4IR Technology Adoption in the South African Airline Industry: Drivers, Constraints and Labour Market Effects

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Abstract

The emergence of 4IR technologies has been presented as holding the promise of drastic transformations, both in the structures of productive systems and in the concomitant skills composition in the coming decades. While high expectations have been placed on the potential socio-economic benefits of these transformations for the South African economy, empirical evidence of the patterns and the effects of 4IR technology adoption is still scarce. This study aims to delve into the adoption of 4IR technologies in the South African airline industry in order to shed light on its drivers, patterns and constraints, and associated effects on labour market dynamics. Using qualitative data collected from interviews with airline executives and sectoral business associations, our findings – based on the technology organisation environment (TOE) framework – indicate that the adoption of 4IR technologies is slowly taking shape, but lagging behind industry leaders in advanced countries. The main drivers of technological change include the post-COVID-19 pursuit of safety standards compliance, cost reduction and international competitiveness. We also identify three major constraints to the adoption and diffusion of advanced technologies in local operations: the availability of commensurate infrastructure, the low scale of operations and an unfavourable trade-off between the required capital investments and the low labour costs in a context of high unemployment rates. While the industry has thus far managed to source the required technical skills for the implemented technological adaptation, the generalisation of 4IR technologies could also be impeded by technical skills shortages. In terms of labour market effects, job displacement has been limited, but is expected to increase as the transition to 4IR technology intensifies. The growth and environmental sustainability of the airline industry require a technology transition combining a more intensive use of digital technologies, green energy sources and the stimulation of alternatives to carbon-intensive air travel.

Key words: 4IR technologies, labour-augmenting technical change, productive skills, labour displacement, airline industry

JEL classification codes: J23; L93; O33; Q42

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1. Introduction

The advent of technologies of the fourth industrial revolution (4IR) appears to form the peak of the economic changes experienced in the course of successive industrial revolutions through which the world has gone (Carvalho et al. 2018). Innovation and technology experts are striving to develop and share essential insights in order to help entrepreneurs and policymakers to smoothly navigate the concomitant technological transformations. The expected shifts in production and interaction paradigms are estimated to be even more transformative than those produced by the previous industrial revolutions.[1]

The fourth industrial revolution is defined by Schwab and Samans (2016) as the advent of "cyber-physical systems" that require novel human and machinery competencies in production processes. The 4IR involves a combination of connection and collaboration, data and high-efficiency analysis, and a fusion of various technologies and human capital in a production system driven by frontier innovations such as artificial intelligence, 3D printing, robotics, biotechnology, blockchain technology, digital devices, smart factories, autonomous vehicles, intelligent machines, big data analytics and virtual reality.

The new social environment, enabled by the advent of the 4IR, is also expected to create dilemmas amongst economic stakeholders and require drastic changes in productive skills, with considerable implications for labour market dynamics. Of particular concern is the threat of work displacement, especially for low-skilled workers, as an increasingly important fraction of human labour might be replaced by machines and automation. It is namely feared that changes in production systems may entail a bias towards highly technical and digital skills, thereby displacing the demand for low-skilled and mid-level-skilled occupations (World Economic Forum [WEF] 2020). According to estimates from the World Economic Forum's "Future of Jobs" report, the advent of 4IR technologies will require organisations to re-skill approximately 40% of their employees in order to keep up with the productive skills requirements (WEF 2020). On the other hand, some analysts expect the expansion of the 4IR to increase production output and shore up economic growth, thereby creating employment and new job opportunities (e.g. Fukuyama 2018; Keidanren 2017; Norton 2017).

[1] The major milestone of the first industrial revolution occurred around 1784, which saw the first successful harnessing of steam for mechanical production. The invention of the first mechanised loom is considered a defining watershed. The second industrial revolution is generally associated with the first introduction of mass production powered by electricity, around 1870. It was characterised by the invention of the assembly line, which spurred exponential growth of industrial production systems. The third industrial revolution was ignited by advances in computing, which started in 1969 and led to first instances of machine programming. This formed the beginning of progressive automation, which brought about computer-controlled production systems and computer-aided design.

South Africa has placed high expectations on the potential of 4IR technologies to help solve the daunting challenges of unsustainably high unemployment, one of the world's highest inequality rates, recalcitrant poverty and a persistently weak growth rate. The country's current president, Cyril Ramaphosa, sees the timely adoption of 4IR technologies as an opportunity for Africa to attract new investments, to industrialise, and to pursue inclusive growth that help tackle some of the thorniest socioeconomic challenges of the continent.[2] Some analysts estimate that technological upgrading in agriculture, infrastructure manufacturing and financial services could unlock up to R1.4 trillion across the South African economy (GetSmarter 2021). Despite high stakes placed on 4IR technologies by numerous observers and analysts, there is hardly any empirical evidence of the effects of their adoption in South Africa. In view of the enthusiasm of South Africa for 4IR technologies, convincing empirical evidence on the dynamics of their related adoption and diffusion is particularly needed to guide policy and to inform the public on the nature of incentive and infrastructure requirements for a smooth and beneficial transition to the new technological paradigm.

The purpose of this study is precisely to bridge this gap by garnering empirical data through discussions with business enterprises that are involved in the adoption of these technologies in order to gain evidence-based insights into the implications of 4IR adoption for firm performance, skills intensification, employment growth and sustainability. The current study focuses on the dynamics and impact of 4IR technologies in the airline industry in South Africa. The main questions this case study on 4IR productive skills in the SA airline industry attempts to answer are the following:

1. What are the main drivers of 4IR technology adoption in the airline industry, and how does cost-benefit analysis affect the adoption choice?
2. What are the main obstacles/constraints to the adoption of 4IR technologies in the airline industry?
3. In which ways are the adopted technologies transforming the operations of the industry, and what are the implications for skills requirement, firm performance, employment, operational and environmental sustainability and social inclusion?

[2] President C. Ramaphosa has instituted the Presidential Commission on the Fourth Industrial Revolution to advise the government on the opportunities for and implications of the adoption of 4IR technologies by the country's economic system. The main recommendations of the commission to the government include: 1) investment in human capital development; 2) establishment of an Artificial Intelligence Institute; 3) establishment of a platform for advanced manufacturing and new materials; 4) acquisition and dissemination of data to enable innovation; 5) provision of incentives for future industries, platforms and applications of 4IR technologies; 6) creation of 4IR infrastructure; 7) review and initiation of 4IR-related policy and legislation; and 8) establishment of a 4IR Strategy Implementation Coordination Council in the Presidency.

In addition to these main questions, we also sought to explore the impact of the COVID-19 pandemic on the choice of adaptive innovations that may have permanently changed the operation process and may be associated with further technology adoption. We structure our technology adoption analysis around a customised version of the technology organisation environment (TOE) framework proposed by Tornatsky and Fleischer (1990). Our research approach makes use of a rigorous analysis of data collected from first-hand sources in order to shed light on the patterns, drivers, constraints, costs and potential benefits that characterise the adoption of 4IR technologies in the South African airline industry. Implications for labour productivity, industry performance, skills development, energy and carbon footprint, employment and the overall structural transformation are equally explored to derive potential policy recommendations. The research also aims to highlight the role of industrial and innovation policies in resolving technology lags and infrastructure bottlenecks, as well as providing the necessary support for the adoption of technologies that can foster structural transformation and improve the overall performance of the South African economy.

The rest of this paper is structured as follows: the next section presents key theoretical considerations on technology adoption and diffusion in order to provide a context to the 4IR adoption process. Section 3 describes the main features of emerging trends in 4IR technology adoption in South Africa and in the global air transport industry. Section 4 explains our methodological approach and study design in more detail. The fifth section provides the findings on the drivers and constraints of 4IR technology adoption. Section 6 discusses the views of respondents on the impact of 4IR technology adoption on the labour market dynamics, shifts in productive skills requirements, income distribution and environment sustainability. The final section concludes the discussion and provides key policy recommendations for industry players and policymakers.

2. Theoretical Considerations for Technology Adoption and Diffusion

2.1 Skills and Capabilities for 4IR Adoption in the Airline Industry

For the announced potential of the 4IR technologies to be transformed into actual economic opportunities for South Africa, the different players in the airline industry need adequate technological capabilities that enable them to absorb technologies developed outside the country (Cohen and Levinthal 1990; Narula 2004). The absorption of foreign technologies includes the capacity to modify them and adapt them to local circumstances in order to optimise the benefits that can be derived within the context of the domestic economy.

