) **social equity** and (C) **economic welfare**. The Gallup World Poll (GWP) consist of a combination of 11 composite indexes. Exploratory spatial data, Pearson	The Null Hypothesis is rejected since in the research "empirical evidence of quantitative and spatial relationships for the 25 composite indices" was found. Pearson correlation coefficient varies from [-1,1]. Very positive correlation(0.75 to 1), positive correlation(0.5 to 0.75), Neutral (<0.5 to<-	GWP,ENESCO,NEF,UNDP

	correlation coefficient analysis and **Wards Clustering** was used to test the Null Hypothesis. The Null Hypothesis states that (1) There is no significant relationships between the 25 composite sustainability indexes.	0.5), negative(>-0.5 to -0.75) or very negative correlation (>-0.75 to -1)	
(4) Beyond the equal-weight framework of the Networked Readiness Index: a Multilevel I-distance methodology. **(Milenkovic et al, 2016)**	The Networked Readiness Index (NRI) describes the degree of ICT(Information Communication Technologies) infrastructure implementation in countries to provide them with a competitiveness advantage. In this research the NRI method is updated with an I-distance weighting to provide an alternative to the method of assigning equal weights to all indicators. It is an iterative process to construct I-distances. From the calculated I-distance value for each indicator, the indicators with the highest correlation coefficient were assigned the highest appropriate weight.	**The NRI Framework consists of 4 subindexes**: (a) **Environment** subindex--18 Indicators, (b) **Readiness** subindex --12 Indicators, (c) **Usage** subindex --16 Indicators and (d) Impact subindex--8 Indicators. The **I-distance method** is used to rank different countries against the 54 indicators. A multilevel I-distance analysis provided ranking based on pillars, subindexes and on countries total score. I-distance squared= D²(r, s)= $\sum_{i}^{k} \frac{\lvert {d^2}_i(r,s)\rvert}{\sigma_i} \prod_{j=1}^{i-1}(1 - {r^2}_{ji.12\ldots j-1})$ where $d_i(r,s)$ is the distance between the values of a variable Xi for entities Er and Es.	OECD
(5) The Role of Innovation in Fostering Competitiveness and Economic Growth: Evidence from Developing Economies **(Terzić, L., 2017)**	**10 Countries** was evaluated to measure innovation to measure "…the significance of innovation in driving economic growth per capita and competitiveness…".The results have indicated a high Pearson correlation coefficient between "… the Global Innovation Index, GERD,GDP per capita, the Summary Innovation Index, Research systems, Firm Investments, Innovators and Linkage & Entrepreneurship…"	**Pearson correlation coefficient** is used to calculate **correlation between different Indexes** and selected indicators egg Firm Investments, Innovators, Intellectual Assets, Global Competitiveness Index, Global Innovation Index, GDP per capita, Research Systems, Human Resources, Finance and support. Firm Investments	EU Data and Global Innovation Index Data
(6) On the Suitability of Alternative Competitiveness Indicators for	In this journal paper **International Price Competitiveness** is investigated. The research indicates that broad based price-and cost-based indicators of price competitiveness are much better at predicting real exports than narrow indicators. Narrow indicators	The real effective exchange rate (REER) means real effective exchange rate which was calculate for 37 different countries. Real effective exchange rate (REER) series serve as indicators of price (or cost)	OECD Data

Explaining Real Exports of Advanced Economies **(Fischer et al , 2018)**	include Producer Price Index (PPI) and Consumer Price Index (CPI). Broad based indicators include real exchange rates, Unit labour cost(ULC),Weighted average of real GDP(GDPW), aggregate real imports of goods and services(IMPS), foreign demand measured by volume of global trade(WT). A total of **37 countries** was analysed and a prediction model	competitiveness. It is calculated according to a methodology jointly agreed upon within the European System of Central Banks	
(7) Geographical Distribution of the European Knowledge Base Through the Lens of a Synthetic Index **(Delgado-Márquez and García-Velasco , 2018)**	Ranking of European Regions is completed based on their scientific and technical knowledge in Europe. This allows firms"… to build regional competitive advantage." The classification of regions is performed through **K-Means Clustering**. A Knowledge Base Index(KBI) is developed which consists of R&D expenditure by business, government and higher education sector(as % GDP), number of R&D Researchers, Employment in science & technology, Employment in high technology environments and Human Resources indicators. A total of 18 variables was selected.	**Factor Analysis** is used to calculate the weight (P_i) of each variable of the synthetic index. The variables with a greater variability have a greater weight than those variables that reflect a more homogeneous distribution. Knowledge Base Index= KBI $=\sum_i P_i X_i$	Eurostat data on HR
(8) The Case for a National Manufacturing Strategy **(Ezell and Atkinson , 2011)**	The paper indicates that manufacturing is important since it is a key driver for overall job growth. Ezell and Atkinson (2011) argues that**"…** it is a principle source of R&D and innovation activity." Ezell and Atkinson (2011) argues that "A central reason why countries need a manufacturing strategy is that if they lose key industrial sectors of an economy, those sectors are likely to be gone for good."	**Economics of Decline**: " An economy that initially controls both R&D and manufacturing can lose the value-added first from manufacturing and then R&D in the current technology life cycle-and then first R&D followed by manufacturing in the subsequent technology life cycle." This is because manufacturing is frequently located near the source of the R&D This implies that manufacturing is important for a country.	Worldbank
(9) *Indicators of relative importance of IPRs in Developing countries* **(Lall, 1992)**	This research reviews technological capabilities at the firm and national level.Lall (1992) states that "At the country level, capabilities can be grouped under three broad headings: physical investment, human capital and technological effort."	Indicators of National Technological Capability for 8 countries was divided into **3 sections:** (a) **Structure and Performance** –7 Indicators (b) **Educatio**n—5 Indicators and (c) **Science and Technolog**y—6 Indicators	Asian Development Bank, World Bank, UNESCO

(10) *Catching Up, Forging Ahead, and Falling Behind* **(Abramovitz, 1986)**	Survey was completed on **16 countries** with a focus on **GDP/hour over 9 years.** The paper also describes The C**atch-Up Hypothesis** which Abramovitz (1986) states as" Countries that are technological backward have a potential for generating growth more rapid than that of more advanced countries, provided their social capabilities are sufficiently developed to permit successful exploitation of technologies already employed by the technology leaders." With the correct social capabilities the lagging country can outgrow the advanced countries. It is very difficult to determine exactly what these social capabilities are. The following "rough proxies" can be used **to measure social capabilities**: (a) **years of education**, (b) **openness to competition**, (c) establishment and **operation of new firms**, (d) sale and purchase of **new goods and services.**	The factors for the rate at which the potential for catch-up is realized : (a) The facilities for the **diffusion of knowledge**, (b) Conditions facilitating or hindering **structural change** and (c) **Macroeconomic and monetary conditions** Abramovitz (1986) argues that the catch-up between **Follower** and **Leader** countries "… in its simple form is concerned with only one aspect of the economic relations among countries: **technological borrowing by followers**." This implies that measuring importation of technologies like industrial robotics, additive manufacturing equipment, plastic injection moulding machines and CNC machines is a proxy for measuring the catch-up of follower countries like South Africa.	Angus Madison data
(11) *Technology and International Differences in Growth Rates* **(Fagerberg, 1994)**	Empirical research has shown that the n**eoclassical theory of growth** is not applicable to countries around the world. The neoclassical growth theory assumes that "…technology is available everywhere to everyone free of charge. "Fagerberg(1994) argues that " Basic research in universities and other public R&D institutions provides substantial inputs to the innovation process"	Fagerberg (1994) argues that countries invest in both **education and physical capital**. Fagerberg (1994) argues that countries with low levels of education and high governmental expenditure in GDP (size of government) as susceptible to saturating their completeness growth well below the level achieved by the leading countries. Fagerberg(1994) indicates that the different empirical studies under **neoclassical** and **technology gap** studies "…inspite of differences in theoretical perspective, the empirical models were often indistinguishable." Thus the variables in the studies can be divided into three groups (a) GDP/capita as a proxy for productivity and/or technology (b) **variables to close the gap between leading and lagging countries s**uch as investments, education, output from innovation activities e.g. papers published (c) Variables of	Descriptive ,Denison Theoretical paper

		economic, political and institutional nature(growth of labour force degree of openness to trade, share of public sector in GDP)	
(12) Meeting the 21st Century challenges of doing business in Africa (**Amankwah-Amoah et al,2018)**	Author's argue that "Technology adoption and diffusion has emerged as a central pillar in Africa's 21st development". Capturing best practices from around the globe will prevent Africa from repeating the same mistakes. The copying and emulating of **existing technologies** is just as important as pushing the frontier on **new technologies** and innovation. Examples of countries which has followed the process of acquiring existing technologies and become successful is South Korea **(Kim, 1997)**	Authors indicate that "…**capital formation**, **technology transfer**, **frugal innovation** and **learning** from other nations. "are important for nations in Africa to meet their 21st century challenges.	Theoretical paper
(13) Constructing a strategy on the creation of core competencies for African companies. **(Li et al.,2018)**	A conceptual model is created. The authors argue that conventional International Technology Transfer (ITT) from technological advanced countries to Africa might not be the correct way. It is indicated that ITT transfers only information and equipment and not technological know-how. **Technological know-how** is a critical source of competitive advantage **(Li et al.,2018).** "…Countries that are further from the global frontier often have limited collective learning capabilities to absorb and integrate the transferred knowledge effectively into their production and development systems." **(Li et al.,2018)**	In this journal paper a knowledge management model is created which can act as a strategic means for African countries to generate critical knowledge to become competitive. The author's argue that there is a link between **core competencies** and **knowledge management.** Core competencies are developed from a **resource based view** and **knowledge based view** to integrate diverse streams of technologies and production skills. The knowledge management process consist of 7 management processes (a) codification, (b) diffusion, (c) articulation (d) internalization, (e) sense making, (f) socialization and (g) integration. All are intangible concepts which is difficult to measure quantitatively.	Theoretical paper

(14) Competitiveness of Electronics manufacturing industry in India: an ISM-Fuzzy MICMAC and AHP approach. **(Singh et al.,2018)**	This research is to identify and build a framework of factors influencing competitiveness of electronics manufacturing in India. The structural modelling called cross-impact matrix multiplication applied to classification(**MICMAC**) is used and analytic hierarchy process(**AHP**) AHP is used to weight the 14 factors based on weight based on survey data from 69 experts	The following factors is crucial to increase competitiveness in the electronics manufacturing industry (a) government role to create the environment (b) human skill development, (c) R&D innovation activities, (d) patent commercialization,(e) product differentiation and (f) cost effectiveness, (f) infrastructure ,(g) technology and (h) raw material. A total of **14 factors** of competitiveness was analysed through MICMAC to measure indirect relationships. MICMAC was used to create 4 clusters for the 13 factors under (a) Independent (b) Dependent (c) Linkages and (d) Independent. The research confirms the importance of **R&D** and **innovation** for making the electronics manufacturing industry (EMI) in India more competitive. Government role, resources, serendipity, performance, user perspective on electronics and capabilities are important factors to consider in the future to build the EMI	Data on the Indian economy
(15) Competitiveness: from a misleading concept to a strategy supporting beyond GDP Goals **(Aiginger and Vogel, 2018)**	Author's develop a definition for competitiveness that focus on improving cost and productivity. Defines competitiveness as "… the ability to create welfare in general and deliver Beyond GDP goals" Beyond GPD goals shifts the focus away from the emphasis of cost. A total of **27 European countries** are analysed. Old perspectives rank consist of (a) Innovation, (b) Education ,(c) Social Investments, (d) Ecological ambition and (e) Institutions. New perspectives rank for Beyond GDP measurement consist of (a) Income per head, (b) Social Cohesion and (c) Ecological Sustainability Linear aggregation with equal weights were used on both indexes.	Authors distinguish between input and output competitiveness. Author's develop a definition for competitiveness that goes beyond the goal of improving cost and productivity. It focus on the ability to create welfare. The research shows "that Social outcomes, ecological and financial outcomes can be high at the same time". The general fear about trade-offs cannot be substantiated. Author's argue that "Using the definition of competitiveness as the ability of a region to deliver beyond GPD goals should be able to stop the	WIFO, Worldbank, Frazer Institute

		critique that the term is a dangerous and misleading concept.	
(16) Strategy development: past, present and future **Feurer R., Chaharbaghi K. (1995)**	In this paper the authors attempt to define a single definition for strategy development. The article also traces the origins of strategy and link it to competitiveness.	"There is now a growing cognizance that no single strategy process or single strategic capability will lead to a sustainable competitive advantage." Organizations must adjust dynamically their characteristics. Organizations must look at the requirements of the environment and adjust their strategy accordingly	Theoretical paper
(17) Review of Environmental Economics and Policy. **Dechezleprêtre,A.,Sato,M. (2017).**	In this paper the effects of environmental policy and regulations on competitiveness of firms are investigated. Provides history of environmental regulations from 1970 onwards.	"Environmental regulation may also alter firms' decisions concerning the volume, type, or timing of their investments". **Environmental policies** can thus affect firms' **long-term competitiveness**. Environmental regulations induce innovation in cleaner/greener technologies. The resulting benefits in the long run is small in comparison to regulatory cost. The greener technologies in the long run do not meaningful impact on production	Theoretical paper
(18) International perspectives on productivity and efficiency **Sharpe ,A.(1995).**	The author reviews efficiency and productivity and indicates that the 2 concepts are interlinked but also distinct in nature. The author reviews the research of Richard Caves and his colleagues and Dollar and Wolff (1993) as well. Paper explains the production frontier and how to achieve maximum efficiency for a given set of constraints.	Author argues that all economist agrees that productivity and efficiency is the key to international competitiveness . This then increases living standards. The **Total Factor Productivity Index(TFP)** as defined by Dollar and Wolff (1993) is: TFP = Y/ [wL + (1-w)K] where w is the wage share, Y is the sector/country's value added to employment (L) and gross capital stock (K).	Theoretical paper

(19) The five competitive forces that shape strategy **(Porter, 2008)**	This is a review paper in which Porter explains his view on competitiveness. The five forces that shape strategy to deal with industry competitiveness are: (a) Threat of Entry of new participant (b) Bargaining power of suppliers where they can erode the profitability of industries further down the supply chain by increasing their OEM prices (c) Bargaining power of Buyers who can force down prices (d) Threat of substitute products or services which puts a ceiling on pricing- affects company profitability (e) Rivalry amongst Existing Competitors that creates price reduction, advertising campaigns, new product introductions	"As much as possible, analysts should look at industry structure quantitatively, rather than be satisfied with lists of qualitative factors." The configuration of the 5 forces depends on the industry and will differ. The 5 forces framework is focused on industry competitiveness whereas Porter's Diamond Model can be applied to measure competitiveness between countries. The five forces help the analyst to shift threat of new entries, shift threat of substitutions, change the supplier or buyer power	Conceptual Paper
(20) From Marshall's Triad to Porter's Diamond: added value? **(Brosnan et al., 2016)**	**Porter's Cluster Concept**: Purpose is to offer clarity on the concept of a "cluster" in Porter's competitiveness framework. The paper looks at the **industrial district** and **industrial complex.** **"Globalisation Paradox":** It is a paradox since lasting global competitiveness lies increasingly in local knowledge, relationships, motivations. In other words items that distant competitive rivals cannot match. The conceptual paper focusses on the various conditions under which successful firms in different clusters becomes productive and competitive.	"Clustering represents a process associated with spatial organisational form which my offer advantages in efficiency, effectiveness and flexibility." Researcher argues that "Porter's Diamond is a self-reinforcing system which can permit increasing returns and reinforces such tendencies of economic activity within agglomerations." It is important to focus on clustering as a process and not within typologies of organisational form. "Porter's Diamond model is the graphical representation of determinants of spatial competitiveness…".(Brosnan et al,2016). Diamond conditions of Porter are the most intensive where clusters are strong. (Porter,1998;Porter, 2003; Delgado et al.;2014). **Porter's Diamond Model with the inclusion of macroeconomic policy, social, political and institutional factors can explain cross-country productivity(Delgado et al.,2014)**	Conceptual Paper
(21) Comparative analyses of competitive advantage	The research analyse the competitive advantage of micro, small and medium enterprises based on Porter's diamond framework. A case study approach. Questionnaire was submitted amongst	Makes use of the five forces Porter's Diamond model in the research. The four attributes are (a) Factor Conditions, (b) Demand Conditions, (c) Related and Supporting industries and (d) Firm	Qualitative data from questionnaire

using Porter diamond model (the case of MSMEs in Himachal Pradesh) **(Kharub and Sharma, 2017)**	industry respondents in pharmaceutical, electrical, electronics, automobiles, food etc. Sample size for interview questions was determined from the national register of companies in the particular industry.385 companies selected. Principal component analysis was completed to determine sample size. The variables under each attribute of the Porter Diamond Framework are:(a) **Factor Conditions**- 2 casual variables and 9 proxy variables, (b) **Demand Conditions** – 2 casual variables and 9 proxy variables , (c) **Related and Supporting industries** - 2 casual variables and 8 proxy variables and (d) **Firm Strategy, Structure and Rivalry**-2 casual variables and 8 proxy variables (e) **Government and chance events -**2 casual variables and 9 proxy variables	Strategy, Structure and Rivalry. **A fifth element** has been added (e) Government and chance events in this research. Government policies directly or indirectly affect competitiveness for enterprises. Chance events is anything that happens that are beyond the control of the companies.	
(22) Towards a new measure of a country's competitiveness: applying canonical correlation **(Wenzel and Wolf, 2016)**	**Economic Competitiveness:** Research focusses on developing a new approach of ranking countries according to their level of economic competitiveness. **Principal component analysis (PCA)** is used to construct the composite indicator. Then **Canonical correlation analysis (CCA)** is used to estimate weights in the calculation of the composite index score. Author refers to the unnecessary use of qualitative indicators. Data led approach to determining the weights. Weights of index variables are determined according to their linkages to a set of development indicators.	Weights of indicator variables are not determined arbitrarily but determined through Canonical correlation analysis. **Competitiveness** is "…understood as a country's ability to benefit from the global exchange of goods and factors." Only variables whose factor loadings exceeds 0,4 are considered linked to the factor. Regular updating of weights over time as suggested by CCA reduces the comparability of rankings across different years.	UNCTAD,IMF, WTO, Worldbank, Penn World Tables
(23) Modelling competitive advantage of nation: a literature review **(Hanafi et al., 2017)**	Create a mapping of competitive advantage of nations. Systematic literature review. The techniques used in solve problems in determining Competitive Advantage of Nations are (1) Framework[Theoretical Framework and Conceptual framework], (2) Analytics, (3) Heuristics and (4) Simulation	The authors indicate that some researchers use a mix method of both quantitative and qualitative data to study competitiveness. The exogenous variable "The Role of Government " motivates the researcher to create strategy and policy for the nation and industry from Porter's Diamond Framework. The review of the research indicates Porter's Diamond Framework are used with 4 attributes, 5 attributes and 6 attributes.	Conceptual Paper

2.3 Capability Maturity Models (CMM), Technology Readiness Level (TRL) Assessments as a measure of competitiveness

Capability Maturity models are reviewed and how this measures competitiveness. The Capability Maturity Model (CMM), Technology Readiness Level Assessment (TRL), Manufacturing Readiness Levels (MRL) and Composite Indexes (CI) are instruments to measure competitiveness. The assessment framework of CMM, TRL and MRL are qualitative in nature. Through the literature review, it highlights that the developed framework for the Manufacturing Composite Index (MCI) is quantitative in nature.

2.3.1 Evolution of CMM

The CMM has its root in entrenching quality and certainty in the management of the process of software development for competitiveness. The Capability Maturity Model (CMM) is a methodology used to develop and refine an organization's software development process (Searchsoftwarequality, 2018). The advent of CMM is traced to Phillip Crosby who worked at Lockheed Martin and wanted to ensure that missiles from a hardware and software perspective had zero defects. This need was fueled by the US military who needed reliable missiles that could reach their targets. The US Air Force was responsible for long-term strategic missile development. The initiative for creating reliable hardware and software was coordinated through NASA, making it a public initiative. The Carnegie Mellon University (CMU) in Pittsburgh won a contract to manage and interpret all the information that came through the program related to the development of high-quality software. This grant created the not-for-profit Software Engineering Institute (SEI) (2018).

Crosby's Quality Management Maturity Grid was the structure that later developed into the full Capability Maturity Model. The Quality Management Grid had five evolutionary stages: (a) Uncertainty regarding quality as a management tool (b) Awakening (c) Enlightenment to conduct a formal quality improvement program (d) Wisdom and (e) Certainty where quality management is a vital part of the company management (Paulk, 2017). Figure 3 shows the development of the CMM graphically from version 1.

At IBM Ron Radice and his colleagues under the direction of Watts Humphrey then adapted Phillip Crosby`s Quality Management Maturity Grid. They identified 12 process stages with 11 attributes measured on a five-point scale. Humphrey eventually took along these concepts to the Software Engineering Institute (SEI) in 1986 and developed the software process maturity framework.

In August 1986, the SEI began developing a process maturity framework. This framework would help organizations improve their software processes. In June1987, the SEI released a brief description of the software process maturity framework and in September 1987, a preliminary maturity questionnaire . In 1991, the SEI released the Capability Maturity Model for Software (Software CMM).

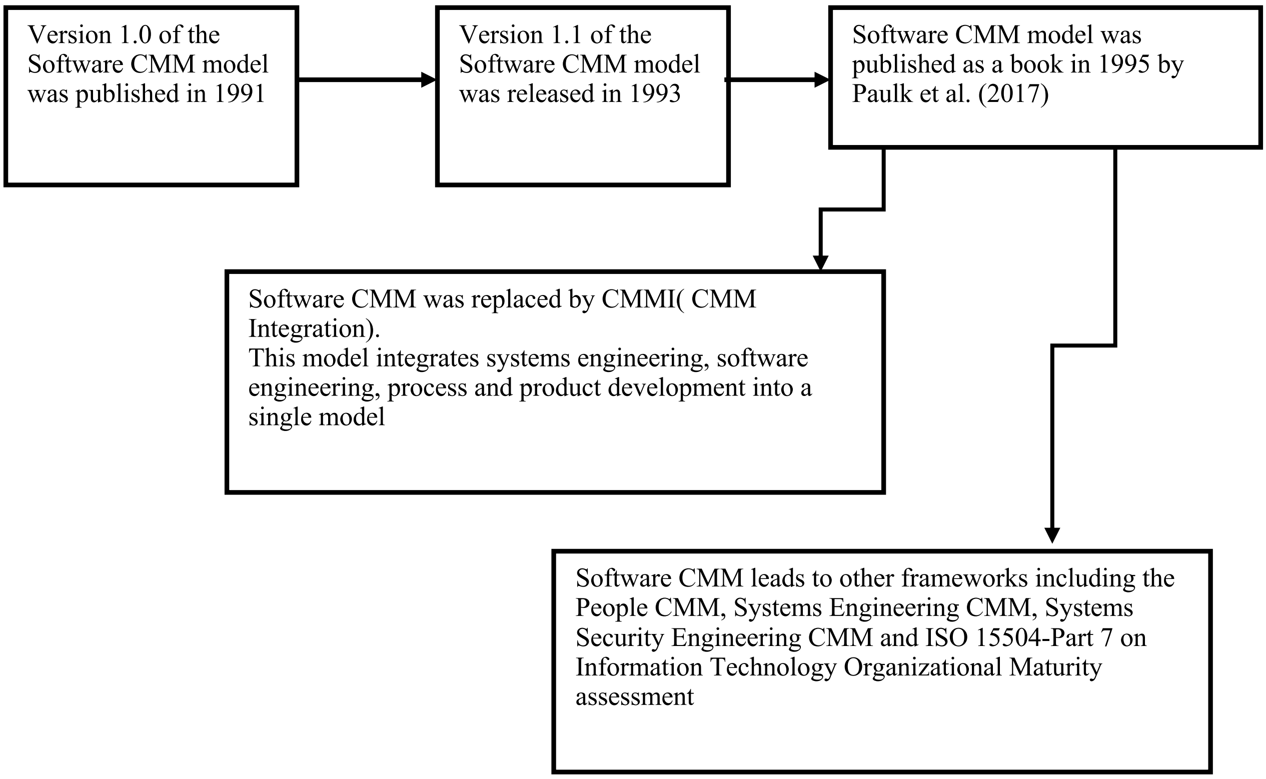

Figure 3. Capability Maturity Model for Software and its evolution

2.3.2 Capability Maturity Models in the Manufacturing environment

The CMM has since been adopted and adapted in various manufacturing contexts.

