The Fourth Industrial Revolution in South African Manufacturing and Connectivity: Case Studies of Automotive and Mining Equipment Manufacturing, along with Transportation and ICT Infrastructure and Services

Rachel Alexander

SARChI Industrial Development Working Paper Series

WP 2021-8c

September 2021

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation

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Industrial Development

UNIVERSITY OF JOHANNESBURG

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ISBN 978-1-77630-388-5

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Funding acknowledgement

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Recommended citation

Alexander, R. (2021). The Fourth Industrial Revolution in South African Manufacturing and Connectivity: Case Studies of Automotive and Mining Equipment Manufacturing, along with Transportation and ICT Infrastructure and Services. SARChI Industrial Development Working Paper Series WP 2021-8c. SARChI Industrial Development, University of Johannesburg.

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Abstract

This working paper focuses on case studies covering two economic areas related to the Fourth Industrial Revolution (4IR) and industrial development. The first area is connectivity services, which includes the cases of transportation and communication services (including infrastructure). The second area is manufacturing, which includes the cases of automotive and mining equipment production. This paper explores industry characteristics, individual firms' experiences with innovation processes, other key actors and industry support environments, and the dynamics of industry-specific production networks. Based on this exploration, the paper identifies how production network structures shape experiences with adopting 4IR systems. This working paper is the third in a series of four.

Keywords: Connectivity, Manufacturing, Industrial development, South Africa

JEL codes: O25, O14, O31, O33, L22, L52, L62, L64, L91, L96

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Acknowledgements

Support for this research was received under the project 'Community of Practice in Industrialisation and Innovation' (grant number 110691), hosted by the DSI/NRF South African Research Chair in Industrial Development (grant number 98627), University of Johannesburg.

The data collection involved a team of researchers, including Antonio Andreoni, Guendalina Anzolin, Marta Bengoa, Erika Kraemer-Mbula, Edward Lorenz and Lotta Takala-Greenish. A previous publication was produced from the same dataset in 2019, entitled *Report on the Adoption of 4th Industrial Revolution Technologies in South African Industry*, written by Edward Lorenz, Milene Tessarin, and Paulo Morceiro.

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1. Introduction

The fourth industrial revolution (4IR) is affecting all aspects of economies. It can be seen as "an era where people are using smart, connected and converged cyber, physical and biological systems and smart business models to define and reshape the social, economic and political spheres" (Presidential Commission on the Fourth Industrial Revolution [PC4IR], 2020). However, changes are experienced differently across economic sectors. Considering four case study industries from two sectors, this paper asks how industry structure shapes 4IR innovation processes. The first sector examined is connectivity infrastructure and services. This sector is explored by considering two case studies – businesses working in information and communications technology (ICT), and businesses working in transportation and logistics. The second sector discussed is manufacturing. This sector is also explored through two case studies – automotive manufacturing and mining equipment manufacturing.

This paper is the third in a series of four working papers that explore the expansion of 4IR in South Africa. This paper and the others in the series are based on interviews conducted with 51 key South African stakeholders between 2019 and 2021 (see Annexure A) and a review of available published materials.

The body of this paper is structured as follows. Section 2 focuses on connectivity infrastructure and services. Section 3 focuses on manufacturing. Finally, Section 4 provides a conclusion that brings together key findings related to the sectoral studies.

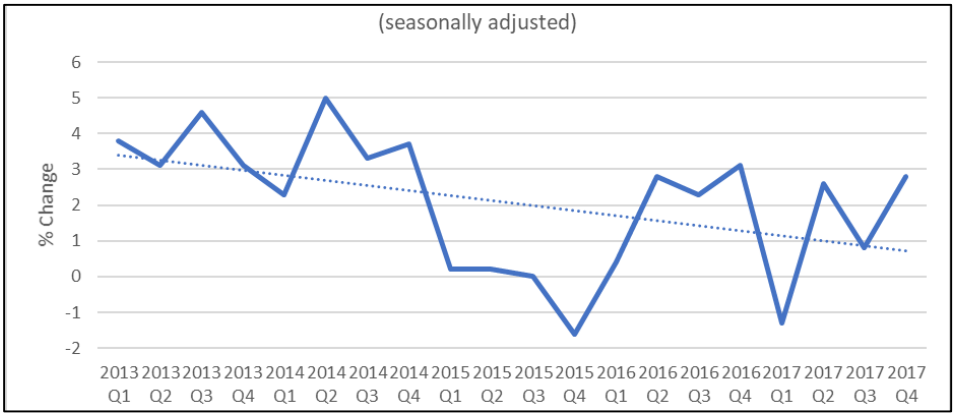
2. Connectivity Infrastructure and Services

To enable the growth and expansion of 4IR in South Africa, particularly for the country's manufacturing industry, suitable connectivity services (including infrastructure) need to be developed. These services are crucial for facilitating flows of digital information and physical products. In addition, the growth of the sector itself can be beneficial, for example through its potential for job creation.

As discussed in Alexander (2022a), the second paper in this working paper series, connectivity services are underdeveloped in South Africa. The resulting challenges are being intensified in some cases as national infrastructure quality has been deteriorating (World Bank, 2018a). A further way to view deficiencies in this sector is to consider that key elements of connectivity services have been contributing less to the national gross domestic product (GDP) in recent years (see Figure 1). Notably, the biggest challenges related to South Africa's adoption of 4IR systems were identified by Deloitte (2016) as connectivity and accessibility.

At the same time as connectivity services have had a declining contribution to the GDP, the share of total business expenditure on research and development (R&D) that is allocated to the transport, storage and communication sector has been increasing. Expenditure rose from 3% in 2008 to 6% in 2017 (National Advisory Council on Innovation [NACI], 2020). This investment is needed as this sector has much room for local innovation and the adoption and adaptation of new systems that have been developing globally.

Figure 1: Contribution of Transport, Storage, and Communication to GDP Growth



Source: World Bank (2018b)

Connectivity services in South Africa are provided by the public sector and by diverse firms. Types of firms include state-owned enterprises (SOEs), foreign-owned multinationals, large South African firms, South Africa-founded firms that have been bought by global players, and start-ups. Based on data from firms registered to pay company income tax in South Africa, ICT, transportation, and storage made up 4% of businesses, provided 6% of employment, and was responsible for 10% of turnover, on average, from 2011 to 2014 (Tsebe et al., 2018). While over half of these firms had between one and nine employees, large firms (more than 250 employees) were major plays. More than 60% of employment was created by large firms and over 60% of turnover was generated by these firms.

While progress has been slow in some cases, connectivity service businesses in South Africa are starting to incorporate 4IR systems. Supporting this development is the fact that many businesses have been involved in innovative behaviour. Innovation for businesses in transport, storage, and communication was reported in the Business Innovation Survey (Centre for Science, Technology and Innovation Indicators [CeSTII], 2020) as being very common in relation to processes (62% reported process innovations), but innovation was less common for products (35%), marketing (32%), and organisational structures (30%).

While communication and transportation can be discussed separately, they are often interdependent, especially in 4IR systems. A key distinction that both share is that their services can be provided through physical infrastructure as well as through other means. It is notable that connectivity services provided through infrastructure have different dynamics, including production network structures, than other connectivity services.

Infrastructure development typically involves large-scale projects that are often based on government tenders. Innovation can develop within infrastructure provision but timelines are typically long. While requiring high levels of investment, improving infrastructure can help South African firms to gain inexpensive and reliable services, and help to decrease product prices. This will allow South African products to better compete with imports and improve the competitiveness of exports (World Bank, 2018a). Public sector decisions can play a major role in shaping how 4IR is incorporated in infrastructure.

Other connectivity services can be provided on a much smaller scale. These can be developed and offered by start-ups with little capital investment. In addition, customers for connectivity services can be small and more willing to experiment than larger buyers. With many service providers simultaneously offering these services to many buyers, room exists for experimentation and development of diverse 4IR innovations.

Overall, with growing innovation and increasing demand related to 4IR, connectivity services have the potential to make a much more positive contribution to the economy. This section considers organisations that provide connectivity services related to transportation (including logistics) and communication and explores recent developments in these areas in order to further explore challenges and opportunities that are being faced as 4IR progresses. The first part focuses on the communications industry, and the second part focuses on transportation and logistics. The third part of this section considers the dynamics of the production networks in which connectivity service businesses operate with the discussion split into one segment that focuses on physical infrastructure and one that focuses on other types of services. The fourth part shares connectivity services businesses' experiences of innovation processes.

2.1 Communication Infrastructure and Services

Connectivity services related to communication can be provided through infrastructure and by businesses that provide other types of communication services. ICT infrastructure involves mobile and fixed-line systems. ICT services can include social networks, analytic, and cloud technologies.

Data services are a major element of communication in 4IR. For example, a respondent from a consulting firm that is providing a 4IR-related service described helping clients to collect and manage data.

> So, our element is more on the data collection side and it collects unstructured data, where we have to aggregate the data into the back – sort of the back of the systems and then transform it into the information that is used for the client. So, you take the temperature side of things … behind the back office, that's where we then have our parameters … what's normal or what's not normal and which alarm to raise … we provide it to the clients who then use it in their operations … So, when the alarm is raised, for instance, they have a process they need to follow through. (F07-I07)

These interactions are only possible with sufficient ability to communicate. New developments related to 4IR and communications are blurring boundaries between businesses. The same respondent went on to speak about their high levels of openness with their clients. .

> What we always represent to our clients is [that] technology is a partnership so [it] requires us to be intertwined quite a lot for us to be able to deliver value to the clients' operations. So, we need to have a really deep knowledge of that. The way we engage with each other should not be a stumbling block to them. All roadblocks must be removed for us to be able to have that very close understanding of the environment. (F07-I07)

ICT can enable a digital revolution for South Africa's health care, education, entertainment, logistics, commerce, and government (Accenture, 2019). Overall, compared to a large selection of countries, South Africa's ICT industry has both positive and negative elements (see Figure 2). However, it is important to note that the provision of services is uneven across the country.

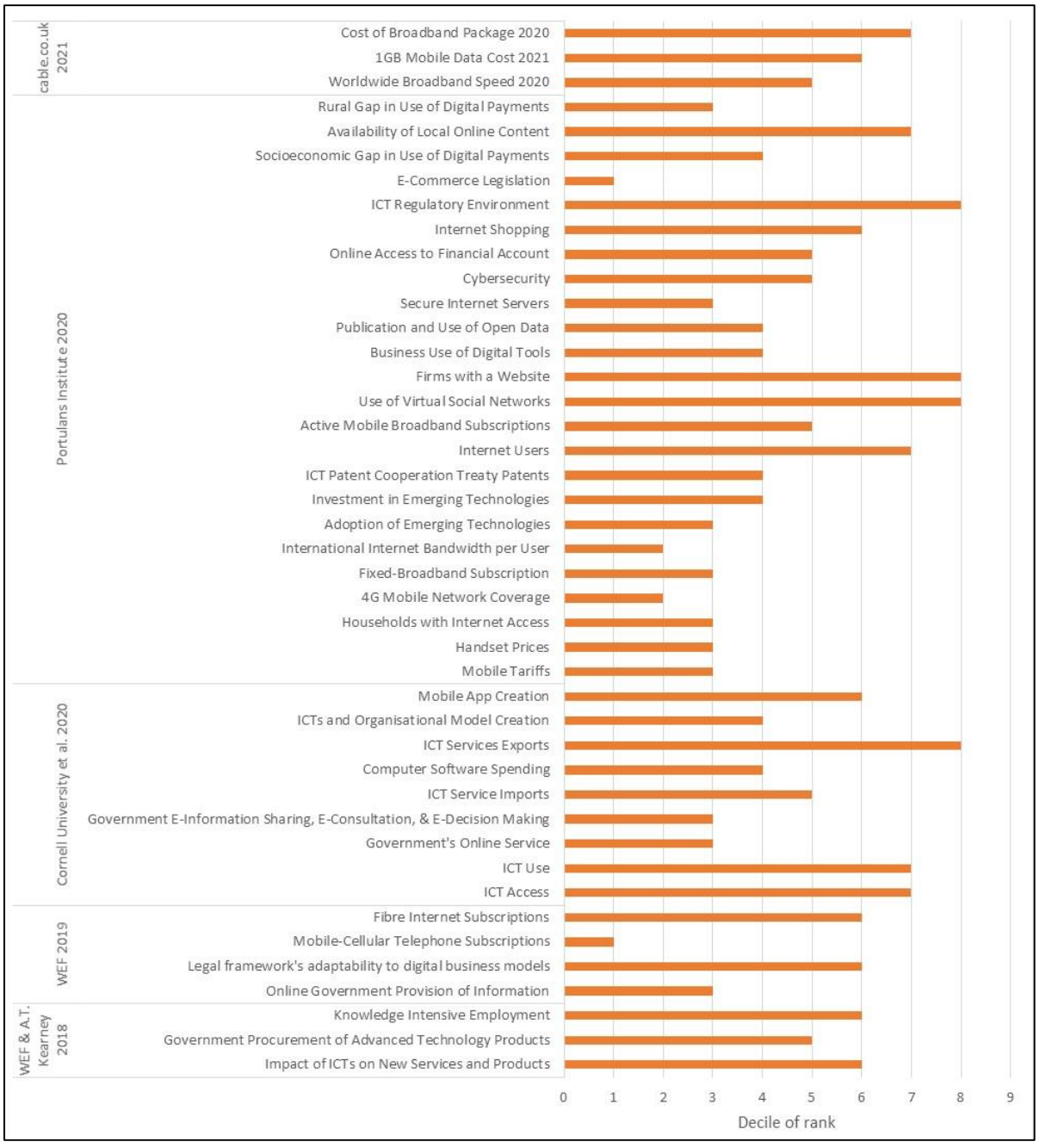
The better ranking elements include the rural gap in the use of digital payments, secure internet servers, the adoption of emerging technologies, and access to and use of internet and phones (international internet bandwidth per user, fixed broadband subscription, 4G mobile network coverage, households with internet access, handset prices, mobile tariffs, and mobile-cellular telephone subscriptions). A national assessment found South Africa to be on track in terms of undersea cables and mobile network coverage and quality (Genesis Analytics, 2019). In terms of where spending goes, the largest revenues were generated in mobile services (see Figure 3). Network coverage increased from 2019 to 2020, with 3G seeing a slight increase, from 99,7% to 99,8% of national population coverage, and 4G/LTE experiencing a bigger increase, moving from 92,8% to 96,4% of national population coverage (Independent Communications Authority of South Africa [ICASA], 2021). By 2020, 5G population coverage was 0,7% (ICASA, 2021). In mid-2021, four cities (Cape Town, Johannesburg, Pretoria, and Durban) had 5G coverage (nPerf, 2021).

A big part of the expansion of 4IR is growing levels of internet provision. Access to the internet in South Africa is growing. Notably, South Africa has invested in fibre roll-out (PC4IR, 2020), and the internet of things (IoT) is also developing. ICT providers are investing in developing IoT networks and solutions (Gain Group 2020). South Africa's number of connected devices is expected to reach 168,4 million in 2021, increasing from 119,2 million in 2016, which will require an expansion of systems such as software-defined networking (SDN) and network function virtualisation (NFV) to create autonomous and zero-touch networks that are self-optimising and safer from cyber-attacks (PC4IR, 2020).

What is notable is that South Africa's ranking in the ICT Development Index dropped from 77th in 2002 to 92nd in 2017 (ITU, 2009, 2017). Many elements are lagging behind global norms. These include the costs of data (cost of broadband package, and 1 GB mobile data cost), user engagement with online content (availability of local online content, and internet shopping, use of virtual social networks, and internet users), creation of online content (firms with websites, and mobile app creation), incorporation of ICTs (ICT use, ICT access, and influence of ICTs on new services and products), ICT service exports, fibre internet subscriptions, and knowledge-intensive employment. A national assessment found that challenges with data affordability are large and steady (Genesis Analytics, 2019). However, while large gaps were found in relation to fixed-line coverage and quality, these gaps were declining. Opensignal rated the best-performing service providers as "very good" for video experience, nearing 90% for 4G coverage, and "poor" for voice app experience, with typical download speeds of 26,4 Mbps and upload speeds of 8 Mbps (Rizzato, 2020). In 2021, South Africa was ranked in a

group of most-improved countries for download and upload speed experience (Fenwick, 2021).

Figure 2: Global Rankings Related to South Africa's ICT Industry[1,2]

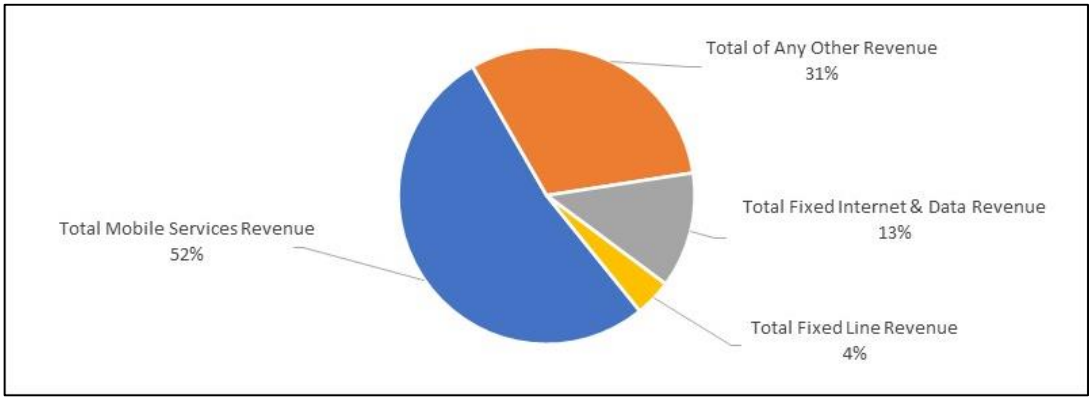


Sources: World Economic Forum (WEF) and A.T. Kearney (2018); WEF (2019); Cornell University et al. (2020), Portulans Institute (2020), cable.co.uk (2021)

[1] Unless otherwise specified, these elements are relevant to all of South Africa's economy, and not connected specifically to businesses providing ICT infrastructure or services.

[2] This figure shows deciles which categorise how South Africa ranks compared to other countries. For example, a position in the first decile indicates that South Africa is in the top 10% of countries.

Figure 3: 2019 Telecommunications Industry Revenue[3]



Source: ICASA 2021

Challenges with the ICT industry are felt in multiple ways in South Africa. One issue is that the overall high costs of telecommunications and internet services can be a barrier to businesses' competitiveness (World Bank, 2018a). High data costs can be a particular challenge faced by entrepreneurs (Bosma et al., 2020). In addition, high data costs may be a barrier to digital labour and product markets (Genesis Analytics, 2019).

The telecommunications industry employs high numbers of people and is expected to have increased growth in the future. Employment in this industry in 2020 included 25 951 skilled workers, 5 050 semi-skilled workers, 527 unskilled workers, and 311 disabled workers (ICASA, 2021). In addition, women made up 37% telecommunication workers. Overall, employment grew by 2,1% over the 6 years leading up to 2020.

This sub-section focuses on the innovation system for communication services in South Africa. The first part discusses the types of businesses that are involved in providing communication services. The second part covers additional key actors and the support environment.

2.1.1 Organisations Providing Communication Services

The telecommunications sector includes fixed and mobile telecommunications services, as well as internet access provision. Over 100 firms were telecommunications licensees in South Africa in 2019 (ICASA, 2020). These are a diverse set of businesses.

ICT infrastructure is an industry in which large players dominate. The early entrants in this industry (Vodacom and MTN) were given exclusive access until 2001 and continue to benefit from economies of scale and network effects. New entrants have struggled to be profitable (World Bank, 2018a).

[3] Note: Includes revenues from telecommunications services earned from retail fixed-telephone, mobile-cellular, internet and data services offered by telecommunication operators (both network and virtual, including resellers) and interconnection, equipment sales and any other revenue.

ICT services have higher levels of competition (MarketLine, 2020a). Larger businesses can provide a wider range of information technology (IT) services, and can develop intellectual property that increases their strengths. Competition for IT services can be global. Early drivers of geographic expansion were based on labour costs, but future developments may be shaped by storage costs and data-flow restrictions. Partnerships between large players enabling broader service provision, such as those related to cyber security, can give these players a competitive edge. South Africa has a large number of experts in this industry. However, they can prefer large, established employers, which can create difficulties for start-ups in attracting staff.

It should be noted, however, that it is relatively easy for new businesses to be established that provide IT services (MarketLine, 2020a). One respondent described the risk of employees potentially becoming competitors.

> You want to stop a guy coming to you and then become entrepreneurial and trying to do it himself … I think the market is doing well. But it creates an entrepreneurial environment. They say I want to do it. And now you create a lot of noise in the market and so on. Some of them can survive. Some not … IT businesses they kill each other for business. (F04-I04)

Companies can also manage IT services internally to save money, but outsourcing them can free up staff time for other things and decrease resources needed to develop in-house capabilities. Government and private organisations are increasingly using third-party IT support (MarketLine, 2020a). Several firms in the set of interviews reviewed to prepare this paper provided IT-related consulting services.

There are many internet service providers active in the South African market, resulting in a lot of competition. Telkom, a partially state-owned company, is a major player, serving South Africa and other African countries. Fibre-to-home services are provided by Openserve (a division of Telkom), Vumatel, Frogfoot Networks and Octotel in urban areas, and smaller providers offer services to gated estates and communities. Major players for the LTE network include Telkom, Vodacom, and MTN.

Large global companies also play a role in providing ICT-related services, with major players in South Africa being International Business Machines Corporation (IBM), Hewlett Packard Enterprise Company (HP) and Capgemini (MarketLine, 2020a). IBM provides cloud services and enterprise software, with diverse clients across South Africa. HP offers compute, storage, and data centre networking services, enterprise networking, and security solutions, and it provides wired and wireless local area network hardware products (e.g., switches, routers, sensors, Wi-Fi access points and software products based on cloud-based management, network management, analytics, and location services). Operating under multiple brand names, Capgemini provides cloud services and product and engineering services.

In addition to the large global players, the ICT market also has smaller local players. Digital start-ups that depend on ICT infrastructure have had some success in South Africa, with

multiple types of offerings. These include financial technology (e.g., SnapScan and Yoko), education (e.g., GetSmarter and Snapplify), e-health (e.g., LifeQ), and online job platforms (e.g., Giraffe, SweepSouth, Domestly, and OfferZen) (World Bank, 2018a).

2.1.2 Additional Key Actors and Support Environment for ICT Firms

Public sector organisations play a big role in shaping options in the ICT industry. As can be seen in Figure 2, elements of government regulation and services related to ICT are split between being globally advanced and globally lagging. Advanced elements include e-commerce legislation, government e-participation, government online service, and online government provision of information. These elements are related to users being able to benefit from e-services.

The lagging elements related to government regulation and services include the ICT regulatory environment and the adaptability of the legal framework to digital business models. Furthermore, in a national study, telecommunication regulations were found to have a large and steady deficiency (Genesis Analytics, 2019). These factors make it more difficult for ICT businesses to operate.

However, South Africa has prioritised ICT across multiple policies. Key documents include the National Development Plan, South Africa Connect (the national broadband policy), the 2012 National Cybersecurity Policy Framework, the National Information Society and Development Plan, and the 2016 National Integrated ICT Policy White Paper (Department Telecommunication and Postal Services, 2016). These policies seek to expand South Africa's ICT sector in ways that support national development.