These capabilities are usually dependent on the supply of adequate levels of human capital that enable firms to identify, select and acquire externally developed complex technologies that require adaptive competence to internalise them and put them to efficient and profitable use (Cohen and Levinthal 1990). Factors related to the size of the firm, as well as its organisational structure and corporate culture, can contribute to influencing its ability to successfully adopt new technologies (Lall 1992). The attitude adopted by firms towards learning is also a critical indicator of technological capabilities (Bell and Pavitt 1993; Kim 1997). Likewise, the ability to learn is part of organisational capabilities, as it reflects companies' attitudes towards new ideas, as well as their eagerness to adopt them (Rousseva 2006). Human capital-related capabilities include managerial skills and competence, technical competence of workers, as well as operational skills and efficiency of employees who are expected to operate and perform their tasks with the newly adopted technology. Requisite capabilities also include the ability to marshal the financial resources needed to finance the acquisition (Habiyaremye and Ziesemer 2006). Operational or production capabilities refer to the efficiency with which existing personnel can expedite the operational tasks with current production methods. These include skills in quality control, equipment maintenance as well as adaptive competence to enable the company to manage adversity and respond to external shocks (Habiyaremye 2021). Linkage capabilities refer to the skills needed to exchange information, resources and technology with subcontractors, consultants, suppliers and technology institutions in order to strengthen the productive efficiency of the firm and to enhance its capacity to manage and diffuse its productive technologies (Lall 1992).

2.2 Technology Adoption and Diffusion: Drivers and Obstacles

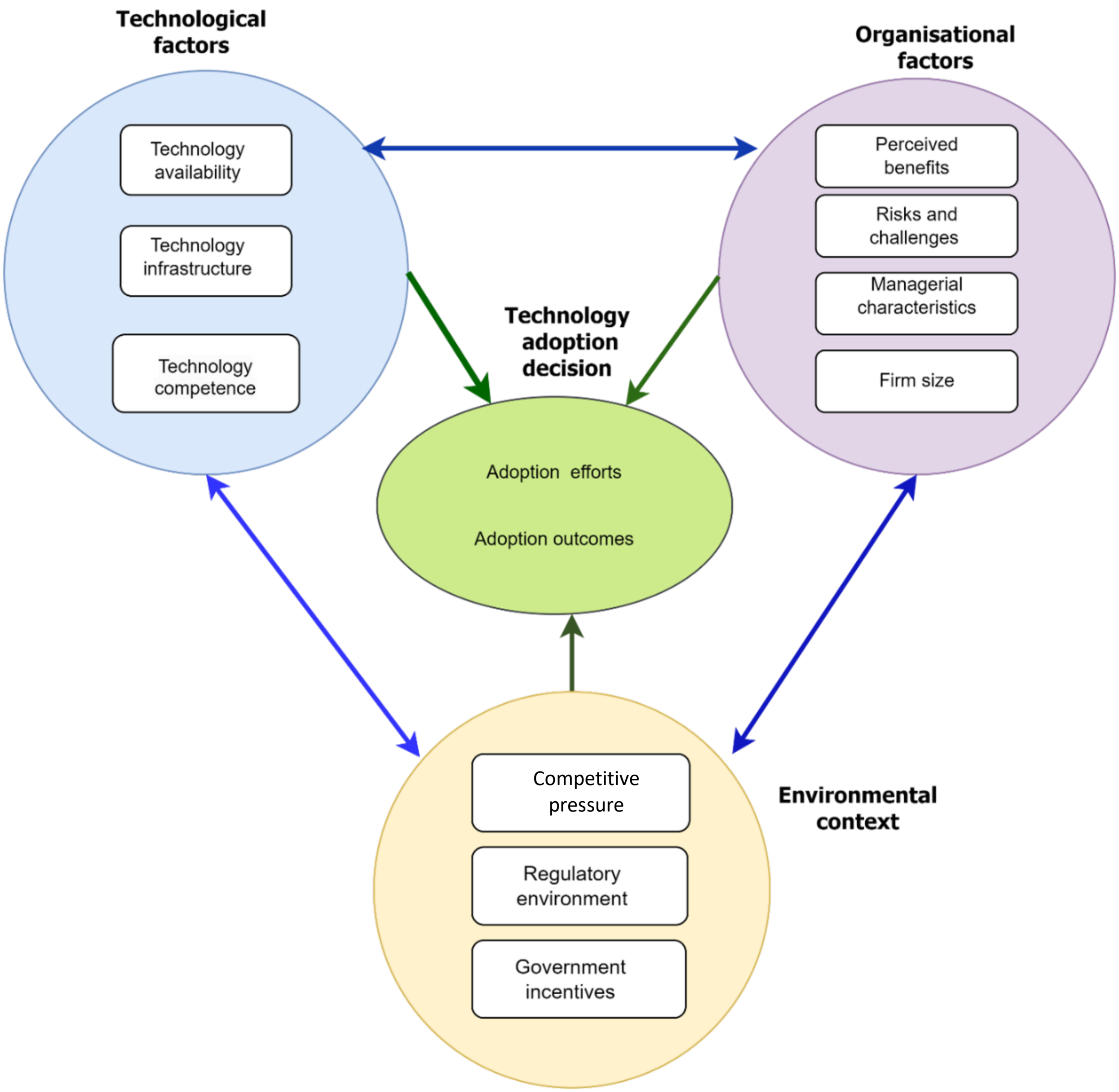
In the technology adoption and diffusion literature, sizeable differences are often observed between the expected diffusion based on the perceived benefits of new technologies, and the actual diffusion that is as effectively achieved (Habiyaremye 2020; Toborn 2011). Here it is important to recall that it is mainly through the diffusion and widespread utilisation of new technologies (products or processes) that the socioeconomic benefits of technical change are realised, rather than merely by the innovation itself (Hall and Khan 2003; Rosenberg 1972; Soete and Verspagen 2021). The potential benefits of 4IR adoption in terms of improving wellbeing in South African society may thus remain limited to a critical number of firms that have adopted such technologies and started using them extensively (Habiyaremye 2020; Monaco et al. 2019). In practice, innovations often diffuse at a much slower rate than what would be expected from potential adopters based on gains from adoption (Rosenberg 1972; Toborn 2011). The literature on innovation diffusion has suggested a number of microeconomic factors that influence the adoption decision at the firm and individual levels, and therefore affect both the rate of adoption and the speed of diffusion. Rogers (1995) proposed five such factors with direct implications for the diffusion dynamics: 1: relative advantage over existing alternatives; 2: compatibility with established social norms; 3: implementation complexity of the new technology; 4: trialability (opportunity to experiment with the technology before adopting it); and 5: observability (opportunity to see the technology in action in other firms). Other important factors in the adoption decision are financing and adoption costs, as well as availability of complementary resources and skills (Hall and Khan 2003). On the other hand, uncertainty, insufficient political support, weak adoption networks and resistance of already established firms can constitute diffusion obstacles (Foxon and Pearson 2008). For newly developed technologies, such as those connected to the 4IR, to diffuse successfully, the capacity of potential adopters to absorb them in their operations and production systems also plays a crucial role (Cohen and Levinthal 1990; Habiyaremye and Ziesemer 2006; Narula 2004). Institutional factors, such as regulatory and market-related policies, can equally hinder or catalyse innovation diffusion (Hofstede 1997; Katz and Allen 1982; North 1990; Talegeta 2014).

Another very useful approach to examine the patterns and drivers of and constraints to technology adoption is the technology-organisation-environment (TOE) framework proposed by Tornatsky and Fleischer (1990). This offers a taxonomy of factors affecting the adoption and implementation of new technologies by categorising them into three main contextual dimensions, namely the technological dimension (e.g. technological infrastructure and practices), organisational characteristics (e.g. organisational and managerial attributes), and the environmental context (e.g. competitive pressure, industry characteristics, regulatory frameworks). As represented in Figure 1, these main contextual domains exert a mutual influence in a dynamic process, while their different elements can either foster or hinder the technology adoption process (Aboelmaged 2014). The TOE framework does not prescribe a fixed set of factors to use for an empirical analysis of the adoption and deployment of new technologies; its strength as an empirical tool resides mainly in its flexibility and adaptability to different disciplines (Aboelmaged 2014). In this paper, we apply the TOE framework to investigate the drivers and patterns of 4IR technology adoption in the airline industry in South Africa. In the technological dimension, we base our analysis on two main considerations: technology infrastructure (Weill and Broadbent 1998) and technological competence (Abdinour-Helm et al. 2003; Ifinedo 2011; Lin and Lin 2008). The availability of a common infrastructural platform plays a critical role in fostering the adoption and implementation process (Weill and Broadbent 1998), while the capacity of an organisation to understand, adopt, use and modify externally developed technological knowledge increases its propensity to adopt and implement new technologies in its operations (Cohen and Levinthal 1990; Lin and Lin 2008).