Ezell and Atkinson (2011) makes use of a matrix with 19 services indicators to benchmark countries in terms of their policies and programs to support SME Manufacturers. PWC (2018) also releases their annual report on Industry 4.0 which is a survey based benchmarking study to understand how companies are going to be making use of digital technologies to improve operational efficiencies. Maturity Index to assess current readiness of industries. This maturity model proposes 6 levels that indicate the Industry 4.0 Maturity levels. The Global IT Professionals Community (2018) identifies 47 Maturity Models in diverse fields from manufacturing to IT.

2.3.3. Technology Readiness Level (TRL) Assessment

Technology Readiness Level Assessment is a technique to measure the competitiveness of an organisation. Technology readiness levels (TRL) is a method of estimating technology maturity of Critical Technology Elements (CTE). Examples are the rocket boosters on a space shuttle. The concept is introduced to indicate the qualitative nature of the competitiveness measurement technique. Technology Readiness Level assessment is normally used to evaluate the maturity of the technology in research and development projects (Bakke, 2017). The Technology Readiness Level assessment was developed by NASA in the 1980`s. Stan Sadin created it and it was used to obtain mutual agreements between research personnel, research management and mission flight program managers at NASA.

The TRL consists of 9 levels as indicated in Figure 4. There are other models where a tenth and eleventh level have been added. However ,the TRL with 9 levels is the most prominent model used in research.

Phase	TRL	Description
Basic Research	1	Basic principles and research
	2	Application formulated
	3	Proof of concept
Applied Research	4	Components validated in laboratory environment
	5	Integrated components demonstrated in a laboratory environment
Development	6	Prototype demonstrated in relevant environment
	7	Prototype demonstrated in operational environment
	8	Technology proven in operational environment
Implementation	9	Technology refined and adopted

Figure 4. Technology Readiness Levels

Upon achieving TRL Level 9, the equipment is expected to be military grade which implies that the product should have passed the infant mortaility part of the bathtub curve for failure rates (Bakke, 2017).

2.3.4 Manufacturing Readiness Levels (MRL)

MRL is related to TRL in section 2.3.3 with a focus on manufacturing to measure competitiveness of organisations. The Manufacturing Readiness Levels (MRL) assessment was developed by the Defense Contract Managenent Agency (2017) in the USA. MRL was developed to assess and ensure that defense development programs have the required manufacturing capability and resources to ensure success of the program. Figure 5 shows sample of the MRL used by DARPA.It also performs a risk assesment to determine cost, schedule and program success. MRL is designed to determine a maturity model for manufacturing based on Technology Readiness Levels (TRL) patterns. It therefore compliments Technology Readiness Level assessments. The MRL consists of nine areas of assessments:

A-Technology and Industrial Base(2 –subthreads)-Benchmarked from MRL 1 to MRL 10
B-Design(2 subthreads) - Benchmarked from MRL 1 to MRL 10
C- Cost and Funding(3 subthreads) - Benchmarked from MRL 1 to MRL 10
D-Materials(4 subthreads) - Benchmarked from MRL 1 to MRL 10
E-Process Capability and Control(3 subthreads) - Benchmarked from MRL 1 to MRL 10
F-Quality Management(3 subthreads) - Benchmarked from MRL 1 to MRL 10
G-Manufaturing Workforce(1 subthread) - Benchmarked from MRL 1 to MRL 10
H-Facilities(2 subthreads) - Benchmarked from MRL 1 to MRL 10
I-Manufacturing Management(2 subthreads) - Benchmarked from MRL 1 to MRL 10

Acquisition Phase		Pre Materiel Solution Analysis (Pre MSA)			Materiel Solution Analysis (MSA)	Technology Development (TD)	
Technical Reviews					ASR	SRR/SFR	PDR
Thread	**Sub-Thread**	**MRL 1**	**MRL 2**	**MRL 3**	**MRL 4**	**MRL 5**	**MRL 6**
	Technology Maturity	Should be assessed at TRL 1.	Should be assessed at TRL 2.	Should be assessed at TRL 3.	Should be assessed at TRL 4.	Should be assessed at TRL 5.	Should be assessed at TRL 6.
A- Technology and Industrial Base	A.1 - Industrial base			Potential sources identified to address technology needs. Understand state of the art.	Industrial base capabilities surveyed and known gaps/risks identified for preferred concept, key technologies, components, and/or key processes.	Industrial base capabilities assessment initiated to identify potential manufacturing sources. Sole/single/ foreign source vendors and vendors of technologies with potential obsolescence issues have been identified and planning has begun to minimize risks.	Industrial base capabilities assessment for MS B has been completed. Industrial capability in place to support manufacturing of development articles. Plans to minimize sole/ foreign sources and obsolescence issues complete. Need for sole/single/foreign sources justified. Potential alternative sources identified.
	A.2 - Manufacturing Technology Development		New manufacturing concepts and potential solutions identified.	Manufacturing technology concepts identified through experiments/models.	Mfg Science & Advanced Mfg Technology requirements identified.	Required manufacturing technology development efforts initiated, if applicable.	Manufacturing technology efforts continuing. Required manufacturing technology development solutions demonstrated in a production relevant environment.
B - Design	B.1 - Producibility Program			Relevant materials/processes evaluated for manufacturability using experiments/models.	Initial producibility and manufacturability assessment of preferred systems concepts completed. Results considered in selection of preferred design concepts and reflected in Technology Development Strategy key components/ technologies.	Producibility and manufacturability assessments of key technologies and components initiated as appropriate. Ongoing design trades consider manufacturing processes and industrial base capability constraints. Manufacturing processes assessed for capability to test and verify in production, and influence on Operations & Support.	Producibility assessments and producibility trade studies (performance vs. producibility) of key technologies/components completed. Results used to shape Acquisition Strategy, Systems Engineering Plan (SEP), Manufacturing and Producibility plans, and planning for EMD or technology insertion programs. Preliminary design choices assessed against manufacturing processes and industrial base capability constraints. Producibility enhancement efforts (e.g. Design For Mfg, Assembly, Etc. (DFX)) initiated.
	B.2 - Design Maturity	Manufacturing research opportunities identified.	Applications defined. Broad performance goals identified that may drive manufacturing options.	Top level performance requirements defined. Trade-offs in design options assessed based on experiments. Product lifecycle and technical requirements evaluated.	SEP and Test and Evaluation Strategy recognize the need for the establishment/validation of manufacturing capability and management of manufacturing risk for the product lifecycle. Initial potential Key Performance Parameters (KPPs) identified for preferred systems concept. System characteristics and measures to support required capabilities identified. Form, fit, and function constraints identified and manufacturing capabilities identified for preferred systems concepts.	Lower level performance requirements sufficient to proceed to preliminary design. All enabling/critical technologies and components identified and considers the product lifecycle. Evaluation of design Key Characteristics (KC) initiated. Product data required for prototype component manufacturing released.	System allocated baseline established. Product requirements and features are well enough defined to support preliminary design review. Product data essential for subsystem/system prototyping has been released, and all enabling/critical component have been prototyped. Preliminary design KCs have been identified and mitigation plans in development.

Figure 5. Manufacturing Readiness Levels Matrix (Defence Contract Management Agency, 2017)

Although MRL as a techniue will be suitable to measure manufacturing capability, it is qualitative in nature. It measures on the macro enterprise scale and will not measure competiiveness between countries on a quantitative basis.

2.4 History of Composite Indexes, their data sources and indicator levels

Composite Indexes have their background in the economic and business statistics fields where it is used on the stock market to indicate how the financial markets are performing. Examples include the S&P Global 100 Index, Europe Stoxx 50, Nikkei 225 and FTSE Eurotop 100. Since the 1960's there has been a proliferation of the composite indexes in various policy domains including industrial competitiveness, sustainable development, quality of life assessment, globalisation and innovation.

A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured (OECD, 2018). The terms "Composite Index" and "Composite Indicator" are used interchangeably. To the best of the author`s knowledge no clear distinction is evident in the literature between the two terms. The terms most often used to describe all the indices is "Composite Index" and as part of this group includes those that have been named Competitiveness Indexes. Both "indexes" and "indices" are acceptable plural forms for "index".

Management consulting firms including Deloitte, Mickinsey and PWC also release Composite Indexes (CIs). Deloitte releases an annual report on the Global Manufacturing Competitiveness Index (GMCI) which compares a list of 40 countries. The Deloitte GMCI (2018) is both quantitative and qualitative. The GMCI consists of the following drivers of competitiveness: (a) Talent, (b) Innovation Policy, (c) Cost Competitiveness, (d) Energy Policy, (e) Physical Infrastructure and (g) Legal and Regulatory Environment.

Literature review indicates composite indicators are used to rank different countries according to predefined variables; and different analysis techniques are applied in order to deduce learnings from the Composite Indicators(Socialwatch, 2018; Asian Development Bank, 2018; Archibugi and Coco, 200; Lall and Albaladejo, 2003; Alard, 2015). This includes making innovation policy decisions for a country and benchmarking countries against each other to identify strengths and areas of improvement.

2.4.1 Existing composite indicators

From the industry literature, academic literature and the 178 composite indexes surveyed by Bandura(2008) a group of composite indexes were identified to understand the most important indicator variables selected, the method of aggregation to develop the composite indexes and the data sources used. This is discussed further in the sections 2.4.2 to 2.4.5. In section 2.6 the measurement framework for the Manufacturing Composite Index (MCI) is discussed. Table 3 summarises the selected composite indexes and by whom they were developed.

Table 3 Summary of Composite Indexes reviewed			
Composite Index	**Developed By**	**Composite Index**	**Developed By**
(1) Basic Capabilities Index-BCI	Socialwatch (2018)	**(11) Deloitte Global Manufacturing Competitiveness Index**	Deloitte (2017)
(2) Country Performance Assessment-CPA	Asian Development Bank (2016)	**(12) BCG Global Manufacturing Cost-Competitiveness Index**	Boston Consulting Group (2018)
(3) Global Competitiveness Index (GloCI)	World Economic Forum (2018)	**(13) PWC Aerospace manufacturing attractiveness rankings**	PWC (2018)
(4) Global Retail Development Index	AT Kearny (2018)	**(14) The Technological Capabilities Index (ArCo)**	Archibugi and Coco (2004)
(5) McKinsey Global Institute Industry Digitization Index	Mckinsey (2018)	**(15) UNIDO Industrial Development Report. The Role of Technology and Innovation in Inclusive and Sustainable Development**	Lall and Albaladejo (2003)
(6) SIPRI Military Expenditure Database	Stockholm International Peace Research Institute (SIPRI) (2018)	**(16) The Science and Technology Capacity Index(STCI)**	RAND Corporation (2018)
(7) Responsible Competitiveness Index	AccountAbility Institute (AAI) (2018)	**(17) The Global Technology Revolution 2020**	Silberglitt et al. (2006)
(8) OECD Science, Technology and Industry Scoreboard	OECD (2018)	**(18) Science and Technology Index (STI)**	Alard (2015)
(9) UNDP(United Nations Development Program) Human Development Index	United Nations Development Program (UNDP) (2018)	**(19) The Global Capabilities Indicator (GLOCAP)**	Filippetti and Peyrache (2011)
(10) IMD World Competitiveness Scoreboard	International Institute of Management Development(IMD) (2018)	**(20) Technological Capability(TC) -Index**	Khayyat and Lee (2015)

Table 4 shows the format used to review the composite indexes studied and presented in Table 5, stating the aggregation method, data sources of the composite indexes and also summarises the review of the relevant papers referencing them.

Composite Index	Summary	Aggregation Equation	Data Source

Table 4. Table format for review of composite indexes

2.4.2 Data sources for indexes

The composite indexes use both quantitative and qualitative data. Data sources used include the United Nations Comtrade database on international trade statistics (UN Comtrade, 2018), the World Development Indicators (Worldbank, 2018), United States Patent and Trademark office (USPTO, 2018) and the Organization for Economic Co-operation and Development (OECD, 2018). Also, data from United Nations Development Program (UNDP, 2018), United Nations Industrial Development organization (UNIDO, 2018), the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2018),The World Economic Forum (WEF, 2018) and Centre for World University Rankings (CWUR, 2016) were utilized.

2.4.3 Indicator levels

The composite indexes reviewed in general consists of three levels of indicators. The groupings according to The Handbook of Constructing Composite indicators (2008) are: (a) Individual indicators - which represent data about a specific variable of quantitative or qualitative data e.g. mean days to import a container into a country; (b) Thematic indicators - indicators are grouped together around a specific theme e.g. business infrastructure; and (c) Composite indicators: when all the thematic indicators (subindexes) are compiled into a single synthetic index, which is an aggregation of the thematic indicators.

2.4.4 Weights in the composite indicators

The different composite indexes analysed use different schemes to assign weights to the subindexes. Nineteen of the composite indexes analysed uses linear method of aggregation. The Country Performance Assessment Indicator from the Asian Development bank (2016) makes use of a Geometric Aggregation Method for subindexes and indicators. Some weights are determined through Principal Component Analysis (PCA), Analytical Hierarchy Process (AHP) and Neural Networks (NN) or by keeping all the weights equally distributed. A weighted composite Index is of the form:

$$\sum_{x=1}^{Q} W_x I_{xn}$$

Where W_x is the weight assigned to the specific subindex and I_{xn}. Each subindex I_{xn} consists of a group of indicators (also called variables) which is aggregated or may also be weighted in the subindex itself. In this research, all the weights are kept equal without any loss of generality. In cases where subindexes need to be weighted, an appropriate weighting mechanism can be easily incorporated.

2.4.5 Link between composite indexes and manufacturing composite indexes

Literature review indicates that composite indexes on manufacturing forms part of the body of knowledge on composite indexes. The composite indexes as a collective, link to the indicator variables that will be proposed as part of the measurement framework of a manufacturing composite index as discussed in section 2.6 . As part of the Manufacturing Composite Index (MCI) developed in this study a sub-objective would be the collation of relevant performance indicators that can be compositioned together in order to show the impact that the importation of emerging technologies have, the training of a workforce and the level of investment into research and education may have on the competitiveness of a country.

2.5 **Porter's Diamond Model**

The Porter's diamond model is another popular framework used by researchers in the analysis of national competitiveness. It consists of four broad attributes that individually and as a system constitute the diamond of national advantage. The four attributes are factor conditions, demand conditions, related and supporting industries and finally firm strategy, structure and rivalry. Factor conditions include measurement of productivity of production inputs, such as skilled labour or infrastructure. Demand conditions focus on the domestic market demand for the industry's product or service. Related and Supporting Industries consider whether the country has the necessary feeder and related industries that are internationally competitive. Firm strategy, structure, and rivalry factor seeks to evaluate the conditions in the nation governing how companies are created, organized and managed, as well as the nature of domestic rivalry (Porter, 1990). This framework views competitiveness as being related to productivity, so a strong focus on cost is a direct consequence (Wenzel and Wolf, 2016).

Researchers have used both qualitative and quantitative scales of proxy variables to operationalise these Porter's conditions. Examples of use of quantitative scales are Postelnicu and Ban (2010) Wenzel and Wolf (2016) and Ketels (2006), while Kharub and Sharma (2017) presents an example of qualitative measurement scales. There are also cases of mixed quantitative and qualitative scales such as Ezeala-Harrison (2014), Chikán (2008) and Sigalas et al. (2013). Some authors have combined some of Porter's conditions (the four diamond corners) while others have extended the structure by including other broad variables. Hanafi et al. (2017) for instance included two other variables, government and chance, creating six sub-structures or conditions for competitiveness analysis. Consequently, models based on Porter's framework have made use of three to six sub-structures when studying national competitiveness.

Scholars have indicated that in the development of composite indicators, too much qualitative variables have been used (Wenzel and Wolf, 2016). Dobbs (2014) noted that the implementation of Porters framework largely utilised qualitative assessments of the given forces. Porter's (2008) also wrote that as much as possible, analysts should look at industry structure quantitatively, rather than be satisfied with lists of qualitative factors. Akpinar et al. (2017) observed that the diamond model in essence is easy to understand, but the diversity of the four sub-determinants are difficult to measure.

While the conditions of the Porter's framework are also relevant in this research, a classification framework with different semantics has been adopted.
Since the goal is to study national competitiveness in the manufacturing industry, the choice of a model particularly apposite for such was made. While the Manufacturing Competitiveness Index (MCI) presented herein implicitly considers the conditions of Porter's diamond framework, a different semantic is used, the variables are quantitative and the framework is also mature. It also easily utilizes data from publicly available sources, and such data are usually more reliable and objective. The publicly available data sources also give a sufficiently large dataset in the sample frame and readily incorporates latest developments.

It should also be noted that based on how the measurement has been done in this work, both the classification based on Porter's Diamond structure and that based on the adapted MCI framework will not necessarily produce different results with the subsequent clustering technique utilized since all proxy variables would still be utilized in either case. Clustering of sub-structure related items may, however, be different. A proposed alignment of the MCI framework with the Porter's diamond sub-structure is further presented in appendix D.

2.6 Measurement frameworks for the Manufacturing Composite Index (MCI)

The conceptual model of the MCI presented in this work is adapted from Delgado-Márquez and García-Velasco, 2018; Fischer et al., 2018; Terzić, 2017; Ezell and Atkinson, 2011; Lall,1992; Abramovitz,1986; Fagerberg,1994; Archibugi and Coco, 2004; Tan and Tan,2014; Milenkovic et al, 2016; Shaker and Zubalsky, 2015; Lall and Albaladejo, 2003. The frameworks are summarised in Table 5.

Lall (1992) argues that at the country level, capabilities can be grouped under three broad headings: physical investment, human capital and technological effort. Tan and Tan (2014) also agree with Lall (1992) that education, physical infrastructure and technological infrastructure are important elements for National Technological Competitiveness (NTC). Physical investment refers to plant and equipment that are needed for industries to exist.

Human capital includes education, formal training and on the job training. Technological effort includes manufacturing, research and design. The NTC uses data from the Worldbank but does not include data on importation of manufacturing technologies. In this work, technological infrastructure and physical infrastructure are important elements to be considered in the conceptual development of the MCI as used in the Asian Competitiveness Institute Index (Tan and Tan, 2014)

Abramovitz (1986) and Fagerberg (1994) indicate that there are three essential ingredients explaining differences in the rate of technological changes across countries. Filliptetti and Peyrache (2011) also argue the three ingredients' proposition, which can be summarised as (1) differences in capital investments (2) differences in the level of education; and (3) differences in the expenditures on Research and Development (R&D) and related innovations. The development of appropriate social capabilities enhances rapid growth in countries that are lagging in technological development (Abramovitz, 1986). This highlights that research in universities and at public Research and Development (R&D) institutions provides input into the innovation process (Fagerberg, 1994). The innovation process is considered a major contributor to economic growth, productivity, competitiveness and employment. Countries are at different stages along this innovation path due to the availability of infrastructure in the country to support innovation and technological capabilities (Archibugi and Coco, 2004). Therefore, the measurement of variables that act as a proxy for infrastructure development assists in completing the analysis on the competitiveness of a country. Innovation is a process that includes generation of new ideas, industrialization and commercialization. In the development of the MCI, variables that can act as a proxy for measuring innovation will be used. R&D creates capacity for absorption of new technologies and aids innovation (Terzić, 2017). Advancement in knowledge leads to innovation which allows firms (and nations) to build competitive advantage (Delgado-Marquez and Garcia-Velasco, 2018).

Empirically, both neoclassical and technology gap studies divide the variables into three groups (Fagerberg, 1994):
(a) GDP per capita as a proxy for productivity and/or technology;
(b) Variables to close the gap between leading and lagging countries (such as investments in education and physical infrastructure, output from innovation activities e.g. papers published);
(c) Variables of economic, political and institutional nature (growth of labour force, degree of openness to trade and share of public sector in GDP).

In the development of an MCI, both the elements of manufacturing, R&D and innovation should be included since they complement each other (Ezell & Atkinson, 2011). Studies indicate that R&D and manufacturing indices are important indicators to measure due to their ability to quantify economic growth or decline (Tassey, 2013). Less advanced countries can accept technologies from others to spurt their growth during the initial stages of development (Terzić, 2017). This can be captured in their level of import of manufacturing technologies as part of the development of the MCI.

The broad based indicators include unit labour cost (ULC), deflators of sales and real exchange rates, weighted average of real GDP, aggregate imports of goods & services (IMPS) and volume of global trade. These broad based indicators are suited well for measuring the competitiveness of countries (Fischer et al, 2018). The competitiveness of a country can also be measured by benchmarking their investments and achievements in the ICT sector (Milenkovic et al, 2016). The Technological Capability (TC) Index is a good example of such artifact for measuring competitiveness (Khayyat and Lee, 2015).

This study uses extant literature to create the conceptual framework for the MCI in order to measure competitiveness by focusing on physical infrastructure, technological infrastructure, education, research and manufacturing capability, including technology import level. The identified shortcoming in literature is the exclusion of variables that specifically measure the impact of importation of manufacturing technologies pertaining to CNC Machining, Robotics, Additive Manufacturing, Plastic Injection Moulding, High Technology Exports and Military Expenditure as technology proxy. The Economist (2018) also states that "…absorption of foreign IP explains 40% of the growth in labour productivity in emerging economies…"

2.7 Clustering of indicator variables from the MCI

Using manufacturing composite indexes with the composite scores provides a basis on which countries are ranked. It is however not able to provide insights into how the countries can be grouped together. Computation of MCI, complemented with clustering algorithm (like Wards and Fuzzy c-mean) have been used to cluster countries (Shami, Lotfi and Coleman, 2013; Shaker and Zubalsky, 2015). "What If" simulation has also been used to make recommendations on structural reforms in the policy of the country (Tan and Tan, 2014).

