Advanced Manufacturing: The key to future competitiveness in the automotive industry

Mbongiseni Makhado and Nita Sukdeo
School of Mechanical and Industrial Engineering
Department of Quality and Operations Management
University of Johannesburg
Gauteng, South Africa
nsukdeo@uj.ac.za
mbongiseni.makhado@gmail.com

Abstract

Advanced manufacturing includes the production of advanced materials and advanced technologies. Manufacturing industries continue to transform with every progression of the technological era. As advancement in technology shapes manufacturing, the role of manufacturing to economic development and competitiveness continues to change. The purpose of the study is to determine whether advanced manufacturing systems lies within the fourth industrial revolution (Industry 4.0). Descriptive statistical analysis was used to assess the effect of advanced manufacturing systems on competitiveness in order to determine the impact on productivity, manufacturing employment and manufacturing contribution to economic competition. The research results revealed a proportionally high increase in productivity and production output that directly correlates with the application of advanced manufacturing systems. However, employment in manufacturing and creation of new jobs correlate negatively with advancement in technology. Therefore, the question of economic competitiveness still remains contentious.

Keywords
Advanced manufacturing, competitiveness, Industry 4.0, economic development

1. Introduction

Manufactured goods have been satisfying the needs and wants of customers since the beginning of mankind. The objective of manufacturing is one of providing products that are essential to customer's physical and social needs. In the contemporary economy, however, this objective has to be fulfilled competitively through effective processing, efficient use of material, as well as reduction and elimination of waste in production. This means that the techniques and methods of manufacturing are no longer just driven by the desire to satisfy needs and wants, they are now driven by competition and the desire to be competitive and profitable while pursuing to satisfy customer needs and wants. This contemporary desire drives and directs innovation and investment choices which organizations create in order to obtain the technology and manufacturing methods to enhance competitiveness and profits. Therefore, many multi-national organizations and developed countries are focusing on large scale resources using more nascent technological manufacturing methods that are collectively known as Advanced Manufacturing Systems. In Germany, this is pursued under the umbrella of Industry 4.0 (Schuh et al 2014) so called because researchers believe that we are in the fourth generation of industrial transformation.

Much like most transformations, prevailing manufacturing industries have progressed over time, with some regions leading the transformation through innovation and technology while other regions are lagging behind. The first recorded form of manufacturing was driven by individually talented artisans who crafted goods by hand. This developed into more organized methods of production systems, in which these skilled craftsman were brought together in a coordinated production systems. The era that followed, was known as the First Industrial Revolution, which began in Great Britain – the dawn of mechanical power, with machines that were powered by water and steam (Ezell, 2016). The development and introduction of electrical power in production lines brought about the Second Industrial Revolution, which was characterized by labor mass production, assembly line manufacturing, and high consumption of steel products. Productivity in manufacturing continued to increase with less and less skilled labor. During this era, science based industries emerged and these included the chemical and electronic industries (Ezell, 2016). Controversy surrounds this third transformation in manufacturing; the debate is centered on whether this transformation is a standalone revolution or part of the second transformation.

The foundation of the fourth manufacturing transformation is associated with the first digital-electronic transformation that empowered information and computer technology (ICT) based systems in the manufacturing setting through computer integrated manufacturing (CIM) and enhanced robotics. This formed the stepping stone of what is emerging today as the forth industrial revolution – bringing about the era of advanced manufacturing systems (Esmaeilian et al 2016).

Every transformation in manufacturing brings new fields of study, new industries and new opportunities of growth. The second industrial revolution created mass employment in the low skill spectrum, a shift from highly skilled craftsman based workmanship. The third manufacturing transformation saw the emergence of new manufacturing industries in the chemical and electronic sciences which brought some sophistication and new fields in manufacturing. The forth revolution is built around a global world community through ICTs and the internet; it promotes distributed manufacturing in a global economy. Although the forth industrial revolution promises great things, the full extent of its impact remains to be seen. This view is supported by the following assertions by some researchers; the emergence of new trends and concepts should motivate the research community to invest in identifying future research frontiers (Esmaeilian et al 2016) moreover, existing building blocks of current manufacturing structures should be examined to determine whether new technologies will influence existing manufacturing infrastructures.

