



THE ROLE OF LEAD FIRMS IN THE DEVELOPMENT OF PRODUCTION ECO-SYSTEMS IN PROCESS EQUIPMENT AND AEROSPACE

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Abstract

Historically, the South African machinery and equipment industry, particularly the mineral processing segment has been a locus of excellence, however, overtime there has been an erosion of capabilities and a loss of competitiveness. This is concerning given the industry's contribution to manufacturing value added, its relative labour absorbing nature and the strong linkages to much of manufacturing as well as to mining and agriculture. The technological change associated with industry 4.0 presents an opportunity to regain and improve competitiveness in the industry. The convergence of ICT and machinery and equipment forms the basis for smart manufacturing and smart societies associated with the technological change. As a result, machinery and equipment is a root industry for the fourth industrial revolution. In this paper, we unpack the process of technological upgrading in the context of industry 4.0 within the production ecosystem of a lead firm in mineral processing equipment as a case study and conduct a comparative assessment with a production ecosystem of a lead firm in aerospace, a leading industry in adoption of 4IR technologies. The purpose of the analysis is to understand the local production ecosystem required to support technical upgrading. The analysis of the two production ecosystems highlight the important role of lead firms in facilitating adoption of new technologies and/or processes; the need for complementary investment decisions within a supply chain, collaborations with public institutions and coordinated interventions by government to ensure successful upgrading.

JEL classification: L64, O14, O25, O30

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1 Introduction

The metals to machinery and equipment value chain (including basic metals, fabricated metals and machinery and equipment) is important for the South African economy for a number of reasons. First, the value chain accounts for 40% of domestic value added of manufacturing exports in 2016.³ Second, the value chain is the largest source of formal employment in South African manufacturing, contributing 267,000 direct jobs. With the downstream industries accounting for much of the jobs, for example, the machinery and equipment level accounts for 42% of total employment of the value chain.⁴ Third, as the downstream industries such as machinery and equipment and metal fabrication produce intermediate products, the value chain has strong linkages to much of manufacturing as well as to mining and agriculture. In addition, these downstream industries are also root industries for industry 4.0 as the convergence between the ICT and machinery and equipment industries is the basis for smart manufacturing and smart societies which are key components of the fourth industrial revolution (Min, Lee, and Aoshima, 2018). As such, the machinery and equipment industry is important for any strategy that seeks to diversify the domestic economy towards higher value add, more employment absorbing and more sophisticated industries and particularly one that seeks to leverage the technological changes associated with industry 4.0.

The metals and machinery study completed in year 1 reviewed the overall performance of these industries and considered issues in foundries and in mining machinery as part of what is effectively a situation analysis. Insights from the analysis of the machinery and equipment industry included the loss of capabilities and competitiveness, reflected in declining market share in the region and deep-sea markets.⁵ This was attributed to various factors, including weak skills, dilapidated infrastructure, and high energy and input costs.⁶ This is concerning given the historical strong capabilities in machinery and equipment. However, it is important to note that while the aggregate picture has been that of decline, there are pockets of success within segments such as mineral processing. The technologies associated with the fourth industrial revolution present an opportunity to regain competitiveness in this key sector, however, caution needs to be exercised as while these technologies present leapfrogging opportunities, the learning by doing amassed by the countries that are leading on the fourth industrial revolution cannot be discounted in maintaining a competitive edge. There is value in understanding the technological upgrading process that has been undertaken by those firms that are continuously upgrading and have maintained international competitiveness.

In this paper, we build on the previous study and take a case study approach to conduct an in-depth assessment of Multotec, a lead firm that has managed to continuously build capabilities and improve competitiveness including though adopting the technologies associated with the fourth industrial revolution. The analysis focuses on the firm's process of

³ DVA contribution calculated from the OECD Trade in Value Added data.

⁴ Rustomjee, Kaziboni & Steuart. (2018). Structural transformation along metals, machinery and equipment value chain – Developing capabilities in the metals and machinery segments. CCRED Working Paper 2018/7.

⁵ Langa, E., Mondliwa, P. & Nkhonjera, M. (2018). Maintaining and building capabilities in capital equipment and related industries in Mozambique and South Africa. CCRED Working Paper 2018/1

⁶ Rustomjee, Kaziboni & Steuart. (2018). Structural transformation along metals, machinery and equipment value chain – Developing capabilities in the metals and machinery segments. CCRED Working Paper 2018/7. Available here: <https://www.competition.org.za/s/IDTT-MME-Final-Project-Report.pdf>.

technological upgrading particularly of the adoption and adaptation of those technologies that are associated with the fourth industrial revolution. This is to understand the capabilities that have been associated with the upgrading process and unpack the support that would be required to assist the rest of the industry to achieve competitiveness. We then conduct a similar analysis on Aerosud, a lead firm in the domestic aerospace industry. The aerospace industry makes for a useful comparison for a number of reasons. First, the industry has been an early adopter of a few of the technologies that are associated with the fourth industrial revolution including additive manufacturing, the internet of things (IoT) presenting an opportunity to learn from this experience. Second, the industry is made up of complex activities and multiple interconnected groups and is governed by global original equipment manufacturers (OEMs) with strict standards that must be met by component manufacturers all over the world, which presents an opportunity to draw insights on the business ecosystem that is required to support firms to achieve competitiveness. Third, the local aerospace industry has received relatively more targeted support from public institutions including government departments, government agencies and science councils, which allows for insights on the institutional support that could be packaged for other sectors.

Innovation and the technological change that is implied by the fourth industrial revolution does not take place in isolation but rather through a range of interdependent investments in new technologies and business models both within a firm and with other firms and institutions. This is because technological upgrading is not necessarily a straight forward process of taking technology off the shelf and incorporating into firm activities. The firm's ability to make effective use of the technological knowledge in efforts to assimilate, use, adopt and adapt technologies (otherwise known as technological capabilities) is a critical part of this process (Kim, 1980). This is consistent with extensive company and industry level analysis which makes clear that capabilities are not simply about acquiring technology or skills but are also to do with the internal 'know-how' of the firm including routines and working practices, and the linkages within clusters and supply chains (see, for example, Sutton, 2012).

Policy-makers are faced with the question of how best to facilitate adoption and diffusion of the new technologies linked to the fourth industrial revolution in order to maintain and improve international competitiveness. There is a gap in terms of research on the impact of Industry 4.0 on developing economies and especially in South Africa. Industries and value chains are heterogeneous both in terms of structure and governance so the implications of Industry 4.0 for productivity gains will differ and for this reason, it is important to understand the nature of the changes for different industries including on the organisation of production and value chains. As such the Industrial Development Think Tank (IDTT) supported by the Department of Trade and Industry (dti) has undertaken research deepening understanding of processes of technological change in the context of Industry 4.0 on key industries. This paper builds on year 1 research on the machinery and equipment and incorporates engineering. In particular, the research answers the following questions:

- (i) What are the most important technological changes?
- (ii) What is the local production ecosystems that is required to support upgrading?
- (iii) What policy responses are required to leverage technological developments?

In section 2, we reflect on the frameworks that allow for the analysis of the research questions and set out the study's approach and methodology. In section 3, we conduct an in-depth study of Multotec and its surrounding ecosystem and in section 4 we conduct a similar analysis of

Aerosud and the surrounding ecosystem. In section 5, we compare and contrast the two ecosystems and draw policy insights.

2 Background

Linkages and technological upgrading

In order to capture the interdependence of the changes implied by the fourth industrial revolution we have reviewed conceptual frameworks that explain interrelationships between firms and other economic actors with a particular focus on those that explain technological upgrading through linkages (See Bell et al, 2018 for the full review). There are a few frameworks that allow for capturing this interdependence and linkages including clustering, global value chains (GVCs), innovation systems and ecosystems.

There has also been a convergence of some of these frameworks for example the co-evolution of GVCs and innovation systems and the integration of innovation systems in clustering literature to better explain the conditions for technological upgrading in the context of globalisation including the emphasis on access to knowledge, skills, demand, finance and institutions (Fagerberg, 2016). In all these frameworks value creation, capture and distribution dynamics depend on production and technology linkages. Production linkages represent the input-output relationships inducing backward/forward investments along and across sectoral value chains (both vertically and horizontally) (Adner, 2017 and Andreoni, 2018). Technology linkages represent the technological relationships inducing inter-sectoral learning, indigenous innovation (e.g. product re-engineering), and diversification pathways.

In particular, the concept of ecosystems with regards to production and technological upgrading has gained traction in the era of the fourth industrial revolution. This is because the development and adoption of new technologies often do not take place in isolation rather, it depends on complementary changes in the firm's environment. These external changes, which require technological upgrading on the part of other actors and collaborations with public institutions, embed the firm within an ecosystem of interdependent technology decisions (Adner, 2006). There are also a number of approaches to ecosystems, here we consider business ecosystems and industrial ecosystems. The business ecosystems approach, used in strategic management texts, focus on a focal (lead) firm and its interrelationships and is concerned with interdependencies across actors and activities, value networks, supply chains and technology systems (Adner, 2017). The lead firm within the ecosystem plays an important role in terms of driving suppliers to adopt new technologies through demand pull effects, aligning the research of public institutions with industry needs and introducing the new technologies to customers. The business ecosystem approach allows for an analysis of components suppliers, related services in engineering and design, key customers and procurement and the potential for lateral migration of capabilities.

The industrial ecosystems approach integrates ecosystems with capability theories, structural learning and economic geography (Andreoni, 2018). The framework is rooted in complex systems theories, which highlights that firms should not be viewed in silos, but rather as part of an ecosystem, where they cooperate, compete and co-evolve to create a system of complementary capabilities around new innovations (Moore, 1993). Though this is not a new concept, its application has increased and evolved in the context of Industry 4.0. The

application of the industrial ecosystems framework is fundamentally structured around capability domains (technology platforms) and sectoral value chains, which suggest that firms may operate within one or more defined sectors along different segments of a value chain. The success of the industrial ecosystems rely on the development of closely complementary capabilities; adoption of emerging technologies; and productive governance models that support co-value creation (Andreoni, 2018).

The role of lead firms in supporting technological upgrading

All the frameworks discussed in section 2.1 emphasise the important role played by lead firms (sometimes referred to as focal firms) in ensuring that the collective is able to realise its objectives. Lead firms are described as those firms that occupy strategically central positions because of the greater number and intensity of relationships that they have with both customers and suppliers (Aldrich 1979). This position is usually reinforced by both their technological and organizational capabilities and their greater access to capital (Giuliani, 2005). The concept of lead firms is rooted in the literature on inter-organizational networks (Lorenzoni & Baden-Fuller, 1995; Powell et al., 1996) and growth poles (Erickson, 1972). Lead firms are generally recognized as drivers of economic growth and structural change enabled through their various linkages and ties to other firms and industries. As such the strategies and orientation of lead firms is important for the development path of a country.

In global value chains, the lead firm undertakes the functional integration and coordination of internationally dispersed activities (Gereffi 1999: 41). The lead firm governs the value chain determining the parameters for participation in the value chain and in turn facilitate market access, fast track the acquisition of capabilities, distribution of gains (Humphrey and Schmitz, 2002). In clusters, lead firms facilitate the information flow and gain access to critical information, which then enables them to strengthen the actors located around them and their capabilities (Burt, 1992). The role in ecosystems is discussed in section 2.3. In all these cases, the “systems integration” role of lead firms is critical as part of building capabilities.

As such, in this paper we focus on case studies of lead firms and their surrounding business ecosystem to unpack the process of technological upgrading in the context of the fourth industrial revolution.

Approach and methodology

This paper seeks to understand the process of technological upgrading and the role of lead firms in driving this process within an ecosystem framework. This is done by analysing two lead firms and the related ecosystems using the business ecosystems approach, which emphasises that individual innovations reside within broader systems (Adner and Kapoor, 2010). The approach places the focal or lead firm as the foundation of the ecosystem and considers the links among different actors involved in a co-value creation process (Adner, 2017). The generic ecosystem framework is distinguished by different types of actors operating within a specific sectoral value chain. These are (i) focal firms (system integrators), (ii) suppliers (iii) complementors and (iv) customers (Adner and Kapoor, 2010).

The study thus involves identifying these various actors and linkages. More importantly, it considers the process of technological upgrading and the impact on the ecosystem within

which various actors are embedded. Essential to this is the role of the focal firm and how it engages with the broader ecosystem or creates linkages of value creation (Adner, 2017).

Although the business ecosystem framework is used here, it does not sufficiently explain the set of technology platforms from which a broader industrial ecosystem encompassing multiple sectoral value chains is built. The industrial ecosystem approach (see Andreoni 2017 and 2018) establishes the need to identify technology platforms (or capability domains), as well as consideration of other supporting structures and organisations linked to technological upgrading (which can be seen as complementors in a business ecosystem perspective). The study therefore identifies the key technology platforms for each lead firm, to understand how they engage with the technology upgrading process both internally and with the broader ecosystem but does not fully adopt the industrial ecosystem approach which would require the inclusion of multiple sectoral value chains that are linked through the technology platforms.