The addition of a clustering algorithm expands the MCI beyond just a ranking score of countries but also categorizes countries visually and displays the clusters for subsequent analysis. Clustering is used because while MCI score may provide rankings of a country, it does not interpret the performance gaps. By allocating countries into groups through a clustering algorithm, it indicates potential categories of competitive clusters and points out how to move across such clusters. Pareto supplemented gap analysis is subsequently used for action plans for countries to migrate across clusters.

2.8 Summary of findings from literature review on Composite indexes

The next section is a comparative presentation of a review of the relevant articles on the MCI. The findings from the journal articles and industry documents on Composite Indexes are summarised in table 5.

Table 5: Comparative review of composite index studies			
Composite Index	**Summary**	**Aggregation Equation**	**Data Source**
(1) Basic Capabilities Index-BCI **Socialwatch (2018)**	The BCI were instituted by Social Watch as an alternative way to monitor the situation of poverty in the world. The index is computed as the **average of three indicators**: 1) mortality among children under five, 2) reproductive or maternal-child health (measured by births attended by skilled health personnel), and 3) education (measured with a combination of enrolment in primary education, the proportion of children reaching fifth grade and adult literacy rate). Maximum score is 100 that can be achieved	**BCI**= (Child Mortality+ Maternal Health+ Education)/3	UN(United Nations)
(2) Country Performance Assessment-CPA **Asian Development Bank (2018)**	The Asian Development bank (ADB) Country Performance Assessments assesses the quality of a country's policy and institutional framework. ADB carries out its annual CPAs using the World Bank's country policy and institutional assessments (CPIA) questionnaire. . Policy and Institutional Rating consists of 11 Indicators which are averaged, Governance Rating with 5 indicators and Portfolio performance rating with 1 indicator. Therefore CCPR consists of 17 composite indicators.	**CCPR**= (Policy & Institutional Rating)$^{0.7}$ x (governance rating)$^{1.0}$ X (portfolio performance rating)$^{0.3.}$ Policy and Institutional Rating =(Economic Management Rating + Structural Policy Rating + Policies for Social Inclusion/& Equity Rating)/3. Composite score ranges from 1 to 36	Asian Development Bank
(3) Global Competitiveness Index (GloCI) **World Economic Forum (2018)**	"The GCI (Global Competitiveness Index) provides information that allows leaders from the public and private sectors to better understand the main drivers for economic growth". The 100 indicators gets a scaled score from 1 to 7 which are aggregated together. The **countries are then ranked from 1 to 140** based on the composite GCI score they achieve which after averaging is between 1 to 7. For the <u>Qualitative Indicators</u> the rank from 1 to 7 was based on survey data e.g. 1= extremely poor research institutes to 7= extremely good research institutes. <u>For the Quantitative Indicators</u> Linear multivariate and univariate regression equations was fitted to the data to get numerical values. A special submeasure is the" filtering" of countries into 5 stages of development based on their GDP/capita thresholds:	**GCI=y1** x Basic Requirements Subindex + **y2** x Efficiency Enhancers Subindex + **y3** x Innovation and Sophistication Subindex. Basic Requirements Subindex consist of { **Pillar 1:** Institutions(21 indicators) + **Pillar 2:** Infrastructure(9 Indicators) + **Pillar** 3: Macroeconomic Environment(5 indicators) + **Pillar 4:** Health and primary education(10 indicators). Efficiency Enhancers Subindex consist of { **Pillar 5:** Higher education & training(8 Indicators)+ **Pillar 6:** Goods Market efficiency(16 indicators) +**Pillar 7:** Labour market efficiency (10 indicators) + **Pillar 8:** Financial market development(8 indicators) + **Pillar 9:** Technological	Worldbank Data of Quantitative and Qualitative(Survey) based data e.g. the Executive Opinion Survey. World Economic Forum Data Sources.

	Stage 1 < $2000. Stage 1 to 2 transition is $2000 -2999. Stage 2 is 3000-8999. Stage 2 to 3 transition is $9000-17000 . Stage 3 is > $17 000. The weights (**y1,y2 ,y3**)are adjusted for the different stages for the 3 subindexes of which the 12 pillars consist.	readiness(7 indicators) + **Pillar 10:** Market Size(4 indicators)}. Innovation and sophistication subindex consists of { **Pillar 11** : Business sophistication(9 indicators) + **Pillar 12:** Innovation(7 indicators) }	International Monetary Fund data.
(4)Global Retail Development Index **AT KEARNY (2018)**	This index measures the attractiveness of countries for retail business and ranks them from highest to lowest attractiveness. Scale from 0 -100.	**GRDI**=25%(Country & Business Risk) + 25%(Market attractiveness) + 25%(Market Saturation) +25% (Time Pressure)	Euromoney, Population Data Bureau, International Monetary Fund data. World Bank, World Economic Forum, Planet Retail
(5)McKinsey Global Institute Industry Digitization Index **Mckinsey (2018)**	The Industry Digitization Index is used to measure the strengths of a country`s digital system and the degree of digitization of industries in the country. "Helps companies to make the correct choices for the impending waves of change "Mckinsey (2018) indicates that China is " …in the top three in the world for venture capital investment in key types of digital technology including virtual reality(VR), Autonomous vehicles, 3D -Printing, robotics, drones and AI."	22 Industries was rated against **3 Subindexes** called (1) **Assets** (2) **Usage** and (3) **People.** The subindex Assets has 2 indicators: (a) Digital Spending and Digital Asset Stock . The subindex Usage has 3 indicators:(a) Transactions(b) Interactions and (c) Business processes. The subindex People has 3 indicators: (a) Enabling Digital workers (b) Digital Capital deepening and (c) Digital employment	Gartner, OECD, Bloomberg, McKinsey Global Institute, Central Bureau of Statistics
(6) SIPRI Military Expenditure Database **Stockholm International Peace Research Institute (SIPRI) (2018)**	Two variables of Military Expenditure and GDP per country which is represented as a percentage ratio. Where possible, SIPRI military expenditure data include all current and capital expenditure on: (a) the armed forces, including peacekeeping forces; (b) defence ministries and other government agencies engaged in defence projects; (c) paramilitary forces, when judged to be trained and equipped	**SIPRI Military Expenditure**= **Military expenditure per country/ GDP of Country**. "The main purpose of the data on military expenditure is to provide an easily identifiable measure of the scale of resources absorbed by the military". "The share of gross domestic product (GDP) is a rough indicator of the proportion of national resources used for military activities, and therefore of the economic burden imposed on the national economy."	NATO, IMF`s Government Financial Statistics Yearbook, United Nation Statistical Yearbook, data from

	for military operations; and (d) military space activities.		national governments
(7) Responsible Competitiveness Index **AccountAbility Institute(AAI) (2018)**	AccountAbility is a global consulting and standards firm that works with business, governments and multi-lateral organizations to advance responsible business practices and improve long term performance.	**Responsible Competitiveness** indicates that an economy`s productivity is enhanced by "business taking explicit account of their social, economic and environmental performance." **7 Sections the index** namely (1) **Corporate Governance** (2) **Business ethics**(corruption) (3) **Progressive public policy** (4) **Building human capital** (5) **Civil society vibrancy** (6) **Corporate contributions** to public finance and(7) **Environmental management**	World Economic Forum Data
(8) OECD Science, Technology and Industry Scoreboard **OECD (2018)**	"The aim of the STI Scoreboard is not to "rank" countries or develop composite indicators. Instead, its objective is to provide policy makers and analysts with the means to compare economies with others of a similar size"	The data of the different OECD countries is presented in **graphical format under 6 areas**: (1) **Knowledge economies** with 3 indicators (2) **Investing in knowledge**, talent and skills with 10 indicators (3) **Connecting** to Knowledge-1 0 indicators (4) **Unlocking innovation** in firms-10 indicators (5) **Competing** in the global economy-10 indicators and (6) **Empowering society** with science and technology -10 indicators.	OECD Database, IMF, International Energy Agency (IEA), Eurostat
(9) UNDP(United Nations Development Program) Human Development Index **UNDP (2018)**	HDI is a composite index measuring average achievement in 3 dimensions of human development. The UNDP believes that human development is attainable for everyone. To UNDP also measure human development in terms of four other composite indices: (a) Inequality adjusted HDI (B) Gender Development Index (c) Gender Inequality Index that highlights women`s empowerment and the (d) Poverty Index	**HDI** consists of (1) **Life Expectancy at birth** (2) **Expected years of schooling** (3) **Mean years of schooling** and (4) **Gross national income per capita**. Composite Index rating is between 0 to 1	Worldbank data source, UNCTAD, UNDESA
(10) IMD World Competitiveness Scoreboard **IMD (2018)**	The composite index benchmarks the performance of **63 economies** based on more than 340 criteria measuring different facets of competitiveness. Rating are from 0 to 100. 241 are used in the composite index – the remaining 82 are for support information	The composite Index consists of 4 main competitiveness factors with 5 subfactors each: (1) **Economic performance** (Domestic economy, international trade, international investment, employment and prices), (2) **Government efficiency** (public finance, fiscal policy, institutional	IMD Data, OECD Statistics, Worldbank, World Trade Organisation,

		framework, business legislation and societal framework) ,(3) **Business Efficiency** (productivity, labour market, finance, management practices and attitudes and values) and (4) **Infrastructure** (Basic infrastructure, Technological infrastructure, scientific infrastructure, health and environment and education). All subfactors are weighted equally at 5%.	World Tourism Organisation
(11) Deloitte Global Manufacturing Competitiveness Index **Deloitte (2017)**	Rating is between 10 to 100. Qualitative data includes feedback from Global CEO`s Survey from 540 respondents. The survey is supported in graph formats by supplemental quantitative comparisons based on available data from Worldbank data sources. However a composite index based on quantitative data is not developed. “This multi-year research platform is designed to help global industry executives and policy makers evaluate drivers that are key to company and country level competitiveness as well as identify which nations are expected to offer the most competitive manufacturing environments through the end of this decade"	**DGMCI** -Manufacturing executives were asked to rate the overall manufacturing competitiveness of 40 countries, today and in five years. "Manufacturing Executives surveyed are from companies of significantly different sizes and global footprint. As such, in order to calculate the 2016 Global Manufacturing Competitiveness Index, competitive driver scores, and policy scores, respondents were given different weights based on their global experience. “Normalized Z Scores is then generated for each country. For the computation, executive responses were standardized to adjust for potential country and cultural response differences, Industry sector, as well as for company size, which is captured through annual revenues in US dollars. Manufacturing executives rates the countries according to 12 drivers: (1) **Talent** (2) **Cost Competitiveness** (3) **Workforce productivity** (4) **Supplier Network** (5) **Legal and Regulatory** System (6) **Education Infrastructure** (7) **Physical Infrastructure** (8) **Economic, trade, financial** and Tax System (9) **Innovation Policy** (10) **Energy Policy** (11) **Local Market attractiveness** and (12) **Healthcare system**	Worldbank data, IMF Data, EIU, UNCTAD

(12) BCG Global Manufacturing Cost-Competitiveness Index **Boston Consulting Group (2018)**	Top 25 export countries are responsible for 90 percent of global exports of manufactured products. Countries are grouped in 4 groups : (a) Under pressure (b) Losing Ground (c) Holding Steady and (d) Rising Global Stars based on cost competitiveness. Data is analysed for 2004 and then in 2014 and the % shifts in the 4 direct cost factors is then calculated to determine how the countries are performing.	**BCG Global Manufacturing Cost-Competitiveness Index** = weighted average of (1) Hourly rate for manufacturing worker, (2) Exchange Rates against US$ Dollar ,(3) Labour Productivity per manufacturing worker relative to US and (d) Electricity cost/kwhr. USA is given a value of 100 and all countries are then compared relative to the USA. If a countries manufacturing cost is lower than the USA it will have a value< 100.	US Economic census data, International Labour Organization, Worldbank data. Euromonitor, Economist Intelligence Unit. Transparency International
(13) PWC Aerospace manufacturing attractiveness rankings **PWC (2018)**	The aim of the Aerospace attractiveness rating is to provide aerospace companies "with information to improve manufacturing supply chains, control cost and plan for future growth	Final Country Rank= Rank=[Rank Labour + Rank Infrastructure +Rank Industry +Rank Economy + Rank Cost + Rank Tax Policy + Rank Geo-Political Risk]. There is a total of **33 indicators under the 7 Subindexes**. For Example Rank Labour = Rank[Score Indicator 1+ Score Indicator 2 + Score Indicator 3 + Score Indicator 4]. Score Indicator 1=WeightIndicator1 X RankIndicator1. The 33 indicators includes: Labour Force, Basic Education, Skilled Education, Advanced Education, Union Flexibility, Quality of Roads, Quality of Railroads, Quality of Air, Internet usage, Quality of electrical supply, quality of proper infrastructure, GDP,GDP Growth, FDI, Labour Cost, Labour Productivity, Political Risk, Overall Tanks Rankings, Capital Expenses etc.	World Economic Forum Data, IBS World, Standard and Poor (S&P)
(14) The Technological Capabilities Index(ArCo)	The Arco composite indicator aims to allow for comparisons between countries over time of their technological capabilities .Index range if from [0,1] after normalising the data according to the formula:(Observed value-minimum value)/(Maximum Value-	**Arco= (1/3)Technology Creation + (1/3) Technology Infrastructure + (1/3) Human Skills**. A fourth dimension Imported Technology = FDI + Technology licensing payment+ Import of capital	USPTO ,NSF, ITU, UNESCO, UNDP

Archibugi and Coco (2004)	minimum value). Arco (2018) also looks at imports ".. based on the assumption that an important source of technological capabilities is also represented by the possibility of a country to access technology developed elsewhere…"	goods was adder later. The Global Technology Index = Arco + Imported Technology with all 4 dimensions/subindexes given equal weight. The Global Technology index due to data availability could only be done for 86 countries compared to Arco which was for 162 countries. Technology Creation={Patents/capita+ S&T Publications/capita}. Technology Infrastructure={ Internet users/capita+ Telephone mainlines and mobiles/ capita + Electricity consumption kwh/capita}. Human Skills={ Tertiary science & engineering enrolment rate + Mean Years of schooling over 14 + Literacy Rate}	
(15) UNIDO Industrial Development Report. The Role of Technology and Innovation in Inclusive and Sustainable Development **Lall and Albaladejo (2003)**	This indicator looks at the components and rivers for competitive industrial performance. To normalise the value of the different indicators the following formula is used: (Observed value-minimum value)/(Maximum Value-minimum value) to obtain ratings between 0 to 1. UNIDO subindexes " is strongly inspired by the work of Khayyat and Lee (2015)". The UNIDO do not combine data into one composite index since they indicate that " data on the various components can be useful and informative as an aggregate indicator" The lack of a composite indicator prevents statistical comparison with other indicators.	**There is 5 subindexes**: (1) **Technological effort**, (2) **Competitive industrial** performance, (3) **Technology imports**, (4) **Skills** and (5) **Infrastructure**. Technological effort have the following indicators={1/2Patents Granted at USPTO/capita+1/2 Enterprise financed R&D per capita}. Competitive industrial performance={ 1/4Manufactured vale added per capita +1/4medium&High Technology share in manufactured value added+1/4 Manufactured exports percapita+1/4 Medium& High technology share in manufactured exports}. Technology imports={ 1/3 FDI per capita + 1/3 Foreign royalties payments/capita + 1/3 Capital goods per capita}. Skills= Tertiary enrolment ratio. Infrastructure={ Telephone mainlines per capita}	UNESCO, UN Comtrade, UNIDO Database, Worldbank
(16) The Science and Technology Capacity Index(STCI)	"The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more	**STCI= {1/4Enabling Factors + 1/2 Resources + 1/4 Embedded Knowledge}**. Enabling factors ={1/2 GDP per capita +1/2 Tertiary Science enrolment ratio}. Resources ={ 1/3 Number of	UNDP,USPTO ,NSF

RAND Corporation(2018)	prosperous. RAND is non-profit, nonpartisan, and committed to the public interest."	institutions per capita+ 1/3 Scientist and engineers per capita + 1/3 R&D Expenditure on GDP}. Embedded Knowledge = {1/3 Patents granted at USPTO/Capita + 1/3 S&T publications per capita + 1/3 Co-authored scientific articles}	
(17) The Global Technology Revolution 2020 **Silberglitt et al (2006)**	Research done for the National Intelligence Council by the RAND Corporation. The aim is to provide US Policy makers with a view of developments worldwide in Science and Technology since the USA is not the dominant players in every technology anymore. This way they can identify opportunities for the USA and "… potentially negative developments that might warrant policy action…"	16 Top Technologies was identified and each county`s ability was scored under 2 dimensions: **Capacity to acquire Technology Application x Driver % and Barriers (%)**. Capacity to acquire Technology Application is defined as the fraction of the top 16 technology application listed for that country x fraction of the ten drivers for implementation applicable to that country. Barriers (%) is defined as the fraction of the ten barriers to implementation applicable to that country. Based on the foresight countries are divided into: (1) Scientifically advanced through 2020 (2) Scientifically proficient through 2020 and (3) Scientifically developing through 2020 and (4) Scientifically lagging	RAND Corporation data
(18) Science and Technology Index (STI) **Alard (2015)**	The research replicated the Rand STCI from 2001 to 2011 to understand how the global rankings of African countries have changed since 2001. Research indicates that most developing countries have increased their global ranking position due to increase in science & technology papers, increase in number of scientist and engineers e.g. China. If the output indicators like patents registered and number of science and technology indicators are divided by the population size of the country it has an effect on the position of some countries with bigger population like China and South African which then moves to lower ranking positions in the overall index. Overall score is obtained for the STI and countries is then ranked from 1 to 53 for the African Countries	**STI= {1/4Enabling Factors + 1/2 Resources + 1/4 Embedded Knowledge}.** Enabling factors ={1/2 GDP per capita +1/2 Tertiary Science enrolment ratio}. Resources ={ 1/3 Number of institutions per capita+ 1/3 Scientist and engineers per capita + 1/3 R&D Expenditure on GDP}. Embedded Knowledge = {1/3 Patents granted at USPTO/Capita + 1/3 S&T publications per capita + 1/3 Co-authored scientific articles}	UNDP,USPTO , NSF

(19) The Global Capabilities Indicator (GLOCAP) **Filippetti and Peyrache (2011)**	In this research the GLOCAP Technological composite indicator is developed and combined with linear programming to develop the Technological Capabilities Frontier under Data Envelopment Analysis(DEA) against. The aim is to highlight differences in the technological capabilities of countries	**The GLOCAP composite indicators consists of 3 subindexes with 9 indicators/variables.** GLOCAP={ 0.3 x Business Innovation + 0.3 x Knowledge & Skills + 0.4 x Infrastructures}. Business Innovation={ 0.15 x Triadic Patents + 0.15 x Business R&D }. Knowledge & Skills = { 0.1 x Total Researcher in R&D + 0.1 x Scientific and technical articles + 0.1 x Public R&D Expenditure}. Infrastructures ={ 0.1 x Personal Computers + 0.1* Fixed-line and mobile telephones + 0.1 x Internet Users + 0.1 x Gross fixed capital formation}. To incorporate the DEA technique into the research a Relative GLOCAP is defined= Glocap /GlocapMax. GlocapMax. is defined as the maximum achievable index that a country can obtain based on the Technological Capabilities Frontier that was developed in terms of the dimensions. Relative GLOCAP has a value between 0 to 1.	Worldbank, OECD, UNCTAD, UNESCO
(20) Technological Capability(TC) – Index **Khayyat and Lee (2015)**	This research was focused on developing a composite index to analyse the innovativeness of developing countries and also to understand the role of Science and Technology in enhancing the rate of innovation	**Principal component analysis** was completed to assign weights to each of the Subindexes. The Overall TC index is a weighted aggregation of 6 principal components consisting of 28 indicators. The 6 Subindexes was not given names upfront since the Principal Component Analysis defined by analysing the 28 indicators that a total of 6 Subindexes gets generated (PC1,PC2,PC3,PC4,PC5,PC6). **TC-Index= {0.321PC1 + 0.306PC2 + 0.064PC3 + 0.059PC4 + 0.046PC5 + 0.038PC6}**. PC1={Patents Granted by USPTO + FDI(Foreign Direct Investments+ Human Development Index(HDI)[50] + Availability of specialized research & training services+ Average number of Citations+ Gross Higher Education Enrolment Rate+ FDI Inflows as % of GDP + FDI	Worldbank

		.outflows as % of GDP}. PC2= { Internet Users/1000 people + Internet access in schools + S&E Journal Articles + GDP per capita + Computers per 1000 people + Mobile Phones per 1000 people + Total Telephones per 1000 people + Internet Users per 100 people + Mobile cellular subscriptions per 100 people}. PC3= {Exports of Goods and Service as % of GDP + S&E Articles with foreign co-authorship}. PC4= {Intellectual Property Protection + Availability of e-Government Services + Quality of Science and Math Education} . PC5= } Patents Granted by USPTO/ million people + Public Spending on Education as % of GDP+ High Tech Exports as % of GDP}. PC6= { International Internet Bandwidth + Adult Literacy Rate + S&E Journal Artic.	

2.9 Development of subindex themes for the modified MCI

In this study, previous composite indexes were expanded by including indicators that specifically focus on manufacturing technologies, which is grouped under a Manufacturing Activity (MA) subindex. Also, the impact of regulatory burdens and bureaucratic processes, which usually results in long lead time are grouped under the Economy and Market environment (EM) subindex.

The improved analytical framework for the enhanced MCI, thus, contains the following subindexes:

- Business Infrastructure (BI) subindex, which measures the infrastructure activity in a country that supports the manufacturing competitiveness of the country. It contains eleven variables that measure investments in infrastructure, including health which is an important indicator of the living standards of the population of the country.
- Economy and Market environment (EM) subindex contains eight variables and identifies how much GDP a country generates per person, indicating the market environment within the country. Bureaucratic obstacles, which can make the establishment of new manufacturing operations in a country difficult are also included.
- Education and Talent (ET) subindex, containing four variables with focus on measuring the level of investment in education. Government expenditures on students are input measurements, whereas number of researchers per million are a output measurement.
- Innovation and Research (IR) subindex, containing six variables and measuring the research output of a country, patent applications and trademark applications.
- Manufacturing Activity (MA) subindex, having 13 indexes and measuring the manufacturing economic activity of the country. To the best knowledge of the author, the variables in this subindex MA4 to MA13 have not been used in a MCI before in this specific format.

3. Research design and methodology

In this section the methods for data collection, calculation of the composite index score cluster formation, gap analysis and the approach adopted for closure of gaps are presented.