1.1 Statement of the problem

Data and literature shows lack of growth of manufacturing in South Africa, manufacturing has been on the decline for about two decades (Williams et al 2014). The decline in manufacturing performance is reflected in employment creation, manufacturing growth and manufacturing competitiveness (Williams et al., 2014). Firstly, manufacturing firms are failing to compete against imported products, such as in steel, food, textile and many other sub-sectors. This in a period of a competitive Rand; it is expected that the depreciation of the local currency would make the market buy local products over imported goods. Secondly, there is a widespread perception in the manufacturing industry and the local industry in general, of a negative trend or relationship between manufacturing jobs and technological advancement. Now that we are in another phase of technological transformation in manufacturing, this relationship between technology and employment is yet to take on another form. Apart from this, there is also a question about the availability of technological capability in developing nations to achieve economic manufacturing growth and industrialization. The most important measures of economic growth and competitiveness are productivity, output, marketshare and employment rate. This research seeks to capture, and explore the effect of advanced manufacturing systems to economic growth and competitiveness.

1.2 Objectives of the study

- To analyze the type of competitiveness that will be yielded by advanced manufacturing technologies.
- To explore the impact of advanced manufacturing systems to the competitiveness of individual organizations.
- To assess the impact of advanced manufacturing systems on employment creation, productivity, product quality and demand (change in sales).

1.3 Rationale and Significance of the study

Advanced manufacturing is considered important in achieving industrialization and re-industrialization of economies. It is also important in reversing de-industrialization and creation of decent remunerating jobs (Williams et al., 2014). Evidence from reviewed literature reveals that almost all leading manufacturing economies which include, the United States, the United Kingdom, Singapore, China and Germany, are investing substantial portions of their gross domestic product into smart factories and other initiatives of Industry 4.0 (Ezell, 2016: Williams et al., 2014). This research is anticipated to contribute to decisions about investments for future competitiveness and to contribute to literature in South African institutes of learning and the industry. Governments around the world are collaborating with industry toward the realization of advanced manufacturing systems (Williams et al., 2014; Esmaeilian et al 2016; Ezell, 2016). Among these, developed nations regard manufacturing as important to future competitiveness and view advanced manufacturing systems of strategic importance in bringing back previously offshored manufacturing jobs to their countries for future competitiveness. Williams et al. (2014) further emphasis that it is crucial for the country to invest and adopt advanced manufacturing technologies as well as supporting conventional manufacturing systems for economic development, employment creation and economic competitiveness. However, the authors did not detail the perceived benefits or potential impact of advanced manufacturing to economic competitiveness.

2. Literature Review

2.1 Economic development and competitiveness

Economic development is portrayed (Rostow, 1959; Lewis, 1955; and Kaldor, 1967; cited in Ferrarini and Scaramozzino, 2015) as a process of structural transformation and increasing productivity through progressive strengthening of capabilities in productivity by reallocation of resources. Competitiveness at a national level is measured by the standard of living and its rate of growth, nation's productivity, and nation's market share in the world market through exports. The competitiveness of a nation's firms determines its competitiveness (Leire, 2013). Past literature about the importance of manufacturing in economic development is overwhelmingly consistent. Past literature regards manufacturing as the engine of economic growth and industrialization. However, recent research continues to raise questions about this past consensus. Arguments are raised about the continual increase in contribution of the service sector to economic growth in both developed and developing economies. Dasgupta and Singh (2005), cited in Szirmai and Verspagen (2015), state that the contribution of manufacturing is declining. There is however, no evidence in researched literature that provide scientific evidence to support services as drivers (or engine) to economic growth. Some researchers contend that manufacturing still retains its role as an engine of economic growth (Haraguchi et al., 2016; Szirmai and Verspagen, 2015) and that complex production structures and technological advancement are concentrated in manufacturing and that manufacturing has critical and stronger linkages with other sectors and spillovers to various service sectors (Szirmai and Verspagen, 2015). These linkages refer to direct backward and forward transactions between different sub sectors and sectors, which creates positive externalities to investment. Spillovers occur in flow of knowledge and technology between sub sectors and sectors. Spillover effects are highest in the manufacturing of complex products, which facilitate broader expansion into other industries (Ferrarini and Scaramozzin, 2016).

2.2 Productivity

Industrial revolutions have led to significant increases in productivity (Schuh et al., 2014). These authors contend that even though increases in productivity have resulted from industrial revolutions in the past, to achieve productivity in the current revolution "Industry 4.0", which is driven by revolutionary social networking, there should be collaborative effort at every level in the manufacturing ecosystem. They argue that this potential lies in the improvement of decision making process, which is fundamentally supported by "data" in manufacturing. In support, Haraguchi et al (2016) stress that manufacturing has high potential for productivity which is based on high accumulation of capital, economies of scale and continual progression in technology relative to other sectors.