The in-depth studies of the two business ecosystems are undertaken to understand the different elements needed to drive effective technological upgrading. First, an in-depth analysis of Multotec, a local lead firm in mineral processing that is already leveraging Industry 4.0 technologies. Multotec was identified on the basis of past research in the mineral processing industry, which shows that the firm has continued to grow its market share in the regional and international market on the back of technological advancements (Rustomjee *et al*, 2018 and Langa *et al*, 2018). The selection criteria is informed by Multotec's heavy investment in R&D competencies, grown export markets and leveraged capabilities to expand into related markets. The analysis of Multotec's business ecosystem is done with comparisons to a multinational (Weir Minerals) also in mineral processing, and a small local firm, also in the mineral processing cluster of activities (Curo Pumps).

Second, a lead firm in the aerospace industry focusing on aeronautical engineering, Aerosud, is analysed for the purpose of understanding a distinct ecosystem that is part of an international value chain. Aerosud is a supplier to Airbus and Boeing and a founder of the 4IR RSA Forum. Its technology linkages with public institutions makes it a relevant case for understanding the role played by these institutions in local production ecosystems.

A comparative analysis is used to demonstrate how Multotec and Aerosud operate differently as lead firms in their respective sectors. This is essential for drawing out specific types of policies that each lead firm, operating in two distinct ecosystems could benefit from.

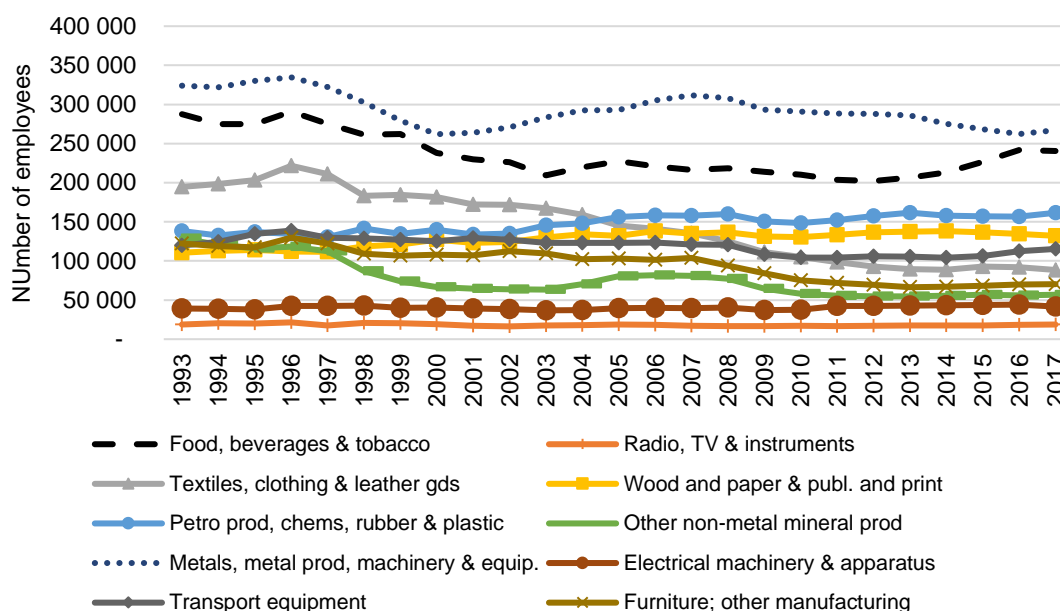
Primary data was collected through interviews, administered with questionnaires with lead firms, their suppliers and support institutions including universities, science councils and government entities. A total of 13 in-depth interviews were conducted (see Annexure 1).

The Machinery and Equipment and Aerospace industries in South Africa

To give some context to the case studies we briefly describe the machinery and equipment and aerospace industries in South Africa reflecting industry performance. Machinery, and equipment products are intermediate goods and are key industries for technological change as they combine a range of sophisticated and complex technologies. South Africa's machinery and equipment sector has a developed industrial base and encompasses the manufacture of

machinery such as mineral-processing equipment, pumps, valves and earthmoving equipment. Machinery and equipment systems have strong backward linkages to the metal products industries. The entire value chain accounts for the largest source of formal employment in South African manufacturing, contributing 267,000 direct jobs in total, of which the machinery and equipment accounts for 42% (Figure 1).⁷

Figure 1: Manufacturing employment in South Africa, 1994-2017



Source: Quantec (<https://www.easydata.co.za>)

The industry also has strong linkages with supporting industries such as engineering services, transport and logistics, and financial services, inducing further employment.

A closer look at product groupings in which South Africa has developed capabilities, reveals that in Zambia, the largest African export market, though exports have grown in absolute terms, South Africa's market share has declined. For machinery and equipment, the share has fallen from 44,5% in 2002 and 31,7% by 2018. A closer look at the groupings reveals even more alarming trends. Mineral processing equipment declined from 77,5% in 2002, to 19,3% by 2018. An exception is with pumps and valves, whose market share has increased from 64,1% to 68% (Table 1).

Table 1: South Africa's share in Zambia imports for selected product clusters

	2002	2008	2013	2014	2015	2016	2017	2018
Machinery and equipment⁸	44.5%	37.7%	31.1%	35.9%	34.7%	36.3%	35.1%	31.7%

⁷ Rustomjee, Kaziboni & Stuart. (2018). Structural transformation along metals, machinery and equipment value chain – Developing capabilities in the metals and machinery segments. CCRED Working Paper 2018/7.

⁸ Products under heading HS84 'Machinery, mechanical appliances, nuclear reactors, boilers; parts thereof.'

Mineral Processing⁹	77.5%	52.4%	28.2%	26.7%	36.8%	34.1%	23.1%	19.3%
Off-road special vehicles¹⁰	59.5%	63.3%	58.3%	78.15	60.3%	41.9%	53.9%	41.1%
Pumps and Valves¹¹	64.1%	61.6%	51.6%	62.0%	74.9%	63.8%	71.5%	68.0%
Conveyor systems¹²	62.0%	65.4%	42.2%	55.4%	40.4%	44.6%	29.5%	36.8%

Source: ITC Trade Map (<https://www.trademap.org>) accessed in 2018

The aerospace industry has also exhibited mixed performance since 2001. The exports of powered aircrafts reached US\$582 million in 2005, which was driven by an increased demand of aeroplanes and other powered aircraft of an unladen weight to India, Netherlands, Seychelles and Angola. Since then, the exports have not reached those values likely because the exports were order based. The exports of parts, on the other hand, has been increasing at a compounded annual growth rate of 15% between 2012 and 2017.

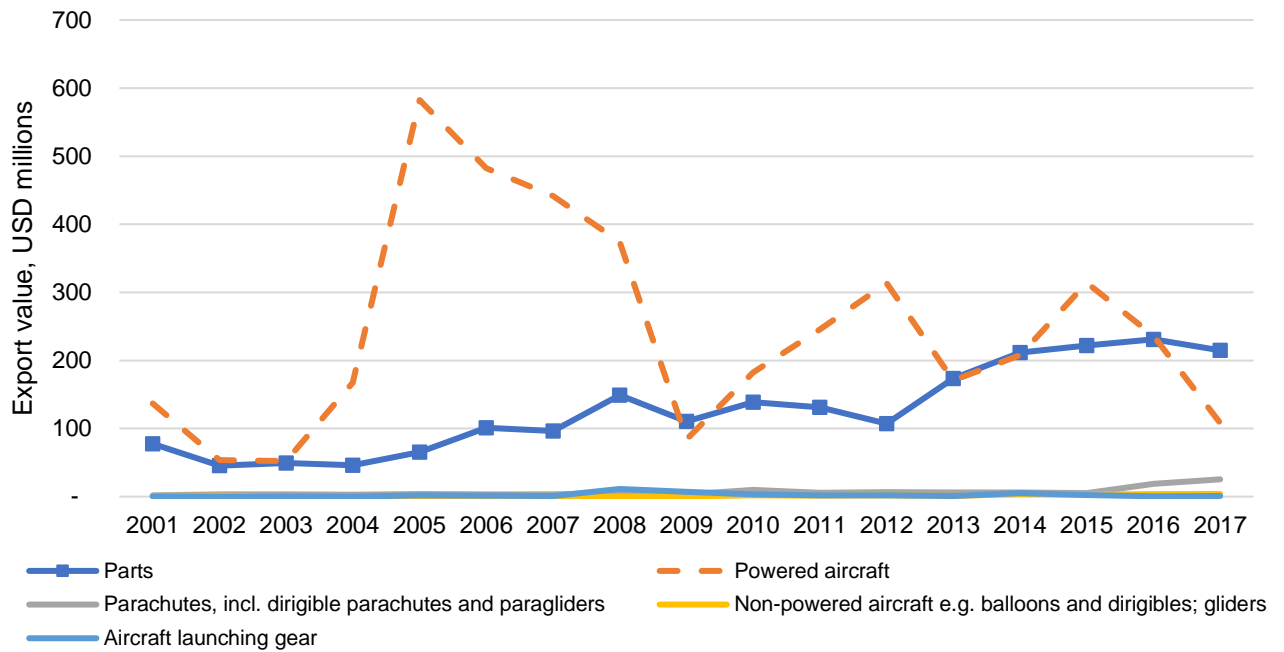
Figure 2: Exports of aircraft, spacecraft, and parts thereof (HS88) to world

⁹ All products under heading HS 8474 'Machinery for sorting, screening, washing, agglomerating, shaping mineral products'.

¹⁰ Products under headings HS 870421 'Diesel powered trucks with a GVW not exceeding five tonnes' and HS 870410 'Dump trucks designed for off-highway use'

¹¹ Products under the following headings: HS 848180 'Taps, cocks, valves and similar appliances, nes'; HS 848190 'Parts of taps, cocks, valves or similar appliances'; HS 841391 'Parts of pumps for liquid whether or not fitted with a measuring device'; HS 841381 'Pumps nes'; HS 841370 'Centrifugal pumps nes'

¹² Products under the following headings: HS 401011 'Conveyor belt metal reinforced vulcanised rubber'; HS 401012 'Conveyor belt textile reinforced vulcanised rubber'; HS 401019 'Conveyor belts of vulcanised rubber nes'; HS 591000 'Transmission or conveyor belts or belting of textile material'; HS 842320 'Scales for continuous weighing of goods on conveyors'; HS 842820 'Pneumatic elevators and conveyors'; HS 842820 'Pneumatic elevators and conveyors'; HS 842831 'Continuous action elevators/conveyors for goods/mat spec design for u/grd nes'; HS 842833 'Continuous action elevators/conveyors for goods/mat, belt type nes'; HS 842839 'Continuous action elevators/conveyors for goods/mat nes'; HS 842890 'Lifting, handling, loading or unloading machinery nes'



Source: ITC TradeMap

The lead firms that have maintained market share in the region and elsewhere have continuously upgraded their capabilities and this includes investing in the latest technologies. We address the question at hand by undertaking a detailed case study of a lead firm in the industry in order to understand the factors that have supported technological and capability upgrading and compare the experience to a second lead firm.

3 Business ecosystem 1: Mineral process equipment

The first lead firm that we consider is Multotec Group in mineral process equipment. The case study highlights a number of critical issues for driving technological upgrading within ecosystems. First, it shows how its linkages to international stakeholders have been key for driving the development of technology and determining its global positioning in a competitive market. Second, the ability for Multotec to internalise its capabilities has allowed for continuous skills development (especially important given industry wide shortages), investments in R&D, and the upgrading of suppliers in its ecosystem. Finally, the role of support institutions, particularly through Multotec's affiliations with universities, has served to strengthen this ecosystem further.

Multotec history and evolution

The Multotec Group (Multotec) was established in 1974 and is headquartered in Johannesburg.

Multotec is an interesting case, partly because the firm has grown over the last two decades unlike the aggregate machinery and equipment industry in South Africa. The firm grew its annual turnover from a R100 million in the late 1990s to R2 billion in 2018. In the same period, the staff complement increased from less than 200 to 1,800 employees (of which 1,200 are

located in South Africa). In 2018, the group had offices in various African countries (Botswana in Orapa, Letlhakane, Jwaneng; Ghana in Accra; Mozambique in Tete; and Zambia in Chingola and Kitwe, as well as operations in Australia (Brisbane), South America (Chile), Canada (Montreal, Edmonton and Vancouver), China (Tianjin) and Europe. Much of Multotec's production is undertaken in South Africa with the branches mostly operating as service centres that do limited manufacturing and focus on assembly and service repairs.

The firm's global growth was initially driven by the internationalisation of South African mining houses such as Kumba (Roberts, 2005), however, overtime it has been more intentional. The firm's strategies have been influenced by the ownership and governance of the firm. Multotec is a family-owned business with 88% German shareholders (who are also family owned). Its shareholders made the initial capital injection and thereafter Multotec funded its own growth and assets. Multotec is thus a self-funded business that has adopted a very conservative, German business model. This has contributed to the firm's long-term approach to investing in developing internal and organisational capabilities, as well as adopting global technologies. The firm's ability to sustain its innovation processes and financial stability therefore needs to be understood in terms of its ownership structure.