3.1 The research methodology to solve the research problem

The methodology has been developed to meet the outcomes of the research objectives identified under section 1. The methodology can be applied to determine the level of competitiveness of a country. A case study of South Africa illustrates how the competitiveness are then measured in the manufacturing environment. Figure 6 shows the flow diagram of the research methodology in graphical format.

1. Journal paper reviews to look at key parameters for the MCI
2. Development and justification of new parameters and MCI
3. Data collection on all indicator variables from suitable data sources
4. Complete matrix of key indicator variables identified
5. Complete composite index scores and tabulate
6. Rank countries according to composite index scores
7. Normalise indicator variable scores between [0,1]
8. Complete Ward`s Hierarchical Clustering to determine clusters and review statistical analysis
9. Calculate the Clusters average and minimum scores
10. Determining the magnitude of gaps between South Africa as the reference country and target cluster using normalised gap values.
11. Complete Pareto Analysis to identify indicator variables that contribute 80% of the normalized gap magnitudes
12. Complete value analysis, estimating USD/unit gap values to rank action items to close the gaps for South Africa
13. Complete action plan for South Africa

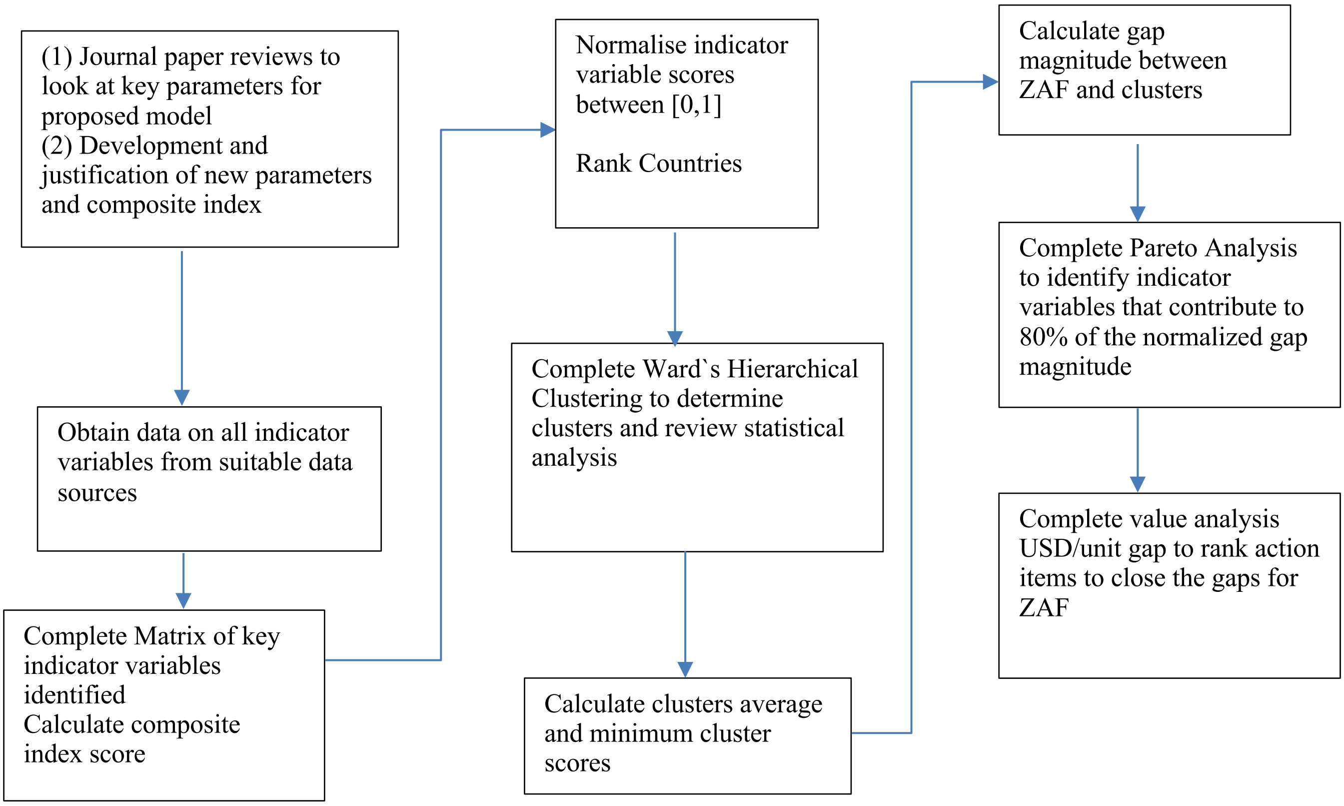

Figure 6. Flow diagram of research methodology

3.2 Data preparation

In this section sources of data, the treatment of missing data, data normalisation, data aggregation and the clustering technique used is describer. The ranking achieved and the value analysis as outputs are also discussed.

3.2.1 Data sources

The data used in the calculation of the MCI, was obtained from the Worldbank (2018), UN Comtrade (2018) and CWUR (2016). Search is conducted on the different database platforms by filtering against the MCI indicator variables and international trade data on relevant machine tools. The data is downloaded in excel format from the databases. Data clean-up is performed and Min-Max normalization is done. Ward clustering analysis was then implemented using excel add-on package, XLSTAT to group the countries into different groups of competitiveness.

3.2.2 Treatment of missing data

There were few missing data points because the Worldbank Data (2018) source and UN Comtrade (2018) have complete entries on most variables; but where there were missing data, the mean values of the non-zero entries of the indicator variables were used. This seems reasonable since the study is not trying to benchmark South Africa (ZAF) against a specific country, but rather against a basket of countries in order to move if from its current cluster to a more competitive cluster. This approach of treatment of missing data is used by Wenzel and Wolf (2016) and The Handbook of Constructing Composite Indicators (2008).

3.2.3 Data Normalisation

To normalize the data, the Min-Max normalization of data was used so that all variables have a value between [0, 1]. The can be represented as

$$Norm\ \ x_{q,c} = \frac{x_{q,c} - \min x_{q,c}}{max\ x_{q,c} - \min x_{q,c}}$$

Where $Norm\ \ x_{q,c}$ is the normalized value of an indicator q for country c at time t; $q = 1, \dots, 42$; $c = 1, \dots, 27$; and t is fixed at 2016 for all indicator variables except the GPD growth rate that was an average over 26 years. Appendix B contains a sample of the table with normalised data for the 42 indicator variables for the 27 countries.

3.2.4 Data Aggregation

Linear aggregation was used in the computation of MCI as recommended by the Handbook on Constructing Composite Indicators (2008). The composite subindexes are calculated as

$$Y_{n,c} = \sum_{n=1}^{j_n} x_{n,c}$$

Where $Y_{n,c}$ is the subindex Y of the MCI for country c; $n \in q{:} \sum j_n = q,\ n = 1, \dots, j_n,\ j_n$ is the number of indicators belonging to the subindex n, $\forall\, Y_n,\ n = 1, \dots, j = 5$ categories (BI, EM, ET, IR and MA) in this case, with $j_1 = 11$, $j_2 = 8$, $j_3 = 4$, $j_4 = 6$ and $j_5 = 13$ and $q = \sum j_n = 42$. The MCI_c can then be calculated for each country as

$$MCI_c = \sum_{n=1}^{j} W_n Y_n$$

Where $\sum_{\mathrm{n}} \mathrm{W_n} = 1,\ \ 0 \leq \mathrm{W_n} \leq 1,\ \text{and}\ \mathrm{j} = 5$ is the number of subindexes.

3.2.5 Clustering method

The goal of clustering is to determine the intrinsic grouping in a set of unlabelled data. This is the rationale behind selecting clustering to group the countries in groups. A cluster is therefore a collection of objects which are “similar” between them and are “dissimilar” to the objects belonging to other clusters.

Agglomerative clustering, divisive clustering and k-means clustering

The k-means algorithm is parameterized by the value k, which is the number of clusters that you want to create. The value k is specified upfront. K-Means clustering requires prior knowledge of K. In this study we want the grouping of the countries to emerge from the underlying data.

Agglomerative hierarchical clustering, instead, builds clusters incrementally, producing a dendrogram. For the calculation of the clusters the Ward technique is used. This technique belongs to the hierarchical agglomerative methods. Agglomerative clustering is a bottom-up approach.

Divisive clustering is generated top-down. This variant of hierarchical clustering is also called top-down clustering. The process starts with all the countries in one cluster. The cluster is split using a flat clustering algorithm. This procedure is applied recursively until each country is in its own singleton cluster. Top-down clustering benefits from complete information about the global distribution of data when making top-level partitioning decisions. In this case we have information available at the macro level of countries by means of proxy-variables and our picture of the complete global distribution is not complete. This clustering method would therefore not be applicable to the grouping of countries from a bottom up approach.

Why Wards Clustering

The Ward's method has an iterative character. It is repeated until each of all the clusters is formed into a single massive cluster. The results of hierarchical clustering can be viewed through a development tree or dendrogram. The root of the dendrogram represents the whole data set. The nodes within dendrogram describe the extent to which the object relates. The results of the cluster analysis are dendrograms obtained by cross-section at different levels (Ward, 1963; Reiff et al., 2016) Fusion criterion of the Ward technique is – at the basis of the squared euclidean distance – the variance criterion. This means that this method minimizes the sum of squares of any two (hypothetical) clusters that can be formed. Very homogenous clusters are thereby formed. Wards Agglomerative Hierarchical Clustering was used in this research to reduce the dimensionality of the data collected on the 27 different countries. Clustering membership of the 27 countries is calculated by variance of the elements. An element will belong to a cluster if it produces the smallest possible increase in variance. A small geometric distance implies high similarity.

The Squared Euclidean distance proximity type was used in the Wards Clustering algorithm of the MCI_c

The geometric distance for clusters of MCI_c is calculated as:

$$\Delta(A,B) = \sum_{i\varepsilon A\cup B} ||\vec{x}_i - \vec{m}_{A\cup B}||^2 - \sum_{i\varepsilon A} ||\vec{x}_i - \vec{m}_A||^2 - \sum_{i\varepsilon B} ||\vec{x}_i - \vec{m}_B||^2$$

$$= \frac{p_A p_B}{p_A + p_B} ||\vec{m}_A - \vec{m}_B||^2$$

Where p_A and p_B are the number of points in clusters A and B, and $\vec{m}_k$ is the center of cluster k where $k = A, B$ when two clusters are considered.

3.2.6 Ranking of Countries and indicators

Ranking of countries was used to determine the positions of the 27 countries on the data collected. A higher rank position implies that the country scored a higher composite index score. Table 6 shows that 6 of the 42 indicator variables were normalised inversely e.g. Time required to start a business in. The indicator variables are EM3, EM4, EM5, EM6, EM7 and EM8. The asterisks * indicates that these indicator variables are related to costs and the aim is to have them minimised for better ranking and competitiveness

Table 6. Indicator variables normalised inversely.

Compensation of employees (% of expense) *	EM3
Bank nonperforming loans to total gross loans (%) *	EM4
Time to Import (Days) *	EM5
Cost to import, documentary compliance (US$) *	EM6
Cost to import (US$ per container) *	EM7
Time required to start a business (days) *	EM8

3.2.7 Value Analysis

The Wards algorithm clustered countries together in groups. The average cluster magnitude and minimum cluster scores were calculated. For the 42 indicator variables the magnitude of the gap between South Africa and the cluster average and minimum scores was calculated. Normalised indicator variables scores were used to eliminate underlying bias in the different indicator variables.

A Pareto analysis identified the indicator variables contributing 80% to the overall cumulative gap magnitude for the different cluster groups. The cost in USD for the Pareto identified indicator variables was divided by the gap magnitude to determine the USD Cost /gap to allow ZAF to close the gap to the average of the identified cluster

3.3 Description of variables of the MCI

This section describes the MCI subindexes adopted in this study and highlights the indicators included in each of the subindexes used for the overall MCI. The additional variables (MA4 to MA13) included in MCI is also justified in this section.

3.3.1 Business Infrastructure (BI) subindex

This subindex measures the infrastructure quality in a country that supports the manufacturing environment and bequeaths manufacturing competitiveness on a country. It includes variables that measures investments into health, which is an important indicator of the living standards of the population of the country. Table C1 in appendix C contains the actual data for the BI subindex.

BI1 Quality of Road, length of paved and unpaved roads

The quality of the road network is an indication of how goods and services can be transported around the country and how easily that can take place.

BI2 Healthcare expenditure as % of GDP

This is the sum of public and private health expenditure. It covers the provision of health services: preventive and curative in nature. This is an indication of the quality of life of the population.

BI3 Improved sanitation facilities (% of population with access)

Sanitation is an indication of the living standard of a country. It is fundamental to human development. Sanitation facilities are a measure of progress in the fight against poverty, disease, and death.

BI4 Fixed telephone subscriptions (per 100 people)

The variable BI4 measures the level of infrastructure investments of a country into telecommunication. In the absence of cellular networks it is important to measure what other means of communication the country has.

BI5 Electric power consumption (kWh per capita)

The consumption of electricity is basic indicators of the size and level of development of a country.

BI6 Secure Internet servers (per 1 million people), BI7 Mobile Cellular Subscriptions per 100 people, BI8 Fixed broadband subscriptions (per 100 people)

The quality the country`s telecommunications, broadband and cellular infrastructure is an important element in investment decisions, and investors take decision for investment based on the available infrastructure. The fixed broadband subscriptions referred to is investments in fibre optic cabling to allow transmission of large amounts of data.

BI9 Foreign direct investment, net inflows (% of GDP)

This variable looks at investments into country to establish warehouses, manufacturing facilities and other long-term infrastructure to conduct trade in that country. Lall(1992) states that "FDI is an efficient means to transfer the results of innovation rather than the innovative process itself."

BI10 Automated teller machines (ATM`s) per 100 000 adults

This variable is a proxy for the financial infrastructure of a country and how easily people can get access to their finances.

BI11 Domestic credit to private sector by banks (% of GDP)

Private investment can contribute to growth. The private sector can be regarded as one of the main engines of productivity and growth. The private sector creates employment and higher growth for the country.

3.3.2 Economy and Market Environment (EM) subindex

This subindex identifies how much GDP a country generates per person, which indicates the market environment within the country. Bureaucratic obstacles are also included, which can make the establishment of new manufacturing operations in a country difficult. The asterisks * indicates that these indicator variables are related to costs and the aim is to have them minimised for better ranking and competitiveness. Table C2 in appendix C contains the actual data obtained for the EM-subindex

EM1 GDP per person employed (constant 2011 PPP $)

A measure to monitor sustainable economic growth of a country

EM2 Bank capital to assets ratio (%)

Measures the financial resilience of the country`s financial institutions. A measure of bank solvency. Illustrates the extent to which banks can deal with unexpected losses.

EM3 Compensation of employees (% of expense)*

Payments to employees in cash for services rendered. The ratio as percentage of expenses should not be high. A higher % wage bill indicates an economy in which the level of manufacturing sophistication is not far advanced

EM4 Bank nonperforming loans to total gross loans (%)*

This variable measures how the country is performing with regard to credit worthiness. Financial instability can disrupt the financial economy of a country. A high ratio may signal deterioration of the credit portfolio.

EM5 Time to Import (Days)*, EM6 Cost to import, documentary compliance (US$)*, EM7 Cost to import (US$ per container)* and EM8 Time required to start a business (days)*

EM5, EM6, EM7 and EM8 measure the ease of doing business in a country. The value of the variables must be reduced, which indicates that a country is competitive. Putting obstacles in the way of doing business in a country will affect the market entry of new manufacturing technologies.* indicates that variables were normalised inversely.

3.3.3 Education and Talent (ET) subindex

In this subindex the focus is on measuring the level of investment within the country into education. The amount of technical staff and researchers in the country are also measured. This implies that both the input and output factors to the education of a country is measured. The number of universities in the top global list is a measure of the quality of research in that country. Table C3 in appendix C contains the actual data obtained.

Lall (1992) states that it is impossible to measure properly technological effort, but rough proxies are available. These proxies include expenditures on R&D as indicated in this subindex, patents and technical personnel available. Fagerberg (1994) argues that countries with low levels of education and high governmental expenditure in GDP (size of government) are susceptible to saturating their competitiveness growth well below the level achieved by the leading countries. Thus it is important to measure investment into education since it acts as a proxy to determine if a lagging country has the potential to catch up with a leading country.

ET1 Government expenditure per student, secondary education (% of GDP per capita) and ET2 Government expenditure per tertiary student as (% of GDP per capita)

The variables ET1 and ET2 measure the capital that the government of a country is spending on education of secondary and tertiary students. This can be regarded as an indication of a country`s ability to make use of higher developed technologies as the level of education increases in the population.

ET3 Number of Universities by Country in Top Global 1000 list per 10 million people

The measure is normalized by dividing by the number of researchers per country so that smaller countries are not unjustly penalized in the measure. This measure can be regarded as an indication of the quality of research a country undertakes.

ET4 Researchers in R&D per million people of the country

This measurement indicates how many people in the country are engaged in the conception or creation of new knowledge, products, processes, methods or systems. It is an important measure of the ability of a country to be competitive with advanced manufacturing processes.

3.3.4 Innovation and Research (IR) subindex

This subindex measures the research output of a country, patent applications and trademark applications. Countries that are further from the global frontier often have limited collective learning capabilities to absorb and integrate the transferred knowledge effectively into their production and development systems (Li et al.,2018). As part of the framework, it is important to include measures on education, innovation and research to benchmark countries. Table C4 in appendix C contains the actual data for IR subindex.

IR1 Research and Development Expenditure as percentage of GDP

The measure indicates how important research and development for a country is. A high percentage value indicates that the country is investing into unlocking more advanced technologies.

IR2: Scientific and Technical Journal Articles published per 1 million people and IR3: Number of Patent Applications Residents of a country per 1 million people

Patent data provide a uniquely detailed source of information on inventive activity of a country. To take into account the different sizes of the country the data on scientific and technical journal articles are divided by the population of the country.

IR4: Industrial design applications, resident, by count per 1 million people and IR5: Trademark applications-Direct resident of the country per 1 million people

The measurement of industrial design applications and trademark application per capita indicates just how active the population of a country is in turning research ideas into activities that can stimulate economic growth

IR6 Charges for the use of intellectual property payments as percentage of GDP
The measurement indicates how ideas from patents are commercialised.

3.3.5 Manufacturing Activity Subindex (MA)

This subindex measures the manufacturing economic activity of a country. Lall (1992) indicates that " All countries need to import technology, but different modes of import have different impacts on local technological development." Abramovitz (1986) argues that the catch-up between follower and leader countries, in its simple form, is concerned with only one aspect of the economic relations among countries: technological borrowing by followers. This implies that measuring importation of technologies like industrial robotics, additive manufacturing equipment, plastic injection moulding machines and CNC machines is a proxy for measuring the catch-up of follower countries. Examples of countries which has followed the process of acquiring existing technologies and become successful is South Korea (Kim, 1997). Table C5 in appendix C contains the actual data for the MA subindex. It is important for emerging economies to absorb technologies from leading economies.

MA1 GDP Growth percent of a country average from 1990 to 2016
This variable measures the GDP growth percentage over a period of 26 years.

MA2 Manufacturing Value Added annual percent of GDP Average from 1990 to 2016
The contribution that manufacturing made to the overall GDP of a country over 26 years.

MA3 High Technology Exports as percentage of GDP
High-technology exports from a country, indicates the ability to manufacture products with high Research and Development intensity. This includes aerospace, computers, pharmaceuticals, scientific instruments and electrical machinery.

<u>The additional variables (MA4 to MA13) included in MCI follows:</u>

MA4 Import of Plastic Injection Moulding Machines for rubber or plastics as a percentage of GDP , MA5 Import of Vacuum Injection Moulding Machines for rubber or plastics as a percentage of GDP and MA6 Import of Blow Moulding Machines for plastics and rubber as a percentage of GDP

The importation of different types of injection moulding machines are measured to indicate the ability of the economy to manufacture plastic parts and equipment.

MA7 Machinery for working rubber or plastics or for the manufacture of products from these materials-3D Printers as percentage of GDP

This variable measures the import of additive manufacturing equipment into the country as a percentage of GDP. Additive manufacturing equipment are also known as 3D printers.

MA8 CNC Horizontal Lathes for Metal, MA9 CNC Boring for Metal, MA10 CNC Milling for Metal and MA11 CNC Drilling for Metal .All four measured as a percentage of GDP.

This indicates the importation of computer numerically controlled machinery (CNC) into a country. CNC machines are used to manufacture more complicated metal products which makes this important variables to measure.

MA12 Military expenditure as a percentage of GDP

The capital expenditures on the armed forces also requires the latest technological developments. Countries acquire technology by importing the latest military hardware.
This measure is used to measure the activity in the country as a proxy for competitiveness. Countries gain their competitiveness by also importing advanced technologies from other countries to "leapfrog" and become more competitive. (Abramovitz, 1986)

MA13 Industrial Robotics Imports as a percentage of GDP

The importation of industrial robotics can be used to measure manufacturing competitiveness of a country. Industrial robots are used in more complicated manufacturing processes

A summary of all these subindexes and their indicators is presented next in Figure 7. The Manufacturing Activity Subindex includes the new variables from, MA4 to MA13.

3.4 Structure of the MCI

Manufacturing Composite Index (MCI)

Business Infrastructure (BI) subindex

Quality of Road Length of paved and unpaved road	BI1
Healthcare expenditure as % of GDP	BI2
Improved sanitation facilities (% of population with access)	BI3
Fixed telephone subscriptions (per 100 people)	BI4
Electric power consumption (kWh per capita)	BI5
Secure Internet servers (per 1 million people)	BI6
Mobile Cellular Subscriptions per 100 people	BI7
Fixed broadband subscriptions (per 100 people)	BI8
Foreign direct investment, net inflows (% of GDP)	BI9
Automated teller machines (ATMs) (per 100,000 adults)	BI10
Domestic credit to private sector by banks (% of GDP)	BI11

Economy and Market Environment (EM) subindex

GDP per person employed (constant 2011 PPP $)	EM1
Bank capital to assets ratio (%)	EM2
Compensation of employees (% of expense) *	EM3
Bank nonperforming loans to total gross loans (%) *	EM4
Time to Import (Days) *	EM5
Cost to import, documentary compliance (US$) *	EM6
Cost to import (US$ per container) *	EM7
Time required to start a business (days) *	EM8

Education and Talent (ET) subindex

Government expenditure per student, secondary (% of GDP per capita)	ET1
Government expenditure per tertiary student as % of GDP per capita (%)	ET2
Number of Universities by Country in Top Global 1000 list(Universities/per 10 million people)	ET3
Researchers in R&D per million people of the country	ET4

Innovation and Research (IR) subindex

Research and Development Expenditure as % of GDP	IR1
Scientific and Technical Journal Articles published/per 1 million people	IR2
Number of Patent Applications Residents of a country per 1 million people	IR3
Industrial design applications, resident, by count per 1 million people	IR4
Trademark applications, Direct resident of the country per 1 million people	IR5
Charges for the use of intellectual property, payments as % of GDP	IR6

Manufacturing Activity (MA) sub index

GDP Growth % of a country average from 1990 to 2016	MA1
Manufacturing Value Added annual % of GDP Average from 1990 to 2016	MA2
High Technology Exports as % of GDP	MA3
Import of Plastic Injection Moulding Machines for rubber or plastics as % of GDP	MA4
Import of Vacuum Injection Moulding Machines for rubber or plastics as % of GDP	MA5
Import of Blow Moulding Machines for plastics and rubber as % of GDP	MA6
Machinery for working rubber or plastics or for the manufacture of products from these materials-3D Printers as % of GDP	MA7
CNC Lathes for Metal: Import of Lathes including horizontal lathes, as % of GDP	MA8
CNC Boring for Metal: Machine Tools for boring by removing metal as % of GDP	MA9
CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type -- Numerically controlled as % of GDP	MA10
CNC Drilling for Metal: Machine-tools for drilling by removing metal, other than lathes as % of GDP	MA11
Military Expenditure (% of GDP)	MA12
Industrial Robotics Imports as % of GDP	MA13

Figure 7 Structure of MCI

4.Case Study of South Africa

The ranking of South Africa is determined and clustering of the overall MIC and subthemes. This illustrates where South Africa is grouped. Prioritising of gaps are completed through normalised gap ranking to allow the items identified to be formulated into an action plan.