A variety of organisations are available to support businesses in the ICT sector. For example, the Innovator Trust supports small black-owned ICT business. In addition, there are a several industry associations. The Information Technology Association represents more than 200 companies involved with supplying information technology equipment, systems, software, and services. Another is the Internet Service Providers' Association. This is an organisation that facilitates exchange between independent internet service providers, ICASA and other government structures, operators, and other service providers in South Africa.

This is an industry that needs many high skilled workers. These needs will grow as ICT incorporates increasing levels of 4IR technology. South Africa's level of digital skills has much room for improvement. The country ranked 126th out of 141 countries in the category of digital skills among active population (WEF, 2019). The Media, Information and Communication Technologies Sector Education and Training Authority is a key public entity that supports skills development for the information technology and telecommunications industry.

2.2 Transportation and Logistics Infrastructure and Services

This sub-section focuses on businesses that provide transportation infrastructure and transportation and logistics services.

New forms of transport based on 4IR systems are on the horizon. Advanced sensors, which can involve machine-to-machine communication, are being used in the logistics and freight industry and have been used by industry to track and scan goods and undertake quality control checks. One South African logistics firm described developing a product-shipping system that can incorporate machine learning.

> Which truck is on its time? … It tells me by RFID [radio frequency identification] when a truck arrives, I can read the GPS coordinates of it as it moves through the yard. I can update it. I'll tell you when it's too long in any area. I give you alerts around it. I can tell you where it is.
>
> … Now we're adding a lot of things … People start to say, okay, I also need to tell the person moving their vehicles to be part of the system. So, I can alert you and say, 'Please move a vehicle from B to C'. (F04-I04)

With 4IR business models, logistics is becoming an integral part of operations and involves systems that integrate different parts of value chains.

> Traditionally, we've been looking at logistics as separate discrete parts of the value chain … Now, [for] the new markets it's a holistic view on the logistics value chain … it is highly possible to have single point of contact, where we've got this business of open … where people plug in, various suppliers plug in into this system, where there's a similar interface with the user and with the supplier of services or supplier of the platform or the actual supplier of goods. So, I see that as the new markets emerging in the industry where the economics model becomes applicable in the industry where there'll be that … integration of various stakeholders. (F07-I07)

Overall, 4IR systems have been expanding in South Africa's transportation and logistics industries. This includes the use of cameras and fibre optic cables that have been installed by private companies. Another element of 4IR that is emerging in transport infrastructure is artificial intelligence (AI). For example, one of the respondents described AI as being part of one of their new products.

> The hardware is accessible. You don't need a massive processor anymore. All you need is something to load your machine-learning model on. And there you go. So, what this does, and it's working now, this is just a little video stream. [It's] supposed to detect people and count them … It starts tracking and then goes from there. But essentially, what you have, is in a very cheap package, you have a reasonable processor with AI. (F21-I37)

While transportation and logistics services are incorporating growing elements of 4IR, barriers exist to further development. Major challenges impeding the adoption of new technologies in South African logistics have been identified (Gain Group, 2020). Key challenges include a

lack of relevant skills (including warehouse management systems, big data, AI, blockchain, drone technology, and robotics) and a lack of standardisation of technology across sectors.

South Africa's transport infrastructure network is the most extensive in Africa, with approximately 750 000 km of roads, approximately 30 000 km of rail tracks – of which 20 900 km are route kilometres, eight commercial ports, and eleven principal airports (Gain Group 2020). South Africa ranks relatively well in global comparisons of logistics services (see Figure 4). Notably, South Africa was the 3rd highest among upper-middle-income countries, after China and Thailand, on the World Bank's (2018c) Logistics Performance Index. South Africa's high ranking for logistics performance by WEF and A.T. Kearney (2018) is a measure of the efficiency of customs and border management clearance, ease of arranging competitively priced shipments, the competence and quality of logistics services (trucking, forwarding, and customs brokerage), the ability to track and trace consignments, and the frequency with which shipments reach the consignee within expected time frames. Strengths in South Africa's logistics system are found in export lines, such as those that facilitate bulk shipping for mines and coal-based chemicals, auto exports, and fruit (Makgetla and Levin, 2020).

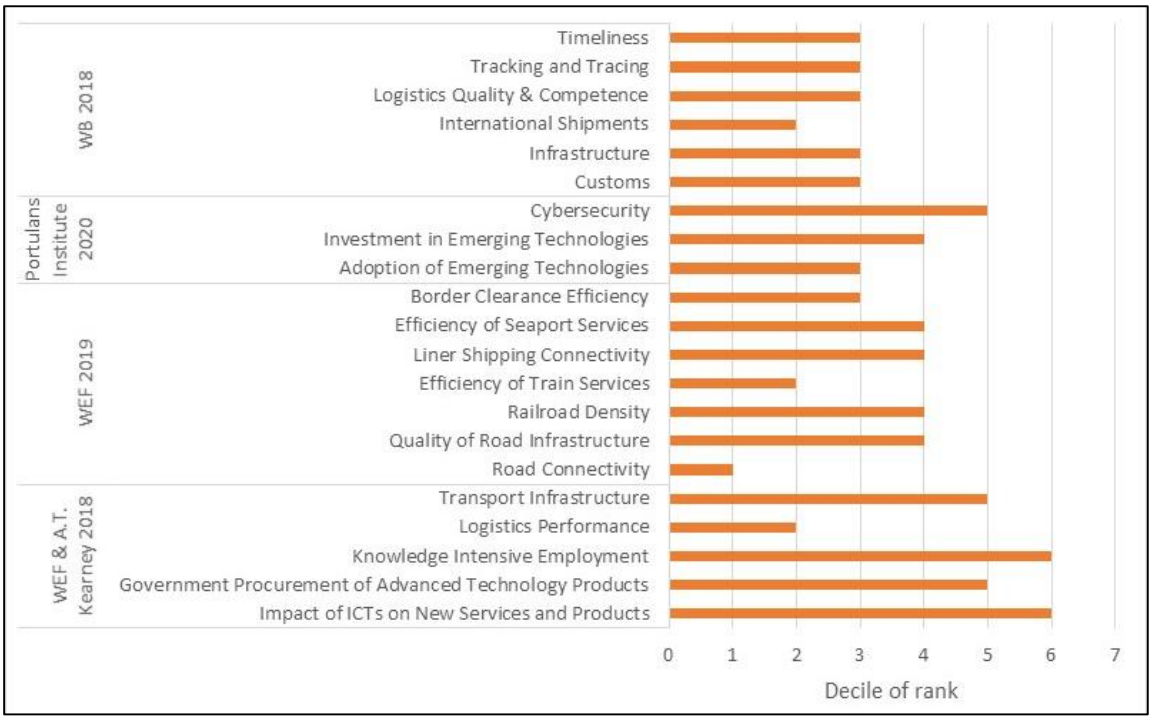
Areas that were ranked poorly are directly connected to the ability of the industry to adopt 4IR systems. These include knowledge-intensive employment, and the impact of ICTs on new services and products. While South Africa's logistics sector may be above the global average, as described below, it still creates many challenges for businesses. Furthermore, it is not adequate to support a smooth transition to efficient 4IR systems.

Logistics services are very important to South Africa's economy (Gain Group, 2020). The national economy is transport intensive due to the large size of the country, with great distances between economic hubs (e.g., Gauteng is about 600 km from the nearest port), the distribution of agriculture and manufacturing from economic centres, the export bulk of commodities from inland mines, and South Africa's dependence on imported high-value consumer goods. Also, of the ten most competitive sectors, seven are heavily dependent on transport (mining; automotive; steel and other metals; fast-moving consumer goods; agribusiness; building, construction and engineering; and retail). Notably, at the end of the 2010s, South Africa experienced a reduction in commercial spending and a contraction in the agriculture, forestry, fishing, manufacturing and mining sectors, which had a negative effect on transport volumes.

The transport and logistics sector has been ranked as being the second least competitive when compared to the country's 16 economic sectors (Barloworld Logistics, 2012). Assessments focused on South Africa have identified transportation infrastructure and logistics services as a barrier. Main weaknesses have been identified as poor rail lines and roads, congestion around ports, lack of provision of safe rest stops on long-distance roads, and a lack of feeder roads (Makgetla and Levin, 2020). Transportation was self-identified as a major constraint for 4,9% of exporters and 3,8% of importers in the period from 2009 to 2013

(World Bank, 2016). Delivery times have also been found to be a challenge for South Africa's logistics system (Department of Trade and Industry [DTI], 2018). A focus on international trade led to the creation of infrastructure serving export routes, which has been overloaded and experienced deterioration, while internal routes not connecting to mining centres have been inadequately funded (Makgetla and Levin, 2020).

Figure 4: Global Rankings Related to South African Transportation Services[4]



Sources: WEF and A.T. Kearney (2018); WEF (2019); Portulans Institute (2020); World Bank (2018c)

Infrastructure quality in South Africa has been declining (World Bank, 2018a; Alexander, 2022a). Transport infrastructure, in particular, suffers from a lack of maintenance (Organisation for Economic Cooperation and Development [OECD], 2020). Following poor rail maintenance, heavy loads shifted from rail to roads from the 1970s, leading to road deterioration (Makgetla and Levin, 2020).

For years, government spending was focused on domestic-use elements of infrastructure (Makgetla and Levin, 2020). Over time, the lack of investment in economic infrastructure meant that the needed repairs and refurbishments became a larger and more expensive project for successive governments. From the 2000s, these expenses were a more difficult challenge after commodity price drops decreased the money available in public coffers.

A particular challenge facing South Africa's logistics industry is high costs. Logistics costs are higher in South Africa than in developed countries, but less than in other BRICS countries

[4] Unless otherwise specified, these elements are relevant to all of South Africa's economy, and are not connected specifically to transportation infrastructure or services.

(Gains Group, 2020). Transportation costs are high because of long distances between domestic production and consumption, high costs and inefficiency of ports, poor quality of freight rail, insufficient intermodal facilities, expensive pipeline transport, and expensive road freight (World Bank, 2018a). High costs for transportation in South Africa protect domestic firms by raising the costs of imports, yet they also increase the costs of domestic products (World Bank, 2018a). DTI (2018) describes challenges with the costs of logistics services as limiting South Africa's industrial development and competitiveness, noting specifically that high costs affect manufacturing revenues and value addition of manufactured goods.

Another issue to consider is international transport (Makgetla and Levin, 2020). Long-distance freight transport is important for South African manufacturers because international trading partners are distant and cities within the country are also far apart. Regional freight transport has been high in cost and slow, with costs in the Southern African Development Community (SADC) region (outside of South Africa) found to be twice as high as domestic transport in the mid-2010s. Transport costs are comparatively high because of asymmetric trade, delays in border crossings and poor infrastructure.

Border delays are a serious problem (Makgetla and Levin, 2020). They can cause increased costs and cause changes in routes, with known points of delay causing companies to change routes. Delays can be caused by inadequate infrastructure and organisational deficiencies, while a one-stop border crossing set up on select roads led to a 50% decline in transit times. SADC border delays have been widely recognised as a challenge since the mid-1990s, but little has been done to address this issue, with South Africa placing more priority on overseas trade facilitation than enabling regional trade.

The rail system is best suited to the consistent flows of high-volume goods that are produced in the mining industry, with two specialised transport lines for coal and iron ore (World Bank, 2018a). However, services are less competitive for general freight rail services. Low use and challenges with connections at ports and inland container depots lead to inefficiency and increased costs .

South Africa's rail system faces many challenges (Gain Group, 2020). One is that items that typically would be transported by rail use road transport because of rail inefficiencies, which include lack of investment in infrastructure, lack of maintenance and inefficient skills. In addition, for some sectors, such as agriculture, the limited access to rail capacity hampers exports. However, projects are being developed to improve export channels. Freight owners have expressed frustration related to the long turnaround times on rail links, damage to loads, and lack of accurate tracking services. Another problem is theft and vandalism of the rail system (F25-I46).

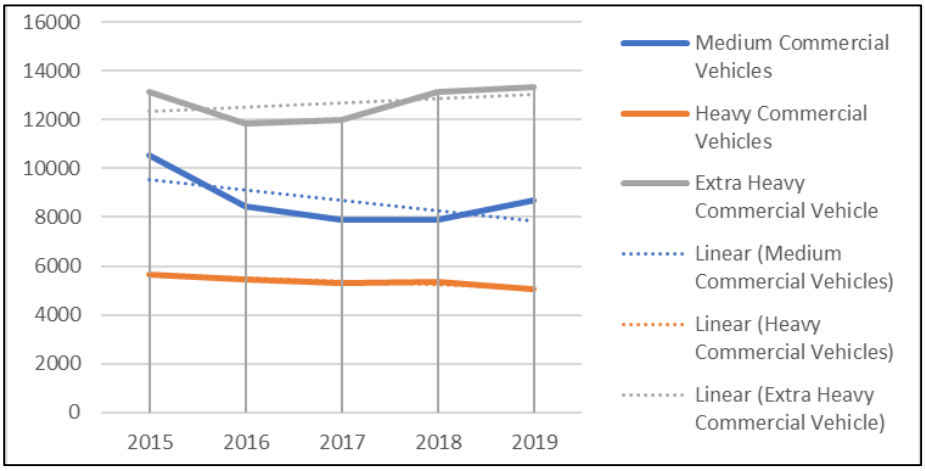
Road freight services are relatively well priced, although there is room for prices to be lowered by incorporating best practices (World Bank, 2018a). A major problem is administrative efficiencies related to regulation, market structure and border procedures, which increase the costs of cross-border routes by 10% to 30%. Furthermore, as mentioned, border delays

can add costs, create additional problems for time-sensitive goods, and reduce the number of trips a truck can complete in a month. Another inefficiency identified by the World Bank (2018a) is that many trucks return to South Africa empty, as demand for exports is higher than demand for imports.

The most common form of freight transportation in South Africa is trucks, particularly for moving natural resources around the country and across land borders (MarketLine, 2020a). The high levels of freight transported by road (77%) have led to the deterioration of roads and high maintenance requirements (Gains Group, 2020). Poor-quality infrastructure increases costs because of higher vehicle maintenance costs, downtimes for repairs and longer driving times because of going at lower speed and on alternative routes (Gains Group, 2020). Another cost-increasing factor is disruptions in electricity supply. These cause traffic jams, interruptions to security and communication systems, affect temperature-controlled and automated storage facilities, create a need for back-up power systems, and create delays (Gains Group, 2020).

Business confidence shapes the demand for trucks (Lamprecht, 2020). Sales of commercial vehicles had mixed trajectories from 2015 to 2019 (see Figure 5). From 2017 to 2019, growth in medium commercial vehicles was driven by growth in online shopping and hub deliveries, while extra-heavy commercial vehicles have continued to expand based on the movement of bulk goods and commodities (Lamprecht, 2020). One challenge is the poor quality of existing road vehicles. An interviewee described trucks having frequent breakdowns and problems as a result of portions of roads with steep upgrades (F10-I13). He described these breakdowns as causing crashes and road delays.

Figure 5: Sales of Medium and Heavy Commercial Vehicles



Source: Lamprecht (2020)

Ports are a major part of South Africa's logistics infrastructure. About 90% of South Africa's exports and imports go through ports (World Bank, 2018a). Port services are impeded by capacity constraints, operational inefficiencies, labour unrest, and disruptions in electricity supply affecting cold-chain transport (Gains Group, 2020). High charges and the inefficiencies of ports are a significant barrier to and a constraint on exports (DTI, 2018).

South Africa's airports function well. Participants in the Gain Group's (2020) study did not experience the same level of frustration with air freight as they did with land-based options.

Finally, South Africa's system of hubs, terminals and warehousing facilities also function relatively well (Gains Group, 2020), and are sufficient in number. However, while warehousing facilities are technologically advanced, they do not use the most modern management systems.

Overall, the transport and storage industry is a major employer in South Africa. Over 330 000 people were employed by registered businesses in this sector in 2019 (Stats SA, 2021). This can be broken down into railway transport (47 385), other scheduled passenger land transport (19 885), freight transport by road (126 178), transport via pipelines (835), water transport (18 813), cargo handling (16 388), storage and warehousing (20 716), other supporting transport activities (24 974), travel agencies and related activities (13 974), and activities of other transport agencies (39 972).

The remainder of this sub-section provides more information about the innovation system surrounding South Africa's transportation industry. The first part describes key organisations that are involved in providing transportation services. The second part considers additional key actors and the industry's support environment.

2.2.1 Organisations Providing Transportation Services

Transportation infrastructure is provided mainly by the public sector through direct management and through SOEs. The freight-forwarding sector involves private-sector domestic and global companies competing for clients. This can drive local businesses to improve their offerings, or it can also push out local businesses that cannot compete.

The main actors in South Africa's logistics sector can be put in four categories (Gain Group, 2020). One is the infrastructure providers and regulators, which include government departments and agencies, as well as SOEs. The second are the service providers, which include freight forwarders, financial services, insurance, logistics technology solutions, third-party logistics providers (handling shipments), fourth-party logistics providers (managing supply chains), shipping lines and agents, airfreight carriers, courier services, private port terminal operators, consultants, private storage facilities, and industry associations. The third category is the enabling environment, which includes customs, regulatory bodies, finance, training, and research. The fourth is customers, such as the freight owners.

Some transport services involve a near monopoly role of SOEs. One of these is Transnet, which provides rail, port, and pipeline infrastructure. Transnet Ports Authority manages eight commercial ports as a landlord and is responsible for their infrastructure and marine services and owns much of the rail infrastructure within the port boundaries. This rail infrastructure is operated by Transnet Freight Rail (TFR). Most terminals are operated by Transnet Port Terminals (TPT). Transnet also owns major container terminals.

Rail supply chains usually involve diverse businesses. Train manufacturers are usually large firms, with a wave of consolidation having taken place in recent years (MarketLine, 2020b). These firms face a limited threat from new entrants. Key other firms involved in rail supply chains are responsible for metal fabrication and rail transport equipment. These companies have faced several challenges (DTI, 2018). Three decades of low demand and inadequate capital investment have led to plants, machinery, and equipment not being modernised. This poor-quality equipment has made it difficult to compete for new projects. In addition, decreasing tariffs have led to a surge in imports, particularly of low-value, high-volume goods. Finally, the global steel surplus has put downward pressure on steel prices and related downstream industries.

South African marine freight operations interact with global marine freight companies. Marine freight is highly regulated, with high fixed costs and with established players holding a large market share. The industry has also experienced a large amount of consolidation in recent years, with large global firms dominating the market (MarketLine, 2020b).

The South African National Road Agency (SANRAL), another SOE, is responsible for financing, designing, maintaining, rehabilitating, and upgrading national toll and non-toll roads, while the provincial and local governments manage other roads. SANRAL uses public tenders to hire private companies. There is intense competition in road freight shipping. Barriers to entry are low for road freight, and new entrants are common (MarketLine, 2020b). Small businesses can easily enter the road transport industry, such as by being truck owner-drivers. South African manufacturers also contribute to providing road transport vehicles. The most popular medium-sized and heavy commercial vehicles were produced by Isuzu Motors South Africa in 2019, while Volvo Group South Africa was the largest supplier of extra-heavy commercial vehicles (Lamprecht, 2020). Labour issues and social unrest are major problems for the trucking industry. At the end of the 2010s, more than 1 000 trucks were destroyed and damaged and more than 200 people were killed due to related violence (Gain Group, 2020).

With a majority government control, the Airports Company of South Africa (ACSA) owns and operates nine airports. Kruger Mpumalanga International airport is privately owned. Gateway Airports Authority, a provincially owned enterprise, runs the Polokwane International Airport. Air freight in South Africa is dominated by large international and domestic players, but smaller companies with localised services also play a role. Businesses offering air freight include global multi-modals, dedicated cargo carriers, and passenger airlines that have diversified into freight services (MarketLine, 2020b). New business entry is limited due to the high fixed costs, which require high volumes to earn profit and high levels of regulation of operations (e.g., safety, security, and staff training) (MarketLine, 2020b). While air freight transport is an expensive option, it can be preferred when speed is an important factor.

Other public entities involved in logistics and transportation include the Road Traffic Management Corporation (RTMC), the Road Traffic Infringement Agency (RTIA), the Road Accident Fund (RAF), the Cross-Border Road Transport Agency (CBRTA), the Railway Safety

Regulator (RSR), the Passenger Rail Agency of South Africa (PRASA), the Ports Regulator of South Africa, the South African Maritime Safety Authority (SAMSA), the Air Traffic and Navigation Services (ATNS), and the South African Civil Aviation Authority (SACAA).

A variety of private domestic and global companies also play a large role in transportation services, with key players such as FedEx (USA) providing ground and air transportation, e-commerce and business services; the MSC Mediterranean Shipping Company (Switzerland) providing container shipping; the South African firm Imperial Holdings Limited providing freight management and logistics services; and South African Express Airways providing air transport (MarketLine, 2020b). Also notable is that some companies have their own internal shipping departments.

As most infrastructure is managed by state-owned companies (and municipal governments), competition is not a major factor. However, there is a lot of competition in freight transport services. In addition to competition between options within each mode of transport (e.g., road, rail, plane), each mode can act as a substitute for the others. There are large incumbents with multinational connections, multi-modal offerings, built reputations and the ability to offer complex and integrated logistics services who play key roles across these markets (MarketLine, 2020b).

One dynamic that is important to consider in relation to logistics businesses is ownership. Investors can shape firms' behaviour. Some companies described having changing ownership structures over time. These include South Africa-founded firms being bought by multinational corporations (MNCs). This process was described by one of the respondents.

> It was started out as a small business by a couple of individuals. And few years ago, a major European company bought a major shareholding in us. And two years ago, it became a fully owned subsidiary of that European company. (F21-I38)

A notable benefit, as described below, is that global owners can help to connect firms operating in South Africa with global technologies.

Another issue faced by some firms is global competition. These firms may have more advanced technology or cheaper offerings. One South African firm described global developments introducing technology that outperforms existing systems.

> So, from the outset, you have a device that measures speed, and it must be either radar or laser. And these are relatively expensive components. And there's a crowd in, I think they are Russian, who have built an AI system, which essentially uses a pair of stereoscopic CCTV cameras, so dirt cheap … And the AI algorithm on that then determines the speed of the vehicle traveling through its field of view. And so, you could do that kind of thing at a dirt-cheap price … that sort of thing becomes possible. (F21-I37)

Another dynamic to note is that entrepreneurship in this industry is growing. Many new start-ups are bringing in 4IR technology and processes. For instance, South Africa houses over 200 logistics tech start-ups (Tracxn, 2021).

2.2.2 Additional Key Actors and Support Environment for Transportation Services

A number of policies are in place to support the development of transportation and logistics in South Africa. Key policy-related initiatives include the National Transport Master Plan (NATMAP) 20150, Green Transport Strategy for South Africa: (2018-2050), the Rural Transport Strategy, the Revised White Paper on National Transport Policy, the Infrastructure Investment Plan, and the National Infrastructure Plan. In addition, South Africa is covered by the SADC Regional Infrastructure Development Master Plan.

South African transportation-related businesses participate in several industry associations. Industry associations related to transportation services include the Chartered Institute of Logistics and Transport South Africa, the Road Freight Association, the Intelligent Transport Society South Africa, and the South African Association of Freight Forwarders. In addition, transportation and logistics start-ups are benefiting from growing levels of venture capital funding (The Baobab Network, 2021).