The firm's activity base lies in engineering and manufacturing of application-specific process equipment solutions for the mining, mineral processing industry. Multotec has developed design capabilities used in the pre-manufacturing phase, manufacturing capabilities maintained by investing in world class machinery, as well as technical and engineering expertise as part of its after-sales offering.

Multotec's key technology platforms and the key technologies that have developed over the last 15-20 years that are impacting the firm today include accelerating design to production processes through additive manufacturing, as well as the need for optimal machine operation to measure, control and predict failures in remote mining locations.¹³ Investing in world class machinery has also been an important part of the firm's upgrading process. The key elements in the processes above are digitalisation and the use of data. These requirements induced innovative changes in the systems and processes of OEM's, like Multotec.¹⁴

The Group's processing solutions (distinguished between capital equipment and consumables) include screening media, mineral processing equipment (cyclones, samplers, spirals, filter pressers, magnetic separators and conveyor systems) and even armour protection products (Annexure 2).

The firm has also migrated laterally to provide solutions for petrochemical, food processing, process water treatment, defence and power generation industries. Lateral migration is taking place in a small product range, mainly in centrifugal pumps. The key factor informing the diversification of Multotec's product portfolio is that the underlying capability, function and know-how (including specialist engineering capabilities), is transferable across these industries.

¹³ Interview with Multotec, 29 May 2018.

¹⁴ Roche, M. (2018). The fourth industrial revolution – hype or reality? A mining perspective. Multotec presentation at the Leadership Forum.

Multotec exports to a number of countries¹⁵ and also has branches across the globe, as mentioned above. The Group's performance is closely linked to the mining industry and for this reason, the firm undertook a strategy that uses the commodity price cycle as a planning tool to diversify its products and markets. The evolution of Multotec's geographical footprint has been key for circumventing the impact of a declining local mining industry, decimated by poor legislation and a lack of foreign direct investment. The firm notes the importance of the regional export market (Zimbabwe, Botswana, Namibia and Zambia) for maintaining and increasing its competitiveness and has subsequently set a target to expand its exports to 70% of its sales (from its current level of 50%) by 2025.¹⁶

Locating Multotec as a lead firm in the business ecosystem

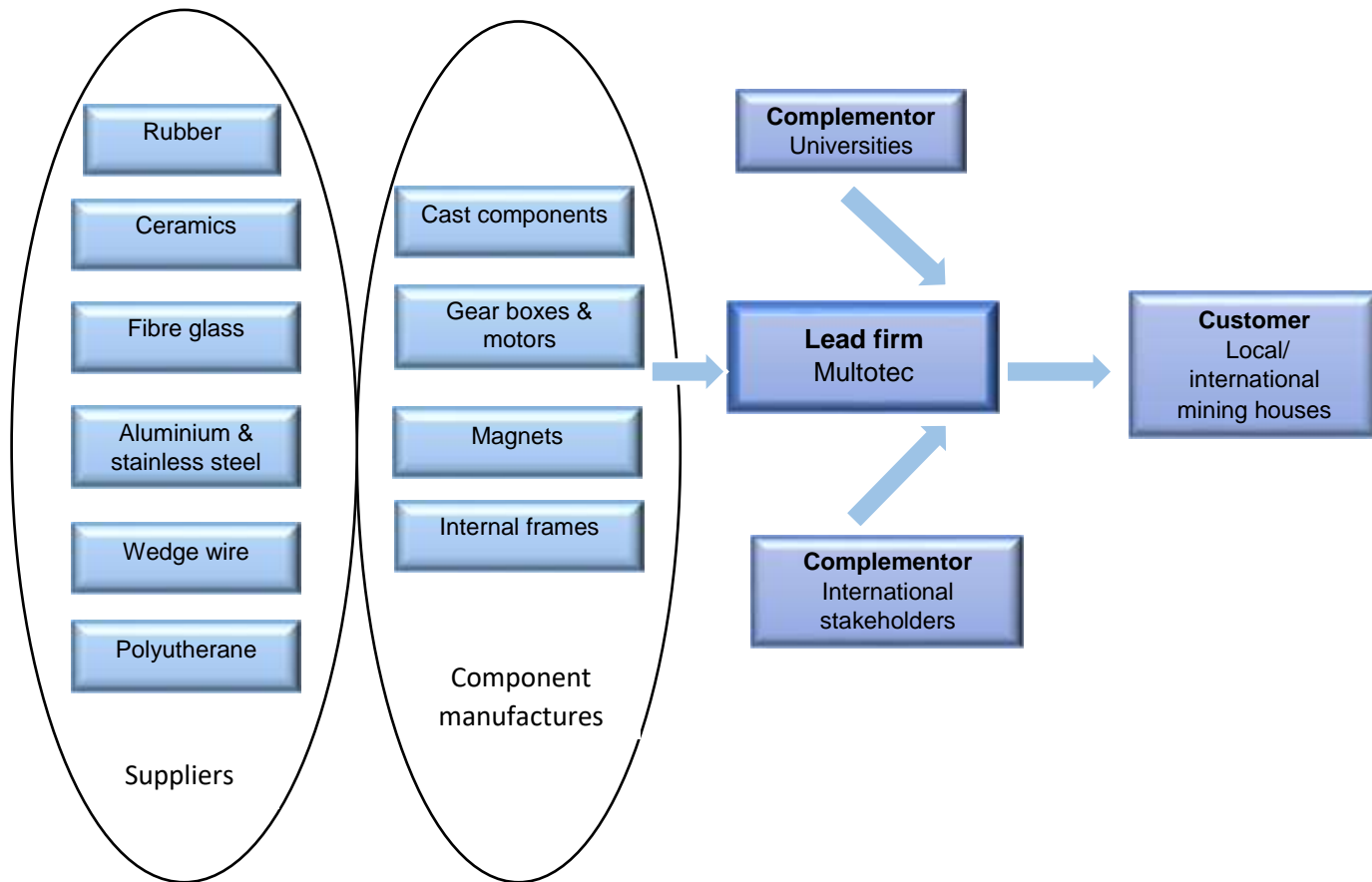
Multotec's ecosystem consists of a network of supply and demand-side actors involved in (direct and indirect) interdependent activities that facilitate a value creation process. Figure 3 below locates Multotec as the focal or lead firm in its ecosystem with linkages to suppliers, customers and complementors spanning from the firm. Multotec is positioned as a lead firm in mineral processing to the extent to which it operates in several markets, but also playing the role of the lead firm by providing a full suite of solutions to its local, regional and international customers. Multotec supplies mining houses with capital equipment and consumables, along with full engineering and after-market solutions.

The firm sources its components and raw materials from a network of suppliers and component manufacturers. This includes raw materials such as polyurethane, raw rubber and ceramics which constitute 80% of raw materials that are imported. Multotec has not only integrated forward (providing after-sale engineering services to mines) but also backwards into manufacturing its own materials (such as rubber and ceramic lining) locally. Iron castings from foundries and some specialised components (robotic welded internal frames) are also supplied by local firms.

¹⁵ Export markets include the SADC region (17%), Rest of Africa (45%) and the Rest of the world (35%) including Australia, South America, North America, Europe, Asia, Middle East and Russia.

¹⁶ Interview with Multotec, 27 August 2018.

Figure 3: Multotec's business ecosystem



Source: Author's representation using interview information

Actors outside of Multotec's direct supply chain also play an important role in the firm's technological upgrading. Multotec's direct and indirect relationships with universities and international stakeholders, positioned as key complementors in Figure 3, have allowed the firm to leverage advances in technology. Institutional linkages with both local and international universities have also created space for R&D collaboration and access to capital equipment for new product development.

To remain competitive Multotec has therefore had to continuously and incrementally upgrade its capabilities. The firm's technical upgrading process has generally occurred over a ten year period. Its ability to provide its markets with a full suite of solutions has depended heavily on internal capabilities (including technical skills and technologies). Its key complementors have also been fundamental to creating value in its ecosystem.

Technological upgrading

We categorise the way in which the lead firm has engaged with the technological upgrading process as internal, external and institutional drivers.

3.1.1 Internal

The main technology-driven changes and innovations include (i) additive manufacturing for rapid prototyping and tool making, (ii) predictive maintenance and monitoring systems and (iii) optimising new and old machinery and equipment. In addition, a shift towards production-related high value services has also been a strategic part of Multotec's offering. These internal drivers of technological upgrading and their impacts on Multotec's ecosystem are discussed below.

Additive manufacturing and rapid prototyping

Value creation in the mineral processing industry requires customisation, hence the importance of continuous, rapid prototyping capabilities.¹⁷ Additive manufacturing, commonly known as 3D printing, has disrupted design and prototyping. First, additive manufacturing has significantly reduced the design and prototyping process. Multotec adopted additive manufacturing for prototyping six years ago and this has reduced time spent on manufacture and testing a prototype before full scale manufacturing from six to eight weeks to two to three days.¹⁸ Multotec is using 3D printing for manufacturing complex moulds for screen panels, and components for cyclones and samplers. This requires significant design capabilities.¹⁹ The use of traditional, (but computerised) manufacturing technologies have also allowed for rapid prototyping.

Second, 3D printing is likely to drive innovations in material science. Access to materials for 3D printing creates a barrier to making 3D printing a mainstream production process. Currently, materials for 3D printing are being imported.²⁰ However, various institutions are researching the potential for making some additive materials locally. In the case of Multotec, a good proportion of their raw material (80%) is imported, so the likely impact on its supply chain may be minimal, as it will require the firm to make significant investments in materials (e.g. polymer or metal based) for additive manufacturing.

Third, the combination of additive manufacturing and virtual simulation software has meant that a firm can go from design to production of tools without the need to have numerous prototypes. With virtual simulation of the production process, product designs can be tested to ensure peak performance, without 3D printing a prototype.²¹ Once the simulation is satisfactory, the design can then be manufactured, eliminating waste and reducing production time. Indeed, smaller firms are looking into running 3D designs under simulation using engineering simulation and 3D design software (such as Ansys).²² Such firms have only used 3D printing on a small scale to test designs (in this case done under a specialist programme with the University of Johannesburg). Although there are existing public institutions such as

¹⁷ <https://www.multotec.com/content/3d-prototyping>.

¹⁸ Interview with Multotec, 7 August 2018.

¹⁹ Interview with Multotec, 29 May 2018.

²⁰ Raw industrial materials used by Multotec include steel products (stainless steel and aluminium), polyurethane, raw rubber, fibre glass, composite materials, wedge wire and ceramic. Of these, polyurethane, raw rubber and ceramic constitute 80% of raw materials that are imported. Most steel products are sourced locally (through Columbus Steel merchants), but some high quality steel grades that are not available locally are imported (through distributors).

²¹ Interview with VUT, 24 October 2018.

²² Interview with Curo Pumps, 14 November 2018.

VUT and the Central University of Technology that can support this, there has been limited collaboration with industry.

Fourth, and outside of 3D printing technologies, Computer Numerically Controlled (CNC) machining has also created opportunities for prototyping. At the foundry level, Weir Mineral's (through its Weir Heavy Bay Foundry) investments in CNC milling machines - for accurate cutting of once-off polystyrene castings, also allows for rapid prototyping required in new product development.²³ Software that accurately simulates casting methods, has also reduced time to market of new product introductions. Multotec similarly uses CNC technologies, but for the development of tooling.

Fifth, additive manufacturing can be seen as an opportunity to print tools such as moulds, in which South Africa has failed to achieve competitiveness despite multiple interventions. Tooling design is a crucial part of product manufacturing, and its initial investment can cost more than the value of a machine. In protecting IP, larger firms keep this task in-house.²⁴ Multotec has over the years invested extensively in new tooling to respond to market demands for specialised and complex applications.²⁵ 3D printing technology also allows firms to produce prototypes before any investments in tooling are made.²⁶ At a broader scale, South Africa's tooling industry is losing competitiveness, and despite the National Tooling Initiative, the industry is weakening. This is in stark contrast with Germany's tooling industry that is highly efficient and produces quality tooling that complements the high performance of its machinery, equipment and electronics industry.²⁷

The combination of 3D printing and tooling suggests that efforts should be made in sourcing materials that are better suited to 3D printing. Polymers, wax, sand and metal powder can be used to manufacture moulds with relative ease, and at reasonable costs – metal 3D printing is in its infancy and is still relatively expensive.²⁸ Previously sand suitable for 3D printing moulds used in sand casting was imported from Germany. This obviously resulted in high costs given the density of sand and associated shipping costs. VUT devised an import-replacement solution. The sand on the shores of Western Cape, when combined with an acid is suitable for manufacturing moulds. This development reduced the costs of sand from R1 000 per tonne to approximately R25. The next stage is to undertake 3D printing of material products that require metal dust. Localising sand and metal dust for 3D printing moulds can create new industries and substantially increase competitiveness for local firms in rapid prototyping. In the next year or so, VUT is planning on locating a sand 3D printing station close to a number of foundries, to reduce travel time and cost as well as damage given the fragility of sand moulds.