4.1 Ranking of South Africa

Twenty seven (27) countries were compared in this study, including South Africa (ZAF), which is the focal country. Table 7 shows the aggregate scores achieved by the countries in the 5 different themes and the overall composite index scores achieved by each country included in the study. The abbreviations used to identify countries in the data is based on the UN Comtrade and Worldbank standard. From the overall score, South Africa (ZAF) ranks 24 out of the 27 countries and ranks 13 in the MA subindex.

The MA ranking has been significantly influenced by the level of import of manufacturing technology into South Africa from other countries as a percentage of South Africa's GDP despite that South Africa has lower number of patents and production of such high end technologies. Countries like the USA and Japan (JPN) will then be ranked lower than ZAF under this subindex since they are net exporters of advanced manufacturing technologies, but earned more points under the IR subindex due to good Research and Development activities within these countries. Without such counterbalancing measurement from the level of import of technology adopted in this study, the entire picture would have been more skewed since a country can engage in manufacturing using an imported technology even when not necessarily developed in-house.

4.2. Wards Clustering

The Ward Clustering method with Euclidean distance implemented in XLSTAT was used to categorize the countries into clusters of competitiveness. The number of clusters was not specified, the optimum number of clusters being that resulting in minimum total error variance, and this easily jumps at the eye. This is an advantage of the Ward clustering algorithm because the vertical clusters can then be sliced at the appropriate point to create the desired number of clusters. From the Figure 8, three clusters would seem ideal. These clusters are named as: (a) Leaders, (b) Followers and (c) Laggards. South Africa is classified as a Laggard based on this analysis. Table 8 shows the countries that constitute each of these groups with ZAF being in the Laggards group.

Table 7: Overall Composite Scores of all the Countries

Country		Theme 1		Theme 2		Theme 3		Theme 4		Theme 5		GMC score	Overall Rank
United Arab Emirates	ARE	5,0	16	4,7	20	1,3	20	0,7	21	3,7	10	15,4	19
Argentina	ARG	2,9	22	4,1	23	0,9	27	0,9	18	2,2	21	11,0	25
Australia	AUS	5,9	11	5,8	7	2,1	10	2,2	5	1,5	25	17,4	12
Brazil	BRA	2,9	23	3,5	27	1,3	21	0,8	19	1,5	26	9,9	26
Canada	CAN	6,3	5	5,1	17	2,3	5	1,5	12	2,6	18	18,0	11
China	CHN	3,3	20	4,2	22	1,2	22	1,1	17	4,5	5	14,3	21
Germany	DEU	6,3	7	5,7	8	2,5	4	2,1	6	3,3	14	19,9	6
Spain	ESP	5,4	13	5,3	16	1,9	14	1,5	13	2,7	17	16,7	15
European Union	EUU	5,5	12	5,6	9	1,6	16	1,6	11	1,6	24	15,8	18
France	FRA	6,3	6	5,3	15	2,7	2	1,7	9	2,5	19	18,5	10
United Kingdom	GBR	6,7	2	5,8	6	2,7	1	1,6	10	1,8	23	18,6	9
Hong Kong SAR, China	HKG	7,2	1	6,6	2	1,8	15	1,3	15	3,8	9	20,8	3
Indonesia	IDN	1,7	26	4,9	19	0,9	25	0,5	25	4,4	6	12,3	23
India	IND	0,8	27	3,5	26	1,3	19	0,2	27	3,3	15	9,1	27
Israel	ISR	5,4	14	5,5	10	2,2	9	2,0	7	3,8	8	18,9	7
Italy	ITA	5,1	15	4,5	21	2,0	11	1,2	16	3,1	16	15,9	17
Japan	JPN	6,0	9	5,3	14	2,3	6	2,3	4	1,3	27	17,2	13
Korea, Rep.	KOR	6,7	4	6,1	5	2,2	8	4,7	1	4,2	7	23,9	1
Mexico	MEX	2,2	25	5,4	11	1,1	23	0,3	26	8,1	2	17,2	14
Malaysia	MYS	3,7	18	5,4	12	2,0	12	0,7	20	8,6	1	20,4	5
Netherlands	NLD	6,7	3	6,1	4	2,6	3	2,7	3	2,4	20	20,5	4
Russian Federation	RUS	4,5	17	3,9	24	1,0	24	0,5	24	3,6	11	13,5	22
Saudi Arabia	SAU	3,4	19	5,4	13	1,5	17	0,7	22	3,6	12	14,5	20
Singapore	SGP	5,9	10	6,7	1	1,9	13	2,8	2	5,1	4	22,5	2
Turkey	TUR	3,3	21	4,9	18	0,9	26	1,4	14	5,4	3	15,9	16
United States	USA	6,3	8	6,5	3	2,3	7	1,9	8	1,9	22	18,8	8
South Africa	ZAF	2,3	24	3,6	25	1,4	18	0,7	23	3,5	13	11,6	24

Table 8: Clustering Classification into Laggards, Challengers and Leaders

Class	**Cluster 1 Laggards**	**Cluster 2 Challengers**	**Cluster 3 Leaders**
Objects	6	6	15
Sum of weights	6	6	15
Within-class variance	1,916	2,274	1,629
Minimum distance to centroid	0,953	1,064	0,758
Average distance to centroid	1,245	1,366	1,185
Maximum distance to centroid	1,636	1,560	1,921
	ARE,ARG,BRA,RUS,SAU,ZAF	CHN,IDN,IND,MEX,MYS,TUR	AUS,CAN,DEY,ESP,EUU,FRA, GBR,HKG,ISR,ITA,JPN,KOR, NLD,SGP,USA

4.3 Interpretation of dendrograms and statistical analysis

4.3.1 Overall dendrogram for complete datasets of 5 themes

ZAF has United Arab Emirates, Argentina, Brazil, Russia and Saudi Arabia as its peers in the Laggards' Group. It can be seen that EM is one of the subindexes that weighs ZAF down significantly, ranked of 25 out of the 27 countries or regions with only India and Brazil achieving a lower score. The analysis of the variables making up this subindex indicates that South Africa has very high compensation of employees relative to other expenses, a higher percentage of bank nonperforming loans, very long lead times to import, very high cost for documentary compliance, high cost of import and a very long time to start up a business compared to other countries in the study. The European Union can be regarded as a region and not a country. Hong Kong(HKG) was clustered separately due to its historical separation from China (CHN).

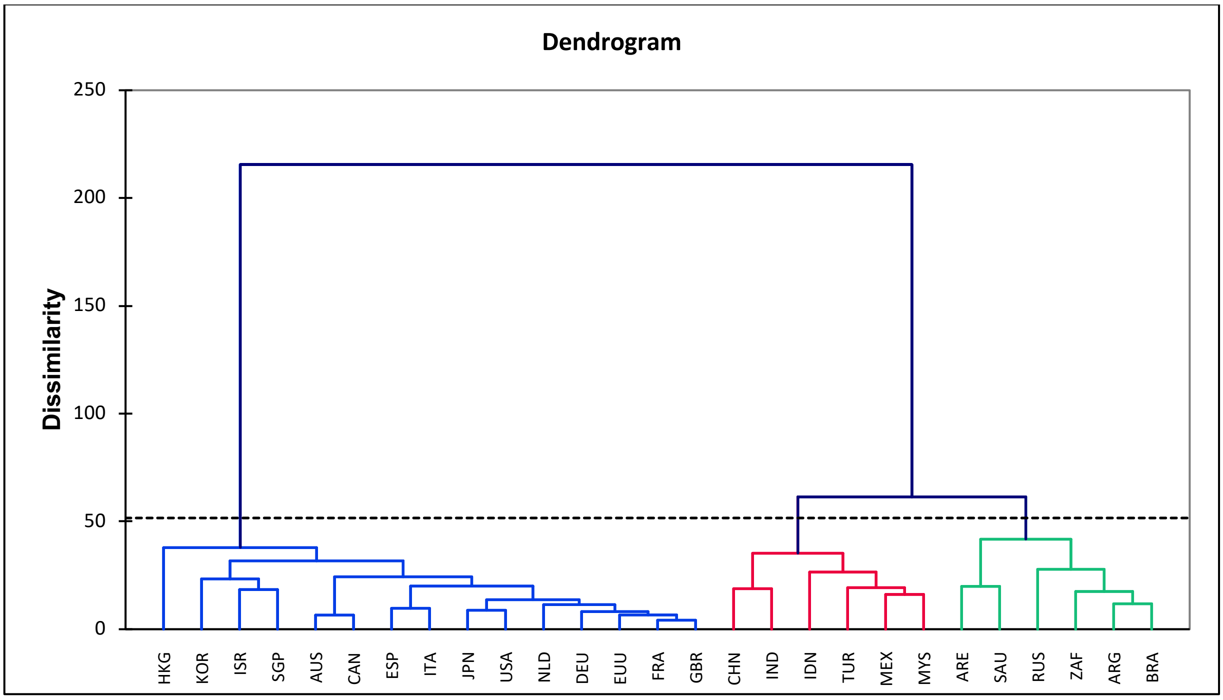

Figure 8. Dendrogram showing clustering of countries

Statistical analysis summary of dendrogram

Wards clustering produced a cophenetic correlation of 0,75 for the data set. The cophenetic correlation coefficient is a measure of how accurately the dendrogram preserves the pairwise distances between the original unmodeled data points. Connectivity-based clustering is based on the core idea of indicator variables being more related to nearby variables than to objects further away.

Table 9. Distances between the central objects of clusters

Distances between the central objects**:			
	1 (ARG)	2 (GBR)	3 (TUR)
1 (ARG)	0	2,423	1,955
2 (GBR)	2,423	0	2,323
3 (TUR)	1,955	2,323	0

****Distance between central objects:** The distance between the three clusters is the distance between group centres or other points considered groups “representatives”(centroid). In table 9 ARG, GBR and TUR are centroids for the three different clusters(Leaders, Challengers and Laggards)

4.3.2 Dendrogram of subtheme

The dendrograms for the 5 themes were also plotted. The cophenetic correlation for the 5 subthemes is summarised in table 10:

Table 10: Cophenetic correlation for subindexes

Subtheme	**Cophenetic correlation**	**Amount of indicator variables; amount of countries**
Business Infrastructure (BI)	0.477	11 variables; 27 countries/regions
Economy and Market Environment (EM)	0,652	8 variables; 27 countries/regions
Education and Talent (ET)	0,667	4 variables, 27 countries/regions
Innovation and Research (IR)	0,609	6 variables; 27 countries / regions
Manufacturing Activity (MA)	0,617	13 variables; 27 countries/regions

Low cophenetic scores indicate that the dendrogram generated through the Ward algorithm is not a full representation of the dataset. A possible explanation is that the subthemes do not contain enough data points against which the Wards algorithm can cluster the data. The overall dendrogram has a high level of correlation of 0,75, which supports this conclusion. Figure 9 indicates how South Africa (ZAF) has been incorrectly clustered with USA, Canada(CAN) which are regarded as leaders. The wrong conclusion can be drawn from such analysis.

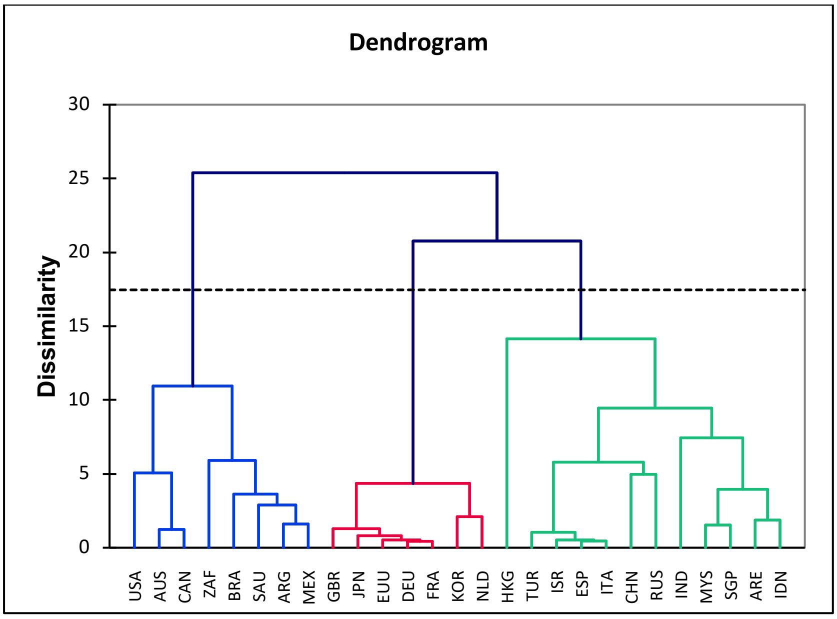

Figure 9. Dendrogram of theme 1: Business Infrastructure (BI) Subindex

Table 11. Distance between central objects for theme 1

Distances between the central objects: Theme 1			
	1 (MYS)	2 (BRA)	3 (DEU)
1 (MYS)	0	0,972	1,319
2 (BRA)	0,972	0	1,486
3 (DEU)	1,319	1,486	0

The cophenetic correlation for theme 2 has improved, but not to the extant that clustering results is a sufficient representation of underlying dataset.

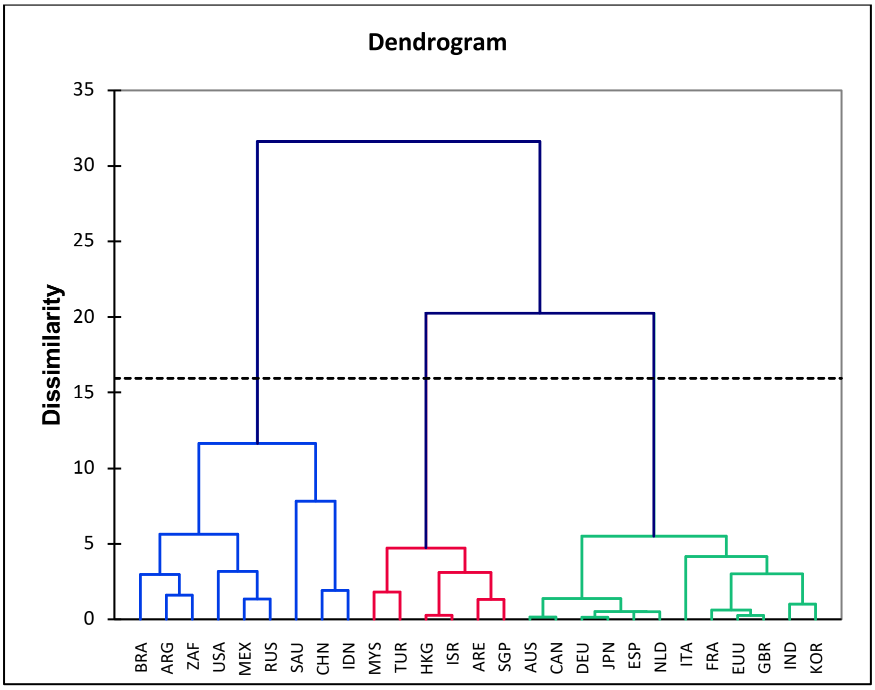

Figure 10. Dendrogram for Theme 2: Economy and market Environment (EM) subindex

Table 12. Distance between central objects for theme 2

Distances between the central objects: Theme 2			
	1 (ISR)	2 (ZAF)	3 (ESP)
1 (ISR)	0	1,075	0,626
2 (ZAF)	1,075	0	0,835
3 (ESP)	0,626	0,835	0

4.4 Subindex analysis for South Africa

Ranking scores was completed for the 5 subindexes. These indicated that South Africa can be considered a laggard at four subindex levels relative to the other countries. It is only in the MA subindex that ZAF is in the follower group. This explain why ZAF is overall a laggard because while other countries are laggards in some instances (e.g. USA is a laggard in theme 5), they are generally leaders or at least followers in many other subindexes.

4.5 Gaps Analysis

To determine the gap between South Africa and a cluster group, the average score for the group was calculated and compared to the ZAF score for each variable to determine the gaps between South Africa and the group. The average and minimum score for the follower and leader groups was calculated to determine the gaps that South Africa will have to close in order to move into each group. In order to determine the actual gap to close for a particular indicator, there is a need to first identify whether the target is to move to a challenger or a leader group for such indicator. Also, ZAF has already surpassed the minimum gap value to move to the follower group on some indicators. This presents opportunities for ZAF to decide whether to stay at the same level or decrease investments in such indicators and divert funds into some more pressing areas when there isn't enough funds to improve on all indicators. All this is discussed later. The gaps in red represent the Pareto Identified indicators to focus on.

Table 13: Gaps between South Africa and the Challengers and Leaders Clustering Group

			Challengers				Leaders			
	Indicator variables	ZAF	Average	Min	GAP Average	GAP Minimum	Average	Minimum	Gap Average	Gap Minimum
BI1	Quality of Road. Length of paved and unpaved road (%)	20,00	57,9	34,0	37,9	14,0	80,9	39,9	60,93	19,90
BI2	Healthcare expenditure as % of GDP	8,80	4,8	2,8	-4,0	-6,0	9,8	4,9	0,96	-3,87
BI3	Improved sanitation facilities (% of population with access)	66	75,5	39,6	9,1	-26,8	98,8	90,8	32,44	24,38
BI4	Fixed telephone subscriptions (per 100 people)	7	10,8	1,9	4,2	-4,7	45,1	33,1	38,47	26,49
BI5	Electric power consumption (kWh per capita)	4 229	2514,3	805,6	-1714,6	-3423,3	8034,9	5002,4	3806,06	773,55
BI6	Secure Internet servers (per 1 million people)	125	44,3	7,8	-80,2	-116,7	1219,0	293,2	1094,46	168,67
BI7	Mobile Cellular Subscriptions per 100 people	142	109,9	87,0	-32,5	-55,4	128,5	84,1	-13,90	-58,32
BI8	Fixed broadband subscriptions (per 100 people)	3	10,2	1,4	7,4	-1,4	34,1	25,4	31,24	22,58
BI9	Foreign direct investment, net inflows (% of GDP)	0,76	2,1	0,4	1,3	-0,4	6,9	0,7	6,17	-0,06
BI10	Automated teller machines (ATMs) (per 100,000 adults)	69,29	56,0	21,2	-13,2	-48,1	106,1	47,6	36,84	-21,74
BI11	Domestic credit to private sector by banks (% of GDP)	66,94	76,1	26,7	9,1	-40,2	110,1	53,2	43,17	-13,79
EM1	GDP per person employed (constant 2011 PPP $)	43 831,00	37229,8	17149,0	-6601,2	-26682,0	92965,1	70706,0	49134,10	26875,00
EM2	Bank capital to assets ratio (%)	8,20	10,3	7,2	2,1	-1,0	7,3	5,2	-0,88	-3,04
EM3	Compensation of employees (% of expense)	14,16	20,8	15,6	6,6	1,4	13,1	5,9	-1,09	-8,25

EM4	Bank nonperforming loans to total gross loans (%)	2,86	4,3	1,6	1,4	-1,2	3,8	0,6	0,91	-2,26
EM5	Time to Import(Days)	21,00	17,4	8,0	-3,6	-13,0	8,5	4,0	-12,46	-17,00
EM6	Cost to import, documentary compliance (US$)	213,00	128,7	60,0	-84,3	-153,0	59,0	0,0	-154,00	-213,00
EM7	Cost to import (US$ per container)	2 080,00	1098,6	560,0	-981,4	-1520,0	1041,3	440,0	-1038,68	-1640,00
EM8	Time required to start a business (days)	45,00	18,2	6,5	-26,8	-38,5	6,2	1,5	-38,78	-43,50
ET1	Government expenditure per student, secondary (% of GDP per capita)	20,89	16,6	10,3	-4,3	-10,6	21,4	16,1	0,53	-4,78
ET2	Government expenditure per student, tertiary (% of GDP per capita)	37,75	35,5	19,5	-2,2	-18,3	26,8	14,6	-10,90	-23,12
ET3	Number of Universities by Country in Top Global 1000 list(Universities/per 10 million people)	1,07	1,3	0,1	0,2	-1,0	7,1	0,0	6,06	-1,07
ET4	Researchers in R&D per million people of the country	437,06	1389,1	215,9	952,1	-221,2	4635,9	2018,1	4198,85	1581,03
IR1	Research and Development Expenditure as % of GDP	1,96	1,4	0,6	-0,5	-1,4	2,3	0,8	0,35	-1,20
IR2	Scientific and Technical Journal Articles published/per 1 million people	173,12	237,7	11,2	64,6	-161,9	1325,0	814,0	1151,90	640,90
IR3	Number of Patent Applications Residents of a country per 1 million people	15,90	139,1	4,1	123,2	-11,8	574,0	32,5	558,12	16,63
IR4	Industrial design applications, resident, by count per 1 million people	12,93	156,0	5,2	143,0	-7,8	252,4	0,0	239,44	-12,92
IR5	Trademark applications, Direct resident of the country per 1 million people	385,32	460,0	0,0	74,6	-385,3	1137,6	293,3	752,25	-92,01
IR6	Charges for the use of intellectual property, payments as % of GDP	0,68	0,2	0,0	-0,5	-0,7	1,3	0,2	0,58	-0,44
MA1	GDP Growth % of a country average from 1990 to 2016	2,46	5,8	2,8	3,3	0,4	2,7	0,7	0,25	-1,73
MA2	Manufacturing Value Added annual % of GDP Average from 1990 to 2016	17,85	23,3	18,0	5,4	0,1	16,4	2,4	-1,42	-15,41
MA3	High Technology Exports as % of GDP	5,8809 7	16,6	2,2	10,7	-3,7	19,4	7,1	13,53	1,27
MA4	Import of Plastic Injection Moulding Machines for rubber or plastics	0,032	0,0431	0,0097	0,0114	-0,0220	0,0135	0,0010	-0,0182	-0,0307
MA5	Import of Vacuum Injection Moulding Machines for rubber or plastics	0,004	0,0070	0,0017	0,0029	-0,0024	0,0012	0,0006	-0,0029	-0,0035
MA6	Import of Blow Moulding Machines for plastics and rubber	0,014	0,0089	0,0023	-0,0049	-0,0115	0,0024	0,0004	-0,0114	-0,0135
MA7	Machinery for working rubber or plastics or for the manufacture of products from these materials	0,023	0,0413	0,0115	0,0178	-0,0120	0,0091	0,0026	-0,0144	-0,0209
MA8	CNC Lathes for Metal: Import of Lathes including horizontal lathes, turning centres	0,008	0,0149	0,0035	0,0067	-0,0047	0,0080	0,0018	-0,0002	-0,0064
MA9	CNC Boring for Metal: Machine Tools for boring	0,000	0,0016	0,0004	0,0014	0,0002	0,0036	0,0000	0,0034	-0,0002
MA10	CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type	0,001	0,0039	0,0011	0,0029	0,0001	0,0024	0,0004	0,0015	-0,0006
MA11	CNC Drilling for Metal: Machine-tools for drilling by removing metal, other than lathes	0,0000 9	0,0017	0,0005	0,0016	0,0004	0,0007	0,0000	0,0006	-0,0001
MA12	Military expenditure (% of GDP)	1,071	1,5	0,6	0,4245	-0,4953	2,1278	0,9345	1,0573	-0,1360
MA13	Importation of Industrial Robotics	0,015	0,0108	0,0038	-0,0045	-0,0115	0,0060	0,0009	-0,0092	-0,0144

4.6: Prioritising gaps for closure

Gaps between ZAF and the challenger and leader groups' minimum and average values were calculated for the 42 variables and shown in Table 13. In order to determine the actual gap to close, it was decided that ZAF should focus on having incremental shift by moving first towards the challenger group, and afterwards seeking to be amongst the leaders. In order to be in the challenger group, if all the indicators can be at least at the challenger group level, then the overall placement would be at the challenger level. This helps to narrow which gap to close and becomes the strategic target for ZAF. The main effort left is to determine how to prioritize each of the indicator gaps to progressively close in order to move to the challenger group.