Finally, skills development is an important issue for logistics businesses (Gain Group, 2020). In the logistics industry, skills and professional development are provided by organisations such as SAPICS (a professional body for supply chain management) and the Transport Education Training Authority, which make significant contributions but have limited capacity. In addition, training in traditional universities lacks adequate practical preparation. Overall, standardisation across training institutions is also lacking.

Private actors have been working with private universities to develop customised training. Interviewees in Gain Group's sector assessment identified a number of training-related needs: identifying best practices; developing partnerships in 4IR-related capacity development; developing more basic skills (e.g., mathematics and English) to prepare students for logistics and supply chain training programmes; bridging the gap between theoretical training and practical work skills; increasing the quantitative content of logistics training; collaborations for training and development for new businesses; and entering into partnerships to help businesses meet export quality standards. The skills gap is expected to widen as new technology becomes more widely adopted.

2.3 Production Networks for Connectivity Services

Networks involved in the provision of connectivity services and infrastructure are often global in scale and involve diverse actors. Key supply chains include the public-sector actors seeking contractors to build infrastructure, organisations seeking ICT services, and organisations seeking freight forwarding. This sub-section explores the dynamics in each of these three types of connectivity services' supply chains (see Table 1). This first part focuses on the procurement of infrastructure and the second part focuses on the procurement of services.

Table 1: Major Connectivity Service Supply Chains

Product or service	Producers	Key buyers
ICT or transportation infrastructure	Private businesses	Public sector
ICT services	Private businesses	Private businesses (and public sector)
Freight forwarding services	SOEs and private businesses	Private businesses (and public sector)

2.3.1 Procurement of Infrastructure

Supply chains involved in developing public infrastructure involve private firms being awarded contracts. For these firms, their main customers are often government agencies or SOEs.

> Main clients are governments. There are a couple of minor private ventures but very, very small so that the majority of business is done through public sector and via tender process. (F21-I38)

A problem with tendering systems is that they can involve corruption and mismanagement. One respondent described difficulties with getting government contracts.

> Because of a lot of corruption in government … there are so many gates that you have to go through, it just makes it very complex. (F10-I13)

Having good tendering processes requires good skills within government to make infrastructure decisions. Problem often exists because government decision makers do not understand the technological issues. There can be good ideas at the top, but the implementation and tendering processes can be problematic.

> The biggest challenges are that the depth of knowledge is very low amongst our customer base … There are pools of knowledge, which used to be very robust and have shrunk pretty radically over time … [over] 10 years and, you know, experience has left or been driven out. (F21-I38)

Two respondents from one of the companies interviewed spoke about tenders requiring defined specifications for an output versus requiring a specific function (in relation to government tenders for transport systems). One thought the functional requirements were more advanced (F21-I38). The other thought that countries using this approach just did not have existing infrastructure, so they can use any system that meets their functional requirements (F21-I37).

> While I understand the rationale for the tender process … it's a flawed system … In a tender situation, you get a completely different set of parameters, you get a specification of what is required, which may or may not be a robust definition of what is required to do the job that is required. My experience over the last couple of years is that … in the Sub-Saharan African region, typically, those kinds of documents are better produced in other countries than they are in South Africa.

> … In the documents that I've seen coming out of other countries where we have been active, those are well put together. [They] actually say, 'this is what this thing, whatever it is that you bring, this is what it must do'. Whereas in South Africa, quite often the tender will say, 'this is what it is'. And as a result, very often it's focused on something.
>
> Now if it says, 'this is what it is', and 'what it is' is ours, that is fantastic. But that's not necessarily right … Focus on functional specification is important. (F21-I38)

A challenge of public procurement is that the government is making decisions about what technologies will be used. The respondent above described how this process can lead to technology being chosen based on an inadequate assessment of the options.

> The fact that we're the first on the block or maybe the last on the block makes the difference of whether the solution which is presented first or last, is selected by the people who get trained and how that interface happens.
>
> In a situation of an absence of understanding, the most convincing story will usually prevail. That convincing story is not necessarily the solution that should be put in place. And it might not necessarily be going in for the right reasons. And I think that's, for me, the biggest risk. And I'm looking at it from a perspective of saying, as a taxpayer, they're spending my money. I want them to spend it on a solution that works as opposed to a solution that matches somebody's specific criteria.
>
> … Very often things get put in which are not the optimal solutions … And that's either because of things that shouldn't be happening, or because people actually don't know the difference.
>
> … And I think, when you get into a situation where management of what needs to go in is well done, it works really well. And as I say, there are pockets of that all over the place. But it's not uniform. The level of manning of government departments where you have robust engineering skills and robust project management, and I don't think I'll be on my own in saying, it's really thin. (F21-I38)

However, this respondent felt that the government's policies are going in the right direction.

> If you look at the government policies that exist, they are brilliant. They really are. Policy wise, we've got some of the best policies that I can imagine around just about everything in our field transport and technology. In terms of implementation, a little bit shy.
>
> … There's a lot of enthusiasm and a lot of drive towards [smart cities]. And there are a lot of people with really good ideas about how to make it happen. How that translates into tenders is sometimes questionable … from the government side. Yeah. They're really good people who keep abreast of everything and do a lot of homework. And, you know, put stuff through the process. The cascade of that those are not necessarily a smooth journey.
>
> … There are there are two elements to be blunt about it. There are political elements. And there are capability elements. And, you know, the capability elements are probably the easy ones to solve, because at least you know, what the solution is. Who knows what the political solutions are?

> … There are a lot of people with all the right ideas in government, whether they are at functional levels, as in levels of implementation or not, I don't know. But certainly, from a policy perspective, and from strategic planning perspective, I don't see to date too many issues. I mean, the fact that we have now a commission under the presidency for 4IR is fantastic. And I think one of the key elements of how good that is, is that they are inviting submissions about the specific kind of thing to them. (F21-I38)

The market for the provision of infrastructure and infrastructure management services is regulated by a set of government standards. In some cases, these standards can limit the adoption of digitally enabled processes.

> If we're starting to sort of talk more about 4IR kind of things, then there are two elements that are critical in this tender environment that are that are really important is standardisation and regulations. The standards are important. But it needs to be recognised that standards will never ever keep up with technological advancements. And as a result, if regulations become absolutely blind to applying standards, then implementation will always be behind the time. Just by definition it will never, standards will never be up to speed with anything that's ever evolving. So, the key elements if you really want to develop an economy in high tech, deregulation is really key. (F21-I38)

However, the respondent did acknowledge that some standards are crucial for enabling integration.

> But then the issue should be that the standardisation that's applied should be about integration. So, interfaces are common, so that somebody comes up with a brilliant idea. It must be able to interface with the existing stuff. So that kind of thinking is what is really critical.
>
> … Standards need to be reviewed, and rewritten from a functional and integrational perspective, as opposed to a technological perspective, because technology is advancing far too quickly. And we don't have the resources to work on standards to keep up with it. I mean, bizarre, but it's true. (F21-I38)

Sometimes standards do not keep up with changing technology, as described by someone from this company, that sells systems with traffic cameras.

> We're building speed cameras. By law, [it's] still required to have an officer operate that speed camera, [but we sell] license plate recognition cameras. (F21-I37)

State procurement of infrastructure creates opportunities to support domestic businesses. However, these tenders are often open to global competition. Hiring domestic firms can be good for the economy and stimulate innovation. On the other hand, global contractors may have a better offering and may also be able to incorporate higher elements of 4IR technologies.

Considering rail, Transnet sources inputs from South African and global supply chains, although a lot of equipment is currently imported (DTI, 2018). South Africa has developed abilities related to rail transport equipment and structural steel, but has seen stagnation and

a decline in sub-sectors such as casting, tooling and foundries. Metal fabrication contributed 16,7% of manufacturing GDP (2,2% of total GDP), R212 billion in exports and provided 31 404 jobs in 2018. A number of domestic producers in this sector have recently launched or expanded, as the government has made concerted efforts to promote local procurement.

2.3.2 Procurement of Connectivity Services

This sub-section discusses key dynamics that are found in buyer-seller relationships in in communication services and transportation and logistics services.

2.3.2.1 ICT Services

Businesses of all sizes procure ICT services. ICT contracts can last for several years or be shorter consulting contracts, with an increasing trend towards shorter contracts (MarketLine, 2020a). As with infrastructure, ICT services are sometimes sought through tender or bidding processes. Two dynamics exist in this process (MarketLine, 2020a). Some companies will look for the lowest cost and are less concerned with quality. For other companies, quality is crucial, particularly for MNCs and government agencies, and this may give rise to high costs. The second type of buyer can control costs by using auctions or price competitions, which involve getting high-quality service providers to compete to offer the lowest price. ICT service providers also include a range of business sizes. Large businesses are able to offer sophisticated services and high levels of customer service. Nevertheless, small businesses can also be very competitive in this industry.

With the growth in short-term contracts and the development of new ICT services, suppliers have the opportunity to innovate to attract new customers. However, they are vulnerable to their buyers ending relationships if another business can out-compete them. As costs of developing new ICT services can be low for digital products, many opportunities exist for suppliers.

2.3.2.2 Transportation and Logistics Services

Buyers of transport services often have a wide range of choices, but are dependent on the transport options available, unless they want to develop their own transportation arm. While many buyers are businesses wishing to move their own freight, other freight service companies can also be buyers (e.g., marine freight buying rail services to provide intermodal offerings) (MarketLine, 2020b).

For traditional freight services, switching costs are very low, unless there is a long-term contract. However, with the growth of more complex service offerings by transportation providers, users may become more dependent on particular service providers. Buyers of transport services are very price sensitive, as this is a cost that can be a big portion of operating expenses (MarketLine, 2020b). However, for some products, speed may be of particular concern, and this may limit options. Prices for transportation services have gone down since 2014, and service providers face high levels of competition (MarketLine, 2020b).

To combat this problem, service providers can differentiate themselves through specialised offerings, such as the ability to transport fragile items.

Typical customers for each type of freight transport differ (MarketLine, 2020b). For marine freight shipping, buyers are sometimes quite dependent on their service providers, as they cannot afford to have disruptions in service. They can rely on the service provider for navigating regulations related to safe and legal shipping, particularly for hazardous goods. However, buyers are in a relatively strong position in the marine freight segment, as they typically are large buyers whose contract loss would be felt by the supplier (e.g., for raw materials such as chemicals, petroleum products, and coal). Customers for rail transport typically include large companies shipping high volumes and other transportation companies, such as marine freight operators providing intermodal services. Air transport is used less, as it is expensive and likely only chosen if a shipment needs speed or high reliability of delivery.

However, in South Africa's case, and with the large role played by Transnet, buyers' choices are shaped by the specific dynamics of the situation. Notably, Transnet plays a dual role, which can create conflicts of interest (World Bank, 2018a). Transnet dominates the value chain, from the products' arrival in ports to their final destination. They run the port and rail systems and provide integrated logistics for cargo and freight. In addition, they also play a role as a regulator by acting as the National Ports Authority, issuing licences and concessions to operate terminals at ports. Another division operates port terminals and the use of port infrastructure. Transnet was found to charge more than the global average port costs for automotive exports and less than average for commodities. However, they planned to correct the discrepancies (World Bank, 2018a).

2.4 Innovation Experiences of Connectivity Service Businesses

Connectivity services firms shared a variety of descriptions of and insights into their experiences with adopting and developing new technology. This sub-section divides these into two types of experiences, namely absorbing external knowledge and internal experiences with innovation.

2.4.1 Absorbing External Knowledge

A major way for South African connectivity service firms to expand their use of 4IR systems is to absorb new technologies. As described in Alexander (2021b), the first paper in this working paper series, this is an active process that requires internal skills. A representative of a logistics company described his firm's experience.

> We'll use hardware from anywhere in the world. But the logic behind it, we put [in] ourselves. (F04-I04)

Another firm also described the process of incorporating new technology.

> I would say most of the technology comes from, more than half … would come from outside. So, we will identify technologies, and then try to see how we can implement it for certain scenarios for certain applications. (F13-I20)

Costs are an important factor when making a decision to adopt new technologies, as described by a representative of another logistics company.

> The business case needs to make sense to pay for the technology. (F09-I11)

Respondents spoke about learning about global developments while visiting other countries as a way to help their businesses. A representative of a company focused on traffic management said,

> I was lucky to visit their traffic control system for Dresden just to give you an idea, so they do it in partnership with the University of Dresden. (F10-I13)

A respondent of a consulting company that works with transport sector firms described the benefits of going to international conferences.

> The conferences I go to, that's a type of networking and seeing what other countries are doing – different companies are doing – I do learn quite a lot on that side, seeing what they working on as well. (F13-I21)

Another key way for technology to enter companies in South Africa is through a global parent company. However, this is not always the case. In some instances, communication pathways are not very effective in MNCs.

> We had a visit from one of the engineering teams [from our parent company], who had specifically built a product for classifying vehicles, and counting axles and using that to calculate toll fees for those vehicles. And there's a massive communication gap. We didn't know they were working on this. They didn't know we had stuff that could already partially fulfil the requirements. So no, they don't really know what we're doing. We don't really know what they're doing. (F21-I37)

Global networks can be important for stimulating innovation.

> Most of my team members are situated around the world … Some of them are [part of my company]. Some of them aren't. So, we do contracting work as well. Most of them are actually [company] employees. … [I focus on] new innovations … our team is quite diverse, different cultures around the world. (F13-I21)

One respondent described how it can be better to look for existing technologies as opposed to trying to make something new. He described the following process when a client has a problem.

> We go and do research and see okay, 'What has been done? Where can we perhaps add value? What other technology that exists can we actually utilise to help them solve the problem?' That type of thing. So, we kind of try and tie different solutions together … You just try and see what pieces you can use. (F13-I24)

Integrating technology from different sources can be a challenge. A respondent from a technology consulting firm described experiencing this type of challenge when developing a new product.

> I think the integration of different hardware and software components, is probably the most difficult thing. So first of all, the base software is essentially a port of what existed. So, what that means is there's software that ran on a specific platform, and some work is done to that piece of software to get it to run on a different platform. So, hardware platform that is. So not extremely challenging, but a lot of work. Implementing and playing around with machine learning. And that kind of thing, is not necessarily straightforward from the get go. So, a lot of research and a lot of trial-and-error kind of work went into getting that right. (F21-I37)

Other ways firms described bringing new technological developments into their businesses included acquiring innovative start-ups and hiring creative young staff. One respondent described how his company learned from acquiring start-ups.

> I think culturally, because we've grown through acquisition … our approach there now is to find convergence and invest in start-ups … Then to use those ideas in our solution. (F09-I11)

Representing an acquired company, another respondent described introducing innovative capabilities that the parent was lacking.

> Large companies typically have to have quite robust bureaucracy to manage the complexity of the business, so that everybody gets the same picture. That is almost destructive for R&D. Because R&D works on the principle of let's look at something and see if it comes up with anything that's worth looking at. Business doesn't like that. So big businesses, unless it was sort of back in the 50s, when Bell Labs and stuff like it had lots of money to give to people to go out and play.
>
> So, in terms of that we, specifically here in that group, are a little bit of an anomaly, because we're a very small team of people, in a reasonably small part of the company, flying pretty much under the radar, nobody's paying too much attention to us, because we don't spend that much money, and there are too many people. So, we kind of are at the edge of creativity within the group. (F21-I38)

One respondent described how his company had a lot of innovative employees.

> Generally, we have quite innovative people. Often, they call themselves entrepreneurial people. (F09-I11)

Another respondent said that his previous experience and interests helped his company to be able to have the knowledge to take on a new product development project.

> In fact, this big UAV [unmanned aerial vehicle/drone] laboratory project is happening, not almost exclusively, because I don't want to blow my whistle, but I don't think [my company] would have had the technical knowledge to [execute this project] inside. They would have had to contract an expert, or outsource it. (F13-I25)

New technology also enters into companies through working with consultants. South Africa houses a set of private businesses that are seeking to promote 4IR and have business models based on introducing 4IR to clients. Several of the firms in the interviews reviewed for this paper offer such services.

Collaborations can involve only one partner, or involve larger groups. A key part of 4IR is building networks for sharing data. Building such networks can involve collaborating with multiple organisations. An issue arises in terms of communication versus privacy. While having a large network that is connected to all actors would be the most efficient for data sharing, many actors want to have control over their own data. One respondent said that businesses often resist sharing their data and highlighted how his business promoted building networks and sharing data.

> There's no willing willpower at this point to make them exist, the connectivity's … We believe we'll always find somewhere somebody that will participate with us … You find a client that wants to participate [if] the contract will be strong enough in terms of money value that the client or the supplier doesn't want to lose it, and we get the value out of it. And once you create a network like that, you are starting to exclude other parties from it unless they participate. And that's the only way to get them to participate.
>
> So, it's negotiation at the end of the day. And you have to prove that you're making progress. So, I have asked you to participate. If you don't want to participate, I'll ask you again to participate at some stage … It is not always possible to do in a competitive environment. Is possible to be done in a non-competitive environment … I say data tells the truth. And for that purpose, whatever the data says whatever the story is, it means that you don't have to feel threatened by it. It will just tell the truth. It's not a political agenda behind it. Data tells us. It's there. This happened that time. They, that location. That time, this was a user, this would happen. And that's what we do. We present it [in a] very honest way. (F04-I04)

2.4.2 Internal Innovation Experiences

Firms described a variety of internal experiences related to carrying out innovation. The experiences shared are divided into the themes of drivers, types of innovation, challenges, and learning.

2.4.2.1 *Drivers*

Multiple drivers were found to be related to the interviewed firms engaging in attempts at innovation. A key element of many of the described innovation experiences was trying to solve a specific customer's problem.

> So, I think, in the South African context, there, because when it comes to engineering, and most product development, you're trying to solve the problem, somebody has a problem, and then they will come to us or somebody sees a need for a product. And then they come to us because we focus on the realisation of that product, taking it from concept through to prototype. (F13-I20)

Furthermore, some companies have a specific objective of providing innovative offerings. This can be with the purpose of obtaining future business. This purpose can be seen in the fact that some companies spoke about trying to innovate in order to attract investors.

Innovation can also be driven by societal challenges. For example, facing problems with stolen rail tracks led some South African companies to develop innovative technologies to deal with breaks in the tracks (Gain Group, 2020).

Environmental challenges can also create drivers. A representative from a logistics company described developing a returnable packaging system to reduce waste.

> We started off with returnable packaging … in the beginning it started off to create a more green environment. (F04-I04)

2.4.2.2 Types of Innovation

Firms also shared experiences related to engaging in different types of innovation. As one part of 4IR is the development of new business forms for existing businesses, organisational innovations can be part of developing 4IR systems. Respondents from one of the companies interviewed described differences between making changes to internal processes versus making changes to products or services offered to customers, highlighting the greater difficulty that can be experienced when making organisational changes.

> A few years ago, we had an innovation fund [at the holding company] level. [It] didn't quite get traction, because again, now you're doing something centrally in a highly decentralised organisation … people having innovative ideas for the organisation. (F09-I11, Respondent 1)

> I think, with innovation, and being a bit more agile is getting to that space of what do you really need to change at the backend. While you can rather do things in the front end, that's adding value, that you can change quickly, and you can quickly move along. Then, having this very heavy change at the bottom, which takes forever, and business units over time. It needs to have a business case for each big change. One in the front end. [However,] one can do much more … doing this heady stuff. So, there's lots of focus on … the sexy or the value to the customer, versus the heavy. But then there are legacies and then you address them as well. You [need time to] change that. (F09-I11, Respondent 2)

Businesses shared experiences of both radical and incremental innovation processes. One company described its process of engaging in incremental innovation.

> It's an iterative process for us, I don't think there's a holy grail of that's where we want to be, and this is what's going to get us there. It's all innovation, and little steps at a time. (F21-I37)

2.4.2.3 Challenges

Firms also described a variety of challenges related to innovation. While connectivity services firms provide the infrastructure that can support the national innovation system, these firms

are also constrained by existing infrastructure systems. One respondent highlighted the need to have sufficient infrastructure in place in order to develop 4IR systems, but how it is still possible to make progress while infrastructure is developing.

> So, don't not do 4IR until the foundation is solid, but while you're doing all of these things out here on the fringe, work on that stuff on the base, and make sure that when these things grow, you give it something to grow on. And that's something that all it needs to do is continually improve. (F21-I38)

Another respondent from the same company spoke about the lack of sufficient data coverage outside of urban areas and how this is a key factor expected to shape the company's activities.

> South Africa specifically, in general, in these kinds of things, we lag what's happening internationally quite a bit. So, if we talk of internet of things in general, and not only necessarily vehicles, for us, big concern is we don't have coverage. In many places outside of major metros, broadband speed's not great. There are a bunch of things on the horizon that seemed to be capable of breaking that. So, if you look at satellite broadband, that kind of thing, which is starting to, to gear up now, that'll considerably change the picture in South Africa. So, for example, you would have a very good connected vehicle experience in Jo'burg or Durban or Cape Town or wherever, but go to the rural areas or less populated areas … that starts to fall apart. For us in terms of our business and what we do as part traffic law enforcement … It definitely will have an impact on what we do and how we do it. (F21-I37)

For companies that seek to experiment with innovating, the attempts are often unsuccessful. Respondents in the interviews reviewed for this paper spoke about failure being an accepted and expected outcome during innovation attempts.

> That's the thing with innovation. And I said to the guys, if you don't try something new, you're never going to know if it fails. It's not necessarily a failure. You can't simulate everything on a computer and say, 'Well, it's simulated. It's going to work. It's not going to work'. You have to sometimes build stuff and see whether it works. I mean we have built a lot of other stuff that doesn't work.
>
> So, with any technological revolution, or innovation or whatever, there must be some failures. Otherwise, you're not going to go forward. And it's very difficult in a government environment to say, you know, let's allow things to fail. You must sort of say, Okay, 5% 10%, how much of our money are we throwing on the water. And that with research, I mean, at the university and so on, I mean, [there's] failure all the time. (F10-I13)

Another challenge firms described was deciding how much to invest in attempting to innovate. They needed to decide if they wanted to develop a new product or service or whether an existing product or service was available that they could incorporate into their business. In addition, they can decide whether they want to allocate internal personnel to an innovation project or hire an outside service provider to work on the project.

> We are not going to take the risk of trying to develop something ourselves and then fail … we would look into developing [it] ourselves, but we quickly then soon realise the risk

> is just too big. Then we partner with somebody to mitigate the risk. Yes, you pay for that. But in the end, you just mitigate the risk. But [for] most of our technologies, we still look towards Europe. (F13-I20)

One respondent spoke about outsourcing innovation as a problem.

> I think, a lot of things that have happened that way in South African businesses, where the good people have gone and the competency no longer exists. So now [it] gets farmed out. And things are bought in and the know-how is now lying outside of where it should be. (F21-I38)

2.4.2.4 *Learning*

Finally, connectivity services firms described different sources of inspiration and learning that supported their innovation processes. One of these was staff having experience working in diverse locations. A representative of a multinational company described the benefits of having international experience.

> The diversity of different environments … It stimulates innovation … It just gives you more options. (F09-I11)

Many respondents also spoke about connecting to online communities to learn about new technology.