In some markets, firms are clearly already using additive manufacturing for production of customised parts and high value intricate parts. It is predicted that in the next ten years the bulk of manufacturing of certain components will be done through 3D printing.²⁹ Firms that are using older ways of prototyping are going to lag by about six weeks in producing prototypes

²³ <http://www.miningweekly.com/article/heavy-investment-into-weir-heavy-bay-foundry-2016-10-03>.

²⁴ Interview with Multotec, 7 August 2018.

²⁵ http://www.miningweekly.com/article/company-announcement-multotec-expands-cyclones-technology-into-non-traditional-minerals-market-2012-12-04/rep_id:3650.

²⁶ <https://im-mining.com/2018/07/16/3d-printing-helps-multotec-develop-test-spirals-cyclones/>.

²⁷ <https://werkzeugbau-akademie.de/wp-content/uploads/sites/17/2015/06/Webversion-Tooling-in-Germany.pdf>.

²⁸ Interview with VUT, 24 October 2018.

²⁹ Ibid.

and this may make them competitively irrelevant in the future Manufacturing replacement parts, that is, once-off parts or smaller production batches, has become cheaper given that parts can be manufactured at lower units without setting up a production process that requires scale. This illustrates that additive manufacturing presents a lower barrier to entry into manufacturing.³⁰

Moreover, given the high cost of steel and energy in South Africa, 3D printing gives component manufacturers more scope to manufacture efficiently, even setting up shop closer to their customers. An important implication is that regional demand is very important for SA firms as they can be close to their customers and also close to their main production facilities in Gauteng. Regionally integrated supply networks and value chains are/can be, an important aspect of South Africa's upgrading. This technology has important implications on restructuring global production, becoming a decisive factor in how value is created and distributed across global value chains (Rodrik, 2018). Another implication for South African firms is the importance of regional demand and the opportunity to be close to their customers, as well as main production facilities in Gauteng. Regionally integrated supply networks and value chains can be an important aspect of firm upgrading in South Africa.

Predictive maintenance and condition monitoring systems

Predictive maintenance and condition monitoring systems can dramatically improve competitiveness in providing solutions to customers. Through reliable internet connectivity, mineral processing firms can collect real time data on the health and performance of machinery and equipment remotely, and how the environment including temperatures, pressure and humidity, can affect its wear and tear. This uses a combination of Industry 4.0 technologies including, sensors, big data, cloud computing, data analytics, IoT and artificial intelligence (AI).

Predictive analytics and the application of condition monitoring systems use cloud-based programs that can be linked to most processing equipment using sensors.³¹ Monitoring equipment and real time feedback has occurred on the back of falling costs of sensors that continuously transmit data with low power and bandwidth requirements. For multinational firm and competitor to Multotec, Weir Minerals, such technology platforms are a key focus, allowing their customers (mining houses) to reduce downtime, improve longevity of equipment.³² Predictive maintenance and monitoring systems have allowed mines and other customers to reduce costs by preventing unplanned downtime, inspecting wear rates, indicating possible design improvements, and reducing manufacturing waste with pre-determined sizing.³³ It is important for firms to demonstrate predictive maintenance capabilities to be able to win new business and, in the near future, firms that do not have these capabilities will be competitively irrelevant.³⁴

New systems and technologies are easing the condition monitoring process for firms. These developments are especially allowing firms to quickly gather data and monitor equipment

³⁰ <https://www.arnoldmachine.com/6-exciting-advances-manufacturing-automation/>.

³¹ <http://www.miningweekly.com/article/pumping-solutions-positioned-to-address-most-pressing-needs-2018-02-02>.

³² <http://www.miningweekly.com/article/pumping-solutions-positioned-to-address-most-pressing-needs-2018-02-02>.

³³ <https://www.multotec.com/content/condition-monitoring>.

³⁴ CCRED Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

remotely and more efficiently. Multotec's current condition monitoring system (Hawke Eye) is a web-based system that uses manual inputs. Accelerometers are placed into their equipment (panels) and the data is collected. The system is primarily used for inventory management and the challenge with this approach is that it is susceptible to human error.³⁵ However, condition monitoring systems have developed overtime and there are accrued benefits from newer applications. Multotec is therefore engaged in a 3-year process with the University of Cape Town's physics department and private firm, Reality AI to develop a cost-effective sensor that can be used as a predictive software tool. The sensors required for condition monitoring in mines are not available off-the-shelf and firms need to go through a process of testing and developing an applicable solution.³⁶

Predictive maintenance and monitoring systems have been a game changer and a firm that does not offer these capabilities will be competitively irrelevant in the next 5 to 10 years. Wider adoption of the technologies that support these capabilities is a crucial component of a strategy to regain regional markets and achieve international competitiveness.

Connectivity is central to any predictive maintenance and condition monitoring application and systems are increasingly centred on data availability and the analysis of data. Monitoring and control makes connectivity central, and this is an area where there is a notable shortage of capabilities (i.e. data scientists and analysts).³⁷ Future developments will include the adoption of new formulations for telematic technologies and hardware platforms that can support different communication networks (Wi-Fi, Bluetooth, 3G/5G).³⁸ The increasing use of mobile applications also gives customers direct access to an interface with machinery. In the context of digital and supply chain collaboration, open source software and systems integration reduces the development cost of applications and time to market, delivering innovation and productivity in this market.³⁹

In South Africa, the adoption of predictive maintenance and monitoring systems highlights a few issues. First, the cost and availability of bandwidth in South Africa lags behind most middle-income countries.

Second, operating these machines and analysing the data requires specific skills such as IT, data analysts, scientists and artisans with IT capabilities, which South Africa lacks. While such a technological leapfrog can result in substantial economic benefits, it needs to be complemented by skills, especially IT-related competencies.⁴⁰

Third, data ownership. An important question that relates to big data is who owns the data? If an OEM is collecting information of the integrity of their machinery at their own cost, then the data is owned by the OEM. However, if the OEM decides to share the data with a third firm, the customer would need to grant permission and the OEM would need to anonymise the data. In South Africa, this closely resonates with the Protection of Personal Information (POPI)

³⁵ Interview with Multotec, 14 November 2018.

³⁶ Multotec believes that they are 4 months away from a prototype and 18 months away from production.

³⁷ Interview with Weir Minerals Africa, 29 October 2018.

³⁸ CCRED Industry 4.0 Autos Dialogue, 18 October 2018.

³⁹ This will allow for operator logbook, machine customisation, parts ordering, electronic training manuals, machine safety and site traffic management.

⁴⁰ <http://www.smallake.kr/wp-content/uploads/2017/05/P020161223538320477062.pdf>.

Act. This has important implications for existing data protection legislation that needs to keep abreast with changes in technology to facilitate trusted data sharing networks.

Optimising new and old plant machinery and equipment

Despite advances in robotics and automation, firms are finding ways to integrate old technologies with the latest machines in the production process. Multotec still uses injection moulding machines and rubber pressers that are approximately 50 years old. This machinery is still able to provide the adequate pressure and temperature required for the manufacturing of screen panels. However, the machines' tooling is updated frequently to enable them to manufacture competitive products. At the same time, new co-injection moulding machines are being used for rubber panels, though not to the machines' full capabilities. These two processes require upskilling, and in this case investing in knowledge transfer between locals and international experts.⁴¹

However, a key technology game changer for Multotec was its injection moulding rubber machine, furnished with new German imported technology, which Multotec acquired through a German partnership in 2010. Previously the firm produced 2,500 (and a maximum of 4,000) injection moulded panels per year. Multotec is now manufacturing 24,000 panels per month using 6 machines, and more advanced technologies. This has allowed the firm to penetrate markets they otherwise would not have been able to enter.

The constant requirement to stay up-to-date and operate the latest machinery and equipment can also result in a polarisation of the industrial base where smaller firms are not able to afford the technological upgrading required (Sturgeon, 2018). For example, CNC machining is gradually replacing conventional manually operated machines and increasing production efficiencies and volumes. This requires strong support for new equipment financing to allow firms to leverage technological changes.

Furthermore, the combination of old and new machinery has proven to be important for smaller firms who are able to re-arrange their production lines to accommodate clients needing urgent repairs. This is harder to effect with more rigid production plants. South African mines demand a quick turnaround time and manual machines are used for these customised repairs. This flexibility is key for maintaining their market.⁴²

The total solution ecosystem

Developments in technologies are introducing new business models and diversifying value streams. This is creating a convergence between industrial manufacturing and service processes. Firms that previously had manufacturing as a core-competence are able to enter other stages of the value chain. The integration of design, manufacture and after-market support (including engineering services) is becoming more evident.

Within the mining machinery and equipment industry, the aftermarket services are a key part of providing a total solutions package. For processing equipment, the size of after-market revenues can be between 13 and 15 times the initial capital cost and installation, hence they offer sustainability for firms. Aftermarket services, together with quick lead times are critical

⁴¹ Interview with Multotec, 29 May 2018.

⁴² Interview with Curo Pumps, 14 November 2018.

determinants of firm competitiveness.⁴³ With advances in technology, firms have moved from simple installation and repairs to the use of monitoring, control and predictive analytics systems (discussed above), which are becoming part of a package of capabilities in the provision of aftermarket services.⁴⁴

In the case of Multotec, its after-sales business component has changed with advances in technology. Previously, the firm would sell and replace products, but now installs, services and monitors equipment. The model changed significantly in the last 10-15 years. Over the years, mining houses have become more involved with administration processes and less with in-house mineral processing and engineering services, resulting in a loss of on-site capabilities. Multotec therefore began offering these solutions to the mines, where they have teams on site. This has minimised downtime and resulted in swift responses which are beneficial to the customer. Similarly, Weir who has been well known for supplying pump technology and equipment, has now positioned itself as an integrated total solutions provider.⁴⁵ This also appears to be giving smaller firms, like Curo Pumps, a competitive advantage in the market.⁴⁶ Such a strategy creates added value to support the client and better integration between operations.

3.1.2 External

This section discusses technological upgrading that has developed around Multotec's business ecosystem. It shows how the impact of the technologies associated with Industry 4.0 can be used to facilitate process optimisation and supply chain integration. This is explained using two cases for capability upgrading along Multotec's supply chain. The importance of internationalisation for driving firm innovation and the adoption of a global benchmarking strategy are also key determinants for technological adaption and Multotec's competitive strength.

Supply chain integration and digitalisation

The first modality for capability upgrading relates to Multotec's supplier of rubber compounds - National Rubber Matmin (NRM). Multotec became the biggest customer of rubber compounding firm NRM, making up 67% of its rubber compounding business, which is also a very niche and specialist area. Following this, Multotec's shareholders were concerned about securing rubber supply and integrated the two businesses through cross shareholding.

This vertical integration suggests a higher level of control and coordination between lead firm and rubber supplier in Multotec's ecosystem. Multotec, for example, manufactures the tools required for rubber manufacturing, in consultation with NRM. Multotec also invested in the machines used by the rubber compounder.

NRM has further made significant strides in optimum material manufacture, such as the development of both heavy-duty and light-duty rubber screen panels using a variety of

⁴³ Fessehaie, J. 2015. Regional industrialisation project: Case study on the mining capital equipment value chain in South Africa and Zambia. Working Paper 1/2015.

⁴⁴ Interview with Multotec, 12 July 2018.

⁴⁵ Interview with Weir Minerals Africa, 29 October 2018.

⁴⁶ Interview with Curo Pumps, 14 November 2018.

compounds.⁴⁷ A bulk of NRM's screen panels are sold to Multotec, according to specific mineral properties, which is important for Multotec's diverse product portfolio. NRM has developed the necessary capabilities to develop in-house formulations and testing and is able to run in-house tests for resistance, hardness and gravity, routine tests for physical properties e.g. elongation, stretch and abrasion.

Multotec's rubber plant, together with its NRM business, which has been adopting new technology applications, generates R200m a year.⁴⁸ Although Multotec makes up a significant portion of NRM's business, this value creation has potential spillovers into NRM's broader ecosystem. The potential for lead firms to be involved in upgrading the capabilities of firms in their ecosystem is an important aspect.

A second, and different modality for capability upgrading in the supply chain developed as a result of Multotec's demand for precision manufacturing (to mould internal frames). A small component manufacturer of Multotec developed capabilities in robotic welding solutions. Multotec stimulated investments by its component manufacturer, to improve its welding process, indicating the role of technology in upgrading production processes and integrating firms within an ecosystem. A globally integrated firm can thus be an important source of demand driven innovation, building up other domestic supplier firms to become globally certified to service both themselves and other clients. This strengthens the local skills base, broadens opportunities and the potential for jobs.

Supply chain integration is a key enabler of efficiencies and collective upgrading for both larger and smaller firms. Suppliers have to be integrated into processes, standards and quality required by the end user (mining houses). As in the case of robotic welding, capacity is being built along Multotec's supply chain to allow for this.

The factors that make capability upgrading along the supply chain possible are digitally networked information and communication applications. Of course, the level of digitalisation and integration varies across manufacturing firms. Although capability upgrading has taken place in the two cases above, unlike Aerosud (discussed below), Multotec is not at present, actively integrating its systems with suppliers.