For the organisational dimension, our focus is on perceived benefits of 4IR technology adoption (enhancing competitiveness, efficiency of operations, cost reduction and operational flexibility, system integration), expected adoption risks and challenges (such as implementation costs, organisation restructuring, compatibility with other organisational processes) and managerial characteristics (such as optimism, innovativeness and attitude towards risk) (Aboelmaged 2014; Rogers 1995). While perceived benefits provide the motivation for technology adoption, the expected risks and challenges tend to dampen the adoption enthusiasm, while managerial attributes such as innovativeness and risk aversion also play a key role in the adoption decision, especially in its timing relative to that of competitors (Awa et al. 2017; Matsepe and Van der Lingen 2022; Van den Berg and Van der Lingen 2019). Less emphasis is put on firm size in this analysis, since many of the technologies considered for the airline industry are in common use.

As for the environmental contextual dimension, we focus our attention on the role of competitive pressure, the regulatory framework and government incentives for 4IR-related innovations. Competitive pressure often serves as the impetus for technology adoption, especially if the new technology is perceived as having the potential to increase operational efficiency or enhance the quality of the provided service (Matsepe and Van der Lingen 2022). Likewise, favourable regulations and government incentives can provide a conducive contextual drive to adopt the new technologies, while bureaucratic complexities and lack of government support can act as adoption impediments (Aboelmaged 2014; Tornatsky and Fleischer 1990). These different influences are summarised schematically in Figure 1 as a customised TOE framework.

Figure 1: TOE framework for 4IR technology adoption in the airline industry in South Africa



2.3 Nature of Technological Change and Effects on Labour Input

Recent discussions on the potential impact of 4IR technologies have portrayed them as being sufficiently disruptive for their adoption and diffusion to herald a technological paradigm shift (Philbeck and Davis 2018). This implies that the combination of such technologies is expected to modify not only the technological and production ecosystems of the coming decades, but also the way our societies shape and manage social interactions as well as socio-economic values. The introduction and diffusion of new products or new production methods in an economy paves the way for technical progress, which constitutes the primary source of long-term economic growth (Aghion and Howitt 1992; Romer 1990; Schumpeter 1942). Technical change leads to output growth through its effects on increasing the factor productivity, i.e. by enabling firms to produce more with the same inputs, or keep the production level constant with reduced input levels (Jackson 1982). Technical progress can therefore be either capital-augmenting or labour-augmenting in its short-term manifestations but, in the long run, its asymptotic direction points towards a purely labour-augmenting balanced growth path (Acemoglu 2003). The associated increase in labour productivity has complex implications for labour-market dynamics, as well as the skills requirements to match the new tasks made necessary by new production techniques (Acemoglu and Restrepo 2018). While the supply shock provoked by labour-saving automation systems can often lead to technological unemployment if other sectors fail to absorb surplus labour (see, e.g., Acemoglu and Restrepo 2017), some theoretical models in this framework, such as the one put forward by Ziesemer (2001), postulate that increased adoption and diffusion of digital and automation technologies have the potential to lead to higher wages and lower unemployment rates in the long run.

This study framed the adoption of 4IR technologies from the perspective of labour-augmenting technological change and analyses its labour market effects within the structural transformation framework in the context of a developing economy (see, e.g., Andreoni et al. 2021; Schlogl and Sumner 2020). It is important to highlight that the adoption of new technology does not function in isolation and only works effectively within a conducive institutional and industrial policy framework (Lall 1992). Likewise, for the benefits of any technology adoption to materialise and generate a tangible socio-economic impact, significant diffusion of the new technology is necessary, as pointed out by Hall and Khan (2003) in their theorisation of technology adoption, while isolated cases of technology adoption are more likely to lead to an increase in income inequality, as illustrated by Lahiri and Ratnasiri (2007).

3. Emerging Patterns of 4IR Technology Adoption in the SA Airline Industry

3.1 Gradual Adoption of 4IR Technologies

The aviation industry is arguably one of the most highly technology-intensive industries. Therefore, by extension, the airline industry, which operates with these technologically sophisticated assets, involves the mastery of multiple advanced technologies. From the technologies needed to ensure the high level of security required in the industry, to the enabling applications that facilitate the ground operations, the airline industry is characterised by many elements that require the deployment of sophisticated technologies that provide opportunities for improving efficiency and transforming the customer experience. That is why technological change has been constant over the decades, even as the basic technologies of the aircraft have remained relatively stable since the 1970. The global airline industry is expanding its technological arsenal in several directions, aimed at making it ready for the digital world of the future:

- Sharing data through secure blockchain technology to reduce transaction costs;
- Using augmented reality and virtual reality for immersive inflight entertainment;
- Leveraging the internet of things (IOT) for optimal baggage handling and passenger service at airports; and
- Ensuring operational and environmental sustainability.

Augmented reality (AR) tools are being deployed to help passengers navigate more easily inside terminals to locate their corresponding check-in desks, departure gates and baggage carousels. AR applications are also being used to support aircraft engineers in performing quick and accurate repairs that can be monitored and signed off by supervisors from a distance. The increased use of these applications is expected to lead to faster repairs, which in turns will lead to fewer equipment breakdowns and a reduced number of flight delays for the aircraft involved. Virtual reality and the metaverse can be used for virtual queuing, which helps airline companies avoid long queues and manage social distancing at potentially crowded screening points.

Another important consideration in relation to the future of technological trajectories relates to the development of technologies that help achieve the goals of net zero carbon emission by 2050, to which a commitment was made at the 77th annual meeting of the International Air Transport Association (IATA). The deployment of 4IR technologies would indeed lead to mitigated outcomes if no measures are taken to prevent the gradual destruction of the planet and its biodiversity. New, more advanced aircraft technologies, including hydrogen- and electricity-powered engines, as well as improvements in the efficiency of existing operations and infrastructure, will play a key role in supporting the achievement of this crucial objective.

3.2 Infrastructure Providers

As the main infrastructure provider for the airline industry in the country, ACSA plays a leading role in determining the type of technological infrastructure available to airlines and ground-handling companies operating at most South African airports. Private infrastructure providers, such as Lanseria Airport, use technologies comparable to those available at ACSA main hubs. Their installed technologies are pivotal to enabling compatible technologies that these operators could possibly adopt. For example, the realisation of the desired readiness of ground-handling operators to adopt the use of autonomous vehicles for baggage transfer and loading will depend on the availability of commensurate infrastructure if ACSA decides to make such investments. The decision to invest in this kind of technological infrastructure, in turn, depends on the estimated scale of operations that will make them profitable, as well as the availability of financial resources to cover the related costs. Because of its constant drive towards modernisation, ACSA has already committed the necessary budgets for fully automated passenger service infrastructure at its three main international airports (interview with ACSA executive, July 2022). Investments will be directed towards additional common-use self-service kiosks, including self-bag-drop facilities, as well as updating existing ones that are not yet operational. ACSA plans to generalise the use of biometrics, facial recognition and e-gates at all main airports in order to align the passenger service with the global best practices in the domain. Planned modernisation includes the adoption of AI-enabled systems to manage passenger services and security control operations.

3.3 Airline Companies

Some of the international airline companies operating at South African airports whose main operating hubs are in advanced countries experience clear differences in operational technologies between their local (South African) operations and the advanced processes that they are able to use at their home bases.[3] Local operations are adapted to the South African infrastructure and tend to be less automated than their foreign operations. While 4IR technologies have started playing an increasingly important role in their operations in Western Europe, North America and East Asia, the ability of these airline companies to use similar technologies in South Africa is constrained by the technological trajectory followed by ACSA. The pilot project for the adoption of face recognition and e-gates in Johannesburg and Cape Town has made these technologies available for use only for South African citizens. Extensions to the use of such technologies will require the integration of complex databases and adapted passport technology. Airline companies expect a positive evolution towards more technologically advanced processes, including artificial intelligence and robotics, as South Africa catches up with global leaders in this domain.