2.3 Employment and Manufacturing

A skilled manufacturing workforce with advanced training, which is distributed throughout the supply chain, is fundamental and key to competitiveness of a country's economy (Davis et al 2012). Expansion of complex production structures and economic development requires availability of broad-based skills in the labor force together with capabilities that adapt to changing technology (Ferrarini and Scaramozzin, 2016). In addition, the authors noted that an increase in complexity of production has a dual effect on enhancing human capital accumulation, through learning and development of skill, and increasing risk of low productivity and product failure due to poor quality. On the other hand, Lewis (1954), cited by (Haraguchi et al., 2016) details that in the presence of unlimited supply of labor, at subsistent wage levels; investors continuously enlarge their investments until all surplus labor is absorbed. Although productivity in the economy as a whole may increase, labor productivity does not increase if the proportion of output expansion is equal to that of labor expansion. When labor productivity remains stagnant and relative wages increase, labor is gradually substituted with technology (Haraguchi et al., 2016).

2.4 Advanced Manufacturing

Advanced manufacturing is built around information and computer technologies (ICTs) embedded electronic technology and autonomous technology. Advanced manufacturing is a term used to describe two different but related elements; the adoption and application of information and communication technology in manufacturing and the reference to manufacturers who manufacture advanced technology components. The first element is referred to as Smart manufacturing or Intelligent Manufacturing (Ezell, 2016).

2.5 Smart Manufacturing

2.5.1 Big data

The challenge in modern manufacturing is not only that of handling and controlling matter, it is also that of handling and managing manufacturing data – material information, process data (data from processes), product data (test reports, inspection reports etcetera) and customer requirements and feedback. Manufacturing processes and products generate enormous amount of data during operation and use, management of this "big data" (collection, transformation to information, storage and retrieval) is vital for organizational competitiveness. Decision making structures and improvement efforts rely on availability and ease of retrieval of the right information at the right moment.

2.5.2 Digital Technology

Digital technology powers connected machinery and production systems to provide real-time awareness at specific points in the manufacturing system. The application of Internet of Things (IoT) in manufacturing is projected to increase productivity by about 15% and create multi trillion dollar savings across world factories (Ezell, 2016). Effective application of digital technology in the automotive industry, aviation, defense and electronic industries is driving predictive production systems, decision making and preventive action. Intel uses predictive modelling on data to anticipate failures, prioritize inspection and cut monitoring costs at its chip manufacturing plants. According to MGI estimates, predictive maintenance is expected to reduce maintenance costs in factories by up to 40% and improve downtime by up to 50%. The American Society for Quality reports that 82% of manufacturers in the US have invested in smart machines and systems, 49% of them have reported fewer defects on products (Ezell, 2016).

3. Methodology

A method of assessing the capabilities of current and future advanced manufacturing systems was adopted. Simply because we have not reached the full potential of industry 4.0; any such calculations would have carried a risk of inaccuracy and prematurity. Therefore, the focus of this research methodology was on the capabilities of advanced manufacturing systems that are in operation in the industry, from which the current capabilities of those advanced systems was examined and the potential capabilities were projected. Manufacturing capabilities were assessed based on - productivity, production output, labor and quality. These are common to any manufacturing environment. A mixed method approach was utilized for the study which incorporated qualitative and quantitative analysis of data.

Ideally, for advanced manufacturing to be considered key to future competitiveness, adoption and implementation of advanced manufacturing technologies should result in the upgrade of the entire manufacturing supply chain in the country, thus creating a supply chain that is reconfigurable and flexible. For an effective reconfiguration and flexible manufacturing system, an upgraded supply chain is required. Ultimately, the discussion about competitiveness rests on the capabilities of the manufacturing system. The capabilities of a manufacturing system in the contemporary economy is focused on agility, quick response, quality and service. Systematic analysis of these manufacturing capabilities will enable inferences and conclusions to be drawn about the impact of advanced manufacturing systems to economic competitiveness.

3.1 Population and sampling

The research centered on the local manufacturing industry. Its primary focus was the automotive sector and its support structure. Purposive sampling was used when selecting three different multinational manufacturers and three different local manufacturers, one in Kwa-Zulu Natal and five in Gauteng Province. Purpose sampling was opted for in order to get an in-depth account and opinion from industry experts who operate on the cutting edge of technology and technological adoption. The automotive industry is one of the select few industries that compete on the international stage. According to Williams et al. (2014), the automotive industry is the only manufacturing sector that has seen manufacturing growth in production and export value since the great recession of 2008. Included in the sample were two multinational electronic and automotive component manufacturers that are based in Gauteng with operations countrywide.