Smaller manufacturers of mineral process equipment are still in the early stages of integrating their supply chain (possibly in the third industrial revolution) and their challenges are seldom about the implementation of advanced applications, but more around basic elements of internal systems and processes. For such firms, accelerating the digitalisation of processes related to ordering, standardised quoting and stock taking applications are essential. Customer relations and other software packages are not readily accessible to smaller firms and as a result their business processes are never fully integrated. This is largely due to the cost attached to purchasing such software, which can come up to R1.5m.⁴⁹ Moreover, firms in the industry often require customised packages with specialised functions and engineering (and not standard, off-the-shelf packages), which may raise costs even further.⁵⁰ Without this financial muscle, such firms develop specialised software tools using internal human resources and capabilities. Other firms could otherwise be put at a disadvantage because they

⁴⁷ <https://www.multotec.com/content/manufacturing-capabilities>.

⁴⁸ Interview with Multotec, 12 July 2018.

⁴⁹ Interview with Curo Pumps, 14 November 2018.

⁵⁰ <https://za.syspro.com/dl/AR/SYSPRO-TechVentive-2015-SYSPRO-Machinery-and-Equipment-IM-AR.pdf>

would be forced to carry out these processes manually and may also not have internal skills to programme such a software.

Optimising linkages between firms requires an integration of systems that allows access to information and data across firms. The level of information sharing that is taking place in these integrated platforms is allowing firms within a single ecosystem to support capability upgrading. The structure and relationships between firms in an ecosystem can therefore serve as value creation linkages that strengthen ecosystems.

Internationalisation and technological know-how

Leveraging intellectual property (IP) is important for building a strong core of innovative firms. An open approach to innovation should in principle encourage firms to engage with various actors, resources and activities in an ecosystem. However, infringements on IP (through reverse engineering) in South Africa, more broadly, hinders on the incentive to design innovative products. Smaller firms in the machinery and equipment sector therefore suggest that patents are not worth the spend, affecting the development of new products and applications and the potential to drive value creation.⁵¹ Moreover, there is a clear emphasis on the need for firms to be internationalised to draw on technologies and know-how from developed markets (e.g. Germany and Australia). Multotec's internationalisation strategy, which embodies cluster relationships, sourcing of latest machinery and technology linkages helped leverage the learnings in their global businesses to remain competitive. The firm's expansion into Australia, in particular, was a turning point both in terms of strategies adopted and firm performance.⁵²

While internationalisation matters for technological upgrading, concerns over IP have meant that long-term relationships and closer (supplier) linkages are also important for incremental product development. For example, a small firm has had to build a 25 year long relationship with its key supplier, in this case a foundry, to ensure that their casting designs (IP) are kept on site. Although the foundry is a completely separate business, it has become integral to this ecosystem.⁵³

Multotec's global competitive benchmarking strategy has also been vital for allowing the firm to be agile and adaptive to technological change, and also establishing an internal culture of continuous improvement. The firm benchmarks itself against international firms, by determining whether they can manufacture at a competitive price and produce better quality products. These "soft" issues have been important for maintaining the firm's competitiveness levels.

3.1.3 Institutional

Understanding the relationships both within and outside the firm's direct supply chain are central to the ecosystem analysis. Institutional factors reinforce the ability for Multotec to leverage technological developments in the digital era. The orientation of the lead firm especially with regards to its R&D competencies, and the strategic priorities of support institutions such as universities are instrumental in facilitating this. Together, these elements

⁵¹ Interview with Curo Pumps, 14 November 2018.

⁵² Interview with Multotec 29 May 2018.

⁵³ Interview with Curo Pumps, 15 August 2017.

require greater levels of collaboration between actors, activities and resources embedded in its broader ecosystem.

Multotec balances its benchmarking strategy, described above, with R&D centres and collaborations with a number of universities (Table 2). VUT as a support institution, is equipped with specialist skills and R100-120m in capital equipment for new product development. Within VUT's Science and Innovation Park, 3D printing is being combined with machine learning, allowing 3D printers to correct for errors while manufacturing to reduce waste.⁵⁴ Such developments represent an important and existing resource that can be leveraged by Multotec and the industry at large.

Table 2: Multotec's institutional linkages

Entity	Areas of engagements
Local universities: <ul style="list-style-type: none"> - Vaal University of Technology - North West University for coal - University of Pretoria for coal and metallurgy - University of Cape Town - Stellenbosch University - University of Johannesburg 	<ul style="list-style-type: none"> - Research and development - Engagements with key process engineering professors - Information exchange around industry developments, identification of specific university programmes and research areas for students - Development of sensors (with private firm Reality AI)
International universities: <ul style="list-style-type: none"> - University of Queensland, Julius Kruttschnitt (JK) Mineral Research Centre – Australia 	<ul style="list-style-type: none"> - Research and development
Mintek and Council for Scientific and Industrial Research (CSIR)	Industry forum which brings together industry experts and academics to share best practice, knowledge, ideas and the latest technology trends ⁵⁵ Project specific training sessions (including around gold, lithium and andalusite)
Atomic Energy Corporation	Radio frequency identification (RFID) technology
Southern African Coal Processing Society	Attendance and presentation of conferences
Southern African institute of Mining and Metallurgy	Engagements with diamond and ore industry
South African Mineral Processing Equipment Council	Primarily collaboration on input into government policies. SAMPEC also assists industry with local content and other issues affecting competitiveness of the industry and facilitates partnerships between industry and research facilities.
South African Capital Equipment Export Council	Engagements on broadening their mandate to include project houses and more localisation
International conferences	Attendance and presentations at the Mining Indaba
Government (the dti)	Getting local content verifications

Source: Interviews with Multotec, 2018

VUT and other institutions work mostly with large and medium firms. The biggest need for these collaborations is with small firms that would not necessarily be able to have these

⁵⁴ Multotec notes that the cost of 3D printing has come down substantially. When it was introduced, the machine cost about R250,000 and now it can be purchased for approximately R30,000 - R40,000

⁵⁵ <https://www.multotec.com/news-articles-events/multotec-briges-mineral-processing-specialised-training>

capabilities internally. A number of these institutions typically charge firms at full cost, including VUT and CSIR.⁵⁶

Local challenges also tend to push firms into other regions, or more conducive environments, allowing them to get support from industry or group ecosystems in multiple locations.⁵⁷ Internationally, Multotec has access to the JK centre at the University of Queensland, which is the largest R&D and technology hub in Australia. The centre is known for collaborating with major mining and mineral processing research groups worldwide. Such international linkages have been an instrumental part of maintaining and increasing Multotec's competitiveness.

4 Business ecosystem 2: Aerospace

Generally, aerospace refers to the research, design, manufacture, operation and maintenance of vehicles that move through the air and space for commercial and military use (Kraemer-Mbula, 2008). This case study will focus on the ecosystem that supports technological upgrading.

This section will provide a brief overview of the aerospace industry and locate Aerosud Aviation (Aerosud), one of the leading companies in the local industry. Aerosud was established in 1990, and has a strong business ecosystem, which is comprised of OEMs, component manufacturers, and includes key complementors such as the department of trade and industry, and science councils. Though government departments would typically form part of a broader industrial ecosystem, we are including them in Aerosud's business ecosystem due to the targeted interventions in the aerospace industry that are supporting capability development including through technological change.

The company's ecosystem has played instrumental roles in contributing towards its dynamism. Aerosud's incremental technological advancements will also be discussed in detail to illustrate how technology disruptions have facilitated competitiveness, while drawing links to the ecosystem.

This case study, in complementing the earlier discussion on the mineral processing case study, aims to assess four main points. First, how the governance model in highly regulated industries determine the OEM-component manufacturer relations, where component manufacturers are prescribed specifications and standards by OEMs. Second, the importance of production and technology linkages and complementary capabilities in supporting an effective production ecosystem to support technological advancements, innovation and skills development. Third, how access to funding and risk-sharing R&D allow room for continuous technology developments. Finally, how technological advancements can lead to changes in product specifications, manufacturing processes and positioning of a company.

Aerosud history and evolution

Aerosud is South Africa's largest private sector aviation-industrial company, with an annual turnover of approximately US\$70 million per annum.⁵⁸ The company has close to 630 employees of which 100 are in design and industrialisation, 400 are in aircraft-parts

⁵⁶ Though at times the institutions are able to access funds to subsidise projects.

⁵⁷ CCRED Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

⁵⁸ Meeting with Aerosud on 16 November 2018.

manufacture and 10 are operating business systems.⁵⁹ Aerosud produces and supplies thermoplastic and composite panelling cockpit and cabin interiors and continuous fibre reinforced thermoplastic (CFRTP), deep-drawn pressings for structural portions e.g. wings and fuselages, and fully-equipped galleys.⁶⁰ The company manufactures close to 1,5 million parts and assemblies per annum (approximately 5,000 parts per day) all for export to international OEMs, including Airbus, Boeing, Spirit AeroSystems and Safran, for their civil and defence operations. The contracts with Airbus account for 40% of its business, while Boeing accounts for 20%.⁶¹

In terms of the aerospace global value chain Aerosud is a Tier 1. Though Aerosud is not a lead firm in the global value chain, it plays a lead role in the domestic industry.

Aerosud's key leaders were part of the design development team at the Rooivalk Combat Support Helicopter Programme under Denel.⁶² From there, the directors established the company, Aerosud, as a maintenance, repair, overhaul (MRO) organisation, with some upgrading capabilities predominantly in military type projects. In 1995, Aerosud embarked on a diversification strategy into the commercial aviation market with the design of galleys and other interior systems. The growth into manufacturing commercial parts was driven by the conditions attached to the offset programmes including the direct defence industrial participation in 1992, that required international companies to invest locally.⁶³ Interviews with the company indicated that the offset programme also provided an opportunity for the company to manufacture parts for Boeing following Boeing's tender to supply commercial aircrafts (Boeing 737, 747, 767, 777) to the local airline, South African Airways.⁶⁴

In 2001, the company independently won its first contract to supply thermoforming and interior composite parts for Boeing (mainly for 737 and 777) and a couple of years later, the company secured another contract with Airbus to supply airline galleys. From there, the company has also manufactured parts for Airbus' tier one suppliers – Libinal Power systems and Spirit Aerosystems.⁶⁵ The ability of Aerosud to secure these contracts and become a competitive manufacturer of aerospace parts is closely linked to the capabilities that characterise its production ecosystem.

The high regulation in the industry implies that the OEMs need to enforce strict standards and requirements along the entire value chain that are internationally acceptable. As a result, the OEMs (Airbus and Boeing) prescribe product specifications and standards to the component manufacturers e.g. Aerosud.⁶⁶ The nature of the aircraft value chain is akin to the automotive value chain, where companies can innovate on the material science, design and manufacturing process, but not on the product's parameters. If the tier 1 manufacturer would like to include new processes or inputs, these should be pre-approved by the OEMs before

⁵⁹ Meeting with Aerosud 16 November 2018 and <http://www.engineeringnews.co.za/article/aviation-companies-to-benefit-from-new-aerosud-growth-strategy-2018-09-21>

⁶⁰ Meeting with Aerosud 16 November 2018

⁶¹ <http://www.engineeringnews.co.za/print-version/a-leading-local-company-warns-of-tough-times-for-the-sa-aerospace-industry-2018-03-16>

⁶² http://www.tabj.co.za/southern_africa/aerosud_aviation-soaring-to_new_heights_within_the_aviation_indu.html

⁶³ http://www.defencweb.co.za/index.php?option=com_content&view=article&id=35800:defence-offsets-can-be-business-multipliers&catid=7:Industry

⁶⁴ Meeting with Aerosud on 16 November 2018.

⁶⁵ <http://www.engineeringnews.co.za/article/aerosud-restructured-for-greater-growth-2014-09-05>

⁶⁶ CCRED Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

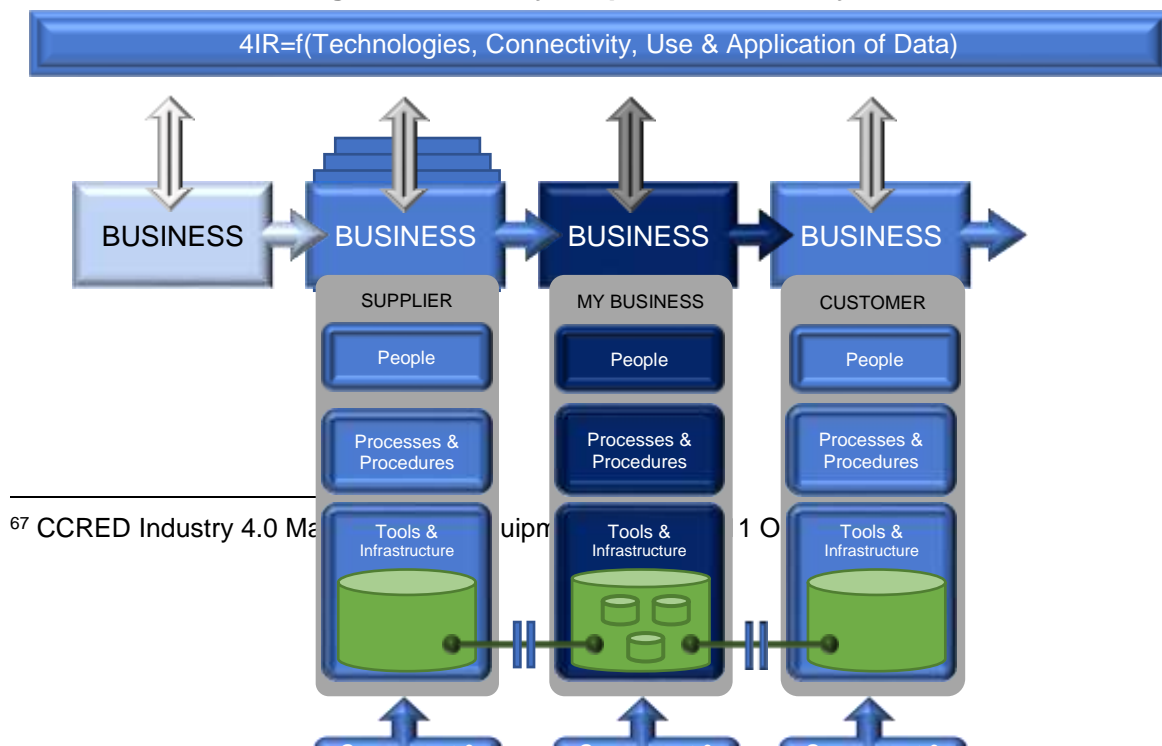
the product can be manufactured. Such requirements therefore require companies that supply the OEMs to meet strict 'non-negotiable' specifications and requirements, be adaptive to the OEMs requirements and all at the same time be innovative.