> So, I'm not, at the moment very actively involved in the maker space, or that kind of online community. But a huge part of why I think I got this job in the first place, was because I was building … things myself, and that wouldn't have happened, if it wasn't for the open-source resources available to me through with YouTube and blog posts. And, yes, all kinds of different online platforms. And that allowed me to learn … my involvement in and utilisation of freely available knowledge and open-source software and hardware has enabled me in what I do right now. (F13-I25)

With technology rapidly evolving, a need for staff to learn continuously has developed.

> I don't know if it's possible to have a formal course that's relevant year after year. I think that's probably the big issue, so yeah, absolutely, it must change. And it will change as far as people are interested in getting the information. So, if you look at the hardware that's successful at the moment … Some of that hardware is powerful enough to, to do a lot of fun projects or useful projects. And if you're looking at doing that kind of thing, the [online] resources to do that are massive. (F21-I37)

Participation in online communities was described as helping to provide experience and knowledge that is applicable to workplace activities. They can be a way for staff to build new knowledge.

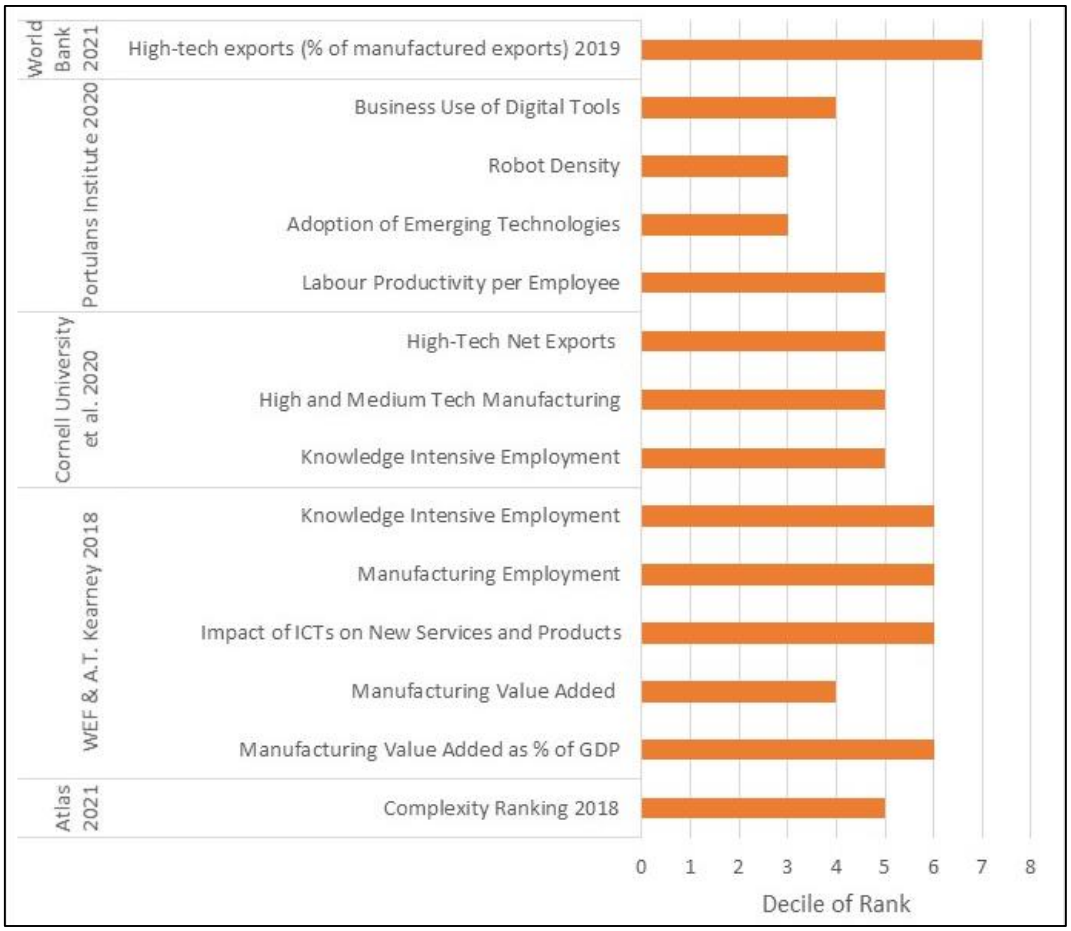
> Particularly nowadays, there's obviously a huge open-source learning community online. And the amount of resources that are available to help people to easily learn things is way better and more than before. So, I think, yeah, if we're going to [get] great young engineers that are going to progress really fast and fit into the IR 4.0 world, then it's really

important that, from the beginning, you realise how quickly you're kind of equipped with the skills, the tools to, to realise that you can find a solution or engineer a solution to almost any problem without needing a ridiculous amount of complicated theory behind you. (F13-I25)

3. Manufacturers' Adoption of 4IR Systems

This section focuses on the manufacturing industry. WEF and A.T. Kearney (2018) found that 25 countries in Europe, North America and East Asia were the leading countries in the best position to benefit from the changes involved in 4IR. These countries currently account for 75% of global manufacturing value added. Compared to a large set of other countries, South Africa is around the middle in various aspects of its economy related to manufacturing (see Figure 6). Two areas that rank relatively well on a global level are the adoption of emerging technologies and robot intensity.

Figure 6: Global Rankings Related to South African Manufacturing[5]

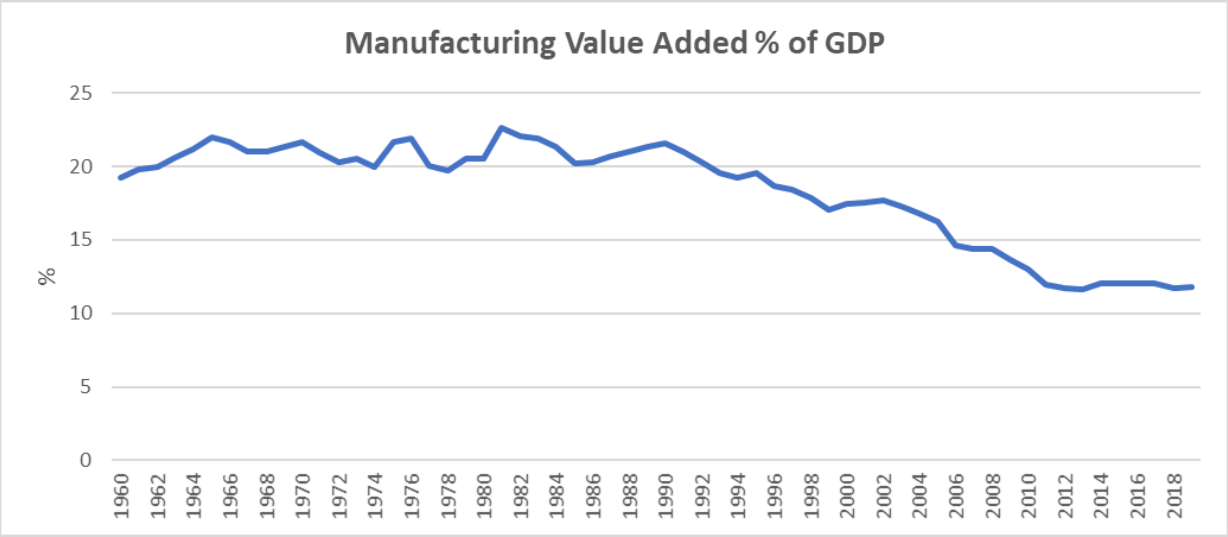


Sources: WEF and A.T. Kearney (2018); Cornell University et al. (2020); Portulans Institute 2020; Atlas of Economic Complexity (2021); World Bank (2021)

[5] Unless mentioned specifically, these categories cover all sectors of South Africa's economy and are not specific to characteristics of manufacturing.

While the contribution of manufacturing value added to the economy dropped significantly from the start of the 1990s until the early 2010s, the decline has ceased since 2013 and the level has stayed pretty consistently around 12% (see Figure 7). This is close to the median of the countries assessed by WEF and A.T. Kearney's (2018) Readiness for the Future of Production assessment.

Figure 7: Manufacturing Contribution to GDP Growth



Source: World Bank (2021)

Medium- and high-tech industries make up 24,4% of manufacturing value added (WEF and A.T. Kearney, 2018). Manufacturing employment is 11,2% of the working population (WEF and A.T. Kearney, 2018). Overall, the manufacturing sector's employment level decreased by 1,1% and its value added grew by 2,3% between 1994 and 2016 (Cunningham, 2018a). Unit labour costs increased from the 1980s to 1990s with the growth of unionisation, and again from 2010 onwards, while labour productivity has been increasing since the late 1990s (Cunningham, 2018a).

The characteristics of manufacturing exports have been changing. Notably, from 2010 to 2017, motor vehicles grew from contributing 13% to almost 18% of the export basket, while motor vehicle parts declined from 6% to 5% (DTI, 2018). At the same time, mining machinery remained relatively stable at around 2%. In 2017, the bulk of South Africa's manufactured exports went to the rest of Africa (38,8%), the European Union (25,9%) and the US (8,7%) (DTI, 2018). Also notable is that exports of manufactured production to the rest of Africa have been growing rapidly (Cunningham, 2018a).

South Africa's value in the Economic Complexity Index (Atlas of Economic Complexity, 2021), which measures the number and complexity of products exported, fell from 47th to 63rd from 1995 to 2018. While South Africa's products were relatively complex in the 1990s, they are less complex by more recent standards (Cunningham, 2018b). While South Africa's high-technology exports have risen from US$500 million in 1992 to US$2,5 billion by 2018, high-

technology exports still only constituted 4,9% of total merchandise exports in 2019, leaving South Africa ranking 92nd out of 148 global economies (NACI, 2020; World Bank, 2021). The frontrunner, Hong Kong, had high-technology exports constituting 65,6% of total merchandise exports (World Bank, 2021). Notably, exports from South Africa to the rest of Africa are often existing products requiring little innovation, with markets having low levels of competition and relatively low standards (Cunningham, 2018a).

Historically, South African manufacturers were protected through distance, history of import substitution, and industrial policy support (World Bank, 2018a). However, recent years have seen high levels of liberalisation (Bell et al., 2018). A number of factors are now contributing to problems in manufacturing. These include low business and consumer confidence, administrative costs rising more than inflation, high rail freight and port charges and inefficiencies, infrastructure constraints (increasingly at the municipal level), growing levels of imports (legal and illegal), low demand, lack of competitiveness, and negligible economic growth (DTI, 2018; PC4IR, 2020).

The national share of business expenditure on R&D by the manufacturing sector was 28% in 2017, which declined from 39% in 2008 (NACI, 2020). R&D expenditure on manufacturing was split between low- (13%), medium- (73%) and high- (14%) technology sectors (NACI, 2020). In terms of medium-technology spending, most went to petroleum products, chemicals, rubber and plastics. However, the sectors[6] relevant to automotive manufacturing and mining equipment manufacturing, the cases in this paper, together received almost half of the investment (see Figure 8).

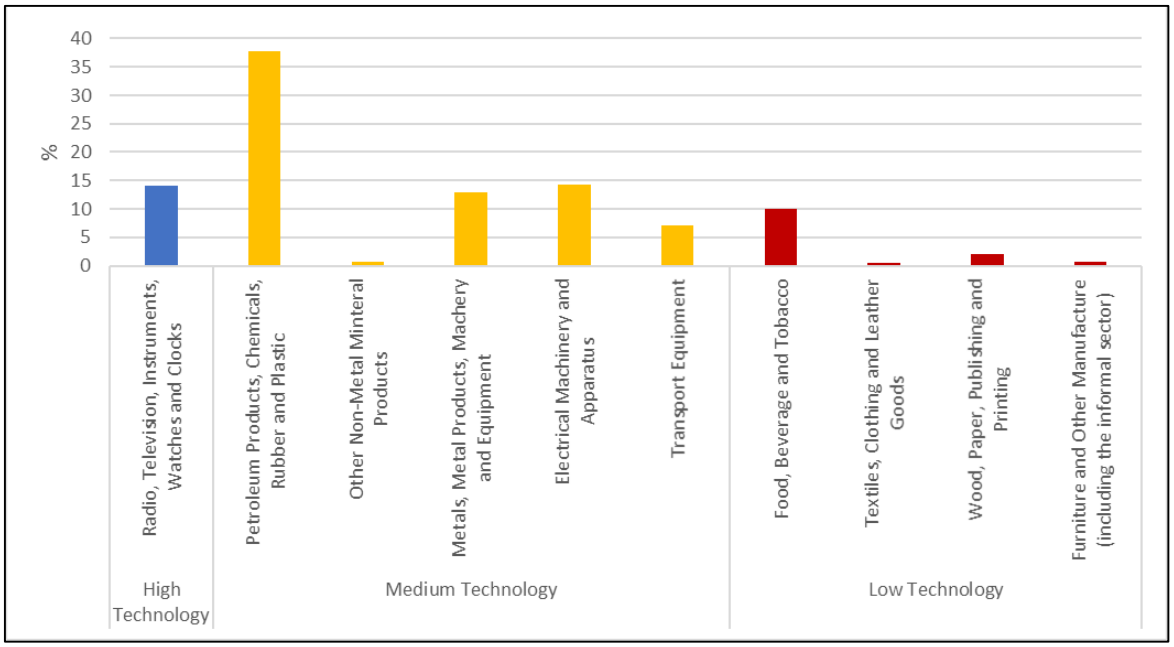
It is notable that the percentage of South Africa's total investment in R&D that has gone to transportation equipment (which includes the automotive industry) has declined from 21% in 2008 to 7% in 2017 (NACI, 2020). In contrast, the share that has gone to manufacturing "metals, metal products, machinery and equipment" and "electrical machinery and equipment" (which includes manufacturing for the mining industry) has increased from 10% (6,6% for metals, metal products, machinery and equipment, and 3,5% for electrical machinery and equipment) in 2008 to 27% (13,0% for metals, metal products, machinery and equipment, and 14,2% for electrical machinery and equipment) in 2017. This change may reflect the growing opportunities for innovation in the mining equipment sector.

Newman et al. (2019) suggest that labour and capital have been misallocated in South Africa's manufacturing sector and that reallocation could improve aggregate total factor productivity (TFP) by between 16% and 22%. Policies create incentives that shape firms' relative allocations of labour and capital. Newman and co-authors find that policy measures explain 11% of the measured misallocation and that changing the policies that influenced these allocations could lead to productivity gains of approximately 2,2% per year, which is

[6] Metals, metal products, machinery and equipment; electrical machinery and apparatus; and transport equipment.

significant when compared to the fact that TFP has been growing at 3% per year. They also find heterogeneity in how this effect is distributed by firm size, with micro- and small firms experiencing the strongest effects. This means that the proposed readjustment of policies would benefit smaller firms the most.

Figure 8: 2017 R&D Expenditure in the Manufacturing Sector



Source: NACI (2020)

Based on data from firms registered to pay company income tax in South Africa, manufacturing made up, on average, 27% of firms, provided 24% of employment and was responsible for 40% of turnover (Tsebe et al., 2018) from 2011 to 2014. Over half of firms had between one and nine employees, and slightly less than 50% of employment was created by large companies (more than 250 employees). Over 60% of turnover was created by large firms.

However, maintaining manufacturing may be a challenge in the future. Firm exit rate in the manufacturing sector exceeds firm entry, and entry and exit are mostly by small firms (Fedderke et al., 2018). Multiple policies are in place to support manufacturing. In particular, the Manufacturing Competitiveness Enhancement Programme is a government programme that provides financial support for manufacturers. Sector-specific policies for automotive and mining equipment manufacturing are described in Sub-Sections 3.1.2 and 3.2.2.

The adoption of 4IR technologies and systems has been growing in South African manufacturing, but often at a slow rate. Compared to other sectors, manufacturing, along with engineering and tech, and trade sectors reported the greatest concentration of innovative activities from 2014 to 2016 (CeSTII, 2020). Overall, South African manufacturing firms most frequently reported making product innovations (60% of manufacturers), followed by organisational (49%), marketing (43%) and process (37%) innovations. Despite this

progression, a representative of a company that makes industrial robots commented on the slow uptake of advanced technology in South Africa.

> So, to make one statement, the South African market is still quite juvenile, when it comes to the adoption of high technology. A lot of people talk hard technology, as you say, there's a big hype around 4.0 and, and AI and all the rest. But there's a very slow uptake. (F20-I41)

South Africa's proportion of high-technology exports, at just below 5% are comparatively low, even in relation to other upper-middle income countries, which had an average of 25% (World Bank, 2021).

Overall, a mix of technologies are used in manufacturing in South Africa. Some businesses are in the early stages of becoming involved in 4IR or have not begun to adopt related practices and technologies. Responding to a question about incorporating 4IR technology into his business, one of the respondents described being at an early stage.

> It is something we are raw with, I'm starting to get like more into it, more exposure, what it's all about. That is something as a company, I think we can take to the next level. So, it's really at the infant stage, to be honest with you. (F14-I27)

As new technologies and business models are developed, with new types of competitive strengths, existing businesses will need to work within a new competitive environment. In some cases, they can remain competitive using traditional practices. In others, they can innovate to adopt new practices, or they may close down. When asked about companies that are lagging in the adoption of 4IR, one respondent said that for some South African firms it may be too late.

> A lot of the companies have missed the boat … because I've missed the boat and my customers have gone elsewhere. How do I justify that reinvestment to get back in front? So, it's a cart to the horse scenario. (F20-I41)

While robotics typically is considered as part of 3IR, moving into 4IR requires increased levels of automation and human-robot interactions. In the interviews, some producers spoke about how they were handling the incorporation of robots into their production processes.

> Basically, we have a high-tech computer system sitting behind our vision. We provide data to the robots that on their case can provide again the right movements or actions that need to be done in a production environment. (F17-I33)

Smaller companies are also becoming more open to introducing robot technology.

> If you took, say, a five-to-seven-year period, I would say there's definitely, if you plotted the graph, there would be a greater, at least interest, or acceptance by smaller companies that a robot is not a space age piece of equipment that that requires a PhD to drive … So, again, it's about the awareness … How do we get to the market? … Everybody has a cell phone, everybody drives a car, everybody has a CNC [computer numerical control], and everybody uses a computer. Same thing. It's just another tool. Yeah, so very much, I think,

> based on more international travel, to be quite honest, where smaller customers are broadening their horizons and say, 'No, this is actually available'. (F20-I41)

Deonarain (2019) looked at the use of advanced robotics and found use in manufacturing to be low. Most robotics are focused on basic automation and do not incorporate smart technologies. However, some automotive producers are using more advanced processes.

Human labour still plays an important role in manufacturing. One company, an automotive original equipment manufacturer (OEM), described that the cost of labour in manufacturing is still lower than investing in robots for all tasks.

> You will never substitute [humans for robots] because the cost of robotics versus labour in South Africa you will never make it tar out. The return on investment is too long. I still need to replace between four and six operators to justify one robot so still doesn't make sense … we could prove that we can compete with the rest of the world we get more and more work … We're still seen as a low-cost force when it comes to labour. (F08-I10)

Firms also shared experiences of introducing and expanding the digital tracking of production processes. Deonarain (2019) provides an assessment of the use of advanced sensors. These sensors were mostly at a foundational stage in manufacturing, but had higher levels of use in the automotive industry. Manufacturers have a lot of interest in using such sensors for processes, such as monitoring, controlling and tracking.

Digital tracking can produce large datasets. South African firms are starting to think about how they can use this data to improve efficiency. This could require the need for powerful computers and the facilitation of cloud computing services.

> Now, when the process automation sector comes from new metrics, they changed to microprocessor-controlled activities, where they then develop something like a DCS they call that today that stands for a distributed control system. But it's kind of a contradiction in terms in the sense of that is a very centralised system, but they call it the distributed control system … now that means that all your data is centralised in a big intelligent system that has lots of algorithms, on board.
>
> That, say if the temperature is going above that value, then that value needs to open or close that type of functionality and what we see happening there in the context of 4IR, is that you will get a lot of decentralised intelligence, decentralised, meaning a temperature measurement device is going to talk straight to an activator. That means that value needs to open if my temperature is too high.
>
> Why do I still need to go via that control system in the middle, or can that control systems sit in the cloud? So, cloud computing is getting more into the discussion.
>
> That also means that if I put it a little bit more in, in a big IT context, then you all know your office network, you plug in a printer and or a PC. And after two minutes by doing a few settings, you can start using that printer and that PC because those devices have … intelligence on board and the network provides intelligence that connects A with B and A and B can interact with the PC and the printer for instance.

> That functionality has not been existing yet in the process environment. And this is happening now. Something that is again an abbreviation, APL: advanced physical layer is, is a physical layer that allows basically your Internet technology, so your connection from your printer or your PC to the network, to bring that to device level into the production environment
>
> … At the same time, the suppliers of the DCS systems are looking more and more to cloud-based computing. And that means that basically the future of process plans which today is a very complex with a lot of wiring and installation type of stuff to a central computer system, will become a distributed device connected to activate and the software behind it might sit either in the cloud or [be] based on edge computing which means to bring more intelligence to the field device and all. (F17-I33)

Many manufacturers are not taking advantage of data that they may already have. Data is often used post hoc, without taking advantage of its predictive abilities.

Virtual reality (VR) systems are also being used to support the internal processes of companies, such as providing training experiences for workers or digital twins that can be used for monitoring and exploring potential changes. They can also be involved in creating interfaces to connect to customers, such as creating virtual showrooms.

Manufacturing in South Africa does not use a lot 3D printing, but there are high levels of awareness, with its main uses currently being for prototypes and testing (Deonarain, 2019). Also, while AI is currently not used widely in the mining industry, more than half of respondents in a survey of industry representatives stated that they were piloting AI programmes (PWC, 2021). An automotive component supplier described an expectation for the growth of these technologies.

> If you look at the big step, we have done from the previous project to now, and where all the automation industry is moving towards the next project will probably have AI and machine learning involved in it. (F12-I17)

While a lot of the discussion here has been about incorporating 4IR into production processes, a large component is also incorporating it into the services offered by products. A respondent from the automotive sector highlighted this industry's frontrunner status in this regard.

> We are also one of the frontrunners that make it possible to connect your internet-based communication to that field device level. (F17-I33)

This section focuses on exploring dynamics within automotive manufacturing and mining equipment manufacturing. Key differences can be found between these industries. Both are being shaped by 4IR but in different ways.

Deonarain (2019) provides an assessment of the use of advanced analytics in South Africa. The strongest adoption is found within the automation and automotive sectors, with others lagging behind. Automotive manufacturing is a sector that has seen widespread adoption of 4IR systems. The automotive industry is using increased levels of automation and data-driven management. These changes have been driven by the demands of MNCs, and success in

adopting these changes affects how South African manufacturing compares with that of competitor locations (Lorenz et al., 2019). In automotive supply chains, the country has some technologically advanced companies producing automotive components (F17-I33). Furthermore, Deloitte (2016) found strong use of advanced analytics and sensor technology in the automotive sector. Respondents described using automated processes in automotive manufacturing.

> No employees. So, in the past it's a front strut. So, it's a break disc, and the brake calliper and so that sub assembly, so you have different steps. And that was really carried by hand from one table to the other. And then now we've made a star layout and the robot is right in the centre. So, and the robot simply, once finished, picks up the good and brings it to the next station. So, it's simply for part handling. We've saved classical productivity activity. (F11-I14)

In contrast, the mining industry has been slower in its adoption of new technologies. Respondents in the interviews reviewed for this paper described many South African mines as using analogue models, with limited adoption of digital technologies. However, this situation may be starting to change. A recent study by PricewaterhouseCoopers (PWC, 2021) identified that South Africa's mining industry has emerging digital champions and innovators.