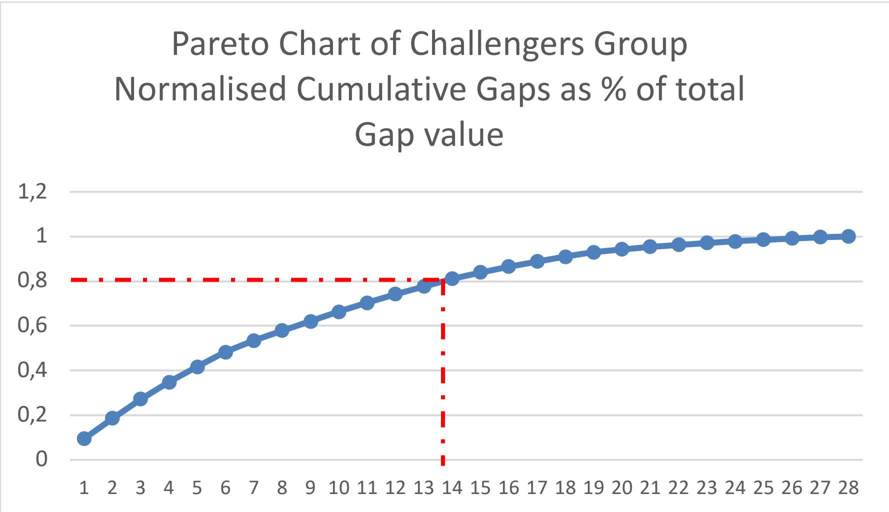

Figure 11: Pareto chart of normalized cumulative positive challenger average gap values

Based on the Pareto principles, about 80 percent of the gaps to be closed would be the main contributors. This should provide insight on which variables to focus on. To achieve this, challenger average gaps for all 42 indicator variables were calculated, sorted and cumulated. This cumulative value is then normalized to 100 percent in order to create a Pareto chart of gaps. Only variables with positive gaps were considered. This is shown in Figure 11. From this chart, it can be seen that 14 of the 42 indicators are responsible for about 81.1% of the gaps and this provides direction for prioritized closure of indicator gaps. Table 14 indicates the contribution of each variable and explains how the 81,12% was calculated.

Table 14. Cumulative contribution of each indicator variable gap

	Gap ZAF to Followers			**Contribution of each variable**	**Cumulative Total Contribution**
1	0,500259073	MA10	CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type	0,095	0,095
2	0,481952011	MA11	CNC Drilling for Metal: Machine-tools for drilling by removing metal	0,091	0,186
3	0,455527191	EM7	Cost to import (US$ per container)	0,086	0,272
4	0,402907801	BI1	Quality of Road. Length of paved and unpaved road (%)	0,076	0,348
5	0,367396386	MA1	GDP Growth % of a country average from 1990 to 2016	0,069	0,417
6	0,343589744	EM8	Time required to start a business (days)	0,065	0,482
7	0,273886308	MA7	Machinery for working rubber or plastics or for the manufacture of products from these materials	0,052	0,534
8	0,23997135	MA5	Import of Vacuum Injection Moulding Machines for rubber or plastics	0,045	0,579
9	0,220826277	MA3	High Technology Exports as % of GDP	0,042	0,621
10	0,220741514	EM2	Bank capital to assets ratio (%)	0,042	0,663
11	0,216196581	EM6	Cost to import, documentary compliance (US$)	0,041	0,704
12	0,206165621	MA8	CNC Lathes for Metal: Import of Lathes including horizontal lathes, turning centres	0,039	0,742
13	0,184120005	MA2	Manufacturing Value Added annual % of GDP Average from 1990 to 2016	0,035	0,777
14	0,179872856	BI8	Fixed broadband subscriptions	0,034	0,811
15	0,150662252	BI3	Improved sanitation facilities (% of population with access)	0,028	0,840
16	0,139102564	EM5	Time to Import(Days)	0,026	0,866
17	0,118421982	ET4	Researchers in R&D per million people of the country	0,022	0,888
18	0,111252573	IR4	Industrial design applications, resident, by count per 1 million people	0,021	0,909
19	0,104732252	MA4	Import of Plastic Injection Moulding Machines for rubber or plastics	0,020	0,929
20	0,072393686	BI4	Fixed telephone subscriptions (per 100 people)	0,014	0,943
21	0,060063978	MA9	CNC Boring for Metal: Machine Tools for boring by removing metal, numerically controlled	0,011	0,954
22	0,047982949	BI11	Domestic credit to private sector by banks (% of GDP)	0,009	0,963
23	0,045765811	MA12	Military expenditure (% of GDP)	0,009	0,972
24	0,037764245	IR3	Number of Patent Applications Residents of a country per 1 million people	0,007	0,979
25	0,036311457	BI9	Foreign direct investment, net inflows (% of GDP)	0,007	0,986

26	0,032780262	IR2	Scientific and Technical Journal Articles published/per 1 million people	0,006	0,992
27	0,023898119	IR5	Trademark applications, Direct resident of the country per 1 million people	0,005	0,997
28	0,017636899	ET3	Number of Universities by Country in Top Global 1000 list(Universities/per 10 million people)	0,003	1,000

Table 14 shows 28 indicator variables of which the first 14 are responsible for 81,1% of the cumulative total. The additional 14 indicators only contribute 18,9 % of the cumulative gap total. Normalised values were used.

4.7 Actions to close the gap

Having identified the 14 key indicator gaps to close, value (benefit per cost outlay) analysis was done to prioritize the sequence of closure of the gaps. The first step was to identify projects to close each gap and do a proper costing of the project. To estimate the cost of projects, information from ZAF Treasury Department (2018), SANRAL (2018), My Broadband (2018), Development Bank South Africa (2018), Businesstech (2018), Container Shipping Trade News and Analysis (2018) together with Worldbank (2018) and UN Comtrade (2018) were used to calculate the Cost in USD per Unit normalised gaps. This is summarised in Table 15. The goal is to prioritize the low hanging fruits that could benefit the economy and those that would have the highest value return. By dividing the cost for each of the 14 action items from Table 15 with the normalized gap value for each indicator variable provides the Cost/Unit Gap value. This is then ranked in order from action items with the smallest cost/unit gap to the action item with the biggest cost/unit gap to identify the action items to be completed first and those to be completed last for South Africa. Our objective is to minimise the total USD per gap or maximize the total gap closed per unit USD. The chronology of action items is then presented. This is also indicated in parentheses in Table 15.

Listed in order, ZAF should complete the following action:

1. Increase import of CNC Drilling Machine tools by $ 4,7 million USD per annum. Countries can gain competitiveness by importing advanced technologies from other countries and become more competitive. (Abramovitz, 1986). This will move ZAF to the Challengers group as indicated in Table 13.
2. Increase import of CNC Milling Machine tools by $8,55 million USD per annum
3. Increase import of Machinery for working rubber and plastics(3D Printers) by $ 8,55 million USD per annum
4. Increase import of Vacuum Injection Moulding Machines by $ 8,5 million USD per annum
5. Increase import of CNC Lathes for Metal by $19,7 million USD per annum
6. Reduce cost for documentary compliance during import by $84,32 million USD per annum
7. Increase broadband subscriptions by investing $186 million USD to increase total subscription base by 559 000 subscriptions.
8. Reduce cost for importation of containers by $ 981,4 million USD per annum
9. Increase the bank's Capital to asset ratio by $ 9,13 Billion USD at a cost of $958 million USD
10. Increase the value that manufacturing ads to the GDP as a percentage by $16,1 Billion USD per annum

11. Invest into increasing the paved roads of SA by investing $ 22,6 Billion USD for Non-Urban and $27,2 Billion USD for Urban Roads.
12. Increase the High Technology Exports of SA by 10,71% which equates to $31,6 Billion USD/ annum

Table 15. Actions to close the top 14 indicator gaps with actual gap average(Ave.) values

	Indicator Variable	ZAF	GAP Ave.	Cost to close GAP	Cost/Normalised GAP
BI1	Quality of Road. Length of paved and unpaved road (%)	20,00	37,87	According to SANRAL (2018) the total proclaimed roads in the country is approximately 535 000 km in length, 366 872 km of non-urban roads and 168 000 km of urban roads. The Development Bank South Africa (2018) indicates that a light trafficked road cost $162 000/ per km to build and heavy trafficked roads > $425 400/km to construct. To increase the quality of the SA paved roads by 38% means an increase of 203 300 km of road length. This represents a cost of $ 22,6 Billion USD for Non-Urban and $27,2 Billion USD for Urban Roads.	Normalised GAP is 0.4. $124,5 Billion per Unit GAP (11)
BI8	Fixed broadband subscriptions (per 100 people)	3	7,36	To close this gap implies that the broadband subscriptions per 100 people be increased by 7,36. According to Mybroadband (2018) it cost around R 5000 per broadband license. To close this gap requires that an additional (55,91/100)7,36 broadband subscriptions be rolled out in SA which is 559 000 subscriptions.	Normalised GAP IS 0.18 $ 1,04 Billion/Unit GAP (7)
EM2	Bank capital to assets ratio (%)	8,20	2,13	According to Businesstech (2018) The top 6 banks in ZAF has a total of $429 Billion USD of assets in 2016. Increasing the Bank capital by 2,13% equates in increase of capital $ 9,13 Billion USD. The lending interest rate is 10.5% which implies that the cost to keep this additional capital will be $958 million USD per annum.	Normalised GAP is 0.22 $ 4,35 Billion/ Unit GAP (9)
EM6	Cost to import, documentary compliance (US$)	213,00	-84,32	Reduce Documentary Compliance for Imports by $84,32 per container. According to Container Shipping Trade News(2018) SA trade in TEU Containers is 2 million per annum of which 55% is imports. Therefore 1,1 million TEU's is imported yearly. This implies a reduction in cost of $ 84,32 million USD.	Normalised GAP is 0,14 $602 Million/ Unit GAP (6)
EM7	Cost to import (US$ per container)	2 080,00	-981,4	Reduce cost to Import a Container by $981,43 USD per container. Cost Reduction is $ 981,4 million USD	Normalised GAP is 0,46 $2,13 Billion /Unit GAP (8)
EM8	Time required to start a business (days)	45,00	-26,80	Reduce time to start a business by 26,8 days. "…bureaucratic work environments in many ways subdue the entrepreneurial	Normalised GAP is 0,34 (unable to cost)

				spirit…"(**Aamankwah-Amoah et al., 2018)**	
MA1	GDP Growth % of a country average from 1990 to 2016	2,46	3,34	This variable cost is difficult to estimate since GDP is made up of different elements	Normalised GAP is 0,37 (unable to cost)
MA2	Manufacturing Value Added annual % of GDP Average from 1990 to 2016	17,85	5,45	To increase Manufacturing Value added by 5,45% for South Africa equates to $16,1 Billion USD	Normalised GAP is 0,18 $89,4 Billion/Unit GAP (10)
MA3	High Technology Exports as % of GDP	5,88097	10,71	To increase the High Technology Exports by 10,71% equates to $31,6 Billion USD.	Normalised GAP is 0,22 $143,6 Billion/Unit GAP (12)
MA5	Import of Vacuum Injection Moulding Machines for rubber or plastics	0,004	0,0029	$8 549 200 increase in import of Vacuum injection Machines	Normalised Gap is 0,24 $35,6 Million/Unit GAP (4)
MA7	Machinery for working rubber or plastics or for the manufacture of products from these materials- 3D Printers	0,023	0,0178	$ 8 555 000	Normalised GAP is 0,27 $31,6 Million/Unit Gap (3)
MA8	CNC Lathes for Metal: Import of Lathes including horizontal lathes, turning centres	0,008	0,0067	$19 765 000	Normalised GAP is 0,21 $94,1 Million/Unit GAP (5)
MA10	CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type -- Numerically controlled	0,001	0,0029	$8 549 200	Normalised GAP is 0,50 $17 Million/Unit GAP (2)
MA11	CNC Drilling for Metal: Machine-tools for drilling by removing metal, other than lathes— Numerically controlled	0,00009	0,0016	$ 4 720 000 increase in the import on CNC machines into SA based on 2016 trade statistics.	Normalised GAP is 0,48 $9,83 Million/Unit GAP (1)

5.Case Study of comparing the quantitative MCI Ranking with a mixed Quantitative-Qualitative Composite Index

As a final part of the research we compare the rankings from the developed MCI with the Deloitte GMCI Ranking. Researchers indicate that in the development of composite indicators, too much qualitative data are used (Wenzel and Wolf, 2016). Porter (2008) also mentioned that much as possible, analysts should look at competitiveness studies quantitatively, rather than be satisfied with lists of qualitative factors. The GMCI has a mixture of quantitative and qualitative variables. On this basis it was decided to compare the MCI to the mixed (quantitative and qualitative) Deloitte GMCI.

Correlation between Deloitte GMCI Ranking and MCI Ranking

The countries common to both the GMCI and MCI were selected and their ranking scores was re-calculated due to the removal of countries not common to the indexes. The GMCI for example did not include the EUU since it is regarded as a region and not a country. In the Deloitte GMCI (2017) manufacturing executives rate countries according to 12 drivers.

Table 16. Original GMCI score

Deloitte GMCI Rank with all 40 countries	
China	1
Argentina	39
Australia	21
Brazil	29
Canada	9
France	22
Germany	3
India	11
Indonesia	19
Italy	28
Japan	4
Malaysia	17
Mexico	8
Netherlands	20
Russia	32
Saudi Arabia	34
Singapore	10
South Africa	27
South Korea	5
Turkey	16
United Arab Emirates	30
United Kingdom	6

United States	2

Table 17. MCI score and revised score after removal of countries not common

	Old Rank MCI	Revised Rank MCI
Argentina	25	21
Australia	12	10
Brazil	26	22
Canada	11	9
China	21	17
France	10	8
Germany	6	5
India	27	23
Indonesia	23	19
Italy	17	14
Japan	13	11
Malaysia	5	4
Mexico	14	12
Netherlands	4	3
Russia	22	18
Saudi Arabia	20	16
Singapore	2	2
South Africa	24	20
South Korea	1	1
Turkey	16	13
United Arab Emirates	19	15
United Kingdom	9	7
United States	8	6

A correlation test was completed between the GMCI ranking and the MCI ranking. A low correlation coefficient score of 0,29 was obtained. This is supported by the scatter plot in Figure 12. The low level of correlation between the GMCI and MCI score is due to the GMCI being a survey based score generated by CEO's that Deloitte engages with. This confirms the concern raised by Porter (2008) and Wenzel and Wolf (2016) that too much qualitative data is used in the development of composite indicators.

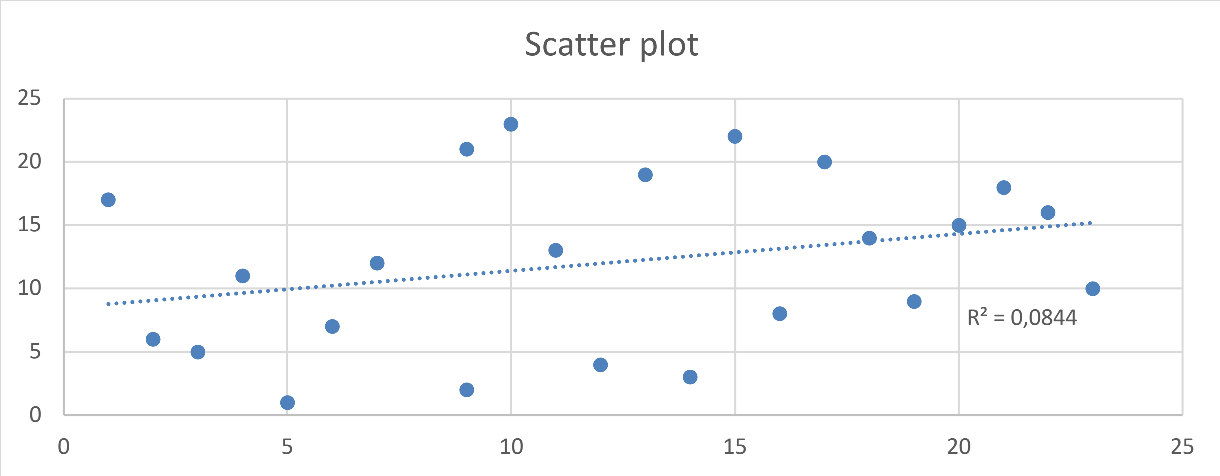

Figure 12. Scatter plot of GMCI and MCI

Table 18 indicates the difference in ranking between the GMCI and MCI which supports the findings in the scatter plot. Countries like Argentina, Australia, Brazil are rated differently when qualitative and quantitative composite indexes are compared with each other. This is a possible reason why measurement frameworks used by some researchers include both quantitative and qualitative data for example the Global Competitiveness Index (WEF, 2018).See table 5.

Table 18. Rank comparisons between GMCI and MCI

	Revised Deloitte GMCI Rank	Revised Rank MCI
Argentina	9	21
Australia	23	10
Brazil	15	22
Canada	19	9
China	1	17
France	16	8
Germany	3	5
India	10	23
Indonesia	13	19
Italy	18	14
Japan	4	11
Malaysia	12	4
Mexico	7	12
Netherlands	14	3
Russia	21	18
Saudi Arabia	22	16
Singapore	9	2
South Africa	17	20

South Korea	5	1
Turkey	11	13
United Arab Emirates	20	15
United Kingdom	6	7
United States	2	6

6. Conclusion

This study examined the manufacturing competitiveness of a group of 27 countries using the Manufacturing Competitiveness Index (MCI) and Wards clustering algorithm. The research objective of developing a quantitative Manufacturing Composite Index was achieved with ranking scores. Variables acting as proxy for manufacturing technologies was successfully incorporated into the Composite Index(CI). The proxy items used to measure MCI sub-indexes in our proposed MCI framework can be aligned with Porter's diamond framework. The classification based on Porter's Diamond structure and that based on the adapted MCI framework will not necessarily produce different results with the subsequent clustering technique utilized since all proxy variables would still be utilized in either case. The items used in measuring Business Infrastructure (BI), Education and Talent (ET) and Innovation and Research (IR) in the proposed MCI framework were found to correspond with the factor conditions of Porter's diamond.

This was achieved by comparing the MCI items to those of some other authors that have operationalized the four diamond corners of Porter. Proxy variables of importation of leading technologies were incorporated into a MCI resulting in 42 indicator variables considered necessary to rank the countries considered. The values of the 42 indicator variable for different countries were obtained from reliable data sources like the Worldbank (2018) and UN Comtrade (2018) and all data points were normalized to obtain a score between [0,1]. The use of Ward clustering algorithm helps to reduce the categories for comparison so that manageable number of groups were extracted for benchmarking of countries.

In the case presented in this study, three distinct clusters were easily identified, and these were named leaders, challengers and laggards. The reference country (South Africa) was classified with the laggards. Group centroid values were used to create targets values and competitive gaps were determined based on national priority targets for shifts. Through the use of Pareto analysis and subsequent ranking, variables contributing 80% of the total gap to close, in order to transition to the target cluster were selected and the cost to close those gaps were cumulatively calculated. The cost to close each gap is then divided by the normalised gap magnitude for that variable to obtain the Cost/Unit gap closed and prioritise the projects in the relevant order of execution supposing funds constraint is an issue. The research objective of determining the gaps that the country needs to close in order to transition from a cluster to another was achieved.

A complete framework from diagnosis to improvement plan was developed by integrating the expanded MCI index with cluster analysis, gap analysis.Pareto analysis and value analysis to determine the pathway a country may follow in order to become more competitive was used. The study was able to produce an action plan for South Africa, to close the gaps and move from the laggards cluster to the challengers cluster in a systematic manner. The action plan produced correlates well with the exogenous variable "The Role of Government " from Porter's Diamond Framework. The action plan also might motivate research analyst to create strategy and policy for the nation and industry from Porter's Diamond Framework. (Hanafi et al., 2017). Government policies directly or indirectly affect competitiveness (Kharub and Sharma, 2017) It also shows that the method developed to measure the competitiveness of a country are useful and can be applied to any country to determine their manufacturing competitiveness. By using a quantitative framework the remark made by Porter (2008) could be addressed, to use more quantitative frameworks. The study was able to illustrate that quantitative composite indexes might not agree with the rankings provided by qualitative frameworks.

Implications for Research and practice

This study has significant impact on the use of results from analysis of competitiveness in that following this methodology, government and practitioners are able to not only measure their performance gaps, but they are also able to develop prioritized actionable plans to close the gap in the most efficient manner such that even when funds are limited, as is usually the case, they are able to decide what order of projects to implement in order to transition across levels. Also, because clustering has been integrated into scoring of countries, performance of target countries are placed in baskets of similar countries and compared to baskets of better performers, else, comparing a country to fifty countries or more makes it difficult to clearly define improvement gaps and target. Also, while most research works have sought to rank countries, inclusion clustering logic makes ranking to provide more meaningful benchmark and illuminates areas for possible further research like how different clustering techniques might behave influenced the clusters identified.