Locating Aerosud in the production ecosystem

In a business ecosystem value is co-created through the links between science councils, government, tertiary institutions, demand actors, technology developers, component manufacturers and raw material suppliers.

Aerosud has been able to map out its own production ecosystem and has identified the players that are vital in the success of the company (see Figure 4). A business is connected to other suppliers/businesses/customers that are comprised of people (skills), processes and procedures, and tools (including software tools) and infrastructure through business processes that encompass software tools. The government and institutions also provide input into the business' ecosystem through for example establishing the legislative and regulatory frameworks, providing strategic support at specific life cycle phases and providing funding for businesses to become digitally mature and competitive. The entire ecosystem is then connected through the 4th Industrial Revolution, which is a function of technologies, connectivity and the use and application of data given that the businesses and customers should operation need to be synched.⁶⁷ This is discussed in more detail below.

Figure 4: Industry 4.0 production ecosystem



Source: Aerosud

The Aerospace Industry Support Initiative (AISI) established in the early 2000s is supported by the DTI and managed by CSIR. AISI aims to contribute towards South Africa's industrialisation, transformation and job creation objectives through supplier development and strategic support initiatives, among others. In the 2017/18 financial year, 75% of the budget was targeted at technology-based supplier development projects, which included technology enhancement, standards and accreditations and supply chain improvements projects. All these mechanisms stand to improve competitiveness, productivity and quality management, having a direct impact on Aerosud's performance. Moreover, Aerosud can then redirect some funding away from supplier development, towards enhancing its in-house capabilities.⁶⁸

The AISI is closely completed by another initiative, which is the Centurion Aerospace Village (CAV). The Centurion Aerospace Village⁶⁹ (next to Aerosud's facilities), another DTI initiative was established in 2006/7, and is supported by the Gauteng Provincial Government, the City of Tshwane and the industry. The Village is developing into a Hi-Tech Advanced Manufacturing Cluster with MRO, innovation and R&D capabilities. The main objective of CAV is to attract domestic and foreign direct investment. The anticipated location of suppliers in the area, and the proximity to Aerosud can create synergies between Aerosud and the tenants, that is, factories, incubation programmes, and so on. Such facilities have further reinforced Aerosud's competitiveness and stand to benefit the local aerospace industry tremendously.

The company also has strong links with the Department of Science and Technology (DST) and Trade and Industry, through the CSIR. The Titanium Centre of Competence⁷⁰, the National Laser Centre⁷¹ and the Material Science and Manufacturing (MSM) Centre⁷² work towards the development of new advanced manufacturing technologies and are supported by the Department of Science and Technology. South Africa's additive manufacturing strategy commissioned by DST aims to leverage off existing additive manufacturing competencies in the country. Additive manufacturing research was spurred by the DST, through the Advanced Manufacturing Technology Strategy.

In 2012, the partnership between CSIR, Aerosud and Airbus referred to as the Aeroswift Project was developed to design laser additive manufacturing (LAM) aimed at reducing component costs production. The partnership explores the application of titanium powder-

⁶⁸ http://aisi.csir.co.za/wp-content/uploads/2018/10/AISI-At-a-Glance-2017_2018-Final.pdf

⁶⁹ <http://www.cav.org.za/>

⁷⁰ <https://www.csir.co.za/titanium-pilot-plant>

⁷¹ <https://www.csir.co.za/csir-national-laser-centre>

⁷² <https://www.csir.co.za/csir-materials-science-and-manufacturing>.

based additive laser manufacturing for the fabrication of large and complex aerospace components.⁷³ The agreement with Airbus and Denel Aerostructures established in 2014 not only aims to develop niche technologies, but will also involve the joint bidding for contracts, all with the objective of strengthening the competitiveness of the local industry.⁷⁴

The Industrial Development Corporation (IDC) – under the Economic Development Department (EDD) – entered as a substantial shareholder of Aerosud at 26% and accorded Aerosud ‘national strategic industrial asset’ status in 2014.⁷⁵ This investment assisted further expansion of the company’s manufacturing capacity as well as in the development of new processes and products.⁷⁶

Aerosud also closely interacts with the suppliers and have a well-integrated supply chain, given the OEMs’ requirements to have oversight of the value chain. The raw materials used in the manufacture process are sourced from 300 suppliers across the world, and of those 99.99% are imported - polymers and high-quality aluminium. One of the requirements passed down from the OEMs to Aerosud is that, Aerosud procures the raw materials independently and then supplies these to the sub-contractors with a work package outlining the product specifications. Value is generated internally, and through Aerosud’s network of 15 local sub-tier manufacturers amounting local value added of 40%. These contractors provide components and services, which are all critical to the company’s operations and range from specialists in machining parts, manufacturing on jigs and tools for the company’s equipment to suppliers of adhesives and other consumables. Aerosud undertakes continuous supplier development, given how the company’s performance is closely connected and dependent on that of its suppliers.

At the service level, there are four sub-contractors providing machining services which have been certified by Airbus under the control and supervision of Aerosud. Aerosud still procures the raw materials independently, which are then supplied to the sub-contractors with a work package, after which they add value by doing the machining and inspections. In some cases, it took 1-1.5 years for the sub-contractors to get to Airbus approval stage. The sub-contractors had to establish quality control systems and programmes facilitated by Aerosud, which included Aerosud providing them access to their internal ERP system to do the material issuing and recording of transactions. The sub-contractors would need to have their own in-house PLM ability to control the numerical control programmes, and in most instances the PLM systems is very basic. While some of the subcontractors are innovative and invest.

The tightly knitted production ecosystem in which Aerosud is located reinforces the assertion that one firm’s competitiveness is dependent on the links and complementary capabilities that it has with other firms, institutions, government departments and science councils. From the early 2000s, the aerospace industry was identified as a priority sector and with that, Aerosud was also accorded as a national strategic industrial asset, which means that it has access to certain resources that an ordinary firm would not be able to ordinarily access. The

⁷³ <https://www.csir.co.za/csir-aerosud-airbus-partnership-takes-new-additive-layer-manufacturing-heights>

⁷⁴ http://www.defenceweb.co.za/index.php?option=com_content&view=article&id=36296&catid=74&Itemid=30 and <http://www.denelaerostructures.com/press-article/Denel-Aerostructures-Aerosud-Aviation--Airbus-Forge-Industrial-and-Research-Alliance/61>

⁷⁵ The other shareholder is Paramount Industrial Holdings.

⁷⁶ <http://www.engineeringnews.co.za/print-version/aerosud-restructured-for-greater-growth-2014-09-05>

technological outcomes of a cohesive and comprehensive production ecosystem will be discussed in more detail below.

Technological upgrading

Aerosud has invested in the research and development of world class machinery and equipment, designing the materials that are required in the process since the early 2000s. Given the company's global presence, the supply chain has been digitalised from the sourcing of raw materials to the delivery of finished parts to the OEM. In the past three years alone, the company has invested more than R3 million in technology upgrading and expanding production capacity, which included the purchase of a new structural composite technology in 2015 which is housed at Aerosud Technology Solutions.⁷⁷

Overall, there are groups of technologies that are enabling the company to remain competitive through supplying its customers with innovative cost- and energy- effective technologies timeously. The main technology driven changes in the industry include additive manufacturing for manufacturing of intricate parts and rapid prototyping, integrating their supply chain using the latest software and most recently the application of augmented reality and robotic welding. The company's position in industry has also changed, and now includes offering services related to assisting local firms adopt 4IR-related technologies.

4.1.1 Internal

Additive manufacturing and material science

Lead firms have made significant investments in optimum material manufacture and additive manufacturing machines in developed economies, especially Germany and USA. In the aerospace industry, this is driven by the demand for lighter and more durable composites which means tier 1 firms like Aerosud are continuously developing unique composite manufacturing technology to improve speed and reliability, and one of such technological development is Aerosud's Cellular Core Technology.⁷⁸ Additive manufacturing also requires the development of new materials that are pliable to 3D printing, and in the case of the aerospace industry this refers to metal powders e.g. titanium alloy.

The move towards additive manufacturing of titanium parts required the manufacture of the additive manufacturing machine and a titanium alloy. Through the Aeroswift Project (a collaboration between Aerosud ITC and CSIR's National Laser Centre), metal additive manufacturing technologies were developed using a power bed fusion that manufactures parts as big as 2,0m by 0,6m by 0,6m using a 5kW laser system, which was one of the biggest and fastest power bed in 2015. The parts manufactured in the 3D printer were designed using computer aided designs (CAD). The complementary expertise from Aerosud ITC and the NLC that brought on board mechanical and optical systems' expertise respectively, was important as they could draw from existing skills, and not learn afresh saving time and lowering development costs.

⁷⁷ http://www.engineeringnews.co.za/article/aerosud-announces-new-initiative-in-its-growth-strategy-2018-09-20/rep_id:4136

⁷⁸ <https://www.aerosud.co.za/research-and-development>.

The Titanium Centre of Competence and CSIR's Materials Science and Manufacturing (MSM) department developed the titanium alloy over a ten-year period.⁷⁹ MSM was able to leverage their previous experience in the commercialisation of a stainless-steel alloy designed for previously state-owned steel company, Iscor. Interestingly, CSIR does not manufacture a wide range of alloys, given that an industry often adopts one alloy. In the aircraft industry, a titanium alloy made of titanium, aluminium and vanadium, has been adopted. The titanium is made into a powder, that can then be moulded for manufacture in the power bed additive manufacturing machine. Once the alloy is developed, it becomes relatively easier to design other metal powders that can be used in other industries.⁸⁰ Moreover, the alloy and the additive manufacturing machine can be commercialised, which can lower the cost of metal 3D printing and increase the uptake in the local industry. Once the machine and alloy have been commercialised, new industries such as the manufacture of steel powders can be created.

The VUT's 3D Printing Centre also produces different components for the aerospace industry. As alluded to above in the mineral processing case study, printing of 3D parts at VUT has gone a step further, through virtual (digital) simulation. Designing products using virtual simulation, and not CAD designs, means that the component can be designed, tested and perfected without manufacturing a prototype. While the benefits of 3D printing are evident, virtual printing will lead to even faster turnaround time and complete elimination of waste.⁸¹

As is the case in mineral processing equipment, additive manufacturing reduces the design to manufacture process and in aerospace, also optimises the production process given that additive manufacturing is not limited to rapid prototyping but includes manufacture of parts. Even though Airbus and Boeing (the main customers) send the specifications of the parts and components to tier 1 suppliers,⁸² Aerosud has some leeway to innovate in the production process given that proof of compliance is met, and regular compliance audits are undertaken by a 3rd party. Such requirements can be onerous on smaller firms that have limited resources to not only automate, but also adhere to such requirements and specifications.

The ability of Aerosud (with its partners) to develop composites has been instrumental in their ability to retain competitive advantage. In the mid-2000s, the company successfully developed continuous fibre reinforced thermoplastic (CFRTP), which allowed them to manufacture components far more energy efficiently and cost effectively, relative to other composites. With CFRTP, the company was able to manufacture a component within four to six minutes, compared to eight to nine hours that's required for curing a conventional composite component.⁸³

Even though additive manufacturing will lower costs, increase productivity and spur innovation, there are risks by international OEMs to re-shore manufacturing capabilities. For example, Boeing or Airbus could decide to re-shore the manufacturing of their parts to USA and Europe respectively, and manufacture locally. This could be a risk for companies like Aerosud that are reliant on orders from such OEMs given that they export 100% of their manufactures and that local OEMs are not competing in the commercial aviation space. However, Aerosud has developed local capabilities such as the titanium alloy parts, that are

⁷⁹ Meeting with CSIR on 15 November 2018.