The main domestic airline companies currently in operation in the country are of relatively limited size, with a technological base adapted to existing airport infrastructure. As most of them have their main bases at the primary hubs of Johannesburg, Cape Town and Durban, from where they service other regional airports, their technological arsenal is congruent with the infrastructure available at these hubs.

[3] Our analysis does not cover technological innovations in the aviation industry itself (including aircraft maintenance and flight-simulation technologies).

3.4 Ground-handling Companies

Ground-handling service providers play a pivotal role in the operations of airlines companies. Baggage handling, airport security, aircraft cleaning and passenger ground transportation service providers need different types of technological equipment that together define the quality of the travel experience. One of the main service providers is testing a technological innovation consisting in an exoskeleton-like suit, which allows baggage handlers to lift and move heavier items more easily. They currently are battling with these items because of the potential for them to cause strain on their bodies. Robotics and drone technology are also already being deployed for some ground-handling operations, especially for cargo handling (interview with ground-handling operations manager, July 2022). The move to automated handling systems is quite expensive in terms of the required investments, but the available technologies are expected to reduce costs and enhance operational efficiency. Automated systems for handling cargo are inspired by the technologies used in/by retail and logistics partners that are sending air cargo packages around the world. The use of automated systems increased during the Covid lockdown period, when restrictions intended to limit the spread of the virus led to minimum human interactions and the introduction of protective measures to avoid contact with people, equipment and baggage. The other dimension of technological transformation relates to the endeavour to adopt clean energy in ground-handling equipment. Some ground-handling operators have declared their commitment to having at least 50% of their ground operation fleet of vehicles, machinery and equipment running on clean energy by 2025 (interview with a ground-handling company executive, August 2022). The necessary licences to operate this new fleet have already been applied for from ACSA. A move to an electric vehicle fleet will require commensurate infrastructure, such as charging stations, and negotiations with the infrastructure providers will be needed to solve the corresponding infrastructural bottlenecks.

3.5 Links to the Tourism Sector

Tourism service providers in South Africa are closely connected to what happens in the airline industry for the obvious reason that international tourists arrive in the country primarily via air transport. Therefore, the adoption of technologies that streamline the flow of passengers at airports has a direct effect on the tourism sector. Tourism executives monitor such technological change in the airline industry with considerable interest and are expected to align their own innovation strategies with those planned by the infrastructure providers and airline operators. Crucial areas of potential innovation and collaboration between the tourism and the airline industry include increased digitalisation of tourist information, and the development of an integrated geographical information system enabling arriving tourists to quickly access data on available local transport, accommodation and leisure services.

4. Methodological Approach

4.1 Design of the Study

Gaining in-depth insights into the effects of technology adoption on the dynamics of skills requirements at firm level requires a close observation of the actual process and a detailed dialogue between the researcher and the people involved in the process at different levels of decision-making and operation of the companies involved. The pertinence of our analysis therefore would depend on how deep we can delve into the different layers of the technology adoption processes in each of the organisation we analysed, rather than relying on the quantitative analysis of statistical data of a large number of firms. As a result, we took the case study approach and attempted to gather as much pertinent information as possible from each of the firms with which we interacted.

Semi-structured interview guides were designed to garner key elements of this information with the view to analysing it using a qualitative approach. The analysis of interview data was carried out on the basis of the background information on technology adoption in general, and the dynamics of the airline industry in a global context.

4.2 Sampling

As the study aimed to garner as much information as possible on the process of adopting 4IR technology, the sampling targeted the entire population of domestic and international airline companies operating at the main South African airports. We also included Airports Company South Africa (ACSA) as the primary infrastructure provider at most domestic and international airports in the country because of the crucial role it plays as the enabler of technologies that can be deployed on the existing infrastructure in the country. Domestic airlines are interconnected through their business association, the Airlines Association of Southern Africa (AASA), while international airlines coordinate their collaboration through the Board of Airline Representatives of South Africa (BARSA).

Interviews were also conducted with the representative of the tourism industry because of its close proximity to the airline industry and the potential influence that the tourism association may have on technology adoption by the airline industry due to shared customers (tourist travellers form the core group of passengers for most airline companies operating in South Africa, according to the board of the Tourism Business Council of South Africa [Interview: August 2022]).

4.3 Data Collection

Contact information on domestic and international airline companies operating in South Africa, including their telephone numbers and email addresses, was obtained from the ACSA portal. After sending emails and making phone calls, preparatory meetings were organised with the head of research and innovation at ACSA in December 2021, which made it possible to prepare to access the different airline companies from which we wished to collect data on their 4IR technology adoption experience. Several preparatory meetings were necessary with the two main business associations to get their endorsement and support to collect data among their members.

Interviews were conducted with local and regional managers of domestic and international airline companies. We also held an interview with representatives of ACSA to have a clear picture of the technological infrastructure at the disposal of airline companies as a common platform for their own technological systems. Our primary aim was to conduct as many in-person interviews as possible, also for the sake of making beneficial use of in situ observations to gain a deeper understanding of how the adoption of technology is handled in practice. Because of the ongoing COVID-19-related restrictions at the time the data collection process was started, many interviews had to be conducted online (Zoom and MS Teams applications). Interviews with some of the airline executives were conducted in person, as condition permitted holding talks at their offices. Additional interviews were conducted with the Johannesburg station managers of some international airline operators via an online platform.

5. Drivers, Patterns and Dynamics of 4IR Technology Adoption in the SA Airline Industry

Table 1 provides a summary of our findings on the drivers of and constraints to 4IR technology adoption by the airline industry in South Africa, grouped according to the dimensions of the TOE framework. Those findings are then described in more detail following the same taxonomy.

Table 1: Summary TOE drivers of and constraints to 4IR technology adoption by SA airline industry

Contextual dimension	Favourable influence	Constraint	Unknown
Technological	-Technology availability -Some technologies fairly developed, already in use overseas -Technological competence: sufficient digital skills base, possibility of external sourcing of foreign talents	-Absence of advanced common digital infrastructural platform -Absence of compatible infrastructure (e.g. 5G networks, physical infrastructure for autonomous vehicles) and digital systems -Some technologies are still in their pre-deployment stage of maturation -Scarcity of technological competence in certain technical skills needed to run and maintain AI systems	-New technological infrastructure -Development of local skills base for running and maintaining highly sophisticated technological systems
Organisational	-Expected benefits of 4IR adoption: simplified travel experience -Cost reduction -International competitiveness -Operational efficiency -Increased security -Sustainable and health-friendly solutions -Management innovativeness and feelings about 4IR technologies -Connection to overseas technological assets and management practices	-Investment costs -Scale of operations insufficient to recoup large investments -Adaptive restructuring efforts and costs -Financial distress of some domestic companies -Centralised decision-making, coordinated from overseas headquarters -Financial leverage structure	-Investment prudence -Attitude towards risk

Environmental	-Government support for 4IR technologies -Clear regulations to minimise risk -Post-Covid-19 recovery through diversification of service arrays -Collaboration with international operators -External risks: future pandemics end geopolitical upheaval	-Privacy protection in the use of biometrics and facial recognition technologies -Ethical considerations in relation to ownership of personal data -High unemployment rate and low labour costs -Immigration laws and bureaucratic procedures impede a speedy sourcing of foreign skills	-Labour displacement effects -Environmental protection -Development of alternative transport systems to lessen the CO_2 footprint generated by expanding air travel

5.1 Technological Infrastructure in the SA Airline Industry

With the theoretical frame of technology adoption as background, we interviewed a dozen executives and managers representing various operators in the South African air transport industry regarding the expected effects of adopting the newest technologies on their operations. The primary thrust for adopting advanced airport technologies is to increase operational efficiency by minimising the time that each aircraft remains in the hangar, i.e. out of active operation, and to allow for a smoother flow of passengers. Major airports in South Africa are equipped with the most modern technological infrastructure for world-class navigation and flight-control systems to ensure safe traffic for aircraft of any size, ranging from regional jets to the superjumbo A380. The ambition of the infrastructure provider (ACSA) is to offer world-class airport technologies to ensure seamless air travel for passengers. However, remarks by airline operators and ground-handling service providers suggest that the technologies they deploy follow the leaders in the domain, but that they cannot afford to be at the cutting edge of the technological frontier because of the limited scale of operations (interview with overseas airline executives, July 2022). Below, we provide a short overview of technologies that are deployed at the main South African airports, along with examples of leading technologies already in use at some leading airports overseas.