3.2 Data collection procedure

3.2.1 Primary data collection

Primary data was collected through open-ended administered questionnaires and through telephonic interviews. Questionnaires and interviews were directed to middle and senior business managers who are responsible for operations management, quality management and production management.

3.2.2 Secondary data collection

Secondary research data was collected through systematic review of latest literature that is available in journals. Additional secondary data and information was collected from technical experts in the field of research and development at Council of Scientific and Industrial Research (CSIR). The researcher also attended Intel IoT webinars where the preparedness of Intel and steps taken towards industry 4.0 were demonstrated.

A qualitative systematic review of literature was conducted based on the Preferred Reporting Items for Systematic review and Meta-analysis (PRISMA) approach. The PRISMA checklist is largely used in the medical field for writing systematic reviews and consists of a 27 item checklist and a 4 phase flow diagram that are used to provide clarity and transparency in systematic literature reviews. A systematic literature review involves identifying, selecting, appraising and critically analyzing several relevant research studies, journals or papers based on pre-formulated research questions. It involves collecting and further analyzing data from research studies that were selected. Systematic literature review was chosen because it helps develop literature accurately in an organized and reliable manner. The other advantage of systematic literature review is that it can provide details about the effects of some phenomenon across a wide variety of settings and methods.

4. Analysis of results

Upon proceeding with presentation and analysis of results, it is necessary to define key competitive factors under consideration in the study. These factors are discussed below:

4.1 Productivity

In the manufacturing continuum productivity can be defined as a measure of effectiveness of a production system and can be calculated as the rate of output per unit of input. Productivity is an important indicator for an organization's production performance and a nation's economic performance. Higher national productivity and productivity growth can translate into better standards of living through increase in real income and disposable income for people. Productivity growth enables profitability in businesses.

4.2 Production Output

This refers to manufacturing production output in volume, of products produced. Progress in technology allows processes to increase production output with no increase in input.

4.3 Quality

Manufacturing quality is embodied in control of variability; variability in processes and products. Quality is defined in tangible and intangible characteristics. Process quality can be measured in variability of the process and efficiency of the process. The output of the process is measured in the quality of the products produced. Intangible quality characteristics are embodied in an organization’s culture and are the drive behind an organization’s performance and success. Tangible quality characteristics often derive from intangible quality characteristics. Tangible quality characteristics are measurable and can be quantified; usually used in process improvement.

4.4 Analysis and representation of primary data

The following figures 1 to 4 present manufacturing data in productivity, production output and quality. Productivity measured as the change in efficiency in the rate of conversion of inputs; production output measured as the change in production volume rate; process quality measured as the change in process first yield and change in process variation from target after implementation of a new technology; with product quality measured as the change in internal manufacturing defects per units produced.

4.4.1 Digital Manufacturing

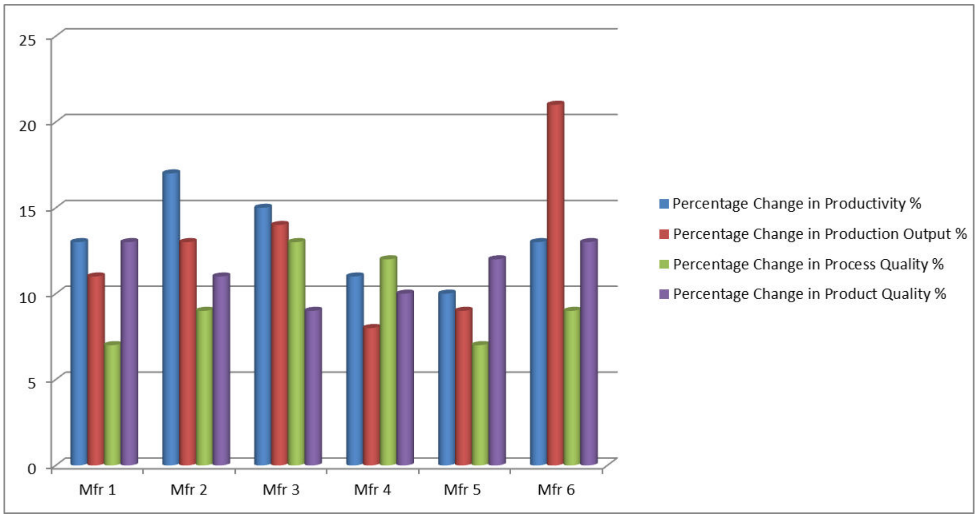

Figure 1. Digital Manufacturing

The automotive industry is at the forefront in digitalization: through networked production systems, production processes are monitored, digitally controlled and optimized for peak performance. The application of digital technology in the automotive industry has seen 13% average increase in productivity represented in Figure 1.