⁸⁰ Meeting with CSIR on 15 November 2018.

⁸¹ Meeting with VUT on 24 October 2018.

⁸² CCRE Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

⁸³ <http://www.engineeringnews.co.za/article/aerosud-restructured-for-greater-growth-2014-09-05>

beneficial to the OEMs and further reinforce Aerosud's competitive advantage. What does become important is the integration of the supply chain to ensure that components can be tracked and are meeting regulatory requirements.

Automation and robotics

Though there has been limited adoption of robots and automation in the Aerosud manufacturing process there are stages that have been automated to improve speed and efficiency. For example, Aerosud has invested in a fully automated robotic welding facility to improve precision, reduce defects and increase efficiency gains.⁸⁴ This technology upgrading allowed for the increase in capacity as required by the Airbus' A320 programme and as a result improved Aerosud's competitiveness. The investment had knock-on effects since Aerosud extended its contract with Spirit Aerosystems.⁸⁵ Absent of these technological advancements, Aerosud may not have been able to secure these orders and may have lost the much-required scale.

The level of automation on the production processes reveals that not all industries or companies are ripe for automation. This would need to depend on the firm's product portfolio to better understand the impact of automation. Companies that manufacture numerous products using a range of inputs may not be ideal for automation, while other industries that have simple and routine tasks may be easier to automate.

Artificial intelligence

Machine learning or artificial intelligence depends on big data and advanced data analytics. Currently, Aerosud captures data on quality, output, defects and failures. The scrap rate is less than 2%, yet this is quite high given that this reallocates workers time to reworking mistakes, reducing time for the manufacture of new components.⁸⁶ The company is in the process of skilling themselves with business intelligence⁸⁷ (BI) using the Power BI software package, which will equip them with the necessary skills to analyse data and provide information that can assist them in decision making.

At the same time, Aerosud (using their internal design engineers) is also heavily engaging in augmented reality and simulation modelling. The company believes the primary benefit would be in their design and industrialisation process more broadly and will closely complement compliance of complex assembly processes. Aerosud is also drawing on the digital twin to run simulations before actual products are manufactured and deployed. The digital twin is also being optimised with the use of the IoT, AI and analytics, and will help solve the problem around having such a complex production system. Augmented reality can allow a technician more context to be able to undertake more rapid analysis and resolve issues, all improving efficiency. Additionally, augmented reality can improve communication and compliance since live information can be transmitted to another party. Airbus has been testing brackets on the A380 using AI, and the time needed to inspect has reduced from three weeks to three days.

⁸⁴ <http://www.engineeringnews.co.za/print-version/local-aviation-industry-needs-to-be-technology-ready-2017-09-01>

⁸⁵ <http://www.engineeringnews.co.za/print-version/local-aviation-industry-needs-to-be-technology-ready-2017-09-01>

⁸⁶ Meeting with Aerosud on 11 November 2018.

⁸⁷ Business intelligence is a technology-driven process for analysing data and presenting actionable information to help executives, managers and other corporate end users make informed business decisions. See <https://searchbusinessanalytics.techtarget.com/definition/business-intelligence-BI>.

Aside from the skills required, such an investment would require a well-developed ecosystem to undertake the R&D and fund the different levels of development.

Evolving into engineering solutions

Aerosud originally developed its business solutions capabilities to meet its own in-house requirements, which included the need to manage long and complex supply chains on the one hand, and to fit into, and coordinate effectively with, the supply chains of global major aerospace companies. The company's continued investment in advanced technologies and adoption of 4IR technologies have introduced new competencies into the company that can be harnessed to support other high-technology industries. As such, Aerosud's new business solutions offering is focused on assisting companies implement 4IR technologies such as the Internet of Things (IoT), complex process control, robotics, ERP, and PLM.

Important to recognise is that additive manufacturing, integrating supply chains, automation and artificial intelligence are all transversal technologies and can be applied in various industries.

4.1.2 External

Integrating the supply chain

Aerosud's production system is complex and involves the use of more than 4,000 materials to manufacture 5,000 different units through numerous steps in the production process.

The Internet of Things is integrating ecosystems and changing business models, which can accrue significant efficiency gains. Aerosud requires software tools to manage in-house supply chains that are long and complex, and at the same time synchronise its supply chain effectively with the OEMs' supply chains in the USA, UK, Germany, France and Spain.⁸⁸ The company identified the business processes as the area with most opportunity for digitalisation and integration both internal and external to business. Automation is often associated with job losses, and to minimise the effects of job losses, Aerosud made a company decision to upskill its labour force and maximise retention where possible.

The easier component of the monitoring and tracking is between the OEMs (Boeing and Airbus) and Aerosud, who have established these systems over the years as a prerequisite. By the 2000s, Aerosud was already using Intel's operating software to manage the product lifecycle management (PLM). The major inflection point occurred when the company switched from Intel to CISPro in 2003. Since then, the company has updated several iterations of CISPro, ensuring that they stay-up-to-date.⁸⁹ The recent partnership with one of the leading logistics company, DB Schenker, will provide more effective support given that DB Schenker redesigned its system to tailor it to Aerosud's corporate strategy.⁹⁰

Tracking components and raw material is slightly more complicated and depends on the supplier's capabilities. While Aerosud and its suppliers do not need to use the same software, there is need for the supplier to have some form of PLM management solution that not only allows Aerosud to track components, but to also monitor Aerosud's changes in inventory

⁸⁸ CCRED Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

⁸⁹ Meeting with Aerosud on 16 November.

⁹⁰ <http://www.engineeringnews.co.za/article/aerosuds-new-partnership-with-db-schenker-south-africa-2018-09-18>

needs in real time. For example, in the manufacture of certain airplane components, specialised grades of polypropylene are imported from overseas. An integrated system allows a supplier in Asia, to track the inventory levels of the OEM's polypropylene in South Africa. When the material is running low the supplier receives an automated order to prepare shipment. As such, Aerosud has equipped their suppliers with simplified PLM or ERP systems to minimise production interferences as this will have a direct consequence on their targets with their customers. In this way, the company is assisting suppliers to upgrade their capabilities and meet international standards that are pertinent for participating in the export market.

Internally, Aerosud uses simple (old) methods to track the stages through which parts and components go through during the different manufacturing stages. For example, after completing each stage, whether welding, painting or stamping each product's bar code is scanned into the grid system that organises the data. This information is then pulled to a central mainframe that allows the production managers to see how far along the manufacturing process each part is.⁹¹ This system predates the IoT but complements the company's operations in digitalising the supply chain. Aerosud also implemented the theory of constraint management philosophy, which focuses on identifying and removing constraints that limit throughput and increase manufacturing capacity.⁹² Supporting this also required substantial investments in various systems and has allowed the company to save R50 million in working capital per annum. These savings were on the back of an investment of a conservative approximated investment of R42 million, which only includes salaries and not licensing costs.

There are other ways through which the time efficiencies have been realized along the supply chain through the investment in the business process systems. For example, when placing orders for materials, the automated system has resulted in saving time by 70-80% since job receipts do not need to be captured manually and are simply captured through the automation. Moreover, an ERP system has three or four constituent parts, of which one of these can be automated. The productivity gains from this process trickle through the whole company, since the production managers can signal when they need material and the procuring officers are aware of when to place the order. Given the speed of 4IR and technology development, in the next 6 months to a year, Aerosud anticipates requirements allowing for an even more integrated and more open access system.

Backward and forward integration of the supply chain improves efficiency, especially given the internationalisation of the aerospace industry. Most of these business management systems and processes appear not to necessarily relate to 4.0, rather they are an evolution of industry 3.0. The mix of old and new technologies for integrating the supply chain reveals how it is important to identify a problem and address it with the most optimal solution. In other words, the latest technologies should not be used for the sake of it, rather technology should be used to meet a need. Smaller companies can start off with simple PLM or ERP systems that meet their business needs and remove bottlenecks, and as the company gets bigger and is more productive then the systems can be updated, the same way Aerosud moved from Intel to CISPro and has now partnered with DB Schenker.

One factor that is hampering the digitalising of the supply chain is the cost of data and connectivity, as previously emphasised. The cost of data and poor connectivity in South Africa puts them on the back foot, given that in certain countries data is free and fast.⁹³ Another

⁹¹ Meeting with Aerosud on 16 November

⁹² <https://www.leanproduction.com/theory-of-constraints.html>

⁹³ CCRED Industry 4.0 Machinery and Equipment Dialogue, 11 October 2018.

concern is access to appropriated trained and qualified staff. While, the programmers are readily available, the bigger challenge relates to the programmer's ability to apply his skills to understand the internal business. Upon recruiting a new graduate, the learning process can take 6 months and up to a year. As such, the company invests time and resources in upskilling to ensure that the team is well-versed with the latest developments.

4.1.3 Institutions

Technology adoption at Aerosud has been facilitated through direct investments by the company, risk-sharing R&D projects with CSIR and the Titanium Centre of competence, and continuous development and improvement of technologies that were developed in-house. The ability to access funding and share the cost of development with supporting institutions has also played a critical role in shaping the firm's technology positioning. Absent of these stakeholders, Aerosud's growth and trajectory may have been different, especially because countries in South Africa that lack these facilities (skills and training, R&D, financing and government support) are lagging.

Aerosud's initial take-off was propelled by the offset programme, which obliged international OEMs to partner with the company on technological transfers, research and development, and provided secured demand in the first decade of its operations. Security of demand enabled the company to make long-term investments and engage in blue sky technology development. The concerted effort by government departments – Science and Technology, Trade and Industry and Economic Development – were further instrumental in the technological leapfrogs the company made.

The IDC's decision to become an equity investor and accord Aerosud status as a national strategic industrial player, shows how development finance is vital in ensuring that companies can invest on an on-going basis. Technical support from the additive manufacturing and material science community to develop a titanium alloy and additive manufacturing machine enabled the company to develop high value products, and in the long-term will lower costs, scrap and time. Government support through the DST and the DTI ensured that this research and development was prioritised

While ground breaking technologies have improved the company's products competitiveness, the management and integration systems are a combination of industry 3.0 technologies that are evolving and involve very basic tracking systems. This presents opportunities for South Africa to leverage off industry 3.0 related technologies and improve supply chain integration that is becoming more critical in the international market.

The company also cited a few bottlenecks that would require government intervention. The skills and training development have largely been addressed through in-house training, given the specificity of Aerosud's manufacturing process and its legacy. Nonetheless, the fact that graduates are not equipped or skilled to be assimilated into the working environment is concerning – this is an aspect of the company's ecosystem that is weak.

Industry 4.0 technology requires that businesses engage in real time and for the supply chains to be integrated and cost and data connectivity were cited as a challenge. Local firms are not adopting product life cycle management techniques at rates that the world is shifting, this can circumvent other business from working with Aerosud as this is becoming a prerequisite.

5 Comparative discussion and policy recommendations

Key insights from the comparison of the ecosystems

The two production systems reviewed in section 3 and 4 above highlight several issues for technology adoption in South Africa. First, they confirm that technologies have different impacts on different industries. For example, additive manufacturing is disrupting the design and prototyping processes of the mineral processing industry while it is disrupting production in the aerospace industry. However, there are groupings of technologies (technology platforms) that work together in order to deliver gains to the industries considered.

3D printing (additive manufacturing) together with ICT systems such as CAD and virtual simulators assist firms with rapid prototyping and customisation. For industries such as mineral processing customisation is critical for competitiveness and rapid prototyping allows firms to have speed to market, another essential element of competitiveness.

South Africa has already invested in public institutions with capabilities in additive manufacturing (Figure 5). The next step is to support a wider set of industries with these capabilities with a particular focus on small, medium and micro enterprises (SMMEs).

Figure 5: South Africa's Additive Manufacturing capability matrix

	Industries - research										
	Aerospace	Automotive	Consumer goods	Creative industries	Defense, peace, safety and security	Energy	Medical	Research	SMME support	Sporting and leisure goods	Tooling and refurbishment
Higher education institutions											
Central University of Technology	Subcritical				Emerging		Building				Building
Durban University of Technology								Building			Building
Nelson Mandela Metropolitan University	Subcritical	Subcritical				Subcritical		Building	Building		Building
Tshwane University of Technology	Subcritical		Subcritical					Building			
University of Cape Town	Subcritical	Subcritical	Subcritical					Building			
University of Johannesburg	Subcritical							Building			
Stellenbosch University	Emerging	Emerging	Emerging	Emerging			Emerging	Building	Emerging	Emerging	Building
University of the Witwatersrand											
Vaal University of Technology	Emerging		Emerging	Emerging			Subcritical	Emerging	Emerging		Emerging
Science councils											
CSIR Defense, Peace, Safety and Security					Subcritical						
CSIR Material Science and Manufacturing											
CSIR National Laser Centre	Emerging				Emerging	Building		Building	Building		Building
<p>Definition: For which industries is your institution performing research to develop AM-based systems, processes, or technologies and what is the current resource allocation</p>											

Source: (De Beer, et al., 2016)

Notes: **Subcritical:** low allocation of personnel/researchers and limited access to AM facilities or infrastructure; **Emerging:** Allocation of senior personnel or researchers an access to AM facilities or infrastructure; **Building:** Research chair and or group with necessary infrastructure and man power to carry out meaningful research; and **Mature:** research chair and group with extensive AM facilities and dedicated man power.