5.1.1 Booking System

Most respondents we interviewed indicated that their airlines use the AMADEUS global distribution system. This system enables airline companies and travel agents to manage their flight inventory and offer the best deals to their customers. AMADEUS is one of the preferred network-based reservation systems globally.

5.1.2 Smart Check-in

All major airports in South Africa have shared self-service check-in kiosks, allowing passengers to print their own boarding passes and avoid long queues. The airline industry is evolving towards the intensification of smart check-in facilities that incorporate facial recognition and self-service bag-drop services. The smart check-in system is designed to allow passengers to drop their bags without having to go to the baggage-drop counter, which can help reduce congestion and delays during busy times. During the Covid pandemic, ACSA intensified the use of touchless screening services with mobile devices to ensure a secure flow of passengers with minimal contagion risks. This kind of technology is expected to save money in the long run through increased check-in efficiency and accuracy.

5.1.3 Security Screening

South African airports have adopted advanced security technologies to help keep them safe for passengers and the public. The use of sophisticated X-ray machines enables airport security personnel to spot any potentially dangerous objects on passengers or in their cabin luggage, while the use of biometrics and facial recognition help to ensure that only authorised passengers and personnel have access to restricted areas. For enhanced security checks, the CT-scanning technology uses X-rays to create a three-dimensional image of a person's body, which enables security personnel to easily identify any objects that may be concealed on the body. The expected adoption of advanced scanning technologies could also enable airport security control to relax the restrictions on 100 ml liquids and enhance the efficiency of security screening.

5.1.4 Baggage handling and tracking system

The automated baggage handling system (BHS) used at South African airports is based on automated departure control systems (DCS) using a baggage reconciliation system (BRS) and hold-baggage screening (HBS) technologies. Baggage transfer on conveyor belts to and from the aircraft relies on HBS and a sort-allocation computer (SAC) system with tilt trays, which automatically direct luggage to the correct dump on the basis of the allocation obtained from the flight-planning module. Actual baggage loading onto and unloading from aircraft remains a manual handling operation based primarily on human labour.

The current state of the art in baggage-tracking systems includes the use of radio-frequency identification (RFID) tracking technology. RFID tags are small computer chips that use radio waves to transmit data, thereby enabling the tracking of objects by electronic readers. They provide an optimal tracking system for passenger luggage on long-distance flights, even when the luggage gets lost or is stolen in transit. The safety and efficiency of baggage handling can also be increased considerably by the use of robotic loaders, as already demonstrated by its utilisation at Saga Airport (Japan).

5.1.5 Immigration Control and Boarding

The current immigration-processing system at South African airports relies mainly on immigration officers to control passengers' documents with the help of a computerised system. The adoption of biometrics and facial recognition technology could enable immigration control to reduce the clearance process time. Such systems use artificial intelligence to identify passengers by matching their photos against records in airport databases. The processing of passengers' documents is thereby rendered more accurate and can be executed faster. In November 2022, the Department of Home Affairs launched a pilot project aimed at capturing biometric data at South Africa's international airports in order to implement its Enhanced Movement Control System (EMCS) at all ports of entry. This pilot is initially running at Lanseria International Airport, OR Tambo International Airport, King Shaka International Airport and Cape Town International Airport to test its functionality before extending it to other airports.

5.2 Technological Competence: Skills and Capabilities

A successful transition to the 4IR technology-driven operating environment requires a commensurate adaptation in skills supply in order to meet the needs of such a technological setting. Observations from our key informant interviews suggest that, for the needs of the airline industry, training in the new skills can be done without disrupting ongoing operations. The set of technical skills required to run the new technological systems became more complex as departure control systems and security checks moved to digitalised systems. Some of the required skills had to be imported from abroad owing to limitations in the supply of highly technical skills from South African vocational and technical training institutions. The inflow of foreign skilled workers has remained rather limited, however, because of the complexities of the work permit-processing requirements and red tape. As a consequence, some operators report frustrations with their inability to source the needed talent from abroad, while it cannot be easily sourced from local supply either. Technical experts for running and maintaining the AI systems, for instance, are readily available abroad, but find it difficult to obtain work visas even when they are critically needed to run such systems in South Africa. While the issue of importing foreign workers into a country with an effective unemployment rate of more than 40% remains contentious, for the needs of post-Covid recovery the discussion needs to shift to marshalling all resources and skills to give a new impulse to the industry. Respondents envision a recovery that will create more jobs, and therefore consider that bureaucratic simplification is needed to enable the inflow of the foreign talent required to implement the adoption of complex technological systems, such as AI and big data analytics.

5.3 Perceived Benefits and Challenges of 4IR Technology Adoption by the SA Airline Industry

All international and domestic airline operators that we interviewed indicated seeing significant potential in the adoption of 4IR technologies and particularly in increasing digitalisation to improve travelling experience and increase the efficiency of ground-handling operations. While some of the most advanced technologies have already been tested in South Africa (for example e-gates at Cape Town International Airport), or in the main hubs of foreign companies operating in South Africa (ex. Schiphol in the Netherlands), the most sophisticated technologies remain on a future agenda. Ultimately, the airline operators consider the adoption of such adoption as an essential move to gain international competitiveness.

Amongst the technologies estimated to have high transformative potential, the following stood out in a synthesis of insights from our interviews with industry players:

- The growing use of biometrics, e-gates and face-recognition systems to improve immigration procedures and streamline incoming passenger flows: the three main hubs connecting South Africa to international destinations are currently in the process of implanting the biometrics and e-gates systems, but they are not yet functional. The system is expected to be put into operation soon, but no precise date can be given.

- The self-baggage drop-in system is expected to be implemented at all major South African airports, but the migration to fully automated systems will take several years as a result of technology maturation and cost-advantage considerations in comparison to existing labour-intensive systems.
- The use of big data to archive passengers' profiles and to improve the travelling experience: some major international airlines have indicated that they regularly make use of big data analytics, but its application is driven primarily by data accumulated in overseas operations.
- The adoption of autonomous vehicles at airports, for which demand increased significantly during Covid-19, as they present a clear potential advantage for reducing contagion risk. Effective implementation requires significant investments in the appropriate infrastructure, which is not yet available, but is expected to be part of the technological landscape at South African airports if the projected conditions evolve according to ACSA's vision.
- Digitalisation and automation of the sanitary checks required since the Covid-19 pandemic started are also expected to contribute to reducing the risk of airport congestion.
- The digitalisation and increasing automation of cargo-handling operations, with particular interest in the digitalisation of goods classification and the potential adoption of 3D scanners to optimise cargo loads: digitalisation in air cargo operations requires related but not identical technologies in comparison to passenger air transport. Increased digitalisation, combined with 3D scanning, can be expected to yield considerable gains in efficiency and drive logistics costs down in the medium to long term. Technologies to drive this digitalisation are mostly embodied in the corresponding machines and equipment, while its implementation requires an alignment with integrated logistics systems. The use of drones for cargo handling is another technological development that airline operators expect to intensify in the future. Drones are expected to increase the accuracy and efficiency of cargo handling, for example by speeding up the collection of light packages for delivery to or from cargo warehouses.
- The deployment of AI for predictive modelling and management decision support systems for light operations makes it possible to connect all available data and propose centralised solutions. AI and machine-learning tools are also deployed in chatbots that provide customised passenger information and can respond to individual queries to help customers solve their flight-related problems.

While most companies that participated in the study are aware of the potential offered by these technologies and are familiar with their working, since they have been implemented in their respective major hubs in their home countries, they mostly consider them as an aspirational goal for their operations in South Africa. Indeed, the existing airport infrastructure does not accommodate many of the systems they use in their overseas operations, and therefore constrains their ability to deploy them locally. However, ACSA confirmed to us that a considerable budget has already been reserved for infrastructure modernisation, including the deployment of digitalisation and biometrics systems to ensure higher efficiency in passenger and cargo flow, as well as enhanced security (interview, August 2022). Nonetheless, the effective implementation of these technologies still faces significant constraints and challenges. Such constraints range from practical concerns, such as equipment, fuel and staff shortages (particularly aggravated by the lay-offs caused by the Covid-19 crisis), to broader financial constraints (such as the financial distress that crippled SAA and led to the liquidation of Comair) and institutional fragmentation (for example, the lack of procedural harmonisation and data integration between airport authorities and Home Affairs on immigration procedures). Structural and ethical considerations are an equally important obstacle (e.g. data availability following the application of the Protection of Personal Information (POPI) Act). There are also specific constraints that are directly linked to the availability of appropriate levels of technical skills: while the supply of digital skills in the sector is considered adequate, high-skilled professionals such as aviation engineers, supply chain managers and specialised data analysts are particularly scarce.