4.4.2 Autonomous Production

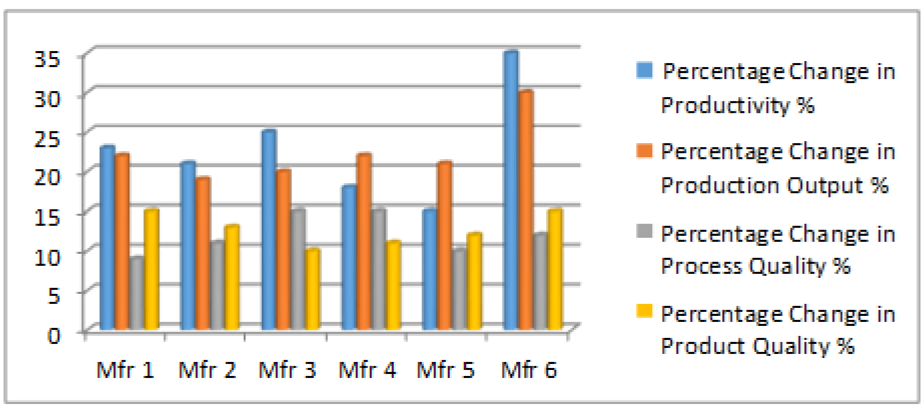

Figure 2. Autonomous Production

Change in manufacturing indicators has attributed to use of autonomous production. Average production output increase of 22% is attributable to autonomous production in different manufacturing plants.

4.4.3 Automation

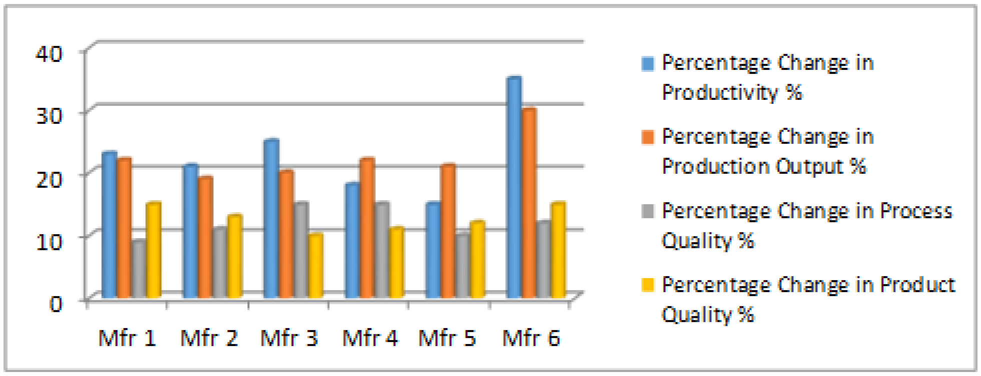

Figure 3. Automation

An average productivity increase of 23 percent and an average improvement in overall quality of 12 percent can be attributed to automated production in different manufacturing plants.

4.4.4 Overall Change in Productivity and Production Output (After application of digital technology in automation / autonomous manufacturing) including labor