This is important as additive manufacturing also has the potential to allow South Africa to leapfrog in terms of tooling. In mineral processing, the requirement for speed to market means that there is a need for quick turnaround time in the production of tools. This is something that South Africa has been weak in for years. Importing 3D printed tools will delay speed to market and it will be important for tools to be printed locally. The ICT systems also allow firms to integrate the value chain which brings about additional efficiencies, however, firms need to be using these systems in order to create this value. The critical systems are Computer Aided Design (CAD), Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP) and Product Lifecycle Management (PLM). 3D printing has disrupted the approach to prototyping but the software and integration of value chains using first the software and then the internet of things is supporting optimisation of processes and leading to efficiency gains.

The combination of sensors, cloud computing, software development, machine learning and artificial intelligence is important for condition monitoring and predictive maintenance. These technologies are useful in so far as they are used together. Sensors collect the data, which is stored and analysed using cloud computing. Machine learning and artificial intelligence allows the equipment to recalibrate in response to the observed conditions for a longer life. The

integration of the technologies required the development of software to allow for communication. This is an area where most of the capabilities are not located in South Africa. Interviewed firms have indicated that mostly international software developers are used. In the last few years, the international companies have also started locating in South Africa. CSIR has developed capabilities to customise sensors for different industries and has worked with state owned enterprises, so far. CSIR is now developing strategies to assist traditional manufacturing, however, again this will be difficult for small firms to benefit from these capabilities as they are charged at full cost. Consideration should be given to aligning different government support programmes so that SMMEs can benefit from these capabilities.

Advanced manufacturing is taking place through the use of robotics, additive manufacturing for production and factory automation. This is the area that firms have been more cautious and adopting robots where benefits have been identified. The aerospace industry internationally is a leader in terms of using additive manufacturing for production. South Africa is not far behind in this area and this was made possible by the collaborations between industry and the CSIR. This group of technologies are posing a major disruption to manufacturing.

The lead firms have both facilitated upgrading of suppliers in their respective value chains. Both lead firms are operating in industries where South Africa has legacy capabilities but staying competitive has involved continuous investment in technological and capability upgrading. In both instances, the relationships with international firms has facilitated upgrading. In the instance of Aerosud, international competition for supplying Airbus and Boeing as well as the quality requirements have meant that the firm has had to adopt technologies to maintain and win new business. Where there are no strong lead firms the development of clusters will be important in supporting upgrading. These clusters will need to be linked to the public institutions which are already playing an important role.

Skills

It is worth noting that South Africa has high levels of unskilled labour. Employment displacement is therefore a concern. Firms have been cautious in the adoption of technologies that replaces jobs e.g. robots. There appears to be an attempt to balance mechanisation and labour retention. This is not unique to South African firms and international studies have observed that flexibility in how factors of production are combined allows for balancing between mechanisation and minimising employment losses (Rodrik, 2018).

However, where there have been some job losses due to technological upgrading given the productivity gains to be derived from automation and AI, Multotec has re-absorbed the employees in different divisions. As more of these technologies are adopted re-absorption will become a challenge. The firms are grappling with reskilling employees for future work. There is need for responsible leadership in managing the impact of Industry 4.0 and at the same time, government needs to implement a longer-term approach towards science, technology, engineering and mathematics (STEM) subjects, including IT, that will equip displaced workers, and prepare them for redeployment into new areas. There is also a need to review current curricula to ensure that South Africa is skilling for Industry 4.0 work.

With lead firms being able to adopt Industry 4.0 technologies, there is evidence that they are equipping their workforce by developing the appropriate capabilities and competencies internally, as well as mobilising talent from abroad to train local teams.⁹⁴ Lead firms like

Multotec and Aerosud are large enough to internalise their training and invest in their human resources. Aerosud established the Aerosud Training and Innovation Centre including an apprenticeship training programme with five trades at artisan and operator level.⁹⁵ While Multotec has formally accredited programmes, including some that enrol 160 students per annum, for apprenticeships.⁹⁶ Multotec has links with universities to allow for this, but notes that there is need to breakdown the skills profile to more effectively match industry needs and university and technical training.

In terms of the critical skills requirement for a firm like Multotec, technical and artisanal skills including electrical and mechanical technicians, mechanical and process engineers, draughtsmen and tool and dye makers need to be developed in light of Industry 4.0. These are highly specialised skills that will allow firms to better respond to technological advancements. The skills loss in the last 20 years needs to be addressed together with the need for upskilling, in order to remain close to the technology frontier. Developing technical capabilities in specialised areas is as important as the development of organisational capabilities, which play a pivotal role in the development of internal processes and how efficiencies can be gained throughout the organisation.

Firms emphasise the importance of combining knowledge and experience from various disciplines (including computer science, engineering and statisticians) in order to extract business value.⁹⁷ Moreover, even within the context of Industry 4.0 developments, operations are still run by people, giving them the power to determine whether systems work successfully or fail. Organisations, in their entirety need to be cognisant of the benefits and challenges of technological change, and this may entail developing a firm-wide digital transformation strategy.⁹⁸

Connectivity

The importance of connectivity underpins the digital era and (soft and hard) ICT infrastructure acts as a critical enabler. In the South African context, the adoption of predictive maintenance and monitoring systems, for example, highlights key issues. First, the cost and availability of bandwidth lags behind most countries. Second, operating these machines and analysing the data requires specific skills such as IT, data analysts, scientists and artisans with IT capabilities, which South Africa lacks. While such a technological leapfrog can result in substantial economic benefits, it needs to be complemented by skills, especially IT-related competences.⁹⁹ High speed, low cost data, data security assurance, reliable broadband networks and coverage, along with continuous investments in physical infrastructure will ensure that the full benefits of Industry 4.0 are captured by firms and their production ecosystems.

Adoption of 3rd Industrial Revolution technologies

The lead firms have capabilities and resources that have supported their technological upgrading. This is not the case for all firms and some of the tier 2 and 3 suppliers, particularly

⁹⁵ The training centre has an Institute of Sectoral and Occupational Excellence (ISOE) for two of the trades. Moreover, the centre is approved by SA: CAA and the TETA and achieved certification from QCTO in early 2017.⁹⁵

are still in the process of adopting 3rd revolution technologies. A distinct SMME strategy is essential if the industry at large is to leverage digital transformation. Strategies can be developed to incrementally encourage the adoption of digitalisation technologies as a start. This can involve establishing an open access, national digital incubation centre, in partnership with lead firms with developed capabilities and institutions with existing resources. A holistic approach to responding to technological change and taking into account the potential role of different actors, is important for future competitiveness and innovation, and will be vital for driving industry wide developments.

Policy Interventions

The externalities and uncertainties associated with the new technologies mean that support for shared investments and coordinated decisions (vertically and horizontally) are even more important. This has implications also for the organisation of the state. The current fragmentation of the state means that leveraging government programmes for technological upgrading becomes a time-consuming process that can be challenging if the government departments' strategies are not aligned and requires extensive coordination. Institutions of industrial policy understood broadly to include industrial policy, trade policy, science and technology, development financing and information technology need to be aligned to support digitalisation.

The Aerosud case study illustrates what can be achieved when capabilities, local procurement programmes, development funding and partnerships with public institution in the innovation system work together. The National Industrial Participation (NIP) programme¹⁰⁰, which is an offset scheme that leverages government procurement arising out of large international purchases, through obliging international contractors to develop and invest in projects that can provide long-term economic benefits, played an important role in terms of Aerosud's growth. The equity stake taken by the IDC meant that Aerosud could invest in technological upgrading and the technological partnerships with CSIR and the universities of technologies supported the adoption and adaptation of technologies such as additive manufacturing to ensure Aerosud's international competitiveness. The challenge is to coordinate these different aspects of policy for a wider grouping of industries. This can start with those that are identified as "root industries" for industry 4.0.

There are existing policy interventions to support research and development, technology adoption and that can be better coordinated to support upgrading even by SMMEs (Table 3).

Table 3: Technology, Research and Development and Incentive Programmes

Institutions	Focus
Mintek	Technology
Human Sciences Research Council (HSRC)	Research
Technology localisation Implementation Unit (TLIU)	Technology
Council for Scientific and Industrial Research (CSIR)	R&D and technology
National Research Foundation (NRF)	R&D
Technology Innovation Agency (TIA)	Technology
Incentives	
<i>Support Programme for Industrial Innovation (SPII)</i>	Technology
<i>Industrial Innovation Partnership Programme (IIP)</i> ¹⁰¹	Technology

¹⁰⁰ http://www.dti.gov.za/industrial_development/nipp.jsp

¹⁰¹ https://www.dst.gov.za/index.php?option=com_content&view=article&id=1944

<i>R&D tax incentive</i>	R&D
<i>Technology for Human Resources in Industry Programme (THRIP)¹⁰²</i>	Skills
<i>IDC prioritisation of AM</i>	Investment

Source: Compiled by authors

The DST's white paper on science technology and innovation is an important step in this regard, however, it will be important to coordinate with other policy instruments.

In the digital era, strengthening (upgrading) the local production ecosystem can improve competitiveness and co-creation in the machinery and equipment industry. This would require a combination of skills and supplier development programmes, technology incubation as well as links to universities, research centres (CSIR and Mintek) and international centres. Research and development is especially vital for building a strong ecosystem that supports innovation and linkages to industry (as in the case of skills). In the case of additive manufacturing, centres such as VUT are important open access facilities for firms. Given that industry is still in the process of responding to “smart manufacturing” and changes in production systems, leveraging existing resources and adequately capacitating universities will help create an environment conducive for adaptation, learning and innovation. Given the importance of the machinery and equipment industry consideration should be given to developing a **masterplan** to assist the industry to upgrade.

Access to high speed data, which is a function of latency, bandwidth and cost, remains a challenge in South Africa. **Reliable digital infrastructure** improves speed to market and inter-connectivity, enabling firms to better manage operating systems and monitor data remotely, and remain relevant in a highly competitive global market place.

In the process of adopting technology, the cost of **licensing software and new machinery** is high, and acute for small firms. This is an area where government can support the costs incurred by firms and the related investment in machinery through appropriate incentive programmes.

The use of advanced technologies requires a pool of **skills and capabilities**. Addressing the country's skills constraints and taking a long-term approach to developing STEM skills, in particular, will be a critical enabler. The local pool of artisanal and technical skills is limited such that lead firms have had to internalise training. In-house training is largely driven by the lack of appropriately skills coming from South Africa's training centres and FET colleges, along with the need to equip individuals with firm-specific skills. Bridging the gap between what firms require and the current education offering is an important test of how government and business can collaborate. The skills that are required in the industries are electrical and mechanical technicians, mechanical and process engineers, draughtsmen and tool and dye makers, data scientists.

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¹⁰² https://www.thedti.gov.za/financial_assistance/THRIP.jsp

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Annexures

Annexure 1: Interview schedule and engagements

Stakeholder	Institution interviewed
Universities	Vaal University of Technology (VUT) Science and Technology Park
	University of Witwatersrand - Wits Business School/ Telkom Chair in Digital Business
Research and development	Council of Scientific and Industrial Research (CSIR) - Materials Science and Manufacturing
Industry	Multotec Group
	National Rubber Matmin
	Aerosud
	Curo Pumps
	Weir Minerals
	Bell Equipment

Annexure 2: Multotec Group's products and proportion of value addition

Branch	Nature of equipment	Product	Internal v external value addition
Multotec Manufacturing	Consumables and capital equipment	Panels for screens – injection molding, polyurethane panels, injection molding rubber panels, compression molded, wedge wire panels, sieve bends, and trommels	Raw materials imported Fully manufactured in-house – design and conversion
Multotec Process Equipment	Capital equipment	Cyclones	Split depending on the product. Plastic or rubber manufactured internally Steel component for cast iron procured from foundries
		Spirals	All steel and components manufactured by subcontractors Fully assembled in-house – design and conversion
		Samplers	Fully manufactured in-house – design and conversion
		Water equipment	Almost all fully imported 10% internal value add

		Filter presses	50/50 split between local manufacture and imports
		Magnetic separators	Magnets imported from China 70% internal value add, including design and assembly
		Pumps	50% internal value add - designs are made in-house Castings are procured from foundries
Multotec Rubber	Consumables, replaced between 8-12 months	Mill linings	Raw materials imported Fully manufactured in-house – design and conversion
Multotec Wear Liner	Consumables for high water areas	Ceramic tiles	Raw materials imported Fully manufactured in-house – design and conversion
MATO	Capital equipment	Mechanical conveyor belt systems	50-50 partnership with German partners
Multotec Rubber	Consumable	Rubber compound manufacturer (National Rubber Matmin) Vertically integrated with Multotec manufacturing and other companies to increase capability and competitiveness	Raw materials imported Local conversion

Source: Interviews with Multotec, 2018