5.4 Organisational and Managerial Attributes

In our discussions with industry executives and managers, we probed their attitudes towards innovation and 4IR technology adoption in their operations. We also sought to understand their general expectations about the transformative outcomes of 4IR technology adoption for their respective companies and for the South African economy. All airline managers and executives expressed a high inclination to more towards innovation and technology adoption and felt constrained by the existing infrastructural platforms available in South Africa. For some of the airlines based overseas, the local executive we spoke to also indicated the limitations they face in local technology adoption as a result of centralised decision-making. The representatives of the state-owned infrastructure provider, as well as the executives of the ground-handling operations, had similarly, very favourable attitudes towards innovation, and were only limited in their propensity to innovate by the degree of compatibility with local infrastructure platforms.

With respect to attitude towards risks, the industry is characterised by high priority being attached to security and the need to comply with all relevant aviation regulations and prescriptions. In the conversations with industry executives, many of the respondents expressed enthusiasm about the new possibilities that 4IR technologies promise to bring about. Most of them appeared to have an inclination to prudence when it came to new investments in 4IR-related technological and physical infrastructure by making their introduction conditional on rational expectations in relation to the long-term evolution of the travel market within regulatory and environmental constraints. In sum, the observed managerial attributes are expected to support the adoption of 4IR technologies in a coordinated and environmentally friendly manner that balances the demands of the country's labour market structure and the estimated changes in the efficiency of business operations.

5.5 Industry Structure and Competitive Pressure

Before the COVID-19 pandemic, the airline industry in South Africa was characterised by a sizeable number of domestic and international operators, with regular scheduled services to and from three main international hubs (Johannesburg, Cape Town and Durban), in addition to six main domestic service airports (Port Elizabeth, East London, George, Bloemfontein, Kimberley and Upington). Lanseria Airport provides privately owned alternative infrastructure that also offers frequent scheduled domestic flight services. The air transport infrastructure comprises other public and private airports with international standards, but they currently offer less frequent services. The grounding and subsequent liquidation of Comair in June 2022 (which accounted for 40% of the country's domestic seat capacity before its financial distress), as well as the financial restructuring of South African Airways (SAA), meant a considerable reshuffle in the domestic air transport industry. In the wake of the crippling restrictions, the industry counts four main domestic operators and 36 international operators. The most important hub for domestic and international flight services remains OR Tambo International Airport (JNB), with a total of 40 operators, while Cape Town International Airport (CPT) accommodates all four main domestic operators and 13 international operators. As for King Shaka International Airport (DUR), it currently offers services for only three of the four domestic and only three international operators.

The current recovery trajectory of the airline industry in South Africa reflects the post-pandemic trends in global air transport in its ramifications for the country's major international hubs. While the global airline industry experienced a considerable drop in passenger flights and a 20% drop in cargo transport when drastic pandemic restrictions were first imposed in April 2020, the cargo transport has recovered most of its lost ground, while domestic passenger transport revenues are still 18.6% below their pre-pandemic levels (ACSA [Airport Companies South Africa] 2023). Revenues from international passengers have even more ground to recover, being at 35% below their pre-pandemic levels, The envisaged recovery strategies include increased digitisation of airlines and airport service systems, increased interconnectivity and standardisation of digital platforms, resource optimisation through the expansion of self-service tools, green airports that adopt renewable energy sources and optimise energy consumption, more digitalised security systems, and the transformation of airports into social hubs by diversifying the array of services offered to passengers. The reduction of the operational capacity of South African Airlines remains a considerable challenge in the effort to restore international connectivity to its pre-pandemic levels, but ACSA's collaboration with international operators is betting on route expansion to achieve the kind of economies of scale that would make it possible to recoup the required investments in commensurate infrastructure.

5.6 Regulatory and Institutional Framework

The various operations and processes involved in running the airline industry require a coherent regulatory framework because of the security implications they represent for travellers, personnel and the general public. Air transport and airport ground operations fall under the regulatory authority of the Department of Transport (DoT), while the control of the emigration and immigration of international travellers fall under the regulatory authority of the Department of Home Affairs (DHA). For the use of biometrics, for example, ethical considerations of who owns and controls access to personal information are critical to the implementation of related technologies while guaranteeing optimal protection of privacy for the users. The implementation of biometrics, face-recognition systems and e-gates in security control at various airports has to rely on databases controlled by the DHA, with the understanding that the state guarantees the necessary privacy protection. As an autonomous state-owned enterprise in charge of managing the main country airports, ACSA also plays a pivotal role in the regulatory framework. Any technology change introduced at an SA airport has to comply with the stipulations and procedures of this complex regulatory arrangement. All new technological systems need to obtain the required homologation by the regulatory authorities before they can be put into use. Collaboration and coordination between these various entities therefore is essential for the success of 4IR technology adoption. Some of our respondents expressed frustration with the slow responsiveness and complexity of bureaucratic procedures in their dealings with the DoT to implement new technologies in their operations (interview with airline executive, August 2022). The institutional setting is generally favourable to business and technological development, with different entities of the Department of Science and Innovation and the Department of Trade and Industry readily equipped to facilitate and support various innovation initiatives in the national economy. As underscored in the introduction, 4IR-related technological innovations are particularly encouraged, as recommended by the presidential advisory council. Airline operators introducing innovations that contribute to technological transformation can therefore be confident of finding a conducive and supportive institutional environment.

5.7 Exogenous Risks

The airline industry in South Africa is currently confronted with various challenges, ranging from the slump caused by the Covid-19 pandemic to the threat of high energy prices amid sanctions against Russia for its military operations in Ukraine, growing social polarisation, the threat of expanding poverty, as well as soaring unemployment rates. Through its innovative technologies, the 4IR is perceived to have much potential to offer solutions to many of these challenges by driving efficiency in production (Fukuyama 2018; Keidanren 2017; Norton

2017). However, its differentiated adoption across the globe also increases the potential to drive the kind of structural change that may widen the gap between technologically advanced countries and technological laggards, which may lead to job destruction for low-skilled workers and a subsequent worsening of income inequality (Norton 2017; Schwab 2017; Speringer and Schnelzer 2019).

Changes in production systems may entail a bias towards high technical and digital skills, thereby displacing the demand for low- and mid-level-skilled occupations. The supply of needed technical skills cannot be assumed to follow automatically, as some technical specialisations are in critically low supply and need to be sourced from abroad. This has the potential for employment displacement if no measures are taken to reorient productive skills and adapt them to the changing requirements of the new technological environment. To counter the undesired effects of such shifts in South Africa, where the unemployment rate is very high and the skills distribution is still biased towards low digital capabilities, preventative and corrective policies need to be put in place to ensure that the transition to 4IR is not only economically efficient, but also socially inclusive and sustainable.

6. Estimated Effects of 4IR Technology Adoption in the SA Airline Industry

6.1 Vision for Technology-enabled Transformation in the Airline Industry

One of the most important impacts of 4IR technology adoption, although intangible and not readily measurable, is undoubtedly its contribution to the societal shifts brought about by the advent of a new era of automated and digitally connected networks of production systems. These systems are estimated to generate positive social changes by transforming how and the speed with which firms and households interact, not only in the workplace, but also in daily behaviour in the private sphere. Most of our respondents envisioned the adoption of security scanning technology capable of providing three-dimensional images of the content of luggage as an indispensable evolution, implying a much quicker detection of security threats. Improved efficiency in security control operations is expected to play a key role in accelerating the technology-enabled transformation, namely through behavioural changes resulting from an improved general sense of security. An integrated security information management system must be built to ensure that the operations run smoothly, with minimum human intervention (interview with an airline company executive, August 2022). This, in turn, will streamline security control and enable the relaxation of some of the restrictions put on liquids and on electronics equipment in cabin luggage, for example (Amies 2022). A partnership has been concluded with a US company to create a library of images and build AI-based algorithms that will use such a library for the quicker identification of threats. The capacity of integrated systems to constantly connect the baggage information to the corresponding passenger also reduces the risk of baggage loss.

Different airline operators estimate that, when the use of IOT connectivity becomes more widespread, with a standardised system, the resulting operating environment will enable the airline industry to enhance security around airports at a time when the use of drones and balloons is increasing the risk of unexpected incidents (interviews with airline executives, July 2022). Blockchain technology could be used to manage the biometric systems and enable passenger flow to be more efficient and more secure.