PWC's (2021) study describes that some companies have clear strategies and are taking action to make progress. Goals include optimising operations and cost reduction, as well as collecting and integrating new data (using IoT and advanced process control). Frontrunners are focusing on achieving smart and connected mining systems across all stages of the process. Some businesses are developing data-sharing arrangements between different functions and between different businesses.

The study also showed that investments in digital technologies are growing in almost all mining companies that responded to the survey. Priorities in digital investments included connecting people and assets to provide insights, and connecting machines to visualise their data (condition monitoring). Platforms to manage, analyse and report on these diverse data sources are also being developed. Major reasons for investing in digital technology were found to be throughput and efficiency increases, lower costs, and improved health and safety.

The digital frontrunners (champions and innovators) in PWC's study are investing in emerging technologies such as blockchain, IoT, and AI to get more value through supply chain and logistics improvements. A few (10%) mining industry representatives said that their businesses were focused on end-to-end supply chain planning (PWC, 2021). Most (over 60%) of mining industry respondents said that supply chain, logistics, and procurement have a highly significant role to play in digital transformation, with more than half saying that they believed investments in these areas will yield very significant benefits. A small group of advanced respondents (10%) were concerned about the availability of real-time or near real-time data to inform decision-making. These developments are creating new demands and opportunities for mining equipment manufacturers.

The ways that 4IR is being employed varies between the automotive and mining equipment manufacturing sectors. Because the end products in automotive supply chains are restricted by OEM standards typically set at a global level, the main space for local innovation is in terms of manufacturing processes. Businesses producing mining equipment seek to continuously improve products and offer products with new features. In contrast to South African automotive parts producers, the South African mining equipment industry has a number of domestic OEMS, which have freedom to change their product designs.

> We don't sit on the product and sell the same product, we will always innovate, innovate, innovate … So, the mining market knows us for innovation. (F19-I35)

Also notable is that automotive manufacturing outputs are more standardised than those of the mining industry, which creates greater scope for automation and the use of industrial robots (Lorenz et al., 2019).

The rest of this section explores the characteristics and experiences of automotive and mining equipment manufacturing in more depth. The discussion below identifies challenges and opportunities that firms producing these products face related to the further adoption of 4IR, first focusing on the automotive manufacturing industry, and then on the mining equipment manufacturing industry. Finally, the third part provides insight into both types of firms' experiences of innovation processes.

3.1 Automotive Manufacturing

The automotive industry had record vehicle production and export volumes in 2019 (Lamprecht, 2020). The contribution of the broad automotive industry to GDP was 6,4% in 2019 with 4% from manufacturing and 2,4% from retail (Lamprecht, 2020). In addition, according to Lamprecht (2020), vehicle and automotive component manufacturing contributed 28% of value addition within domestic manufacturing output. Furthermore, in 2019, motor cars and motor vehicles, parts and accessories contributed 8% of South Africa's export value (United Nations Statistics Division, 2021).

DTI (2018) highlights the strengths of the motor vehicles, parts and accessories sub-sector. With strong connections to global supply chains, this sector has benefited from supportive industrial policy for over a decade. The sector provides opportunities for domestic production (and exports) of parts and accessories for motor vehicles. As the leading exporter within manufacturing since 2012, its value added (GDP) was R31,6 billion in 2016, equivalent to 5,9% of total manufacturing GDP.

South Africa is a strong global player in automotive production. In 2019, it had the 24th high value of exports of motor cars and other motor vehicles designed principally for the transport of persons (motor vehicles), and the 37th highest value of vehicle, parts and accessories (component parts) (United Nations Statistics Division, 2021). The value of exports of motor vehicles has been growing over the past 10 years, while component parts have been declining (see Figure 9). In 2019, most motor vehicle value from exports came from Europe and the UK

(74%), with the next largest destinations being Japan (6%), USA (5%), SADC (4%), Australia (3%), and South Korea (3%). For the value of component part exports, SADC was the largest contributor (38%), followed by Europe and the UK (36%), USA (5%), Argentina (4%), China (3%), and Thailand (3%).

South Africa's automotive industry has high levels of technological capability, with process development being a particular strength (Black, 2020). However, production has low levels of local content, with many components being imported (Bell et al., 2018). Furthermore, the industry is highly dependent on imported technology and has low levels of domestic R&D, with limited links to local research institutions (Black, 2020).

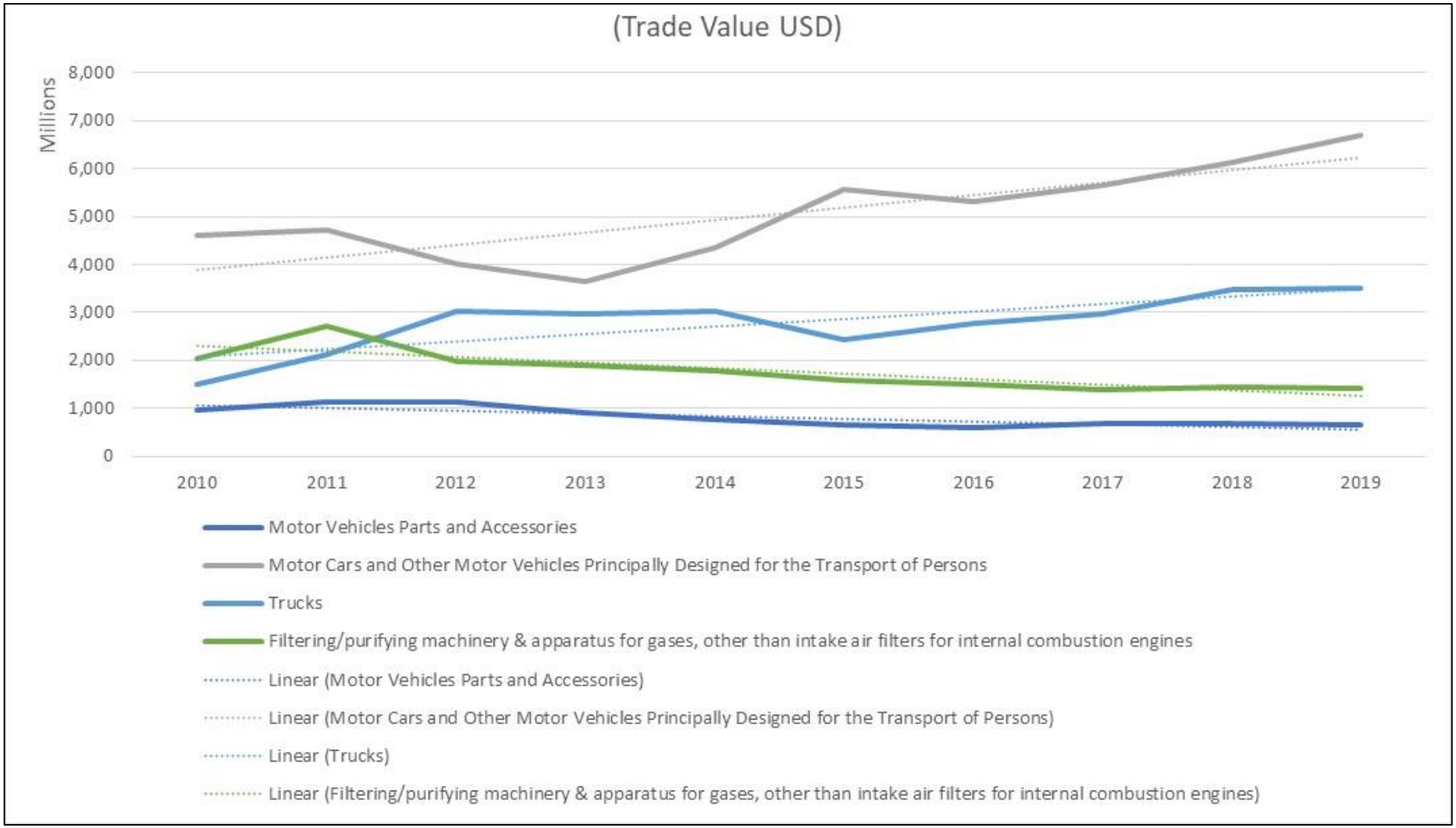
Overall, the sector has quite different characteristics than other forms of manufacturing in South Africa, which have stronger domestic firms and R&D (Black, 2020). As design often takes place in other countries, the core competencies of automotive OEMs in South Africa are integrating and coordinating the system, including the supplier network (Lorenz et al., 2019). South Africa's industry is not as sophisticated as that of Thailand or Mexico (Bell et al., 2018).

The automotive sector creates many direct and indirect jobs through forward and backward linkages, with estimates of three indirect jobs created for each direct job (World Bank 2018a). It is estimated that, if the downstream activities of wholesale, retail trade and maintenance are included, the employment generated was 322 220 in 2018 (DTI, 2018). Average monthly employment by vehicle manufacturers was 30 250 in 2019 and 80 000 for the component sector (Lamprecht, 2020). However, employment levels have been decreasing. Making up 6,8% of manufacturing employment and 5,9% of manufacturing value added in 2016, employment in motor vehicles, parts and accessories decreased by 1% while value added grew by 3,8% from 1994 to 2016 (Cunningham, 2018a).

In general, employment in the industry has mixed outcomes (Lamprecht, 2020). Employment in automotive assembly has gone down since 1995, but overall employment in the sector has performed better than that of other manufacturing subsectors. In addition, employment has grown in the automotive service sector (e.g., distribution, repair and fuel provision).

South Africa's automotive manufacturing industry involves a production network with a wide variety of firms connected across different stages of production. The first part of this sub-section provides an overview of the businesses that are involved in automotive manufacturing. The second part covers additional actors and the support environment for automotive manufacturing. Finally, the third part discusses the structure of networks within which automotive manufacturing firms work.

Figure 9: Vehicle and Component Part Exports



Source: United Nations Statistics Division (2021)

3.1.1 Automotive Manufacturing Firms

Automotive manufacturing clusters are found in Gauteng, the Eastern Cape and KwaZulu-Natal, with OEMs at the centre with tiers of associated supplier businesses (see Table 2). The industry includes seven light-vehicle OEMs (BMW, Ford, Isuzu, Mercedes-Benz, Nissan, Toyota and Volkswagen), a number of medium- and heavy-capacity vehicle OEMs (e.g., Iveco, JMC, MAN, Scania, and Volvo), and over 400 automotive component firms (DTI, 2018).

Table 2: Automotive Clusters

	Gauteng	KwaZulu-Natal	Eastern Cape
OEMs (manufacturing plants)	BMW SA, Nissan SA, Ford Motor Company of Southern Africa	Toyota SA Motors	Volkswagen Group SA, Mercedes-Benz SA, Isuzu Motors SA, Ford Motor Company of Southern Africa engine plant
Medium, heavy, extra-heavy commercial vehicle and bus companies	Babcock, Eicher Trucks, Fiat Group, Ford, Hyundai Automotive, Iveco, JMC, MAN Truck & Bus, MarcoPolo, Peugeot Citroen, Powerstar SA, Scania, Tata Trucks, Volvo Group Southern Africa	Bell Equipment, MAN Truck & Bus, Toyota (Hino)	FAW Trucks, Isuzu Motors, Mercedes-Benz SA (Freightliner and Fuso), Volkswagen Group SA
Number of automotive component companies	200	80	150

Source: Lamprecht (2020)

The automotive manufacturing sector is dominated by foreign-owned firms. Different to other manufacturing industries in South Africa, a lack of large local firms means that this is not a sector with a high level of local technological development (Black, 2020). The system benefits MNC exporters by allowing import rebates, which has led to a significant use of downstream imports and reduced opportunities for tier 2 and 3 producers (Bell et al., 2018). The medium and heavy vehicle sector is small with multiple brands (e.g., Toyota, Nissan, Mercedes Benz, MAN, Scania, and Tata), which operate semi-knocked-down plants that involve importing almost-finished trucks and doing minor assembly in South Africa (Lamprecht, 2020).

South Africa has about 180 first-tier automotive suppliers (Lamprecht, 2020). About three-quarters of them are foreign-owned MNCs, and this proportion is growing. The technological capabilities of automotive sector OEMs are much higher than first- and second-tier suppliers (Lorenz et al., 2019). Domestic first-tier component suppliers use a mix of local and imported content in their own supply chains. Lower tier component producers have a higher proportion of South African owned companies than the first tier.

Diverse original equipment components and aftermarket parts are made in South Africa, with the bulk of components sold as original equipment components for OEMs or as replacement parts (Lamprecht, 2020). About half (49%) of domestic component suppliers' sales in 2019 went to OEMs, a third (33%) to exports, with smaller amounts to aftermarket (15%) and other component (3%) sales (Lamprecht, 2020).

South Africa has produced relatively few examples of automotive sector product innovation in recent decades (Black, 2020). Some firms produce simple products, mainly for the aftermarket, with proprietary technology and their own brand names. Some firms produce more sophisticated products, such as alarms, anti-theft devices and wheels, some of which have resulted from electronics expertise developed in the defence industry. One of the respondents in the interviews reviewed for this paper described a challenge with supplier firms having low R&D capacity. He also emphasised that global network connections can be important.

> I think from a supplier point of view, it's going to become more and more critical, because the design centres are not here. The R&D canters are not yet here. They mainly [have] production-based operations to satisfy a market for producing. The suppliers that have strong global affiliates, and have access to the R&D and the development and that support will survive. Providing they can be cost effective. The smaller suppliers that are purely local, there will be some work because press parts are press parts. They'll continue. I don't think they will change whether you go to high tensile steel or current steels. Your tools change. All your equipment changes, but the process to make the product is quite similar. So, but there will be some suppliers, where I think they don't have the technological link to their global suppliers or the mother companies, [that] will struggle to survive. (F22-I39)

In some cases, firm relationships have created trust that has led to support being given by buyers to suppliers. Lower tier businesses in automotive supply chains often get financial assistance from their buyers, the first-tier producers.

> [Automotive component suppliers] tend to rely on the tier-ones' interest-free loans, because then we know there's an urgent requirement for these tier-ones to spend that money. Unfortunately, because of the nature of localisation, the tier-ones often want to spend their enterprise development to develop a supplier to supply a new component. Due to barriers around the cost of tooling, technology, raw materials, they often are not feasible. The tier-ones have realised these interest rate loans can be used to bolster the support to the existing tier-two suppliers … Interest-free loans, [for] some suppliers are not feasible, they need grant funding, but an interest-free loan, that's the cheapest capital you're going to get in an open market. Most of the tier-twos take it. (S09-I40)

Foreign ownership can be more valuable than licensing when it comes to vehicle producers obtaining export contracts (Black, 2020). However, the situation is different for component producers (Black, 2020). Domestic and foreign-owned component producers were both found to export 17% of their output in 2006. Part of the reason for the low exports by foreign-owned firms is that these firms are located in South Africa specifically to target the South African

market. An area in which foreign- and domestic-owned component parts differ is the level of imports in their production. In 2006, foreign-owned producers imported 54% of their inputs, whereas domestics firms only imported 29%.

A number of opportunities exist for component suppliers to grow (Lamprecht, 2020). They have the opportunity to increase exports or to expand their sales to domestic OEMs by supplying larger volumes of current products or by adding new products. However, these growth paths require investment and skills development. Overall, the South African automotive sector is an important driver for small and micro-scale enterprise (SMME) development (World Bank, 2018a).

3.1.2 Key Additional Actors and Support Environment for Automotive Production

South Africa has targeted the automotive sector as an important industry for achieving economic growth. A number of diverse policies and support services have been established to support this industry. Some are described below.

Running from 1995 to 2012, the Motor Industry Development Programme (MIDP) sought to promote the global integration of South Africa's industry and increase the competitiveness of businesses (Lorenz et al., 2019). Measures included removing local content requirements, reducing tariffs and using import-export complementation (giving import duty credits to assemblers and component manufacturers when outputs are exported). A consequence of the integration process was changes to ownership structure, which involved global companies acquiring majority ownership in local assembly plants as well as increasing their foreign direct investment (FDI) in component suppliers, particularly through developing joint ventures (Lorenz et al., 2019).

To benefit from the import-export complementation policy, foreign-owned vehicle producers helped domestic component firms to increase their exports by facilitating access to their global networks (Black, 2020). This has provided benefits to some component suppliers (new investment, and importing new technology and best practices). However, it has mainly benefited foreign-owned firms. The focus has been on catalytic converters and the benefits have not been widespread across the industry. Overall, the import-export complementation policy led to rapid liberalisation of imports (Black, 2020).

Replacing the MIDP in 2013, the Automotive Production and Development Programme (APDP) emphasised the promotion of volume production by creating a volume assembly allowance for OEMs and a production incentive for OEMs and component manufacturers (Lorenz et al., 2019). It also provided grants for capital investments through the Auto Investment Scheme (AIS).

A new APDP is being developed that aims to increase production by more than 70%, increase local content in South Africa-made vehicles from 35% to 60%, and double sectoral employment (World Bank, 2018a). One respondent described this programme as follows.

> If you put up a new auto plant like this, the first eight years is an example you don't pay any corporate tax. Where we sit and talk here how wonderful [the] APDP program [is], you know that you get 30% back on any investment or whatever; they do far better than that, from a policy perspective. That's why. There's no other reason. There's no other magic to it. (F08-I10)

To increase the competitiveness of domestic component suppliers, the Automotive Supply Chain Competitiveness Initiative (ASCCI) was also established in 2013 and funded by suppliers, OEMs, government and labour (Lamprecht, 2020). The organisation seeks to increase supplier manufacturing value add, capabilities, local content in supply chains, and employment. The Black Supplier Database was also developed as part of the supplier capability programme to provide a list of black-owned automotive component manufacturers.

There have also been regulations on who could be involved in maintenance and repairs under warranty, which allowed only authorised service providers sourcing parts from approved providers. These regulations limited opportunities for new entrants (World Bank, 2018a). Approval processes were not transparent and were linked to being association members, which created a cost barrier. To open up competition in this area, the Competition Commission South Africa (2021) produced new guidelines to regulate the aftermarket.

A key pillar shaping policy has been the Automotive Masterplan 2020. The plan focused on local market optimisation, regional market development, localisation, infrastructure development, industry transformation, and technology and associated skills development. This plan will be replaced by the South Africa Automotive Masterplan (SAAM) 2021-2035. The new plan will seek to expand South African vehicle production to 1,4 million per year by 2035, while increasing the localisation of components (Lamprecht, 2020). Widening the domestic supplier base is a key part of the agenda and is seen to have a benefit for OEMs, as it reduces the risks associated with exchange rates and logistics. To promote large-scale production, the Executive Oversight Committee, chaired by the Department of Trade, Industry and Competition, has set up six task teams to focus on SAAM's six pillars. These pillars are localisation, domestic market optimisation, regional market development, infrastructure development, industry transformation, and the development of technologies and skills required by industry.

Furthermore, the Automotive Industry Transformation Fund (AITF) is intended to broaden and deepen the participation of black and historically disadvantaged entrepreneurs in the automotive industry. This fund will also allow automotive OEMs to participate, if they comply with all five elements of the generic Broad-Based Black Economic Empowerment scorecard,[7] including the ownership element(Lamprecht, 2020; National Association of Automobile Manufacturers of South Africa [NAAMSA], 2021). However, an equity-equivalent system is available to address the ownership element. The fund will seek to upskill black employees and

[7] A government programme designed to support black empowerment.

entrepreneurs; expand black-owned dealerships, authorised repair facilities and workshops; increase the contribution of black-owned component suppliers to supply chains; and create employment opportunities for young and female black workers. The fund will also help with the implementation of SAAM, particularly related to the target of increasing black-owned tier two and three suppliers.

The World Bank (2018a) outlines three difficulties with promoting the development of local suppliers. First, the levels of production in South Africa do not have enough volume to make local production profitable for some elements. Second, OEMs have limited time, money, and human resources to devote to supplier training. Thirdly, in relation to tier two and tier three suppliers, OEMs have limited incentives to invest in supporting them, and tier one suppliers have fewer capabilities for training.

Businesses in this industry are members of a number of industry associations. These organisations are often involved in shaping public policy. One association is NAAMSA. Its members include 20 companies involved in making passenger cars and commercial vehicles. These companies employ more than 30 000 people and NAAMSA also represents 21 companies involved in the importation and distribution of new motor vehicles.

Another association is the National Association of Automotive Component and Allied Manufacturers (NAACAM). It represents automotive component manufacturers and has approximately 130 manufacturing members, approximately 80% of which are first-tier suppliers across 200 regional manufacturing sites. It also has 30 associate members who are service providers.

The Retail Motor Industry Organisation (RMI) represents the retail motor industry. The RMI is an umbrella association, with 8 000 members. The National Automobile Dealers' Association (NADA), which incorporates the Motorcycle Dealers' Association and is one of eight associations within RMI, focuses on new vehicle franchise dealerships and some used vehicle outlets, and has about 1 800 businesses as members (Lamprecht, 2020).

The major OEMs in South Africa, as well as NAACAM, are also affiliated with the independent African Association of Automotive Manufacturers (AAAM). The South African Tyre Manufacturers Conference (SATMC) represents Bridgestone, Continental, Goodyear and Sumitomo (Lamprecht, 2020). AAAM promotes supportive policies for the automotive sector with the aim of connecting African countries and creating a pan-African automotive industry collaboration (Lamprecht, 2020). The Motor Industry Ombudsman of South Africa (MIOSA) is the accredited dispute-resolution forum for issues related to the South African Automotive Industry Code of Conduct,[8] which can affect inter-business relationships and consumer industry relationships. Finally, the Automotive Industry Export Council (AIEC) is an export-

[8] The South African Automotive Industry Code of Conduct is accredited by the Minister of Trade, Industry and Competition and arises from a regulation in the Consumer Protection Act.

promotion organisation. It covers passenger cars, trucks and buses, original equipment components, aftermarket parts and accessories.

A number of other organisations provide services to support automotive manufacturing. Some of these focus on quality. The South Africa Bureau of Standards plays an important role in quality standards in South Africa's automotive industry by ensuring the compliance of components and systems with relevant standards for ISO and other certifications. The South African Automotive Benchmarking Club (SAABC) is a privately funded, not-for-profit initiative that provides benchmarking services for the automotive component sector with the goal of promoting world-class manufacturing, with most members in KwaZulu-Natal (Black, 2020).

Some organisations focus more generally on supplier development. For example, the Durban Automotive Cluster (DAC) was established as a partnership between eThekwini Municipality and the automotive industry in KwaZulu-Natal. It promotes learning and productivity among its members (Black, 2020). Also, the Automotive Industry Development Centre is a state-supported initiative that operates mainly in Gauteng to provide supplier development (Black, 2020).

For some jobs, firms are experiencing a skills gap. Some specialised skills, such as programming skills for programmable logic controller (PLC) computer control systems and for specialised laser welding systems, are in short supply and are provided mainly by parent companies and a few local suppliers (Lorenz et al., 2019). Technical institutes are providing technical skills such as mechatronic skills or maintenance skills, but automotive sector employers perceive quality to be low, with many potential recruits being rejected. Also, mid-level new technical staff trained at technical and vocational education and training (TVET) institutions were found to need substantial on-the-job training.