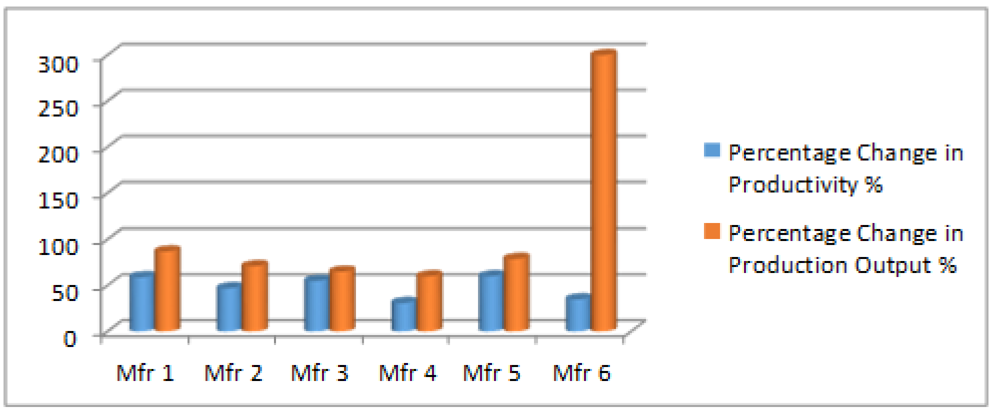

Figure 4. Overall Change in Productivity and Production Output

Overall change in productivity, production output and quality cannot be attributed to the application of digital technology in manufacturing or the use of automation technology alone. A variety of manufacturing parameters such as continual improvement of the new technology after implementation, technical bank of the labor force and the level of complexity of manufactured products contribute to the overall change in manufacturing performance.

4.5 Analysis and representation of secondary data

4.5.1 Employment in the Automotive Industry

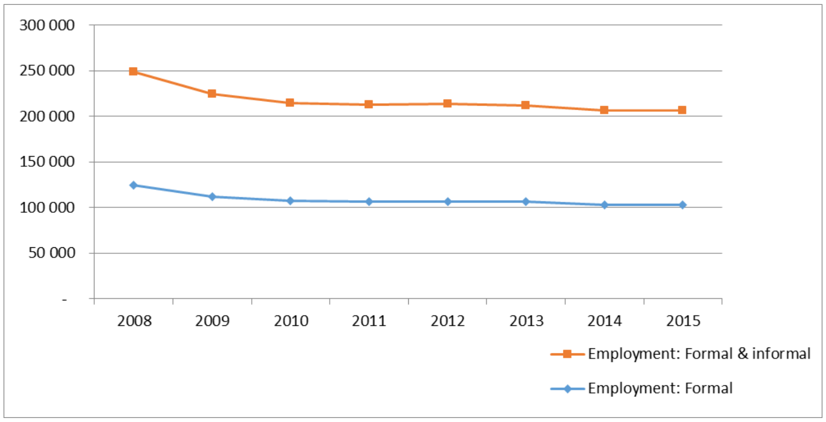

Figure 5. Employment in the Automotive Industry

Only the trend in employment activity can be commented on from Figure 5, which shows a steady decline in manufacturing employment between 2008 and 2010, a period after the great recession. Automotive manufacturing employment did not decline further after stabilizing in the period between 2010 and 2015, neither did the automotive sector produce net gains in employment in this 5 year period (2011 - 2015), in both the formal and informal sectors.

4.5.2 Remuneration per employee

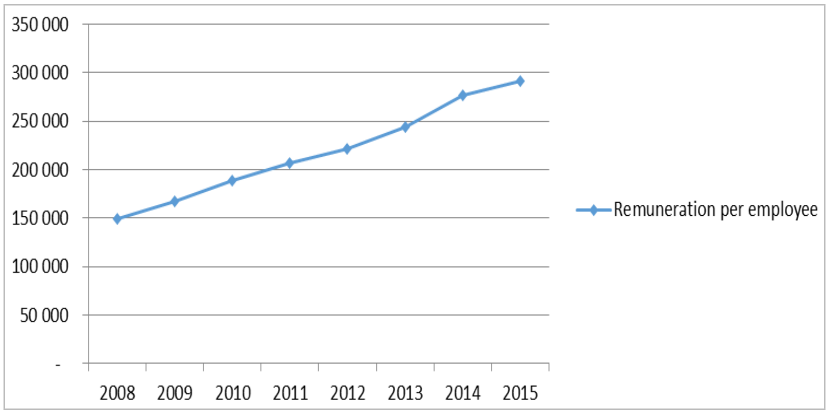

Figure 6. Remuneration per employee

There has been a steady increase in remuneration per employee in the automotive industry throughout the period between 2008 and 2015, despite the economic setback of 2008 and the period afterwards. This steady incline in remuneration per employee could be attributable to a positive trend in employee productivity that directly translates from advancement in manufacturing technology. The increase in labor remuneration may also be attributed to the decline in manufacturing employment in the automotive industry where automation and autonomous production systems replace skilled to semi-skilled labor creating excess in remnant high to highly skilled labor force.