7. References

Abramovitz, M. (1986). *Catching Up, Forging Ahead, and Falling Behind*. The Journal of Economic History, Volume 46, No.2, pp.*385*-406.

Akpinar, M., Can, Ö., Mermercioglu, M. (2017). Assessing the sources of competitiveness of the US states. Competitiveness Review. Volume 27, Issue: 2, pp.161-178.

AccountAbility Institute (AAI),*Responsible Competitiveness Index*. Available at: http://www.accountability.org/, [Accessed on the 11 January 2018].

Aiginger,K., Vogel, J.(2018). *Competitiveness: from a misleading concept to a strategy supporting beyond GDP goals*. Competitiveness Review Journal, Volume 25,No.5,pp.497-523.

Alard, G. (2015). *Science and technology capacity in Africa: A new index*. Journal of African Studies and Development, Volume 7, No.6, pp. 137-147.

Amankwah-Amoah, J., Egbetokum, A., Osabuttey, E.,L.,C. (2018). *Meeting the 21st century challenges of doing business in Africa*. Technology Forecasting and Social Change Journal, Volume 131,pp.336-338.

Archibugi, D., Coco , A. (2004). *A New Indicator of Technological Capabilities for Developed and Developing Countries (Arco)*. World Development Journal, Volume 32, No.4, pp.629-654.

Asian Development Bank Country Performance Assessment. (2016). Available at: https://www.adb.org/sites/default/files/institutional-document/232401/country-performance-assessment-2016.pdf, [Accessed 10 January 2018].

AT Kearny, *The 2017 Global Retail Development Index*, Available at: https://www.atkearney.com/documents/20152/435674/The+Age+of+Focus%E2%80%93The+2017+Global+Retail+Development+Index.pdf/d99729b6-f190-2f4d-c7e6-aca980eaf31a, [Accessed 10/01/2018].

Bandura, R.(2008). A Survey of Composite Indices Measuring Country Performance: 2008 Update. United Nations Development Program, Office of Development Studies, New York.

Bakke , K. (2017). *Technology readiness levels use and understanding*. University College of South-East Norway.

Boston Consulting Group. (2018). *Global Manufacturing Cost-Competitiveness Index*. Available at: https://www.bcg.com/, [Accessed on the 12th January 2018].

Brosnan, S., Doyle, E., O' Conner, S.(2016). From Marshall's Triad to Porter's Diamond: added value?. Competitiveness Review. Volume 26,Issue 5, pp.500-516.

Buckley, P.J. (2017). The competitiveness of emerging country multinational enterprise: Does it derive from CSA's or FSA's. Competitiveness Review, Volume 27, Issue 3, pp.208-216.

Chikán, A. (2008). National and firm competitiveness: a general research model. Competitiveness Review, Volume 18,No.1.pp.20-28.

Dechezleprêtre, A., Sato, M. (2017).*Review of Environmental Economics and Policy*. Volume 11, Issue 2, 1 July 2017, Pages 183–206.

Dobbs, M.E.(2014). Guidelines for applying Porter's five forces framework: a set of industry analysis templates. Competitiveness Review, Volume 24,Issue 1, pp.32-45.

Businesstech. (2018). www.businesstech.co.za, [Accessed on 12th August 2018].

Center for World University Rankings (CWUR). (2016). http://cwur.org/ [Accessed on the 11th December 2017].

Clayton, C. (2018). Harvard Business Review, www.hbr.org, [Accessed on the 19th September 2018].

Coates,V., Farooque, M., Klavans, R., Lapid, K., Linstone, H.A., Pistorius, C., Porter, A.L. (2001). *On the Future of Technological Forecasting*. International Journal of Technological Forecasting & Social Change, Vol.67, 2001, pp.1-17.

Container Shipping Trade News and Analysis. (2018). www.joc.com, [Accessed 14th August 2018].

Cusumano, M. (1994). *The limits of lean*. Sloan Management Review, 35(4), pp.27-32

Defense Contract Management Agency. (2017). http://www.dodmrl.com/DCMA_training_SEP_26_16.pdf, [visited on the 5th December 2017

Delgado-Márquez, B.L., García-Velasco, M. (2018). *Geographical Distribution of the European Knowledge Base Through the Lens of a Synthetic Index.* Social Indicator Research Journal, Volume 136, pp.477-496.

Development Bank of South Africa. (2018). www.dbsa.org, [Accessed on the 24th July 2018].

Deloitte Global Manufacturing Competitiveness Index, Available at: https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Manufacturing/gx-global-mfg-competitiveness-index-2016.pdf, [Accessed 13th December 2017].

Dollar, D., Wolff, E.(1993). *Competitiveness, convergence, and international specialization*. Journal of International Economics, Vol.37(3-4),pp. 265-268.

Ezeala-Harrison, F. (2014). Relative Impacts of Quantitative and Qualitative Indicators of International Competitiveness. Journal of International Business and Economics. December 2014, Volume 2, No. 4, pp. 01-16

Ezell, S.J, Atkinson, R.D. (2011). *The Case for a National Manufacturing Strategy*. The Information Technology and Innovation Foundation.

Fagerberg, J. (1994). *Technology and International Differences in Growth Rates*. The Journal of Economic Literature, Volume 32, No.3, pp.1147-1175.

Feurer R., Chaharbaghi K. (1995), *Strategy development: past, present and future*. *Management Decision*, Vol. 33 Issue: 6, pp.11 – 21.

Filiippetti, A., Peyrache, A. (2011). *The Patterns of Technological Capabilities of Countries: A Dual Approach using Composite Indicators and Data Envelopment Analysis*. World Development Journal, Volume 39, No.7, pp.1108-1121.

Fischer, C., Hossfeld, O., Radeck, K. (2018). *On the Suitability of Alternative Competitiveness Indicators for Explaining Real Exports of Advanced Economies.* Open Economies Review Journal, Volume 29, pp.119-139.

Global IT Professionals Community. (2018). https://list.ly/list/CZ-maturity-models, [Accessed on the 7th January 2018].

Hanafi, M., Wibisono,D., Mangkusubroto, K., Siallagan, M., Badriyah, J.K. (2017). Modelling competitive advantage of nation: a literature review. Competitiveness Review. Volume 27,Issue 4, pp.335-365.

Handbook of constructing composite indicators: Methodology and Users Guide (2008).ISBN 978-92-64-04345-9. ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD)

Hannigan, T.J, Hamilton, R.D III, Mudambi, R. (2015*). Competition and competitiveness in the US airline industry*. Competitiveness Review Journal, Volume 25,No.2.pp.134-155.

History of Massachusetts. (2018). http://historyofmassachusetts.org/industrial-revolution-america, [Accessed on 21 September 2018].

Larossi, G. (2013).*Measuring Competitiveness at the Subnational Level*: *The Case of 37 Nigerian States*. The Business and Economics Research Journal, Volume 6, Issue 2, pp.193-218.

International Institute of Management Development, *IMD World Competitiveness Scoreboard*. Available at: https://www.imd.org/wcc/world-competitiveness-center-rankings/World-competitiveness-yearbook-ranking/#WCY, [Accessed on the 12th January 2018].

Infosys white paper on Industry 4.0. (2017). https://www.infosys.com/engineering-services/white-papers/Documents/industry-4.0-real.pdf, [Accessed on the 5th December 2017].

Jameson, ML.J. (2014). *Disruptive innovation as a driver of science and medicine*. The Journal of Clinical Investigation, Volume 124,Number 7, page 2822-2826.

Kaldor, N. (1957). *A Model of Economic Growth*. The Economic Journal, Volume 67, No. 268 ,pp. 591-624.

Kharub, M., Sharma, R. (2017). Comparative analyses of competitive advantage using Porter diamond model (the case of MSMEs in Himachal Pradesh). Competitiveness Review, Volume 27 Issue: 2, pp.132-160

Khayyat, N.T., Lee, J. (2015). *A measure of technological capabilities for developing countries*. Technological Forecasting & Social Change Journal, Volume 92, pp. 210-223.

Ketels, C.H.M. (2006). Michael Porter's competitiveness framework-recent learnings and new research priorities. Journal of Industry, Competition and Trade. Volume 6,No.2, pp.195-208.

Kim, L. (1997). *Immitation to Innovation: The Dynamics of Korea's Technological Learning*. Harvard Business School Press,Harvard.

Krugman, P. (1994). *Peddling Prosperity: Economic Sense and Nonsense in the Age of Diminished Expectations*. W.W.Norton & Company Publishers.

Lall, S. (1992). *Technological Capabilities and Industrialization*. World Development Journal, Volume 20, No.2, pp.165-186.

Lall, S., Albaladejo, M. (2003). *Indicators of relative importance of IPRs in Developing countries*. International Centre for Trade and Sustainable development (ICTSD), Switzerland.

Li, S., Clark, T., Silince, J.(2018). *Constructing a strategy on the creation of core competencies for African companies*. Technology Forecasting and Social Change Journal, Volume 131,pp.204-213.

Milenkovic, M.J, Brajovic, B., Milenkovic, D., Vukmirovic, D., Jeremic, V. (2016). *Beyond the equal-weight framework of the Networked Readiness Index: a multilevel I-distance methodology*. Information Development Journal, Volume 32(4), pp.1120-1136.

McKinsey Global Institute Industry Digitization Index, https://www.mckinsey.com/global-themes/china/digital-china-powering-the-economy-to-global-competitiveness, [Accessed 11/01/2018]

My Broadband. (2018). www.mybroadbrand.co.za, [Accessed on 7th August 2018].

OECD Science, Technology and Industry Scoreboard, Available at: http://www.oecd-ilibrary.org/docserver/download/9215031e.pdf?expires=1515673427&id=id&accname=guest&checksum=8ECDFA41AFAEB0702F28E50090D046BA, [accessed on the 11 January 2018].

Organization for Economic Co-operation and Development (OECD). (2018). Available at: https://stats.oecd.org/glossary/detail.asp?ID=6278 , [Accessed on the 8TH January 2018.

Paulk, M.C.(2017). *A History of the Capability Maturity Model for Software*. Carnegie Mellon University, www.asq.org, [Accessed 22 August 2017]

Porter, M.E. (1990). *The Competitiveness Advantage of Nations*. Harvard Business Review, www.hbr.org, [Accessed on 13th September 2018].

Porter, M.E.(2008). The five competitive forces that shape strategy. Harvard Business Review, Volume 86,Number 1,pp.78-93.

Postelnicu, C., Ban, I.M.(2010). Some Empirical Approaches of the Competitiveness Diamond-The Case of the Romanian Economy. The Romanian Economic Journal, Volume 36.

PWC Aerospace manufacturing attractiveness rankings, Available at: https://www.pwc.com/us/en/industrial-products/publications/assets/pwc-aerospace-manufacturing-attractiveness-rankings-2017.pdf, [Accessed on the 15th January 2018].

Feurer, R., Chaharbaghi, K.(1994). *Defining Competitiveness: A Holistic Approach*. Management Decision Journal, Vol.32,Issue 2,pp.49-58.

RAND Corporation, The Science and Technology Capacity Index(STCI), Available at https://www.rand.org/content/dam/rand/pubs/monograph_reports/2005/MR1357.0.pdf, [Accessed on the 16th January 2018].

Reiff, M.,Surmanová, K.,Balcerzak, A.P.,Pietrzak M.B. (2016). Multiple Criteria Analysis of European Union Agriculture. Journal of International Studies. Volume. 9, No 3, pp. 62-74.

Scott, B.R. (1985). *U.S Competitiveness: Concepts, Performance, and Implications,* U.S Competitiveness in the World Economy. Harvard Business School Press.

Search software quality. (2018). https://searchsoftwarequality.techtarget.com.[Acessed on 28 November 2018].

Shaker, R.R, Zubalsky, S.L. (2015). *Examining patterns of sustainability across Europe: a multivariate and spatial assessment of 25 composite indices*. International Journal of Sustainable Development & World Ecology, Volume 22(1), pp.1-13.

Shami, A., Lotfi, A., Coleman, S. (2013). Intelligent synthetic composite indicators with application. Soft Computing Journal, Volume 17, pp. 2349-2364.

Sharpe ,A.(1995). International Perspectives on Productivity and Efficiency. Review of Income and Wealth Journal, Series 41, Number 2,pp.221-237.

Sigalas, C., Economou, V.P., Georgopoulos, N.B, (2013). Developing a measure of competitive advantage. Journal of Strategy and Management. Volume 6, No.4, pp.320-334.

Socialwatch Basic Capabilities Index. (2018). Social Watch Organisation, Available at : http://www.socialwatch.org/, [Accessed 10/01/2018].

Software Engineering Institute.(2018). https://www.sei.cmu.edu, [Accessed on the 17th May 2017]

South African National Roads Agency Society Ltd. (2018). www.nra.co.za, [Accessed 23th July 2018].

Stockholm International Peace Research Institute, SIPRI Military Expenditure Database, Available at: https://www.sipri.org/databases/milex, [Accessed on the 11 January 2018].

Singh, M., K., Kumar, H., Gupta, M.P., Madaan, J. (2018). Competitiveness of Electronics manufacturing industry in India: an ISM-fuzzy MICMAC and AHP approach, Measuring Business Excellence Journal, Volume 22,pp.88-116.

Tan, K.G, Tan, K.Y. (2014). *Assessing competitiveness of ASEAN-10 Economies*. International Journal of Economics and Business Research, Volume.8, No.4, pp.377-398.

Tassel, G. (2013). *Beyond the Business Cycle: The Need for a Technology Based Growth* Strategy. National Institute of Standards and Technology, United States Department of Commerce.

Terzić, L. (2017). *The Role of Innovation in Fostering Competitiveness and Economic Growth: Evidence from Developing Economies.* Comparative Economic Research Journal, Volume20, Number 4, pp.65-81.

The World Economic Forum (WEF). (2018). Available at: https://www.weforum.org/, [Assessed on the 19th January 2018].

The Economist. (2018). "An empire of the mind". Volume 428, Number 9109, September 15th,pp71.

United Nations Comtrade website. (2018). Available at: https://comtrade.un.org/data, [accessed on the 27th July 2017, 15th August 2017, 08th January 2018].

United Nations Development Program (UNDP). (2016) Human Development Index, Available at: http://hdr.undp.org/sites/default/files/2016_human_development_report.pdf , [Accessed on the 12th January 2018].

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2018). Available at: https://en.unesco.org/, [Accessed on the 20th January 2018].

United Nations Industrial Development Organization (UNIDO). (2016). Industrial Development Report. Available at : www.unido.org , [Accessed 15th January 2018].

United States Patent and Trademark office (USPTO). (2018). Available at: www.uspto.gov, [Accessed on the 12th January 2018].

Vishnevskiy ,K., Karasev, O., Meissner ,D. (2015). *Integrated roadmaps and corporate foresight as tools of innovation management: The case of Russian companies*. International Journal of Technological Forecasting & Social Change, Vol.90, 2015, pp.433-443.

Ward, J. H. (1963). Hierarchical Grouping to Optimize an Objective Function. *Journal of American Statistical Association,* 58(301), pp. 236-244.

Wenzel, L., Wolf, A. (2016). *Towards a new measure of a country's competitiveness: applying canonical correlation*. Competitiveness Review, Volume 26, Issue 1, pp.87-107.

World Development Indicators. Worldbank data base, Available at: www.worldbank.org , [accessed 15th August 2017, 09TH January 2018].

World Economic Forum. Available at https://www.weforum.org/agenda/2016/01/what-is-the-fourth-industrial-revolution/ [accessed 28 November 2018].

Zagloel, Y., Jandhana, I.B.M.P. (2016). *Literature Review of Industrial Competitiveness Index: Research Gap*. International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia, March 8-10.

Appendix A South Africa in the manufacturing context

8. Placing South Africa in the manufacturing context

8.1 UN Comtrade Import analysis

To determine the magnitude of the manufacturing environment in South Africa, data from the UN Comtrade (2018) data repository was collected. By using the standard international trading codes for different commodities, data was obtained for the year 2000 till 2016. Import data for plastic injection moulding machines, CNC Machines, Industrial Robots, Additive Manufacturing system were obtained.

Since the year 2000 South Africa has imported a total of over $US 4 Billion of manufacturing equipment to support the local manufacturing industry as summarised in Table B1

South Africa	**$ USD**
845891 Lathes/Turning Centres numerically controlled for removing metal	252,343,671
845921 Numerically controlled metal working drill machines	66,626,205
845931 Boring-milling machines CNC controlled for metal	47,150,119
845951 Milling machines op. by removing metal, knee-type, numerically controlled	8,279,485
845961 Milling machines (excl. knee type) op. by removing metal, numerically controlled	148,757,288
847710 Injection-moulding machines	1,297,100,945
847730 Blow moulding machines	626,019,676
847740 Vacuum moulding machines & other thermoforming machines	150,533,695
847780 Machinery for working rubber/plastics/for the manufacture of products from these materials	1,163,134,068
847950 Industrial Robotics	287,291,182

Table A1. Import of different manufacturing equipment into South Africa

Appendix B

9. Sample of normalised Indicator variables for the countries

Table B1 Country	Parameter	Quality of Road. Length	Healthcare expenditure as % of GDP	Improved sanitation facilities (% of population with access)	Fixed telephone subscriptions (per 100 people)	Electric power consumption (kWh per capita)	Secure Internet servers (per 1 million people)	Mobile Cellular Subscriptions per 100 people	Fixed broadband subscriptions (per 100 people)	Foreign direct investment, net inflows (% of GDP)	Automated teller machines (ATMs) (per 100,000 adults)	Domestic credit to private sector by banks (% of GDP)	GDP per person employed (constant 2011 PPP $)	Bank capital to assets ratio (%)	Compensation of employees (% of expense)	Bank nonperforming loans to total gross loans (%)	Time to Import(Days)	Cost to import, documentary compliance (US$)	Cost to import (US$ per container)	Time required to start a business (days)
United Arab Emirates	ARE	1,00	0,06	0,96	0,37	0,71	0,13	0,80	0,29	0,06	0,22	0,38	0,65	0,35	0,00	0,72	0,88	0,27	0,91	0,91
Argentina	ARG	0,24	0,14	0,94	0,37	0,15	0,02	0,44	0,38	0,01	0,19	0,00	0,21	0,63	0,76	0,93	0,00	0,69	0,13	0,71
Australia	AUS	0,36	0,46	1,00	0,55	0,63	0,49	0,17	0,71	0,09	0,73	0,68	0,57	0,14	0,85	0,98	0,85	0,74	0,64	0,99
Brazil	BRA	0,00	0,38	0,72	0,32	0,12	0,02	0,23	0,28	0,11	0,43	0,26	0,11	0,43	0,83	0,80	0,50	0,73	0,13	0,00
Canada	CAN	0,36	0,53	1,00	0,68	1,00	0,43	0,00	0,88	0,05	1,00	0,41	0,53	0,00	0,84	1,00	0,77	0,58	0,42	1,00
China	CHN	0,40	0,19	0,61	0,22	0,21	0,00	0,09	0,52	0,03	0,30	0,75	0,08	0,31	0,69	0,80	0,23	0,56	0,83	0,73
Germany	DEU	0,99	0,59	0,99	0,90	0,42	0,56	0,20	0,89	0,03	0,35	0,34	0,56	0,09	1,00	0,80	0,88	0,72	0,72	0,88
Spain	ESP	0,99	0,43	1,00	0,68	0,31	0,14	0,17	0,68	0,06	0,45	0,52	0,52	0,27	0,86	0,70	0,81	0,72	0,55	0,85
European Union	EUU	0,82	0,50	0,96	0,69	0,35	0,34	0,25	0,77	0,10	0,23	0,44	0,51	0,34	0,73	0,74	0,74	0,99	0,70	0,89
France	FRA	1,00	0,61	0,98	1,00	0,42	0,29	0,13	1,00	0,04	0,41	0,44	0,60	0,08	0,57	0,80	0,73	1,00	0,53	0,97
United Kingdom	GBR	1,00	0,44	0,99	0,87	0,29	0,48	0,26	0,92	0,31	0,54	0,64	0,49	0,19	0,71	0,80	0,92	1,00	0,72	0,96
Hong Kong SAR, China	HKG	0,40	0,35	0,85	0,98	0,36	0,33	1,00	0,83	1,00	0,15	1,00	0,71	0,48	0,69	0,98	0,96	0,85	0,94	1,00
Indonesia	IDN	0,55	0,00	0,35	0,04	0,00	0,00	0,43	0,01	0,00	0,17	0,10	0,05	0,96	0,65	0,86	0,15	0,58	0,90	0,72
India	IND	0,44	0,13	0,00	0,00	0,00	0,00	0,02	0,00	0,04	0,00	0,19	0,00	0,21	0,69	0,48	0,34	0,65	0,53	0,64
Israel	ISR	1,00	0,35	1,00	0,69	0,39	0,10	0,32	0,65	0,10	0,55	0,27	0,48	0,21	0,45	0,94	0,77	0,82	0,94	0,87
Italy	ITA	1,00	0,45	0,99	0,54	0,28	0,11	0,38	0,59	0,03	0,36	0,38	0,62	0,03	0,75	0,00	0,46	1,00	0,67	0,94
Japan	JPN	0,79	0,52	1,00	0,84	0,48	0,37	0,30	0,73	0,01	0,53	0,47	0,47	0,03	0,99	0,80	0,73	0,73	0,73	0,86
Korea, Rep.	KOR	0,74	0,32	1,00	0,94	0,66	0,76	0,26	0,97	0,01	0,35	0,68	0,42	0,35	0,86	0,80	0,88	0,93	0,88	0,97
Mexico	MEX	0,30	0,24	0,75	0,24	0,09	0,01	0,03	0,27	0,06	0,16	0,07	0,16	0,56	1,19	0,80	0,72	0,74	0,33	0,91
Malaysia	MYS	0,74	0,09	0,93	0,22	0,26	0,03	0,38	0,18	0,12	0,13	0,58	0,31	0,61	0,13	0,94	0,85	0,85	0,94	0,78
Netherlands	NLD	0,89	0,56	0,96	0,66	0,40	1,00	0,31	1,00	0,28	0,13	0,51	0,60	0,05	0,92	0,88	0,92	1,00	0,75	0,97
Russian Federation	RUS	0,65	0,30	0,54	0,36	0,39	0,07	0,53	0,44	0,06	0,73	0,41	0,26	0,54	0,75	0,46	0,41	0,61	0,00	0,89
Saudi Arabia	SAU	0,26	0,13	1,00	0,17	0,59	0,02	0,49	0,23	0,02	0,26	0,23	0,83	1,00	0,69	0,95	0,50	0,00	0,60	0,79
Singapore	SGP	1,00	0,15	1,00	0,57	0,55	0,30	0,42	0,59	0,56	0,18	0,63	1,00	0,42	0,42	0,96	1,00	0,90	1,00	0,99
Turkey	TUR	0,88	0,18	0,92	0,21	0,14	0,02	0,09	0,30	0,03	0,28	0,28	0,33	0,58	0,42	0,80	0,62	0,64	0,63	0,94
United States	USA	0,61	1,00	1,00	0,61	0,83	0,56	0,29	0,76	0,06	0,35	0,21	0,75	0,67	0,88	0,96	0,95	0,74	0,61	0,95
South Africa	ZAF	0,15	0,42	0,44	0,08	0,23	0,04	0,39	0,03	0,01	0,24	0,28	0,21	0,32	0,73	0,86	0,35	0,45	0,24	0,44