These challenges show a gap between the TVET system and the needs of companies. Making practical work experience a formal component of training may help to bridge this gap. In addition, automotive-sector employers found basic numeracy and communication skills to be weak in lower skilled roles (Lorenz et al., 2019). The low numbers of people for roles such as technicians, artisans, professionals, and managers are reflected in the wage premium for these jobs (Black, 2020). Some firms are providing in-house training. The Manufacturing, Engineering and Related Services Sector Education and Training Authority (merSETA) is responsible for training for the automotive industry, which mainly involves reimbursing firms that undertake training according to approved plans (Black, 2020).

3.1.3 Automotive Production Networks

Automotive supply chains in South Africa typically have global lead firms. Automotive manufacturing production networks are concentrated on the production of vehicles and component parts for MNC's brands. Key buyers are South African-based OEMs, higher tier suppliers, and users of spare parts (see Table 3). In general, products must meet the specifications of OEMs' designs.

Table 3: Automotive Supply Chains

Product or service	Producers	Key buyers
Vehicles and component parts	South African factories of MNCs and South African component suppliers	South African-based global OEMs, higher tier suppliers, and aftermarket buyers

At a global level, the automotive industry has moved towards using fewer first-tier suppliers (Black, 2020). In emerging economies, domestically owned firms have limited opportunities to become first-tier suppliers. They have more opportunities to become lower tier suppliers, or may be limited to providing replacement parts. In the automotive industry, experience has shown that, when global firms set up production facilities in a country and their first-tier suppliers follow suit, connections are made with local supply chains and technology transfer to local firms takes place (Black, 2020).

In South Africa, domestically owned firms mainly play roles as second- and third-tier suppliers (S09-I40). Original equipment components – first-tier suppliers for automotive OEMs – typically have globally recognised names and can be high-value capital-intensive items. Powertrain and telematics are high-value, capital-intensive components that together account for 50% to 60% of the value of a modern vehicle and are mainly imported into South Africa (Lamprecht, 2020).

Another option is for South African component producers is to sell their products in the aftermarket. More than half of passenger cars and light commercial vehicles (57%) purchased in South Africa were imported in 2019 (Lamprecht, 2020). South Africans keep their cars for a long time, which creates a situation that requires a large amount of aftermarket parts. However, many of these parts are imported from China. Also notable is that South African automotive exports to emerging markets are increasing. In particular, there have been significant increases in component exports to the Czech Republic, China, Mexico, and Singapore (Lamprecht, 2020).

However, component suppliers operating in South Africa have to compete with global producers of identical products. This challenge is exemplified by the fact that imports of original equipment components by the seven OEMs in South Africa increased by 9,2% between 2018 and 2019 (Lamprecht, 2020). This situation creates pressure to lower production costs. A respondent described firms experiencing pressure to automate production.

> Because a lot of them visit the big automotive companies, they see the need and the drive for automation. Also, it's kind of forced down from the European companies. (F03-I03)

While standardised product requirements limit opportunities for product innovation, component suppliers have room to, and can feel pressure to, engage in process and organisational innovation. Process innovations, such as increasing automation, are particularly important, as they can lower production costs and help South African producers

to become more globally competitive. In some cases, global lead firms can support suppliers with developing and incorporating process innovations. A representative of a global lead firm with an office based in South Africa described helping to manage the supply base.

> We take care of two main aspects of the business. The one is the maintaining the current production at the supplier base to make sure our plant builds the data volumes. And the second is to launch new projects or changing points at the supply base. And that's [in] particular the equipment and the tooling that goes to make those components. (F22-I39)

Overall, process innovation in relation to automotive manufacturing in South Africa is an area that has a lot of potential for 4IR systems to develop.

3.2 Mining Equipment Manufacturing

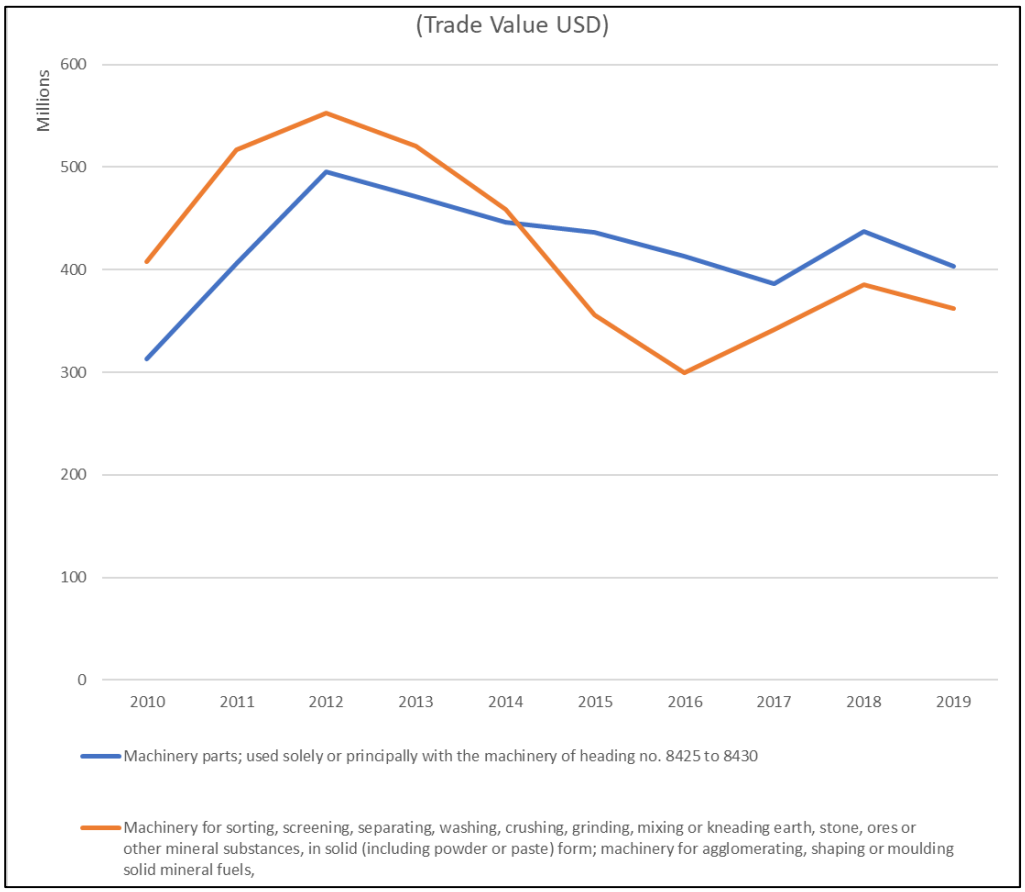
While the metals, machinery and equipment industry has lost capabilities and seen growth in import penetration, particularly for machinery and equipment, mining equipment has escaped this general trend and remained competitive (Bell et al., 2018). While a large volume of the equipment used by South Africa's mines is currently foreign made (S03-I45), domestic production remains strong. Notably, mine spending on new machinery and transport equipment increased strongly in 2019 (Minerals Council South Africa, 2020). Mining equipment makes up 14% of national manufacturing value added (Lorenz et al., 2019). From 1994 to 2016, the growth in value added from machinery and equipment was 2,9% and its contribution to manufacturing value added increased from 5,2% to 5,8% (Cunningham, 2018a)

However, the value of exports of mining equipment has decreased slightly over the last 10 years (see Figure 10). The main destinations for machinery for sorting, screening, separating, washing, crushing, grinding, mixing or kneading earth, stone, ores in solid form, shaping, moulding machinery for solid mineral fuels by trade value in 2019 were SADC (52%), Australia (7%), Guinea (3%), the USA (3%), and Canada (3%). The main destinations for mining equipment components (see footnote of Figure 10) in 2019 were SADC (74%), Australia (5%), the USA (4%), and Belgium (2%). Together, these products made up almost 1% of the value of commodities exported in 2019.

Worker health and safety is a critical concern for the mining industry. Mining is a very dangerous industry in South Africa. In 2019, there were 51 fatalities and 2 406 serious injuries; however, both fatalities and injuries saw large decreases over a 20-year period, as they were 309 and 6 253 respectively in 1999 (Minerals Council South Africa, 2020). Mining equipment manufacturers play a role in shaping risks for workers.

Mining equipment manufacturing is an area that shows technical sophistication (Cunningham, 2018a). Mining equipment producers sell their equipment to mines and customise the equipment to the needs of South Africa's industry, particularly for deep mining (Lorenz et al., 2019). Notably, South African mining patents have been cited more than patents in any other South African sector (Kaplan, 2011).

Figure 10: Mining Equipment Exports[9]



Source: United Nations Statistics Division (2021)

In 2019, the metals, machinery, and mining equipment industries made up the largest source of formal employment in manufacturing, with 284 000 jobs (Andreoni et al., 2021). Capital equipment manufacturing, a category comprised of machinery and equipment used in production, employed 80 000 in 2019, around 5% of manufacturing employment (Trade and Industrial Policy Strategies [TIPS], 2021).[10] Education levels for capital equipment

[9] Machinery heading no. 8425 to 8430 includes: Pulley tackle and hoists other than skip hoists; winches and capstans; jacks pulley tackles and hoists other than skip hoists or hoists of a kind used for raising vehicles; ship's derricks; cranes, including cable cranes; mobile lifting frames, straddle carriers and works trucks fitted with a crane, overhead travelling cranes, transporter cranes, gantry cranes, bridge cranes, mobile lifting frames and straddle carriers; forklift trucks, other works trucks fitted with lifting or handling equipment; other lifting, handling, loading or unloading machinery (e.g., lifts, escalators, conveyors, teleferics); self-propelled bulldozers, angledozers, graders, levellers, scrapers, mechanical shovels, excavators, shovel loaders, tamping machines and road rollers, bulldozers and angledozers; and, other moving, grading, levelling, scrapping, excavating, tamping, compacting, extracting or boring machinery, for earth, minerals or ores, pile-drivers and pile extractors; snow ploughs and snow blowers.

[10] South African capital equipment manufacturers mainly produce for mining, construction, electric power generation and distribution (including renewables), and food processing (TIPS, 2021).

manufacturing are higher than the rest of manufacturing with 70% of the total workforce having secondary education or higher in 2019, compared to 50% in other manufacturing.

This sub-section focuses on mining equipment manufacturing. The first part discusses the characteristics of the firms that work in the industry. The second part highlights key additional actors and the support environment. The third part considers the production networks that are involved in this industry.

3.2.1 Mining Equipment Firms

Multiple types of firms are involved in mining equipment manufacturing in South Africa. These can be businesses that produce component parts, such as pumps, valves, and motors. Component part producers can produce parts for diverse types of end users.

In addition, firms can be OEMs, which produce final equipment for the sector. There are approximately 50 major South African mining equipment OEMs (S03-I45). These firms can provide equipment for different stages of the mining cycle (including mine development, access development, stoping, and logistics) and can support diverse mining activities (e.g., drilling, blasting, and cleaning) (Mandela Mining Precinct [MMP], 2022).

Some firms are locally owned, and some companies are part of large multinationals. Within large groups, South African companies can play different roles. One respondent described the role of his firm within a multinational.

> We have [the company] group. And within [the group], we've got a bunch of operating companies … now got some local shareholding. It's got some international shareholding ... Take international and they have subsidiaries [in multiple countries and some are] just sales … So, then they go out and they'll make bull bars for clients or, you know, whatever. They can utilise the skills … what tends to happen is that [the South African location] plays a role of a sort of a technology centre and a supply. (F15-I30)

3.2.2 Key Additional Actors and Support Environment for Mining Equipment Production

The mining industry is guided by the National Development Plan and the Minerals Council of South Africa's modernisation vision for 2030. The Department of Science and Technology (DST) is supporting the implementation of the South African Mining Extraction Research, Development and Innovation (SAMERDI) Strategy, which the Council for Scientific and Industrial Research (CSIR) developed and has been tasked with leading. This initiative seeks to ensure the sustainability of the mining industry.

A key sectoral initiative is the MMP launched by the DST and the Department of Mineral Resources. The MMP seeks to support research, development and innovation to address technical challenges and socio-economic imbalances. The MMP project was developed to drive local content by making South Africa a centre of excellence for mining sector goods and services through building R&D capacity (DTI, 2018). It is run as a partnership between the

mining industry (Chamber of Mines) and the government (DST, DTI, and the Department of Planning, Monitoring and Evaluation).

The MMP involves several R&D programmes and a supplier-development initiative. MMP's projects include (DTI, 2018):

- Modernisation of current operational mines
- Mechanised mining of gold and platinum
- Non-explosive rock breaking
- Advanced ore-body knowledge
- Real-time information management systems and mining 4.0
- Optimisation of the mining supply chain

Several industry associations operate in relation to mining equipment production. The Mining Equipment Manufacturers of South Africa (MEMSA), launched by the DTI, has the goal of developing local mining supply chains. MEMSA's programmes support local equipment producers in areas such as skills, including using data (Lorenz et al., 2019). Lower-tier producers can be part of different organisations. For example, the South African Pump Manufacturers Association (SAPMA) represents the interests of pump manufacturing and is federated to the Steel and Engineering Industries Federation of Southern Africa (SEIFSA).

In terms of product development, as digital technology and 4IR spreads in this industry, demands for new skills are developing. Many of these skill needs are similar to those needed in relation to the spread of 4IR across diverse sectors. For example, while mining equipment producers have the potential to begin to offer monitoring practices as a service to the mines, this may be difficult because of a shortage of South African engineers with advanced analytic skills (Lorenz et al., 2019).

3.2.3 Mining Equipment Production Networks

Mines have a number of elements in their supply chains. They buy a mix of ready-made and custom-made machines. In addition, transport and storage are a major cost for the mining sector in South Africa (Minerals Council South Africa, 2020).

South African mining equipment supply chains feature domestic brands, and the equipment is sold to both mining companies in South Africa and around the world. The structure of the supply chain is outlined in Table 4. Long-term relationships often exist between mines and mining equipment manufacturers (Lorenz et al., 2019).

As mentioned above, mining equipment producers can provide inputs for multiple types of buyers that are not confined to the mining sector. For example, one company involved in making mining equipment also described making parts for industrial doors (F02-I02). Exports by mining equipment producers have grown within Africa, particularly in Zambia, the DRC and Mozambique, where South African OEMs also have joint ventures and wholly owned subsidiaries (Lorenz et al., 2019).

Local OEMs use a combination of local and imported inputs. An industry representative described the large amount of local sourcing.

> For most of the companies, the majority of the products are mainly local content. For some of them, it's very high, 80, 90, 100% local content. But it depends … The ones where you'll find that there is a proportion of imported content is like some of the big machines where there are very specialised engines, axles, and something called a 'drive train' … There are some specialised components and some of the IT components that are imported. But on the whole, their products are above 50%, often 60, 70, 80, and above 90% local content. (S03-I45)

Table 4: Mining Equipment Supply Chains

Product or service	Producers	Key buyers
Mining equipment, component parts	South African OEMS, component producers	Mines, higher tier suppliers

There are many opportunities in relation to using 4IR technology in the mining industry. One key challenge has been that many companies in the mining industry have been slow to adopt new technologies. A key consideration the level of skills that mines need to effectively use 4IR technology. Managing data is a challenge for mining companies, with difficulties including the complexities of data custodianship and cybersecurity (PWC, 2021). In addition, workers in mines can have low skill levels.

> Our people, the skill level is so low, that some mines don't even require a driver's licence to be able to operate a machine. So, we always ask that question, 'say you allow the person to drive a 4,5-million-rand piece of equipment, but you won't allowed him to drive your car of half a million' … They don't want to send the guys for training and stuff like that. (F19-I35)

Consequently, mines as buyers often do not have a demand for 4IR-type equipment.

> South Africa used to be very far in the lead with … deep-level mining. But with this whole 4IR, slow to change
>
> … So, some companies have seen the light and they are going ahead. They're pushing it hard.
>
> And some companies are still stuck in very old methodologies. We found the average age of the people that we engage with traditionally are close to retirement age. So, for me, from a sales perspective, I'm still trying to get them to buy software that's been around since the 90s … It's still seen as a new software. Now you want me to go and sell you cyber security and all that sort of stuff and still tell you that the IT world is now your master. That's not going to happen. (F06-I06)

However, more and more mining companies are starting to realise that 4IR technologies have a lot of benefits, as was shown in the PWC (2021) report. One of the interviewees described the current situation.

> Mining is on that journey but has started that journey late, especially in South Africa. It's going to catch up very quickly as well, I can see that. Because there's such a major effort in doing so and because COVID has accelerated it. (S05-I48)

However, differences can be found between mines.

> [Mining Company 1] is a great example they realise they need to change the way they're doing things and they've been very progressive around that so I would say [Mining Company 1]'s really changing. That's awesome to be part of that. You can see that change happening. The guys are like they're in it. [Mining Company 2]'s been in it for a while, [Mining Company 3]'s also been quite advanced for a while. But you older guys like [Mining Company 4] in that are beyond. But and I think that top structure could be changing as well that they could start to become more optimal, because they've bought up a lot of old plants. (F06-I06)

Another company, which sells services to mines, described the situation of mines as buyers, further highlighting diversity.

> I would say clients can probably be differentiated between early adopters and the mainstream and then the late adopters. Certain clients have already moved along a value stream. They've got clarity in their mind where they're going. Others might just be exploring. (F23-I43)

A key component of 4IR is the growth of services. This is being experienced in the mining industry, and some supplier companies are beginning to offer digital services to mines. Services being developed include monitoring to support preventative maintenance and improve safety. Opportunities related to new services create even more space for mining industry suppliers to innovate.

However, smaller companies can struggle to compete against frontrunners. One company spoke about the possibility of using data to show customers that their products are better than that of their competitors.

> We get people that favour other companies … So, if we create live data … this will be the clever move for us because we will create [a] level playground. (F19-I35)

Overall, mining equipment producers have a lot potential for innovation. They can offer new products and services that incorporate 4IR-related features. They can also incorporate 4IR into their processes and business models.

3.3 Manufacturers' Innovation Experiences

Responses in the interviews reviewed for this paper illustrate multiple aspects of how manufacturing companies innovate in South Africa.

3.3.1 Absorbing External Knowledge

One element of national innovation is importing global technology. Importing machinery and equipment is a major source of technology transfer in South Africa's automotive sector. This

is a dynamic that may be strengthened by having foreign-owned companies working within the country. Notably, foreign automotive component firms have been found to use more modern technology (Black, 2020). One way these imports can happen is through technology agreements and licensing. These arrangements can provide important sources of knowledge.

As diverse new 4IR technologies are currently available and being developed globally, South African firms have many options for adopting innovations. One respondent described opportunities for the successive adoption of new technologies.

> So, where do you start? In my mind what we're pushing is the virtual. So first do a digital twin, because that's going to be the much cheaper way of figuring out what do you do next, and then you run simulations. If I had to put a whole load of IoT sensors down, this is what's going to happen, if I have to automate half my plant, this is what's going to happen. If I have to design that whole process with new robots replacing some of the humans, this is what's going ... This is what it's going to look like ... if... and then we can work at savings costs cuttings, et c*etera*. What's the budget for that? (F06-I06)

Another respondent described the benefits of bringing together multiple new technologies to create a dramatically improved service.

> We configure a response for digital transformation which is multifaceted. And is built up of the different competencies which I just mentioned which are they have to be people who understand strategy, people who understand technology, change management, paradigm change as we call it, and ultimately software and some of these technologies … which are robotics, et c*etera*. But it's that overall package which we think is quite unique to what we do … We try to create an integrated service at a low cost by having the best skills set. And we always say, it must be twice the value at half the cost of the competitors. *W*e are quite confident that, that is what we offer. (F18-I34)

One key way for knowledge and technology to enter South Africa has been through FDI. After 1994, the growth of international trade increased foreign ownership of firms in South Africa (Black, 2020). Links to global networks became important for acquiring technology and getting access to global markets. Foreign-owned assemblers often prefer to source from joint ventures or foreign-owned subsidiaries of MNCs. South African component companies consequently often have had to look for global partners or be confined to selling aftermarket parts. South African firms that have been successful with exports tend to not be first-tier firms and have included producers of automotive glass, electronic control units, aluminium wheels, exhaust systems, filters and burglar alarms. Technological upgrading of firms in South Africa has been mainly through foreign technology transfer as opposed to domestic R&D. Informal knowledge transfers have also happened through foreign technical experts and advisers working in assembly plants and component firms.

When local component firms have come under the control of MNCs, R&D is often downsized or shut down (Black, 2020). However, these firms do not necessarily downgrade technologically, as they may be absorbing new technologies from the host firms, which may

be more advanced than previous activities. With the option of global sourcing, locally owned firms may also stop doing their own R&D.

One respondent described getting access to global technological developments through their membership within an MNC.

> There's a lot of benefit in [being part of an international group]. And I'll give you an example. Now again, in my plants, we do something called oil quenching. We use hydraulic oil in our hydraulic system. And we had two major fires in there, because of the hydraulic oil. If you get a leak in your system that hydraulic oil sprays out on to. You'll see the blades are 900, 950 degrees, red hot, in you know, you put a flammable liquid on it. Right, everything goes up … Because we belong to [an] international group, this product called water glycol … It was used successfully in other plants. So, I introduced it in here. And then we had some cases where the pipe burst. It sprayed onto that and nothing happened. Okay, you know, the old operators sort of ran away and came back and said, 'Oh, nothing happened'. So that there was pure benefit from being international … because products tried and tested methods used elsewhere benefited us. (F14-I28)

Another MNC described how 4IR-related monitoring is facilitating higher levels of global knowledge sharing.

> We use data in huge amounts throughout our business. And some of it we share between the plants globally, right, so that we can all look at each other's data. And we can compare notes and improve. I can ask them questions, if I see a result in their business that, that I don't see in mine on that same measurable that I can ask them and they help us then with how did they achieve that. So, there's a lot of that sharing happening. (F08-I10)

Another key issue is that MNCs can provide training related to global best practices. In one of the interviews, the respondents spoke about the automotive sector MNCs bridging the gap between their requirements and the skills that employees received through the South African education system.

> Many of the companies because they come from a global HQ structure, they've got company-specific training material that they deliver either in-house or through a nominated third party. It usually tends to cover production, technical upgrading … the challenge with us is the general calibre of a young person coming out of a TVET or university, the skills are not specific enough for the component suppliers so they have to do a lot of in-house training. (S09-I40, Respondent 1)

> Generally, what we find is a mismatch between the TVET graduates, their qualifications, the skill sets that they hold, and what the markets are asking for. Most [component suppliers], I think almost all of the Tier 1s, will have some level of in-house training that they put their people through to make sure that they are meeting their work-specific requirements. (S09-I40, Respondent 2)

In addition, in some cases businesses that are part of MNCs can also have high levels of independence in their operations.

> It's not like we have, you know, feedback coming that you've introduced this in one of our companies in Romania, and we need to look at doing it here, as well. We are in a group, but each, each element of the group essentially does different things. We're the only company in the whole group, including the international companies that do [a certain type of] parts. (F14-I29)

Sometimes innovation is concentrated in global locations and South African companies use the technology developed.

> We do small R&D stuff here, which is more kind of application based for certain customers. But of course, head R&D sits in you know, in our [Country A] offices, and some, to a lesser degree and get more application or concept design in our [Country B], our [Country C] and our [Country D] factories. (F20-I41)

In addition to relationships within MNCs, partnerships were described with both domestic and foreign companies that help to drive innovation. One company described the need to share global knowledge both within their company and with their customer base.