4.5.3 Labor Productivity

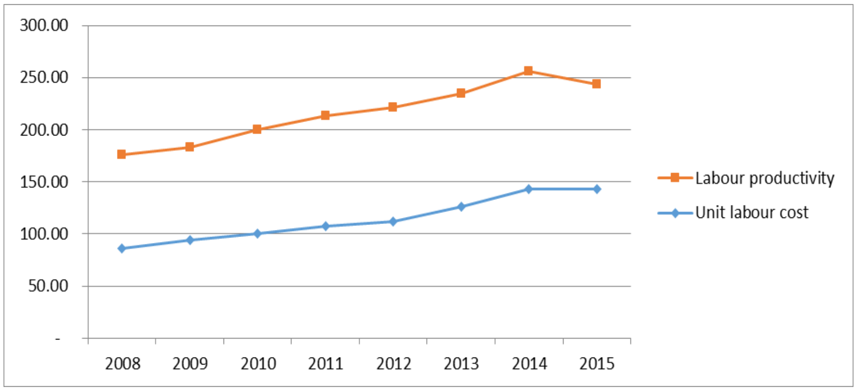

Figure 7. Labor Productivity

It can be concluded that unit labor cost increases with increase in labor productivity as depicted in Figure 7. A negative trend in manufacturing employment in the auto sector is seen, when productivity and production output increase with the application of advanced manufacturing technology in the sector. Manufacturing employment decreased by 17% between 2008 and 2015 as labor productivity increased by 12%, in the same period.

4.5.4 Relationship between productivity and employment

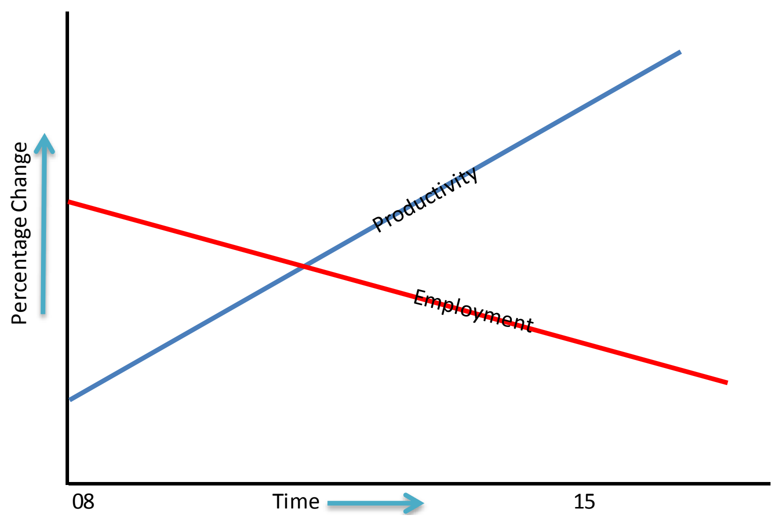

Figure 8. Relationship between Productivity and Labor

Figure 8 represents a theoretical simulation that was drawn from the research study. It depicts a relationship between the increases in general productivity in the manufacturing environment and decrease in employment associated with advancement in manufacturing technology.

5. Conclusions

From the study it can be concluded that technological advancement in general and advancement in manufacturing in particular has had an influence on the traditional economic relationship of supply and demand. Progress in technology has reduced concept-to-market cycle time and shortened product life cycle, which has changed the consumption behavior of the customer. As a result of a shorter manufacturing cycle (in some instances the cycle is reduced by more than 200%, Reuters, http:reut.tv/2yXLfrt 2017) and shorter product life cycle, the change in consumption behavior drives up the cycle of demand and supply in the market, which stimulate economic activity and economic growth. The concepts of collaborative manufacturing, autonomous reconfigurable manufacturing systems and autonomous flexible manufacturing systems provide agility and strategic positioning for future competitive advantage in meeting varying market demand.

5.1 Manufacturing competitive advantage

The aspects of competitive advantage that look to decide location of manufacturing production in the near future are market value size, collaborative supply chains, talent, availability of technology, productive infrastructure, energy costs and availability, economic climate, market policy and political condition, management of information and big data. There however, seems to be a reversal trend in the location of production facilities. Manufacturing production is moving back to industrialized regions where manufacturing firms are leveraging technological advancement in hope to compete against low production cost non-industrialized regions, having eliminated the factor of high labor costs that are synonymous with their economies. This reversal in trend is founded upon new factories that are manned by armies of robots in place of armies of employees that used to perform the work (Reuter.com, Oct 2017). The economic benefits to the regions to where manufacturing production moves to will not be in job creation.