The vision of a future configuration powered by automation includes the introduction and expansion of self-driving airside car mobility system. Supporting infrastructure will require intensive investments and adequate personnel training to ensure a well-resourced capacity to control the functioning and maintenance of this infrastructure, as well as the associated digital systems. Airline operators are of the opinion that a backup system in the form of traditional mobility and baggage-loading equipment with manual handling personnel will remain needed for a long period before the operating environment moves to full automation. To mitigate the risk of fraudulent attempts by those who seek to take undue advantage of automated systems, human control will remain crucial for the success of technological change.

6.2 Operation and Production Costs

The operational changes that have come about with increased digitisation have been incremental. For instance, some operators find it challenging to adopt the most advanced computer systems for fear of system incompatibility. This is because ACSA airport management computers are still running on legacy systems. In certain cases, they manage to build workaround systems that enable them to bypass some of the inhibiting technical challenges associated with the older systems that they have to interact with in the airport. Such compatibility issues are inhibitors of technological modernisation, and limit the speed at which operators can move to fully integrated information systems.

Since the technological shifts that were made necessary by Covid restrictions, the trend has been to strive to an app-based system relying on information access through tablets and phones, whereby passengers can more easily access most of the information they need. Transit and boarding information can easily be shared through such systems to streamline passenger fluxes.

In the absence of integrated information systems, transit can remain challenging, especially in terms of the transfer of baggage between airline operators, which sometimes may require passengers to retrieve their luggage at transit airports and check in again. In such cases, visa issues may bring about additional complications, as passengers may need to obtain a visa to get to the luggage-collection points. The introduction of integrated systems not only helps reduce such problems, but can also result in significant cost reductions, as the people and resources devoted to dealing with the resulting complication can be redirected to other operational tasks (interview with airline company executives, July 2022). One airline operator asserted that the shift to a digital and virtual revenue-management system had enabled the company to halve its costs. Artificial intelligence systems centralised in the main (overseas) operation control centres of some international airlines have been deployed successfully in management decision support to optimise operations and minimise costs. Centralised decision-making from their main operation control centres is used by these airlines to support operations at all the destinations they service. They have also conducted pilot projects to use robots to guide passengers in their overseas hubs. Such technology is furthermore being trialled in loading baggage onto aircraft with the purpose of using it to make up for expected shortfalls in human resources as the baby boom generation exits the labour market (interview with overseas airline company executive, July 2022). Considering the labour market in South Africa, which is characterised by cheap labour costs and a high unemployment rate, robotisation has not been prioritised in local operations. Because of the incremental approach to the introduction of new systems, the different instances of the adoption of new technology by the airline industry have been structured in a way to enable employees to adapt to operating methods by way of adequate skills training, with only limited employment loss (interview with airline company executive, July 2022). More significant employment losses were due to the considerable impact of Covid-19 on air travel, especially with the resulting collapse of several domestic operators.

6.3 Industry Recovery and Growth

The post-Covid-19 recovery is slowly picking up, but the industry has expressed the need for structural measures to support the necessary efforts towards the transition to a technology-enabled operational environment. Such a transition is seen as an important component of the technological innovation strategy aimed at adapting the operating structures to the requirements of the 4IR technology environment. Industry growth is projected to build on advances in high-speed connectivity, a more intensive application of AI in operations management, as well as the diffusion of cloud and quantum computing services (McKinsey 2020). Immersive reality techniques and machine learning will play an equally important role in the future growth of the sector. Technical constraints still make it difficult for the aviation industry to move to fully electric engines, while the use of renewable fuel sources in jet engines is still in its infancy (Carroll 2021). The infrastructure provider and ground-handling companies, as well as airlines executives, however, are considering an increased use of clean energy in the ground operation fleet (including aircraft-towing trucks) to limit the carbon footprint of their operations. The recovery of the airline industry is intimately linked to the recovery of the tourism sector. In July 2022, data from ACSA indicated a recovery rate of 87% in the rate of passengers arriving at Cape Town International Airport in comparison to the pre-Covid numbers (Damiyani 2022). Comparable data for OR Tambo International Airport show that passenger volumes, both international and domestic, are still below their pre-pandemic levels (ACSA 2023). This sluggish recovery implies a slow adjustment to 4IR technologies, as new investments need to be recouped through growth in revenue from higher passenger volumes.

6.4 Change in Skills Requirements

The introduction of common-use self-service terminal equipment has facilitated the efforts to tackle long queues, but has not led to a dramatic change in productive skills requirements among the respondent airline operators. A large portion of the operating tasks are still carried out using traditional check-in counters, especially since the self-baggage drop-in system has not been made operational. While future technology uptake is expected to require the acquisition of more advanced skills to ensure an optimal system administration and maintenance, airline and ground-handling operation executives expect the current skills mix to persist in the foreseeable future, especially since the labour market conditions, with high unemployment rates, make automation less profitable than it would be if labour costs were high. Together with government policies that favour labour-absorbing production systems, the high investment requirement and low profitability explain why many do not feel the drive to invest considerable capital in automated systems.

6.5 Labour-market Outcomes and Implications for Income Distribution

The introduction and widespread access to common-use terminal equipment for self-service kiosks has contributed to increased efficiency of the passenger service and led to cost savings at the various airports where they have been put in service. Even as increasing numbers of passengers are able to make effective use of these kiosks for self-check-in, some number of airport personnel will remain needed to provide back-up assistance for passengers who may not be very familiar with the digitalised system, or in the case of malfunction. The expected intensification of biometrics and self-bag drop-off kiosks, if the corresponding use diffuses widely, could lead to shifts in employment and a reorientation of skills requirements towards a higher demand for advanced skills for the control of digital systems, while the demand for traditional skills is expected to slump. Airline and ground-handling operators expect that, by the time AI is widely adopted to facilitate passenger flow and security management, the demand for skills will also move towards more sophisticated capacity to control and maintain such systems, which will take place at the expense of some of personnel within the current skills mix. A change in skills demand that favours more advanced technical skills is likely to result in exacerbating income inequality, as the handful of highly skilled workers obtain well-paying jobs, while the demand for low-skilled work falls. Without a reskilling and well-structured labour redeployment programme, the intensification of 4IR technologies in SA would threaten to increase income polarisation in an economy that is already among the most inequal in the world.

6.6 Operational Sustainability and Environmental Protection

Air transport is among the most carbon-intensive activities, with an estimated average of 90 kilograms of CO_2 emissions per passenger per hour of flight.[4] Emission data for 2020 suggest that the aviation industry accounts for 2.5% of global carbon dioxide emissions (Ritchie 2020). To mitigate the consequences of this intensity, efforts have been made to develop fuel-efficient engines and aircraft designs. Moreover, investments have been made in the development of biofuels that can be used in existing aircraft engines without modification. Airline companies renewing their fleet with more fuel-efficient aircraft, or using fuel produced from renewable energy sources, are signalling their commitment to reducing their environmental impact. Even though there are obvious limitations in what airline operators can use as alternative forms of propulsion, especially for large, long-haul airliners, the use of clean energy such as green hydrogen batteries and electric engines can still be intensified for fleets of airport vehicles and towing (push-back) trucks. Interview respondents also reflected on the possibility of using a different propulsion system with clean energy for taxying, which would still to reducing the carbon footprint. They estimate the related fuel consumption to be high enough for significant gains to be made with such an alternative propulsion system. Because of the high costs involved in investing in such new systems, transition is likely to be slow in the absence of good coordination, because the required investments represent a first-mover disadvantage. Increased collaboration among airline operators and coordination with the infrastructure providers are necessary to overcome the first-mover disadvantage hurdle, because the transition is estimated to have a positive payoff in the long run. Any form of airport operation optimisation is equally a welcome source of sustainability gains, as small streams add together become mighty rivers. Some respondents indicated that they were collaborating with airport management partners in Germany to examine how some of the techniques used to optimise operations and minimise carbon emissions could be adopted in South Africa.