> And we are working together with a lot of international companies. And guess what a lot of them are, again, from German origin. But there are also a few companies that are active in South Africa … and the question that we are facing, that all the automation companies are facing, but that the entire industry is facing with how do we keep pace with technology change?
>
> And I cannot send every other day people to headquarters in Germany to bring the skills back to South Africa. So hence, we are talking about [an online training system], where we are taking the initiative and you're getting there are already most of the things are still in Germany and still in a test phase. But you can Google already to that site. And you can have a look.
>
> Wherever we are, not only going to provide those training modules in an online shape for our own staff, but also for our customers, for the users. Because we are at the end of the day, we are all sitting in the same boat; I can develop an interesting new technology type of concept. But if on my customer side, I don't have qualified people to be able to work with it, then I have a problem. My customer has a problem. So how do we solve our joint problem here? And that's the approach we're taking. (F17-I33)

International connections help companies to gain broader perspectives and develop new solutions. This dynamic was described by one of the interviewees.

> [We] don't do [R&D] as a department, per se. But we do it as an exec team, so when we go to the board meetings with the CEO of the group, we actually do spend X amount of time in terms of you know, looking at that type technology, because we've got [factories in multiple countries]. So, we've got an international footprint. Our CEO travels quite a bit. And because of that, I think the nice thing is you get a very good feeling for – if you use your SWOT analysis in a methodology – get a very good feeling for what's happening in the different countries because going to Germany, we've got a company. They've got more tied up with them. You know what's happening in the German market. Then you go

> to Turkey, you know, and so I think that helps us a lot. Being not just a South African company, but being International. (F14-I27)

Broadly, global connections can facilitate diverse forms of knowledge sharing and development. One respondent highlighted the value of internal cooperation and the benefits that can be had by allowing people with diverse backgrounds to enter the country.

> The country that can be flexible in allowing people in and out and skills transfer because that's solving it. This 4IR is people centric. We want your brains … We're engaging with people overseas … So, people must come here. Play around. Yeah, and then go back out again. For that to happen, we can't have stuff like only people with scarce skills can come to the country. That nonsense must go away. (F06-I06)

Another way for companies to get access to global technology is for staff to visit other countries. As with connectivity services companies, manufacturers described learning from global visits.

> Everybody tends to go for batteries. We don't think that's the wagon that everybody should jump on. Because I visited a company in China and the biggest concern about batteries is to make the batteries. There's not enough material because the biggest thing in batteries is zinc, and there is not enough zinc. So, the Chinese are already one step in front of us. Because they are looking currently not building the batteries, they have the batteries. So, they're currently looking [at] how they can actually recycle the batteries to be able to produce the amount of batteries that they needed. So, it was quite an eye opener when I got there and I thought, 'What is your technology on batteries and this and this and this?' And they said, 'well, currently we stopped the technology a little bit. We're looking how to recycle the batteries.' Why? Because there's not enough zinc. And that's currently the challenge. (F19-I35)

Furthermore, when firms are part of global supply chains, their buyers can introduce new technology. Automotive best practices involve assemblers developing close linkages with component suppliers and providing support (Black, 2020). One of the respondents in the interviews reviewed for this paper described the strong role played by automotive sector MNC buyers in training their suppliers.

> We physically go send them in and we develop their production system for them. Train their employees. We spent months in there to try and get them to follow the same standards and work in the same way. (I08-F10)

Buyer demands can also be a trigger for engaging in internal innovation processes. An emerging dynamic in the automotive industry is rapid growth of transformative new technologies, such as connected, self-driving, and alternative fuel-powered vehicles. These changes are fundamentally part of 4IR. Automotive suppliers in South Africa are already seeking to adopt new technologies that will prepare them for these changes, and this has increased the costs of staying in business (Lamprecht, 2020). At this point, only the largest suppliers can afford these costs. As these changing requirements expand across the global automotive industry, suppliers will need to learn new skills and, in many cases, develop

abilities to produce new types of components. One of the respondents described how this process can be assisted through global technology imports.

> There's always this conversation: what happens if we stop making ICEs [internal combustion engines] and make electric vehicles? What's going to happen? How will the supply base catch up? And actually, it's not a challenge. Because if suddenly Ford decides they will now be making battery EVs, all that's going to happen is [MNC supplier] is going to source from one of their sister companies initially, a fully assembled battery. They'll look to localise later because South Africa does have a relatively well-embedded electronics manufacturing capability from other sectors, military, defence, aviation. It's not going to be that suppliers are going to go out of business overnight. (S09-I40)

Another key way in which innovation can be introduced to companies is by working with domestic collaborators. A key type of partnership is working with consultants. The interviews reviewed for this paper involved multiple consultants who help firms adopt 4IR-related practices. In addition, some companies described the process of working with consultants.

> [Company Name], so they are assisting us because obviously, they've done it with several companies. And, you know, total productive maintenance requires that the operator is one of the key pieces of that program. So, you've got to have a more engaged employee, you know, on the line from that. (F14-I26)

Often, using 4IR technologies can involve making changes to how a company is run. One respondent described a lack of internal skills for developing 4IR systems leading to a need to hire consultants.

> It's probably a mindset change. I think it's, from a management perspective, there is a recognition that [we] could become more efficient in the way that we do things and that might be upskilling using consultants, going out and getting the necessary technology transfer to be able to do that, but it is obviously at the cost potentially of an operator. And the company's value system is such that we sort of wouldn't want to do that very quickly.
>
> … But it's kind of, it's probably getting to the point we were going to have to make some decisions at some stage.
>
> … Do we want to continue making it? Well, yes, we do. Because there's a market for it. But we, as it currently stands the way that we're doing it, it's just not viable. So, we either have to look at a different way of doing it. Upskill certain people and, unfortunately, loose certain people or close down the complete operation and lose everyone in that operation. (F15-I30)

3.3.2 Internal Innovation Experiences

Interviewees also shared experiences of how their companies engaged in innovation. This sub-section considers three main topics: drivers for innovation, challenges with innovating, and experiences of managing change processes.

3.3.2.1 *Drivers*

A key issue for manufacturers can be the influence of their buyers or industry lead firms. Lead firms can create both drivers of and barriers to innovation processes. As discussed above, such dynamics differ significantly between automotive supply chains and mining equipment supply chains.

One dynamic is customer-driven innovation. One respondent described mining companies' desire for increased safety as shaping their design process.

> As we see a safety inquiry from the mine, they come to us and say we're not happy with X. Then we change them. We change them to suit what the mine wants. So, the mines come to us and say, 'We don't want the chain exposed'. We change it. We don't do it anymore. We do it in a completely different way. (F02-I02)

The solutions that manufacturers provide can be based on a problem that is inherently related to 4IR processes, or they can also use 4IR processes to address a seemingly basic problem.

> So, we've done this for the mines … The mine actually came to us and said … they want to be able to see the machines' data all the time. We said that it's easy to do. So, we broke, we broke it up into four phases. We said, phase number one, we're going to build an intelligent machine. It will be able to give you anything that you require. Step number two will be able to transfer the data without a cable to a ... device, you'll be able to walk past the machine, or stand next to the machine and on your phone or your Android device, whatever you have available, you'll be able to see the data on your telephone. So, they liked it. They thought, 'Yes, that is rocket science'. For us, that's not really. That's been done … we take technology, and we basically put it on our equipment, and we modified a little. (F19-I35)

In some cases, the customers have an ongoing connection to a design process.

> It's a four-year project. But we do work in stages, of course, with small demonstrations, or proof of feasibility in between. So, the project is being funded by clients. The client, of course, wants to see progress. So, at certain stages, we'll [show it]. Okay, I have completed the robotic arm. I'll demonstrate that and they see, okay, it's working. And I might request slightly better materials or components to use to improve on that arm. If that's fine, we move on … to the next body parts, or add different functionality.
>
> For instance, we have already included some machine vision, which is one of the components actually requested by the clients. And now we have the body, which is technically just the housing and the sensor, combined with some software applications as well. And that by itself is already a product which satisfied the clients' requirements. (F13-I21)

Another issue is that there can be a difference between the stated requirements of customers and the benefits that new technology can provide. Another respondent described seeking to innovate on the basis of a combination of customers' expressed desires and customers' needs that were identified by his company.

> [So,] some customer demands, but the customer doesn't always know what they want. So, they sometimes know what they want to do, but they don't know what is there available to be able to do it. So, we see this all the time. We always use the nice theory where they say you need [to] buy a quarter [inch drill]. [They] buy a quarter inch hole, not a quarter inch drill. So, the customer thinks it's a drill, but you only want to drill the hole. You couldn't care if it's a drill or it's something [else] that makes [a hole] as long as you can get the hole in the material. So, the same when you buy a drilling machine … You couldn't care about drilling machine. It's what the drilling machine is going to do. So, what is the job that you need to do?
>
> So that's the approach that we always take. So, some of it, we actually see what's going on in the market. And we obviously see gaps and stuff like that, and then we will target those markets. And some of it is actually a customer that actually comes with an idea. But, end of the day … he comes to us with a problem and he says, 'How [are] we going to solve this problem?' And then we come up with idea. (F19-I35)

For mining companies, manufacturers sometimes have to educate their customers about the benefits that different types of equipment can provide.

> They're engineers, they just spec something and tell someone to go buy a light but the problem is, to just tell someone to go buy a light is like telling you go buy a pickup because I need to move something, 'Okay, how big is your something?' 'No, I can't tell you', 'Okay, what type of pick up do you need?', 'No, I need a pick up'. So, that's a problem. It's been diluted to the point where anything is acceptable until it doesn't work and that's where we come in. We come in with a special solution where we actually address the problem. We look at the problem and pull it back to a product. Then we address [it]. (F01-I01)

Requirements for mines were often described as low tech. However, several respondents described the potential benefits that can be derived from mines adopting increasing levels of technological solutions.

> To make the marginal mines more profitable, you have to use optimal efficient systems, tools, knowledge, technology, et c*etera*. To make it from marginal to actually valuable, that's where 4IR is going to kick everything. (F06-I06)

In contrast to the mining equipment experiences of customer-driven innovation described above, companies in automotive supply chains shared experiences of being constrained by lead firms' requirements. A car parts manufacturer described having no freedom.

> What they want is what they want. We can't change it in any way whatsoever … They don't want you to change it. So, one of the guys from [the car company office] can walk into this Mexico plant and know exactly how to fix this and go into the plant in South Africa and know exactly how to fix it. That's it. That's the idea behind the standardisation. (F05-I05)

Another way that new technology can be introduced is through the programmes run by industry associations. Both the mining equipment and automotive sectors have various

associations that are supporting the transition to 4IR. One association representative described their role.

> We help them with industry 4.0 adoption, implementation, training, sourcing the hardware, with the end goal to get them more competitive. Because the thinking is the more competitive, they are the more likely they will be to meet the OEMs requirements, because the OEMs expect a price reduction over time. But also, it opens an opportunity for them to start exporting and start competing with those low-cost destinations. (S09-I40)

A major reason for companies to choose to automate and adopt 4IR was to increase their competitiveness. Key issues included increasing efficiency and quality. One respondent highlighted how it can be expensive to have employees doing tasks that can be automated.

> To be able to drill those holes, you've got a guy who gets the basket. He turns it upside down. He puts it on the drilling machine, measures out or, puts a template on there … Then he drills it out. And he probably has to drill a pilot hole, and then he has to drill a finishing hole. He's been here for 30 or 40 years. And every year, he's got an above-inflation increase.
>
> … And its manual drilling. I mean, there's no way that we're going to be competitive when you have someone that is doing something like that. So again, those types of things. And I think this is unfortunate, you know, in South Africa, where jobs are in such high, well not in high demand, I mean, we just don't have the jobs for the people. But it comes to a point now where we've cost ourselves because of the labour inefficiencies that we have, and the cost of the labour, that we can't compete on that anymore.
>
> … Someone who can program to get the thing lined up and drill those holes is probably going to do it a whole lot faster. He's not going to go on lunch break. You can set the thing up. It can run overnight, whatever it might be. There's obviously capital investment in that. The efficiencies go up. So, we're nowhere near being able to do that. But it's not to say that, that is not possible. It's quite easily possible. (F15-I30)

Another key concern is that humans can make mistakes. Automated tracking systems can experience problems relating to the way humans behave. For example, humans can make mistakes when scanning things (F23-I40). One respondent described how automation ensured quality.

> That's the reason why we automate is because if you keep the volume and then quality, for also, consistency … with manual operation you can't keep up. (F12-I17)

Digital sensors in 4IR systems are another key way of ensuring quality.

> So, 10 years ago, we would have been expected to measure one part per week, or one part per month, say, for example, and that measurement even happened with an automated process, but very slow tactile process. Today, we can measure a part much, much faster. And we measure it with the optical head and a scanning type of process, because the customers know, we can measure it faster. The customer says I don't want one measurement per month anymore, I want to have three measurements per day, or

> three measurements per run. And so, this is also so the customer's requirements are changing in line with the technology because they know that technology is moving faster. (F12-I19)

Another driver that was shared was the desire to protect the health and safety of workers and to ensure that products are standardised and safe for end users.

> The safety critical structures like in the body size and the under body and the structural integrity of the vehicle to make sure that you maintain the good quality and safety of [it] and the welding and pressing. And once you see, I think you'll be able to see whether [and] where they're using robotics and some of the jobs are not only based on safety or quality … some of it's quite difficult to manufacture, the bulky, big parts. And it's dangerous for the people to work or it's difficult for them to work and do it manually. You have to have a lot of kind of manual jigs and fixtures and things like that. Whereas, if you do it robotically in cells, you can use a lot less space, and you can be more efficient and you can obviously take people's health into consideration to put it that way. (F22-I39)

Replacing human operators with automation reduces safety risks.

> The main reason we're utilising the robots in one is because it's handling very hot material. Material is at 990 degrees and we had to. We relay to the whole cell. Just to give you some information, previously, we had [a] heating furnace [that] would process bars to - talking bars about 1,5 meters long diameter of about 30 millimetres. So, the heating furnace would process the bars, heat them up to 990 degrees. And then the old way was that we have two operators. So, one would take one bar and give it to a forming unit … It would form the shape, and then the operator would take it and put it into the oil. The next operator would be standing on the opposite side and he takes the second bar … [to form it and] put into the oil. And then they go back. [So,] one by one … I just have two forming units. So, when we introduced the robot … the robot could keep up with the heating furnace.
>
> So, obviously two operators were eliminated [from] the forming unit. One of the forming units was removed and the operator was fast enough to be able to feed from the heating furnace to the forming unit straight into the glandular. So, there will be layered changes in terms of the quantity of forming units required, the space required, and obviously the number of operators. (F14-I29)

Decisions to automate also arose because of dangerous work combined with quality concerns.

> How it impacted on their lives? Well often, back problems or wellness issues. And issues like that. Heavy weights. So, we clearly want to avoid that aspect. The other thing is, it was to be able to keep the product as stable as possible. So doing it in the right places was key … So, the business case was valid, in terms of doing it. (F11-I16)

Addressing environmental goals can also drive innovation. A representative of a company that producers springs for the automotive industry described how environmentally-driven changes shape production requirements at all levels.

> With the legislation in the automotive industry, globally, at the moment, where they're trying to reduce the emissions and the carbon footprint, where they're going battery operated, you find less and less of the vehicles requiring heavier springs, you see? So that means they going to go to the coil springs, are going to be lighter. (F14-I28)

Finally, another driver is the vision of company management. PWC (2021) found that, in the mining industry, as with other industries, CEOs are the primary drivers of digital transformation, with the second most common internal driver being lower-level leadership positions. PWC note that top-down leadership needs long term buy-in from operations personnel. In some cases, this can be part of a company's identity.

> The company has been built on innovation. And that is what we stand out for in the market. (F19-I35)

A company that sells 4IR-related solutions described customers' senior management as being the drivers when looking for new solutions.

> I think [our customers] don't want to be left behind so there is interest from my specific niche bunch of engineers and what's going on. But where we're finding the biggest interest is from a much higher level, so you'll see executive level. They have to strategise the next 20/30 years ahead. That's not the role of my people. My people are just doing it. So, it's the top-level guys that have to strategise going forward, and they need to map out the way of what's the future of the operation going to look like.
>
> Then, it's going down a little, a couple of levels lower to management team. So, you've got these little business units that have been set up - the chief digital officers … chief technical officers, et cetera. So, those departments have been created to try and understand and get a handle and strategise going forward. Actual implementation is a whole other story. (F06-I06)

3.3.2.2 Challenges

Respondents described a series of difficulties with adopting 4IR technologies in their businesses. A key constraint for many businesses is having the money to implement changes. When asked about the use of cobots in his factory, one respondent described a lack of money for investing in new technology.

> Our general budget for such stuff is really limited. And we always battle to keep like, you know, to get the maintenance done. And you know, the offices and furniture, and to still sort of carve out a little bit and still play in that field. (F11-I15)

Another respondent, who worked for a consulting company, described identifying potential changes for a client in a situation where the client lacked the financial means to implement them.

> Then we were speaking to one company, which for them, it was very simple. And that's they had the market share. They basically were, I want [to] say the only company manufacturing the stuff they did in the region, and everything was brilliant, for 30 years. And now, all of a sudden, the region is open. People are coming from outside and the

> market is declining. People don't want all the 'things', the 'whatever' they wanted … They want newer ones quickly. And that's the other thing we're seeing is, is the customer now demands a new design tomorrow.
>
> But because of the fact that the factory is 30 years old, you can't do that. I mean, it takes a day plus to switch over from one line to another line. And their issue was we want to make more money. So, we want to run more efficiently. And we want to be able to switch over quicker. And then it really becomes a – you go [to] the end and you study the processes and you see if they can [make it] with a machine. Can they do it? … You can do the planning, you can speed up in terms of turn one, turn two. You can do the planning. But because of the machines and unless the change the machines, the physical change over on the factory floor is going to be slow.
>
> It's just that's a limitation of what they have. So … we went all the way up to study in terms of what we suggest they do, and then, they didn't have the money to do that. So, that thing is parked, until they can find resources. (F13-I22)

As described in the second paper in this working paper series (Alexander 2022a), interdisciplinary work can be an important component of developing 4IR systems. However, many companies lack experience in interdisciplinary working. For example, South African firms may not have a history of integrating IT into mechanical systems in factories.

> These guys are now blending more and more with your mechatronics, you know the different types of engineers, process engineers. So, there's now a clash of cultures. So, the IT world. If you talk to two [of] my guys, the traditional CNI guys, they do not get on well with the traditional IT guys. All the IT on a plant all they were supposed to do back in the day was install your computer and make sure you got internet. Make sure your printers working. That was the traditional.
>
> Now with the convergence of all these technologies, big data, cloud, cyber security, et c*etera*, artificial Intelligence, big data analytics, all of that is on the IT world side. It's starting to come over the, you will see your executive-level digital officers et c*etera*. They want that knowledge because they've got to start doing optimising their operations and where do they go? Now these poor guys here, the CNI guys, are like, you know, they've become more important now. But I don't think they're as prepared as what they could be for the 4IR. They're a bit behind. So other engineering disciplines are closer to that 4IR transformation.
>
> … We are behind. Because we can see when we get like conferences, like when they talk about stuff, it's already – They always mentioned round two years ago, we started this or three years ago, we started that.
>
> … So, we sit with this interesting situation where the people that we need [for] 4IR technologies the most are becoming less. The requirement for the 4IR technologies, you know, these digital twins, et cetera, people that would be providing inputs into that are becoming less.
>
> … You got this clash of cultures. Now you've got this IT bunch, like proper IT. Now you're mixing them up into our world, the industrial world, and there are some very interesting

> issues that are coming out. So, we see that where we, where I go and give a normal sales presentation on software, a lot of times, I'm hardly even talking [to] our people who have to use it, I'm talking to IT departments. And 2016 is when that change started happening. We started seeing that sort of change … very rapid. (F06-I06)

While there is growth in cross-company interdisciplinary collaboration, the related changes to how decision-making takes place can cause problems.

> And then you've got your CNI guy who's got a couple of different types of licenses and things. You've got tax consultants … the business consultant who comes in and has to analyse each business unit. He asked my people, who are very shy and conservative, 'Why do you need all this software if you're not using it?' And for him to explain the complexities to this tax guy. And you know it's got very complicated. The management of this documentation side of things, the understanding the business unit and understanding who are now the new role players in our world.
>
> So, I mean, we've had guys, tax consultants like Mazars that understand our world very well. And the tax people … In my mind they have got nothing to do with our world, but they making business decisions on behalf of the CNI guys, which is a specialised field. So, you can see there's some inherent dangers in that. If you're not hundred percent in my world, and yet you're determining how my world must function as part of the bigger picture of the businesses itself. (F06-I06)

As with innovation in connectivity services, manufacturers described failure as an inevitable part of innovation processes.

> Because we're a general engineering company, that's really what we are. We're able to do and make pretty much anything. And because of that, we are willing to try. I mean, we fail all the time. But we also don't fail a lot.
>
> … I'm full of ideas as well. This is what it is. Try it, done. There you go. So, the customer might not like it. He might say it's horrible. Ok, then we try again … A lot of the stuff turns into nothing. So, we do spend a bit of time wasting time, but it's also good. (F02-I02)

Failure was described as bringing benefits through learning by doing.

> There is quite a lot of tricks we learned over the years. So, we demagnetise the parts. We found that the magnetism causes the machine to fail. Couldn't figure out what it was, long time ago. And what happens is all these parts are held, well not, on that machine, are held on with a magnet. And the magnetism goes into the parts. And we don't know that. And it demagnetises when they are finished and we load another from that side. It's a simple thing but it makes a very big difference. We pick up failures. (F02-I02)

Some companies described benefits of attempting multiple new exploratory projects.

> So, every single person that works here wants to work here. We have a passion and we build stuff, and then it doesn't work and then we build something else. But production is always on the one side.

> And the innovation part is continuous going. We currently have four prototypes running at the same time, in our workshop. So, he's always been putting the money back into the company … He loves to build stuff. That's his passion. So plenty times we will waste money building stuff … And he will say, 'It didn't work. Okay, let's do something else'. (F19-I35)

Another challenge that businesses experience relating to adopting 4IR is a fear of the new ways of working that can be involved. Particularly, many 4IR systems involve high levels of data sharing. Some companies prefer to keep their data proprietary, but this can impede the adoption of new systems.

> That's the big problem is if you hide your IP [intellectual property], you become inefficient. It's I don't know how people [are] going to handle this. And we have, we can have a huge mind shift change around this whole, you know, the traditional ideas of selling buying all of that has to change. All of that has to change. So that's where I see the big problem is going to be coming in. It's the mindset. (F06-I06)

An overarching theme that came up in many of the interviews was a tension between saving money through automation versus a desire to save jobs. Company management reported being conflicted on the issue of reducing employment to save money.

> Yeah, that's [what] you need, if you're bringing in new technology, you're going to need the volume, but also bear in mind, as I said to you, South Africa has to create employment. So, there have to be a balance of how we do it in this in this context of the South African. So, it's not just the volume, even if you get the volume. How do you manage? Just 4IR, it takes work away from the lower levels or … the lower end of the food chain. (F22-I39)

This was mentioned several times in relation to car parts.