5.2 Labor and Employment

Employment plays a critical role in economic growth and development. Growth in the rate of employment and in labor participation translates into direct economic growth. Through increased spending by a nation's labor force and expansion of the middle class, the living standard of a nation is enhanced. Therefore, employment is a key ingredient to economic success and to economic competitiveness. The ability of generating high production capacity through technological advancement with constant decrease in manufacturing employment, indicate that labor will no longer be the important component that contributes to competitiveness in manufacturing. Traditional competitiveness of the economy that was once driven through employment generation and labor participation no longer seems probable under Industry 4.0. A probable scenario is indirect employment creation and support of jobs in manufacturing related fields that constitute the advanced manufacturing value chain.

Employment opportunities may arise in new industries that will emerge around advanced manufacturing. Employment opportunities may also arise in providing engineering solutions that address the still labor intensive manufacturing sectors such as textiles where the need for human skill is still indispensable.

Judging from historical and current trends, jobs that have been lost will not be recovered and jobs will continue to be shed. On one hand, governments and industry are increasing investments in advanced and smart manufacturing systems; on the other hand, governments are faced with the realities of population growth and unemployment growth that has an added burden from economic migration and human migration in general. The means of expanding job markets and creating jobs are constantly diminished and running out. Governments of developing markets are also faced with the reality of shortages of skills that are necessary to support sustainable advanced industries. Future competitiveness in labor lies in innovation and talent. New careers in advanced manufacturing are emerging in mechatronics, a study of a combination of mechanics and electronics. There is a growing demand for people in maintaining equipment and machinery and less demand for operators.

References

Esmaeilian. B, Behdad. S and Wang. B (2016). The evolution and future of manufacturing: A review. Journal of Manufacturing systems. www.elsevier.com/locate/jmansys

Ezell. S. J. (2016). 2016 Policymakers guide smart-manufacturing-pdf. http://www2.itif.org/2016-policymakers-guide-smart-manufacturing.pdf

Ferrarini. B and Scaramozzino P (2015). Production complexity, adaptability and economic growth. Structural Change and Economic Dynamics. www.elsevier.com/locate/sced

Haraguchi. N, Cheng. C. F. and Smeets. E (2016). The importance of Manufacturing in Economic Development: Has this Changed? World development vol. 93. www.elsevier.com/locate/worlddev

Leire, (2013) what is competitiveness? http://www.tci-network.org/media/download/1185

Schuh. G, Potente. T, Wesch-Potente. C, Weber. A. R and Prote. JP (2014). Collaboration Mechanisms to increase Productivity in the Context of Industrie 4.0. Robust Manufacturing Conference (RoMaC 2014). ScienceDirect. www.elsevier.com/locate/sced

Szirmai. A. and Verspagen. B (2015). Manufacturing and economic growth in developing countries, 1950 – 2005. Structural Change and Economic Dynamics.
www.elsevier.com/locate/sced
Williams G, Dr. Cunningham S and Prof. De Beer D (2014). Advanced Manufacturing and Jobs in South Africa: An Examination of Perceptions and Trends. Paper Presented at the International Conference on Manufacturing-Led Growth for Employment and Equality, Johannesburg, 20 and 21 May 2014.

Biographies

Nita Sukdeo is currently a full time senior lecturer in the field of Quality and Operations Management, and the BTech Quality programme leader in the Department of Quality and Operations Management, at the University of Johannesburg, Gauteng, South Africa. She obtained a Masters in Quality from the Durban University of Technology and a PhD in Engineering Management from the University of Johannesburg. She is an upcoming young researcher in the field of total quality management and operations management. Her field of expertise also include quantitative analysis, quality management systems, quality auditing and risk assessment. She is a qualified Lead Auditor, proficient in ISO standards and certification. She is one of the directors of the Society for Operations Management in Africa (SOMA), as well as a senior member of the South African Society for Quality (SASQ).

Mbongiseni Makhado is a quality practitioner and a final year student at the University of Johannesburg. He is an experienced Quality Manager and head of department with a sound track record in process improvement, problem solving, quality planning, quality control, quality assurance and continual improvement. Mr. Makhado holds an honours degree in Textile Technology at the National University of Science and Technology in Zimbabwe, a certificate in Total Quality Management (TQM) at the University of South Africa, and has successfully completed a Bachelor of Technology degree in Quality at the University of Johannesburg. In addition to this, Mr. Makhado has completed courses in quality auditing, internal auditing, Lean Six Sigma, Lean, skills development facilitation in which he sits in the skills development committee at his workplace. Registered with South African Quality Institute, SAQI, South African Institute of Management, SAIM and The Chamber of Engineering Technology (CET) as a professional member. Holds a South African critical skills visa in Quality Management Systems.