Appendix C

9. Indicator variables values from data sources: Business infrastructure (BI) subindex

Table C1		BI1	BI2	BI3	BI4	BI5	BI6	BI7	BI8	BI9	BI10	BI11
Country	Parameter	Quality of Road. Length of paved and unpaved road (%)	Healthcare expenditure as % of GDP	Improved sanitation facilities (% of population with access)	Fixed telephone subscriptions (per 100 people)	Electric power consumption (kWh per capita)	Secure Internet servers (per 1 million people)	Mobile Cellular Subscriptions per 100 people	Fixed broadband subscriptions (per 100 people)	Foreign direct investment, net inflows (% of GDP)	Automated teller machines (ATMs) (per 100,000 adults)	Domestic credit to private sector by banks (% of GDP)
United Arab Emirates	ARE	100	3,64	98	23	11 264	391	204	13	2,58	65,68	85,89
Argentina	ARG	29,00	4,79	96	23	3 052	62	151	17	0,77	60,10	13,51
Australia	AUS	40,00	9,42	100	34	10 078	1 436	110	30	3,48	168,03	142,93
Brazil	BRA	6,00	8,32	83	20	2 601	79	119	13	4,39	108,82	62,19
Canada	CAN	39,90	10,45	100	41	15 542	1 253	84	37	2,07	222,99	92,10
China	CHN	43,50	5,55	77	15	3 927	21	97	23	1,52	81,45	156,70
Germany	DEU	99,10	11,30	99	54	7 035	1 644	115	38	1,51	91,67	77,32
Spain	ESP	99,00	9,03	100	41	5 356	420	110	29	2,52	112,94	111,51
European Union	EUU	83,41	10,04	98	42	5 909	996	121	33	4,18	68,33	96,44
France	FRA	100,00	11,54	99	60	6 938	849	103	42	1,72	104,38	96,89
United Kingdom	GBR	100,00	9,12	99	52	5 130	1 408	122	39	11,44	129,49	135,70
Hong Kong SAR, China	HKG	43,50	7,88	91	59	6 073	961	234	35	36,49	50,59	203,78
Indonesia	IDN	58,00	2,85	61	4	812	10	149	2	0,40	54,75	33,11
India	IND	47,00	4,69	40	2	806	8	87	1	1,96	21,24	49,77
Israel	ISR	100,00	7,81	100	42	6 601	293	132	28	3,87	132,98	65,37
Italy	ITA	100,00	9,25	100	33	5 002	333	140	25	1,50	94,14	85,71
Japan	JPN	80,11	10,23	100	51	7 820	1 071	130	31	0,71	127,80	103,31
Korea, Rep.	KOR	76,00	7,37	100	56	10 497	2 201	123	41	0,77	91,67	143,34
Mexico	MEX	34,00	6,30	85	15	2 090	41	88	13	2,56	52,63	26,71
Malaysia	MYS	76,00	4,17	96	14	4 596	106	141	9	4,56	48,11	123,94
Netherlands	NLD	90,00	10,90	98	40	6 713	2 906	130	42	10,48	47,55	111,17
Russian Federation	RUS	67,40	7,07	72	23	6 603	215	163	19	2,57	168,70	92,10
Saudi Arabia	SAU	30,00	4,68	100	12	9 444	58	158	11	1,15	74,42	57,98
Singapore	SGP	100,00	4,92	100	35	8 845	890	147	25	20,74	57,69	132,91
Turkey	TUR	88,74	5,41	95	14	2 855	80	97	14	1,43	78,08	66,19
United States	USA	63,00	17,14	100	37	12 987	1 623	127	32	2,58	91,67	53,15
South Africa	ZAF	20,00	8,80	66	7	4 229	125	142	3	0,76	69,29	66,94

Indicator variables values from data sources :Economy and Market Environment (EM) subindex

Table C2		EM1	EM2	EM3	EM4	EM5	EM6	EM7	EM8
Country	Parameter	GDP per person employed (constant 2011 PPP $)	Bank capital to assets ratio (%)	Compensation of employees (% of expense)*	Bank nonperforming loans to total gross loans (%)*	Time to Import(Days)*	Cost to import, documentary compliance (US$)*	Cost to import (US$ per container)*	Time required to start a business (days)*
United Arab Emirates	ARE	100 907,00	8,49	36,67	5,30	7,00	283,00	625,00	8,20
Argentina	ARG	44 364,00	11,23	13,17	1,84	30,00	120,00	2 320,00	24,00
Australia	AUS	91 097,00	6,55	10,44	0,98	8,00	100,00	1 220,00	2,50
Brazil	BRA	30 753,00	9,27	11,00	3,92	17,00	106,90	2 322,80	79,50
Canada	CAN	85 114,00	5,16	10,97	0,60	10,00	163,00	1 680,00	1,50
China	CHN	27 196,00	8,10	15,55	3,95	24,00	170,90	800,00	22,90
Germany	DEU	89 309,00	5,98	5,91	3,95	7,00	108,24	1 050,00	10,50
Spain	ESP	83 833,00	7,79	10,18	5,64	9,00	108,24	1 400,00	13,00
European Union	EUU	82 962,52	8,42	14,23	4,83	10,64	4,46	1 079,54	10,04
France	FRA	94 807,00	5,94	19,03	3,95	11,00	0,00	1 445,00	3,50
United Kingdom	GBR	80 639,00	7,03	14,95	3,95	6,00	0,00	1 050,00	4,50
Hong Kong SAR, China	HKG	108 473,00	9,78	15,55	0,85	5,00	57,00	565,00	1,50
Indonesia	IDN	24 190,00	14,41	16,64	2,90	26,00	164,40	646,80	23,10
India	IND	17 149,00	7,16	15,55	9,19	21,10	134,80	1 462,00	29,80
Israel	ISR	79 070,00	7,22	22,72	1,61	10,00	70,00	565,00	12,00
Italy	ITA	96 705,00	5,49	13,65	17,12	18,00	0,00	1 145,00	6,50
Japan	JPN	77 064,00	5,47	6,18	3,95	11,00	107,00	1 021,30	12,20
Korea, Rep.	KOR	70 706,00	8,49	10,31	3,95	7,00	27,00	695,00	4,00
Mexico	MEX	38 306,00	10,56		3,95	11,20	100,00	1 887,60	8,40
Malaysia	MYS	56 649,00	11,00	32,54	1,61	8,00	60,00	560,00	18,50
Netherlands	NLD	94 951,00	5,69	8,35	2,53	6,00	0,00	975,00	3,50
Russian Federation	RUS	50 024,00	10,36	13,70	9,44	19,40	152,50	2 594,50	10,10
Saudi Arabia	SAU	124 267,00	14,80	15,55	1,38	17,00	390,00	1 309,00	17,80
Singapore	SGP	145 824,00	9,23	23,84	1,22	4,00	40,00	440,00	2,50
Turkey	TUR	59 889,00	10,73	23,64	3,95	14,00	142,00	1 235,00	6,50
United States	USA	113 922,00	11,59	9,74	1,32	5,40	100,00	1 289,00	5,60
South Africa	ZAF	43 831,00	8,20	14,16	2,86	21,00	213,00	2 080,00	45,00

Indicator variables values from data sources: Education and Talent (ET) subindex

Table C3		ET1	ET2	ET3	ET4
Country	Parameter	Government expenditure per student, secondary (% of GDP per capita)	Government expenditure per student, tertiary (% of GDP per capita)	Number of Universities by Country in Top Global 1000 list(Universities/per 10 million people)	Researchers in R&D per million people of the country
United Arab Emirates	ARE	20,21	28,55	1,08	2 003,39
Argentina	ARG	20,75	16,27	0,68	1 202,07
Australia	AUS	16,51	22,32	11,19	4 530,73
Brazil	BRA	22,64	29,50	0,87	698,10
Canada	CAN	20,21	28,55	8,82	4 518,51
China	CHN	20,21	28,55	0,70	1 176,58
Germany	DEU	23,16	36,56	6,90	4 431,08
Spain	ESP	20,21	22,50	8,61	2 654,65
European Union	EUU	24,03	26,74	0,00	3 485,36
France	FRA	26,89	35,06	6,58	4 168,78
United Kingdom	GBR	20,21	38,03	9,90	4 470,78
Hong Kong SAR, China	HKG	17,11	24,62	8,17	3 248,50
Indonesia	IDN	10,26	19,49	4,43	3 282,50
India	IND	15,68	49,15	0,11	215,85
Israel	ISR	16,12	19,06	8,19	8 255,40
Italy	ITA	22,85	26,19	7,92	2 018,09
Japan	JPN	24,70	24,58	5,59	5 230,72
Korea, Rep.	KOR	22,46	14,63	7,02	7 087,35
Mexico	MEX	16,21	41,65	0,16	241,80
Malaysia	MYS	20,82	49,86	0,96	2 261,44
Netherlands	NLD	23,94	33,28	7,64	4 548,14
Russian Federation	RUS	20,21	14,64	0,35	3 131,11
Saudi Arabia	SAU	20,21	28,55	0,93	3 282,50
Singapore	SGP	20,21	22,41	3,57	6 658,50
Turkey	TUR	16,23	24,30	1,26	1 156,51
United States	USA	22,81	28,14	6,96	4 231,99
South Africa	ZAF	20,89	37,75	1,07	437,06

Indicator variables values from data sources: Innovation and Research (IR) subindex

Table C4		IR1	IR2	IR3	IR4	IR5	IR6
Country	Parameter	Research and Development Expenditure as % of GDP	Scientific and Technical Journal Articles published/per 1 million people	Number of Patent Applications Residents of a country per 1 million people	Industrial design applications, resident, by count per 1 million people	Trademark applications, Direct resident of the country per 1 million people	Charges for the use of intellectual property, payments as % of GDP
United Arab Emirates	ARE	0,87	181,14	1,62	184,67	865,25	0,88
Argentina	ARG	1,96	183,66	12,45	23,17	1 190,67	0,38
Australia	AUS	1,96	1 981,41	94,96	116,92	1 951,66	0,28
Brazil	BRA	1,96	234,15	22,35	15,84	629,51	0,29
Canada	CAN	1,96	1 592,79	117,87	21,96	622,52	0,63
China	CHN	2,07	291,18	702,31	400,01	0,01	0,21
Germany	DEU	2,88	1 222,65	573,19	546,40	789,45	0,30
Spain	ESP	1,22	1 148,53	60,27	371,39	1 064,36	0,40
European Union	EUU	2,05	1 183,85	194,37	165,80	653,75	1,17
France	FRA	2,23	1 084,58	213,85	196,42	1 299,99	0,53
United Kingdom	GBR	1,70	1 482,88	226,50	184,67	749,82	0,45
Hong Kong SAR, China	HKG	0,76	835,42	32,53	181,71	1 956,80	0,58
Indonesia	IDN	1,96	11,21	4,05	10,15	142,04	0,19
India	IND	0,63	70,50	9,50	5,16	189,24	0,24
Israel	ISR	4,27	1 322,11	150,34	122,73	293,32	0,38
Italy	ITA	1,33	1 094,22	360,08	0,02	865,25	0,25
Japan	JPN	3,28	814,02	2 038,19	195,43	928,83	0,40
Korea, Rep.	KOR	4,23	1 148,27	3 264,18	1 285,79	3 122,72	0,66
Mexico	MEX	0,55	102,81	10,69	13,56	711,02	0,03
Malaysia	MYS	1,30	568,18	40,79	20,10	511,11	0,45
Netherlands	NLD	2,01	1 787,03	129,68	184,67	865,25	6,19
Russian Federation	RUS	1,13	246,24	202,77	18,12	237,71	0,39
Saudi Arabia	SAU	1,96	236,57	22,15	9,95	229,99	0,88
Singapore	SGP	1,96	1 900,83	261,98	141,60	961,43	6,49
Turkey	TUR	1,96	382,36	67,31	486,88	1 206,28	0,09
United States	USA	2,79	1 276,71	892,33	70,04	938,43	0,24
South Africa	ZAF	1,96	173,12	15,90	12,93	385,32	0,68

Indicator variables values from data sources: Manufacturing Activity (MA) subindex

Table C5		MA1	MA2	MA3	MA4	MA5	MA6	MA7	MA8	MA9	MA10	MA11	MA12	MA13
Country		GDP Growth % from 1990 to 2016	Manufacturing Value Added annual % of GDP Average from 1990 to 2016	High Technology Exports as % of GDP	Import of Plastic Injection Moulding Machines for rubber or plastics	Import of Vacuum Injection Moulding Machines for rubber or plastics	Import of Blow Moulding Machines for plastics and rubber	Machinery for working rubber or plastics or for the manufacture of products from these materials-3D Printers	CNC Lathes for Metal: Import of Lathes including horizontal lathes, turning centres	CNC Boring for Metal: Machine Tools for boring by removing metal, numerically controlled	CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type	CNC Drilling for Metal: Machine-tools for drilling by removing metal, other than lathes--Numerically controlled	Military expenditure	Importation of Industrial Robotics
United Arab Emirates	ARE	4,98	17,92	16,63000	0,009	0,003	0,004	0,014	0,003	0,001	0,001	0,00330	5,644	0,001
Argentina	ARG	3,41	19,86	9,00820	0,014	0,003	0,007	0,010	0,003	0,001	0,001	0,00025	0,955	0,002
Australia	AUS	3,11	11,19	13,51306	0,005	0,002	0,002	0,003	0,002	0,001	0,001	0,00059	2,001	0,001
Brazil	BRA	2,52	16,52	12,30504	0,007	0,001	0,002	0,006	0,002	0,000	0,001	0,00008	1,318	0,005
Canada	CAN	2,25	11,38	13,83190	0,010	0,002	0,002	0,006	0,007	0,001	0,004	0,00193	0,991	0,005
China	CHN	9,75	32,02	25,75365	0,011	0,003	0,002	0,012	0,007	0,000	0,003	0,00132	1,923	0,008
Germany	DEU	1,63	22,88	16,66115	0,017	0,001	0,002	0,015	0,014	0,002	0,005	0,00022	1,181	0,010
Spain	ESP	2,05	15,62	7,14610	0,016	0,001	0,004	0,009	0,010	0,013	0,001	0,00042	1,204	0,008
European Union	EUU	1,73	17,51	16,86122	0,004	0,001	0,001	0,004	0,007	0,000	0,001	0,00022	1,513	0,003
France	FRA	1,58	14,04	26,84725	0,007	0,001	0,002	0,006	0,010	0,003	0,002	0,00080	2,262	0,004
United Kingdom	GBR	1,96	13,12	20,81216	0,010	0,001	0,000	0,005	0,005	0,003	0,002	0,00009	1,824	0,002
Hong Kong SAR, China	HKG	3,85	2,44	10,70571	0,052	0,001	0,003	0,010	0,003	0,023	0,002	0,00169	2,410	0,011
Indonesia	IDN	4,92	24,54	6,62896	0,028	0,010	0,011	0,033	0,006	0,003	0,001	0,00136	0,876	0,004
India	IND	6,57	17,96	7,51776	0,010	0,002	0,003	0,035	0,004	0,001	0,004	0,00051	2,475	0,004
Israel	ISR	4,48	17,92	19,66319	0,012	0,003	0,006	0,011	0,007	0,001	0,004	0,00057	5,660	0,004
Italy	ITA	0,72	18,24	16,63000	0,016	0,001	0,003	0,010	0,016	0,003	0,003	0,00144	1,503	0,007
Japan	JPN	1,18	21,98	16,78206	0,001	0,001	0,002	0,003	0,003	0,000	0,000	0,00003	0,934	0,001
Korea, Rep.	KOR	5,37	28,35	26,83989	0,015	0,002	0,005	0,013	0,011	0,001	0,003	0,00100	2,607	0,009
Mexico	MEX	2,85	18,72	14,68694	0,109	0,013	0,017	0,061	0,034	0,001	0,006	0,00193	0,575	0,015
Malaysia	MYS	5,94	26,24	42,80095	0,060	0,011	0,015	0,068	0,014	0,003	0,003	0,00339	1,406	0,023
Netherlands	NLD	2,09	14,39	16,63000	0,009	0,001	0,001	0,008	0,011	0,001	0,004	0,00013	1,191	0,007
Russian Federation	RUS	0,66	15,51	13,76032	0,019	0,006	0,002	0,011	0,016	0,003	0,004	0,00089	5,398	0,001
Saudi Arabia	SAU	3,94	10,06	0,77416	0,016	0,007	0,017	0,014	0,002	0,001	0,000	0,00041	9,850	0,001
Singapore	SGP	6,22	23,82	49,27543	0,020	0,001	0,002	0,027	0,010	0,001	0,003	0,00130	3,354	0,017
Turkey	TUR	4,75	20,29	2,15970	0,040	0,003	0,005	0,040	0,026	0,002	0,006	0,00178	1,714	0,011
United States	USA	2,44	13,60	18,99152	0,009	0,001	0,002	0,004	0,005	0,001	0,001	0,00034	3,282	0,002
South Africa	ZAF	2,46	17,85	5,88097	0,032	0,004	0,014	0,023	0,008	0,000	0,001	0,00009	1,071	0,015

Appendix D: Proposed alignment of the MCI framework used with the Porter's Diamond Model

The proxy items used to measure MCI sub-indexes in our proposed MCI framework can be aligned with Porter's diamond framework. This was achieved by comparing the MCI items to those of some other authors that have operationalized the four diamond corners of Porter. The summary of this alignment is presented next.Factor conditions: The items used in measuring Business Infrastructure (BI), Education and Talent (ET) and Innovation and Research (IR) in the proposed MCI framework were found to correspond with the factor conditions of Porter's diamond. This can be observed from models of Kharub and Sharma (2017), Postelnicu and Ban (2010).Demand Conditions: Considering that the focus of this work is the competitiveness of nations and not firms in a country, per se, most of the MCI variables do not fall in this category.

This makes sense as Buckley (2017) has noted that Firm Specific Advantages (FSAs) are local in relevance and do not give a good indication of national competitiveness, and most items in this category seem to reflect more of FSAs as opposed to Country Specific Advantages (CSAs), which the other diamond corners reflect. Only two of the Manufacturing Activity (MA) items are classified as demand condition items.Related and Supporting Industries attribute: High technology export and adoption has been used as indicator items for this sub category by researchers like Postelnicu and Ban (2010). Generally, the proxy variables adopted depends on the focus of the research and the items under the Manufacturing activity sub-index of our MCI seem to fit well here, also being industry specific. The diverse industry contexts can be seen in Shafei (2009), Rugman and D'Çruz (1993), Pettus and Helms (2008), Gawad et al., (2014), Setyawan (2011), Molendowski and Zmuda (2013), Ksu and Liu (2009) and Moon and Lee (2004).Firm Strategy, Structure, and Rivalry attribute: To measure this attribute proxy variables that measure how easy it is to setup and operate a firm has been measured, and the Innovation and Research (IR) sub-index in our MCI is appropriate here. Similar items can be found in Hsu and Liu (2009).

Porter’s Diamond Framework

Factor Conditions. This includes measurements of production, such as skilled labour or infra- structure. Variables that identify things needed in order to compete.

Quality of Road Length of paved and unpaved road	BI1
Healthcare expenditure as % of GDP	BI2
Improved sanitation facilities (% of population with access)	BI3
Fixed telephone subscriptions (per 100 people)	BI4
Electric power consumption (kWh per capita)	BI5
Secure Internet servers (per 1 million people)	BI6
Mobile Cellular Subscriptions per 100 people	BI7
Fixed broadband subscriptions (per 100 people)	BI8
Foreign direct investment, net inflows (% of GDP)	BI9
Automated teller machines (ATMs) (per 100,000 adults)	BI10
Domestic credit to private sector by banks (% of GDP)	BI11
Number of Patent Applications Residents of a country per 1 million people	IR3
Industrial design applications, resident, by count per 1 million people	IR4
Trademark applications, Direct resident of the country per 1 million people	IR5
Government expenditure per student, secondary (% of GDP per capita)	ET1
Government expenditure per tertiary student as % of GDP per capita (%)	ET2
Number of Universities by Country in Top Global 1000 list(Universities/per 10 million people)	ET3
Researchers in R&D per million people of the country	ET4
Research and Development Expenditure as % of GDP	IR1
Scientific and Technical Journal Articles published/per 1 million people	IR2

Demand Conditions. Domestic market demand for the industry's product or service

Manufacturing Value Added annual % of GDP Average from 1990 to 2016	MA2
GDP Growth % of a country average from 1990 to 2016	MA1

Firm Strategy, Structure, and Rivalry. “The conditions in the nation governing how companies are created, organized, and managed, as well as the nature of domestic rivalry.”

GDP per person employed (constant 2011 PPP $)	EM1
Bank capital to assets ratio (%)	EM2
Compensation of employees (% of expense) *	EM3
Bank nonperforming loans to total gross loans (%) *	EM4
Time to Import (Days) *	EM5
Cost to import, documentary compliance (US$) *	EM6
Cost to import (US$ per container) *	EM7
Time required to start a business (days) *	EM8
Charges for the use of intellectual property, payments as % of GDP	IR6

Related and Supporting Industries. *Does the country have any* supplier industries and other related industries that are internationally competitive?

Import of Plastic Injection Moulding Machines for rubber or plastics as % of GDP	MA4
Import of Vacuum Injection Moulding Machines for rubber or plastics as % of GDP	MA5
Import of Blow Moulding Machines for plastics and rubber as % of GDP	MA6
Machinery for working rubber or plastics or for the manufacture of products from these materials-3D Printers as % of GDP	MA7
CNC Lathes for Metal: Import of Lathes including horizontal lathes, as % of GDP	MA8
CNC Boring for Metal: Machine Tools for boring by removing metal as % of GDP	MA9
CNC Milling for Metal: Machine Tools for Milling by removing metal, knee-type and not-knee type -- Numerically controlled as % of GDP	MA10
CNC Drilling for Metal: Machine-tools for drilling by removing metal, other than lathes as % of GDP	MA11
Military Expenditure (% of GDP)	MA12
Industrial Robotics Imports as % of GDP	MA13
Manufacturing Value Added annual % of GDP Average from 1990 to 2016	MA2
High Technology Exports as % of GDP	MA3

Figure 13 Proposed alignment of MCI framework with Porter’s Diamond Framework