6.7 Impact of Covid-19 and Other Threats

Air travel was one of the most profoundly affected activities from the time Covid restrictions were put in place in the first quarter of 2020. The years of the pandemic have been particularly difficult for the airline industry in general, but South Africa has been one of the hardest hit, as it witnessed the financial distress and collapse of several of its main domestic airline companies, including the already ailing national flag carrier, South African Airways. According to IATA estimates, the global airline industry was at risk of losing USD 9.6 billion in revenues and 44 million airline-related jobs in the year 2021/2022 as a result of the Covid-19-related slump. The measures imposed to curb the spread of the virus brought about profound changes in travel behaviour and necessitated technological adaptations. Technological

[4] Adjustments for total carbon footprint put the average at 250 kilograms per passenger per hour of flight.

adaptation helped mitigate some of the adverse effects of the imposed restrictions. While the health authority information system at South African airports was primarily paper-based and caused considerable challenges to airlines before the pandemic, adaptation measures put in place enabled a more intensive use of touchless passenger controls and digital tablets for boarding operations. Whereas hygiene and physical protection measures were used extensively to compensate for the lack of touchless passenger flow control systems, the progressive adoption of such systems has provided the impetus for increased digitalisation, which will remain useful long after the Covid restrictions have been lifted.

7. Conclusions, Policy Implications and Recommendations

Air transport is one of the industries in which the adoption of 4IR technologies creates great opportunities for considerable efficiency gains and transformative social changes. In the airline industry in South Africa, the pattern and rate of 4IR technology adoption was found to be positively driven by the technological lead observed in advanced countries, the favourable attitude of industry executives towards innovation, and the capacity to source the requisite technically skilled personnel – either locally or from abroad. However, while the overall distribution of digital skills in the sector is fairly good, high-skilled professionals such as aviation engineers, supply chain managers and specialised data analysts are rather scarce, and simplifying visa procedures would facilitate a seamless sourcing and deployment of the necessary skills for the technology adoption process. Despite considerable efforts by the infrastructure provider to invest in advanced physical and digital infrastructure platforms, technological infrastructure compatibility still constitutes a non-negligible limitation in terms of the rate of 4IR adoption.

While most airline and handling operations executives who participated in the study appear to have a clear picture of the potential benefits offered by such technologies, and have seen them in action at major air transport hubs outside South Africa, they mostly consider them as an aspirational goal for their operations in South Africa in the near future. ACSA, the main infrastructure provider, however, has indicated that considerable budgets have already been reserved for infrastructure modernisation, including the deployment of digitalisation and biometric systems to ensure higher efficiency of passenger and cargo flow, as well as enhanced security. The cost of investment needed, and the centralisation of investment decision-making at some airline companies, are among the other obstacles to the adoption of 4IR technologies, considering the large-scale operations needed to recoup such investment. The regulatory environment is not perceived as constituting a sizeable constraint to adoption, although the slow responsiveness of the bureaucratic apparatus is perceived as causing unnecessary delays. As for the environmental factors, there also are practical concerns, such as fuel and staff shortages (particularly aggravated by the lay-offs caused by the Covid-19 crisis), financial difficulties (such as the financial distress that crippled SAA and led to the liquidation of Comair), and institutional fragmentation (for example, the lack of procedural harmonisation and data integration between airport authorities and the Department of Home Affairs on immigration procedures). Structural and ethical considerations are an equally important obstacle (e.g. data availability following the application of the POPI Act).

Regarding the labour market effects of 4IR technology adoption, whereas technological change can be expected to lead to shifts in skills requirements and job displacement, this study has not uncovered any significant labour displacement resulting from the gradual adoption of 4IR technologies in the airline industry thus far. However, various interview respondents expressed concern that job displacement may occur in the future as technology adoption intensifies. The smooth transition to digital and automated systems was made possible by adapting to the changing skills mix requirement through training in new skills and the reconversion of existing employees.

The most job losses have come from the heavy restrictions imposed on air travel during the Covid-19 pandemic: employment recovery to pre-Covid-19 levels will be conditional on the post-pandemic rebound of the travel and tourism industries. Although job losses due to the Covid-19 pandemic worsened the already highly skewed income distribution (with low-skilled workers being disproportionately affected), direct testimony from our key informants did not point to any significant job losses that could be associated with the adoption of advanced technologies by their companies. Finally, environmental and climate change consciousness has given rise to many airline operators directing more attention to the adoption of green energy, both for aircraft and for the fleet of ground transportation, baggage handling and towing vehicles. The respondents agreed that, despite the limitations imposed by the requirements of jet engines for long-haul air transportation, the future of the airline industry must and will be greener through efficiency gains and the diversification of energy sources wherever possible in their ground operations.

In the light of global trends in the technological advance of the aviation and air transport industries, the South African airline industry will have to make strategic choices, including investments in smart technology adoption not only to overcome existing weaknesses and bottlenecks, but also to create a new impetus for the overall profitability and sustainability of the sector. In particular, five areas are identified as being of crucial importance and requiring careful consideration:

7.1 Modernisation of Airport Infrastructure as a Platform for the Adoption of New Technology

The technological content and the amenities of airport infrastructure play a key role in determining the set of technologies airline operators can adopt in their local operations. For the expected recovery of the South African airline industry to harness the benefits of the smartest technologies and be ready for the future of travelling, the infrastructure provider needs to strive for a more profound modernisation of existing airport facilities by adopting best practices that enable digitalisation and automation. Without adequate technological infrastructure, airline operators could remain constrained in their ability to deploy efficient technologies in their South African operations, even as they have the means to apply them in the major overseas hubs which are setting the trends. As such transformation requires considerable investments, a careful analysis of the long-term benefits of this transition is necessary to ensure positive returns and spillover benefits.

7.2 Digitalisation and Automation

This will have to cover multiple operations across the board, from self-service check-in and bag-drop to baggage handling in the airport, but also departures and transfers integration, as well as cargo services. Advances in these fields may allow seamless passenger flows, avoid congestion and improve the comfort and security of the travel experience. However, the sustainability of all future innovations will have to be examined from all perspectives, including financial feasibility, the possibility of labour-displacing effects, and the privacy implications of increasing data-handling.

7.3 Pre-emptive Intersectoral Skills Planning

For South Africa to participate fully in the digital revolution that accompanies the 4IR it will have to undertake some fundamental transformation in the area of local digital skills. The relatively low level of available digital skills literacy remains a daunting challenge to the county's aspiration to harness 4IR as a source of technological transformation. While the potential benefits of the increased adoption of 4IR technologies are clear, the intensification of digitalisation and automation may lead to labour displacement and to changes in skills requirements. In a country with extremely high rates of unemployment, industrial policy will have to anticipate the trajectory of technological change with its employment effects and provide the necessary support for strengthening labour absorption in sectors that are less prone to automation. While the successful adoption of 4IR technologies requires specific skills for which advanced training is needed, the reskilling of negatively affected employees is also essential to facilitate their absorption into the so-called automation-resistant sectors. A narrow collaboration between the industry, the SETAs and the Department of Higher Education and Training (DHET) will be necessary to ensure both an adequate supply of the skills required to adopt and operate these new technology systems, and a reorientation towards new growth sectors.

7.4 Environmental Sustainability

The contribution of the industry to global emissions and its environmental sustainability will be an essential consideration for the sustainability of the sector. The level of competitiveness of individual companies and national industries will be determined largely by how green their future transformations will be. In this regard, smart technological development may help achieve important steps in terms of fuel-efficiency, the reduction of current emissions, improvements in waste-cycle management and the wider use of clean, green energies. Achieving greener air travel will also require a shift in travel habits to reduce the passenger mileage, because technology alone will not be enough if the fuel and emission efficiency gains are followed by a growth in flight hours. The development of alternative travel infrastructure, such as a high-speed rail service, offers one the most credible alternatives to alleviate the environmental impact due to the crowding of air travel.

7.5 Policy and Institutional Coordination

Better institutional coordination and policy alignment will be necessary at several levels. For example, to improve immigration procedures, a closer collaboration between airport authorities and the DHA will become very important. For matters related to additional sanitary measures, a closer partnership with the Department of Health is necessary to ensure that the protocols that are critical to the protection of our health do not become a drag on the competitiveness of the industry. In order to secure increasing sustainability and adopt smarter, greener technologies, a commitment by all stakeholders from all operations (airlines, ground handling and cargo) will be strictly necessary (including associations like AASA and BARSA). Matters related to infrastructure innovations will require more effective collaboration between all airlines, the Air Traffic Navigation Centre (ATNS), ACSA, and the Department of Transport. For the growth of the industry, important competition matters will have to be solved, with special focus on the issuing of licences on new routes, moving beyond exclusive bilateral agreements and reinstating an efficient licensing department (DoT).

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