> Preferably, I wouldn't like to lose the people within at least like to keep the head count static for the next couple of years and rather than utilise those people somewhere else. So, the idea is not really to reduce people, but just to enhance production but now that's why we are quite sensitive about in our store in supporting the community and South Africa. Because we are to create jobs as well, but we have to have a balance. And I think we will always be aware of that, but … we've got shareholders and stakeholders in the group. So, we cannot go over to the one side and let this side fall. It's always about balance. (F14-I27)

It was also mentioned in relation to the mining industry.

> The challenge of this country is that we need to mine deep and we need to mine far, which means how do we do that? Hence the reason we also have a lot of safety issues because it's getting more and more critical. So, organisations like a CSIR, a mining department in particular, are looking into how do we solve that. I will be implementing those new technologies in there. It's also our customers to answer your question, are scratching their head as a matter of speaking and are saying how can we start implementing automation. But that doesn't necessarily mean that I need those 340 000 people anymore. So, it's kind of a conflict, and then we can grow the business. But we

> need to do that with less people. And that's a complex thing I wouldn't like to sit in the mining sector, their shoes. (F17-I33)

One respondent described fear of the effect that changes in technology is having in relation to job losses.

> [Our services] reduce the workforce. And that's been an economic drive, not a technology drive. So, as we've seen, we've seen whole departments. That's how I get very confused. Who's actually running the process? Because the guys who need to run the process plant are often chopped dramatically, or designing process plants. So, you'll have like a team of six, a month later then there's only one left. He's still got the work of six so it means that there are inefficiencies there. So, in our world, it's major. It's actually quite scary. Who's replacing them? It's not being replaced with technology. (F06-I06)

People working in factories can be concerned with how the use of new technology can affect their jobs.

> So, my people will be more interested in the actual technology itself. What does it do? Is it just some new-fangled thing? So, they wanted [it] very simplified. So, they want to know if we have a digital twin. How does it impact this person on the ground? He is expected to keep that information, accurate up-to-date data flowing into the digital twin. Otherwise, there is going to be issues. It's going to be garbage … He's got he's got more work on his plate. He's got to make sure that the information that never really was there before is now accurate and has been forwarded. (F06-I06)

A number of companies reported that they were expanding production but not hiring new people. Automation is expanding productivity per worker, but instead of letting people go, they are able to keep current employees by expanding production.

> Yes, you find the contrast in the plant with the younger [ones wanting] to go more technical and more lazy, with the old guys [they] are more manual. And that's the two scenarios I have [in] my plan at the moment. So, managing that dilemma, from an HR perspective.
>
> … So, change is always difficult from a human perspective to handle. So gradually we're moving in that direction to accept these things. With the older generation actually, sort of retiring most of them in the late 50s, early 60s, you find you'll see the old men out in the plants now. So, as they fall away, and more [of] these YES [Youth Employment Service] programme guys come up … filling the gaps slowly, it's a matter of the timing. (F14-I28)

Managers highlighted that creating jobs was a priority in South Africa.

> South Africa has to create employment. So there has to be a balance of how we do it in this context of the South African. So, it's not just the volume, even if you get the volume. How do you manage? Just 4IR it takes work away from the lower levels or the how do you call it the lower end of the food chain. So, I am sure you've, we also picking it up in our research. (F22-I39)

One respondent described being able to keep some operators after processes were automated to fulfil jobs related to monitoring the robots.

> Previously that would have been let me say … four and reduced it to two. But one of the operator's jobs is monitoring the robot. So, they would have had basic skills in terms of how to reset the robots to the home position, and also, skills to know when they needed assistance from a maintenance or from the technicians to come and sort out issues. Like they wouldn't be able to move a robot position or do an adjustment to a program. But they would have been able to do basic resetting of the robots.
>
> … We brought in creating a new position. We tried to upscale the maintenance artisan, the team manager, and our let's call it my PLC technician. And so, I'm what we've noticed with that is that guy does we can we've sent, I don't know, maybe eight guys on the robot training courses. Okay, and maybe two of them have picked up what they need to pick up.
>
> So, there's definitely an aptitude there … One of the guys, he went on one course. And, you know, he was able to do it the next day, or the guys, you send us three or four times. And what I, what I do think is, is with this kind of technology, especially with the robot technology is fear. It's they're afraid of doing something wrong. Okay. They're not confident. And to be honest, there is that with robots. There is kind of a safety issue as well. And we did have one of our guys actually [get] hit with the robot. He wasn't too badly injured. But … [they have to] have confidence in what they're doing, and they have to have the aptitude to pick it up.
>
> … There's definitely a fear of the new technology … And … I don't know how well the guys are being prepared and the schooling … up to the matric level, how much exposure they have been getting in the past. (F14-I29)

In some cases, companies experience pressure from customers to reduce costs by reducing workers. This situation was described by one respondent.

> To be honest, a lot of it has been customer driven, to a certain extent. And, you know, because we are constantly getting audits or visits from our customers to look at cost reduction. And then each of the customers will have their own buzzwords and their own, and whatever it is – the lean manufacturing, the interface with the robot, whatever. Ford is the six sigma. And Isuzu would have would have different ones. So, I'd say it's been a lot driven by the customer, and by the requirement for cost reduction. (F14-I29)

One respondent spoke about the need to make South Africa attractive to potential investors.

> If you want to attract foreign direct investment, to grow the economy, and with that reduce the unemployment, and that is done to the benefit of all the people in South Africa, you need to get your act together and make sure that manufacturing capabilities, manufacturing effectiveness, productivity, are getting on a global scale level and are no longer done in the South African context. The only way to do that, it might be a little bit harsh, but I'm saying is by applying new technologies and optimisation. And that might lead in some domains to job losses.
>
> But if you increase the competitiveness of this country, then at the end of the day, we will be all winners. And we hope it's good to have programs to re-educate, re-skill, up-

> skill people that lost their jobs into the direction of the jobs of tomorrow. In that context, the robots and cobots are an absolute must. (F17-I33)

Respondents described not wanting to reduce jobs but experiencing pressure from investors to be efficient. Some companies had weighed the options and decided to move forward with technical solutions.

> The balance between investment and jobs. And then over the last, I'd say maybe five years, we've tried to use every possible saved budget to push into new technology. So, 3D printers, we got a few. (F11-I15)

Companies experienced tensions between wanting to promote employment and the efficiency that can be created through automation. An area where compromise can be found in relation to this challenge is the use of cobots or assistive technology, which is being applied by some companies.

> You know, if you go 100% automation, it's not as efficient or as cost effective. If you find the right balance, where you can have the automation and the operator as well. (F14-I29)

Another respondent described how they could avoid laying people off by relying on attrition and redeployment if they needed fewer employees due to automation.

> We tried to balance the investment that we put in and still maintain some kind of equitable employment ratio … So even if we do put something in, people don't get retrenched. We try to keep them and put them into some attrition pool. And if people resign or retire or move on, then we absorb the labour that way. So, it's quite sensitive in this country, because you don't want to be seen to be negatively impacting the employment. (F22-I39)

The ability to gain improvements through automation was not a universal scenario for all businesses. In some cases, respondents described humans as being more efficient.

> So even if you automate the line with big robots the line will always be slower than what operators can be. So yeah, we had a look at it but for our specific applications. It doesn't work. (F12-I17)

In some cases, firms felt there were technical challenges that could prevent the adoption of automation and 4IR systems. Some parts of production were described as difficult to automate and track, even when there would be a clear benefit.

> I'd say it's an element of the ease of automating it … So, we have a tempering furnace, the tempering furnace determines the hardness of the coil. And the hardness is the customer requirement. The customer doesn't care what temperature we run it at. The customer doesn't care what speed we run it at. The hardness is all they want to know … Typically we'll run the furnace. And the hardness results will come maybe two hours later. And by that time, we've processed 600 coils, right? So, there's no real time feedback … I would say our challenge is the technical ability to come up with a solution. (F14-I29)

Another challenge related to innovating and adopting 4IR technologies is the lack of adequate infrastructure.

> We want to transfer this data to surface. So instead of just standing next to the machine, we actually want to take this to surface. So, there's still a big gap in the market, because Wi-Fi is expensive to have Wi-Fi underground or communication … There are a few mines that I'm aware now that run full systems Wi-Fi underground … Well, some of it, [the] majority of it now doesn't [have] Wi-Fi. [The] majority of mines still don't have Wi-Fi and some machines are not Wi-Fi ready. So, because the mines have equipment that's maybe four or five years old. So, on that point, then you struggle because then you don't have data. You need to actually go to the machine and it's difficult to get all the data now. So, some mines we have 20 machines, and we have a full-time guy looking after the machines, but believe it or not, not even he can get all the data. So, some of the mines track some data, that people log by hand and then they have a planner that actually reads it in. And then you build on that data. (F19-I35)

This can be a critical challenge for manufacturers.

> We are lucky that we have GSM coverage and I'm specifically saying GSM without going into 3G, 4G, or LTE. Even there, and, and again as a consumer, but that counts for the industry as well. Do we always have 4G available? Or aren't we from time to time and working more on the 3G or I even saw E appearing on my screen. What was that again?
>
> In Europe, we already have pilot projects in cities that are testing 5G; I don't want to get into the debate. So 5G is 100 times faster than 4G. But it's not only speed, it is latency, it is broadband, it is all those things … My model of my robot with a vision camera and stuff like that is today all wired. But tomorrow, you can do that wireless also provided you have the infrastructure for it. And that's again today a problem, but also an opportunity, because a lot of development needs to take place.
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> Now the interesting part of the 5G suppliers is that they need to invest a large amount of money today, and only will get the return on that in three to five years. And that's a cash flow problem for these guys. But that's a completely other discussion. (F17-I33)

3.3.2.3 Managing Change Processes

When companies shared their experiences of adopting 4IR technologies, their stories provided insight into how change in their businesses is managed. In some cases, respondents were developing and offering completely new technologies. In other cases, businesses described processes of incremental innovation. A company that provides VR-based training described slow changes taking place.

> None of us has the secret formula. Nobody knows exactly how to do this. What we have to do is to put it out there and we have to learn from how people behave in these experiences so we can improve them. If we can't make it better then how do we ever, how do we make a product that can be sold and work? You think about if you had to pick up the first iPhone now and try and use it. You'd be immensely frustrated. Not just because it's so slow but because it's not as intuitive. The design isn't as good as it could be because it takes user generated feedback for that to actually happen. So, were pulling out projects trying to do this, trying to incentivise companies to give it a try. (F16-I31)

Another company that provides equipment for mines described processes of continuous improvement.

> Small and design changes regularly. We can't change it that often but probably once a year we will do a small change and we will do a very big upgrade every couple of years. (F02-I02)

Some respondents described pressure to adopt broad-ranging new technologies related to a general push to adopt 4IR. Some respondents described technology being applied just because of the hype.

> We tried this human robot cooperation where nobody, you know, really needed it [in the] first place. (F11-I15)

Some companies described purposefully moving slowly with adopting new technologies.

> I can tell you we just had the discussion now in the meeting that that I was in. We really will only use technology if there is a benefit in it for us, we don't believe in industry 4.0. Let's put the big banner up and we just start implementing left right and centre. It's got to add value and make a difference for me. There are some applications. From an ergonomic perspective where we plan to use things like cobots … to make it easier with the new installations that we're going to do for [our] 2022 programme. (F08-I10)

Respondents described the need for creative solutions. Adopting 4IR systems can require a process of creativity. Finding creative solutions is difficult and requires bringing people with different backgrounds together and engaging in multi-stakeholder collaboration.

> I think only the most progressive will be able to handle that kind of change [such as setting up a digital twin]. So, if you've got a strict hierarchy in the business, CEO, CFO, CDO, CTO, your next level of management … It remains [in] silos.
>
> I understand the reason for the silos, because each department needs to make sure its safety first. So, you got to know what you're doing. And it's specialised, highly specialised knowledge embedded in each of those silos. And you got to be absolutely focused. What it's going to take is it takes ambassadors and diplomats to operate between the different silos … You're going to have to have very strong strategic creative thinking has to happen from the highest level down to the most bottom level.
>
> Because this is the thing … the one word that I wanted to highlight is 'creative'. We don't have enough creatives in industry. So, we've got all this technology that's there. We've got this whole pile of tools to play with. But we haven't got enough creative people to figure out what to do with all this stuff. And how to blend it with other creatives or other types of tools or industries, et c*etera*. How do we bring this together?
>
> So, a classical example is I made friends with a chap. They do their traditional world is cyber security … So, they've got nothing to do with our world. They're 'fintech' guys. They have got nothing to do with us … I was introduced through the CSIR. So, we came together. So, they're in their world. We're in our world.

> And we realise, 'Hold on, if we work together, and we can provide solutions for the wireless technologies that is starting to come through so your IoT devices, et cetera'. If we can create solutions for that, so they would use our software to map it all out. Where are all these things, and what are the specifications, data, et c*etera*. attached to that specific instrument? The cyber-security guys are going to ringfence that piece of equipment with their knowledge from the fintech world.
>
> … You got to be very creative. You and another key term is no judgment. You can't prejudge. So, you can't say you're from this world. What do you know about my world? … we can't prejudge this piece of technology that has always traditionally been in that world. We have got to says to ourselves, 'What if?' The whole time we have got to ask 'what if?' (F06-I06)

Another respondent said that IT and management people really need to understand how production works to be able to develop effective systems (F14-127). He suggested that people should have work experience in all parts of a company when they start.

Some companies that were interviewed focused actively on innovation and developing new products. One respondent described that firms can be proactive about 4IR-related innovation (F09-I12). Others described ad hoc situations in which they would be innovative. One company described very informal systems for innovation processes.

> We stood here yesterday and said, 'This is the problem'. I think we should go do this. Production managers. I think we should try that. Yeah, you spend another 10 minutes thinking about it, talking about it. Go away. Come back and say you know what? That idea is brilliant. Let's go make one. One of the supervisors was part of the discussion. He goes, 'There, it's done' … Normally, if it's simple, I just say 'Here, make me five of these. Can you try?' if it's a little bit complicated, we need to know exactly [what] the customers' needs are. So, you have to have a bit of a discussion. (F02-I02)

Another company described occasionally developing new products when clients had needs outside of their regular offerings.

> If we quote anything to a customer that is not a standard welding system, something very specific to that application, then we have to do a lot of proof of concept to prove that it actually works for them to consider the purchase … [R&D] is very much an ad hoc basis, and then we'll call in whichever expert we require. From within that, we do have [Name 1]. He's our application specialist. So, he's, he's the guy that if we don't know what to do, we say please figure this out. And then we have [Name 2] who's the ideas guy. And together with some maybe a welding guys or electronics guys, or our laser vision guys, we then configure the team for that application. Whether it be gripper technology or welding technology. (F20-I41)

A key aspect of 4IR is that new technologies are changing the way innovation and design processes take place. For example, the ability to create models more realistically using 4IR systems is changing how design processes happen. Within companies, software

developments make it easier for less-qualified people to make models quickly (F15-I30). This can involve creating simulations.

> There we've got our solid works drawing … I started doing all the drawings on the drawing board by hand. Yeah. And so here we have embraced the fourth revolution four years ago. By getting solid works and getting a 3D printer. But you know, that's what it is. So, we're now able to be much more efficient in terms of growth. We now have over the years forced ourselves not to just make a pen and paper drawing with a ruler if you're lucky. We now make a proper drawing on the computer. Before we ever make a pot. I mean, I remember we didn't have time to get a ruler. Just make a drawing by hand. Sizes are important. Put the sizes and make five prototypes. Yeah, now we don't. It's quicker to do it on the drawing. So, he makes a drawing, the computer prints the drawing, [you] go and try it out. (F02-I02)

This process can also involve the easy ability to print 3D models.

> Most of [our 3D printers] are in the R&D department. We have about 100 people in R&D here that do all sort of technical requirements, adoption of, of the vivo stuff design in there, where they do from part approvals to testing and all that stuff. They have four, five 3D printers that they've been working with. It's been used for, what they showed me so far that we used for, not for like, series applications, but more for making [the] special tools they're designing. We've got a motorsport division that does track racing and rallies and stuff like that. They were doing parts for them. Some extraordinary kind of things. (F11-I15)

However, firms still find value in working with real prototypes.

> Because I always say, an idea on a board is one thing. But I always say let's build this, because if we build it, and we put in on the floor, we can try and test it. Then, we can verify all these wonderful tests that you guys are always discussing in a boardroom and stuff like that. And for us, we know what we can do more or less. We have a good idea.
>
> … So, when we have a concept, we will get the concept maybe 80, 85%. And in that 15% [when] we're building, when we actually build a piece of equipment, where other people normally do it opposite. They would spend months and months and months to get this product so perfectly. And then sometimes they build it and it's not perfect. So, our mind-set is normally let's get something and then work from that something. (F19-I35)

New technologies can also be used to aid in decision-making processes.

> This thing can get very complex. There is no way on earth that you can actually as a mining person can deploy any of these things without going through this whole process. Just in case you smother something or miss something. It could be a crucial part of the jigsaw. So that's how it becomes crazy, the guys don't know. Where do you start? … What we want to do is have it like your digital twin. You pull these technologies through, and you run it in a digital, advanced simulation. Then you can see, okay, in this specific type of a mine, when I do this, this and this are going to bring me this kind of value. So, then we know, okay, we need to plan … Which do we deploy first? And we run those scenarios the whole time. (F06-I06)

Finally, when firms begin to use globally developed technologies, it can also lead to further internal innovation. As technologies develop globally, firms can incorporate ongoing changes into their own innovation processes.

> We're currently busy with a big battery. [A colleague] actually wanted to build a battery-operated machine also about 10 years ago and the technology wasn't available at that time. So, if we had to fit batteries in the machine, it would have been 13 ton … Life has changed … now we get actually four times the capacity what he can get in the same size. And it weighs only 1.2 tons … So, we actually built the [battery] and it's in our workshop. (F19-I35)

4. Conclusion

This paper has shown different trajectories and experiences related to how 4IR is being adopted across connectivity services and manufacturing. Both sectors are shown to involve case studies that function through divergent value chains that shape the freedom that firms have to innovate and adopt 4IR systems and technologies. A key finding is that the nature of the lead firms in each case plays a role in determining producers' innovation opportunities.

Four types of value chains were identified. One is related to infrastructure provision for public-sector buyers. In this value chain, the lead buyer is the public sector, which can choose to predefine characteristics of the infrastructure project or to define functions that the infrastructure should provide. These decisions shape the ability of producers to innovate.

A second type of value chain is found in other connectivity services. Businesses offering these services have freedom to innovate and create new products that they can sell to a wide range of customers. These services could be seen as producer driven.

A third type of value chain exists for automotive production. Global automotive companies have a high level of control over product qualities. Suppliers to automotive manufacturing are typically limited to carrying out process innovation.

Finally, a fourth type of value chain is found for mining equipment producers. These companies have freedom to innovate and create new products and services. Also, innovation carried out in conjunction with customers was found to be common.

Across the diverse types of firms that participated in the interviews, a variety of innovation experiences were shared. A number of drivers were identified as stimulating innovation. Drivers include:

- solving customers' problems
- seeking to stand out in the marketplace
- addressing social (e.g., ongoing societal-level problems, or direct risks to workers' or users' safety) and environmental challenges
- learning about new methods through activities of support service providers (e.g., receiving training)

- trying to reduce production costs
- attempting to improve production quality
- following through with objectives set by senior management or lead firms

The experiences that were shared demonstrate that South African companies are engaging in multiple forms of learning and innovating. Different forms of connections were shown to facilitate learning, including those with domestic and global actors. Notably, key sources of learning that were shared include buying equipment that incorporates externally developed technology, visiting other countries, engaging with other businesses within the same MNC, buyer-seller relationships, working with consultants, participating in multi-actor collaborations (e.g., data sharing), and individuals engaging in skills development (e.g., online courses and training workshops).

Firms also expressed a variety of challenges. A key challenge was deficiencies in existing infrastructure. Another challenge is that new technology can be expensive. Furthermore, the lack of interdisciplinary communication, even within individual firms, was perceived as a barrier preventing higher levels of innovation. Finally, a key tension was that some companies reported struggling to balance the objectives of providing jobs and harnessing opportunities for technological efficiency, as some forms of technology that provide efficiency have a risk of leading to job losses.

The next and final paper in this series, *Key Opportunities and Challenges for 4IR in South Africa* (Alexander, 2022c), brings together the experiences discussed in this paper and the characteristics of South Africa's innovation system explored in the second working paper in the series, *Assessing the Ability of the National Innovation System of South Africa to Facilitate the Fourth Industrial Revolution* (Alexander, 2022a). It draws out key opportunities and challenges related to the expansion of 4IR, and also considers how the expansion of 4IR is influencing and may influence key economic development outcomes in South Africa.

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Annexure A: Overview of Interviews

A key source of data for this paper is a set of 51 interviews conducted with businesses and key stakeholders involved in connectivity services and manufacturing in 2019 and 2021. An overview of companies that were interviewed is provided in Table 1, and an overview of the stakeholders that were interviewed is provided in Table 2. The interviews typically had one or two representatives from the organisation. Interviews were recorded and transcribed.[11] Transcripts and notes were reviewed and coded using qualitative data analysis software to systematically draw out key findings.

Table 5: Companies Interviewed

Firm identifier	Interviews	Type	Firm size[12]
F01	I01	Lighting manufacturer	Small
F02	I02	Parts manufacturer 1 (machine and spare parts manufacturer)	Medium
F03	I03	Robot manufacturer 1 (collaborative robots)	Micro
F04	I04	Logistics 1 (packaging and logistics provider)	Large
F05	I05	Parts manufacturer 2 (automotive and locomotive parts)	Large
F06	I06	Engineering software producer	Small
F07	I07, I08, I09	Consulting for 4IR 1 (digitisation and design)	Large
F08	I10	Automotive OEM 1	Large
F09	I11, I12	Logistics 2	Large
F10	I13	Traffic management 1	Medium
F11	I14, I15, I16	Automotive OEM 2	Large
F12	I17, I18, I19	Part Manufacturer 3 (car parts)	Large
F13	I20, I21, I22, I23, I24, I25	Consulting for 4IR 2 (mechanical engineering design and prototype services, also transportation management projects)	Medium
F14	I26, I27, I28, I29	Parts manufacturer 4 (car parts)	Large
F15	I30	Mining equipment manufacturer 1	Large
F16	I31, I32	Consulting for 4IR 3 (VR)	Small
F17	I33	Consulting for 4IR 4 (automation)	Small

[11] Except for one respondent who did not want to be recorded and one interview where the recording failed. In both cases, detailed notes were taken.

[12] Size is measured by number of employees. Micro is fewer than 10, small is 10 to 49, medium is 50 to 249, and large is 250 or more.

Firm identifier	Interviews	Type	Firm size[12]
F18	I34	Consulting for 4IR 5	Missing
F19	I35	Mining equipment manufacturer 2	Medium
F20	I41	Robot manufacturer 2	Small
F21	I37, I38	Traffic management 2	Large
F22	I39	Automotive OEM 3	Large
F23	I43	Consulting for 4IR 6 (mining)	Medium
F24	I44	Consulting for 4IR 7 (logistics)	Small
F25	I46	VR training	Micro

Table 6: Stakeholders Interviewed

Stakeholder identifier	Interviews	Description
S01	I36	4IR-focused industry association
S02	I42	Government agency
S03	I45	Mining industry association
S04	I47	Government agency
S05	I48	Government agency
S06	I49	Government agency
S07	I50	Logistics industry association
S08	I51	4IR-focused industry association 2
S09	I40	Automotive industry association

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