NATIONAL SCIENCE AND TECHNOLOGY FORUM
DISCUSSION FORUM ON ADVANCED MANUFACTURING AND AUTOMATION

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DAY ONE

Opening and welcome (Jansie Niehaus, Executive Director of the National Science and Technology Forum)

Ms Niehaus, Executive Director of the National Science and Technology Forum (NSTF), welcomed everyone to the Discussion Forum on Advanced Manufacturing and Automation, which was being held in parallel with the South African Innovation Summit.

Opportunities for South African companies in the 4IR space (Yanesh Naidoo, Director: Digital Strategy, Jendamark Automation)

Jendamark Automation designs and builds production lines in two areas of the automotive sector, namely production trains and catalytic converters. The company builds lines that meet requirements not only for South Africa but for anywhere in the world, and exports include a differential assembly line for General Motors and a fully autonomous production line for catalytic converters in the Netherlands. Jendamark is well established in the production line business, but realised in planning for the fourth industrial revolution (4IR) that future opportunities are likely to be in the digital services domain.

Jendamark is a South African company with its head office in Port Elizabeth, and employs 320 people. The company has an international footprint with an office in India opened three years ago. The decision to open this office was based on the expected growth of the automotive industry in India and also on India's focus on emissions. The small company that was initially acquired employed some 20 people, and currently 220 people are employed in the Indian office. Several years ago, a sales and service office was opened in Germany to enable Jendamark to interact with customers in their own language and culture. The service part of the company was established to provide support, which is the basis for the office in the USA. A sales component will be developed in the USA in the near future. The production lines designed by Jendamark are built in South Africa, and 95% of all the machines are exported. Anywhere in the world where there is an automotive hub, there are machines built in Port Elizabeth.

The new activities of the company will be aimed at digital services. There is a great deal of discussion about electric vehicles, but the current offerings of Jendamark are not designed for this market. The introduction of electric vehicles is taking place more slowly than portrayed in the media, and there are still very few in the market. Major manufacturers are working in this domain mainly to compete with Tesla. Jendamark realises that the company might be too small to influence the market, but it is still essential to be involved. Some electric vehicle products have therefore been targeted, such as the tuk-tuk in India. The production line for this vehicle was designed in virtual reality and built in India.

An interesting development that underlines the changes that are taking place is a project to build a completely autonomous taxi to compete with Uber. Zoox, a start-up company in Silicon Valley, has received US$800 million in funding to develop this taxi, which is a robot and probably the next generation transport system. The production line is being designed and built in Port Elizabeth.

The Fraunhofer-Gesellschaft, Germany's national research organisation, was contracted to investigate the reasons for the increase in German manufacturing costs and found that the cost of labour was the main contributor to higher costs. The retirement age in Germany is relatively high and people work until they are older; a 70-year-old operator is more expensive than a 20-year-old one, for example. Furthermore, Germany has a highly qualified workforce and a shrinking population and thus fewer people coming into the workplace. The solution proposed by Fraunhofer was called the Industry 4.0 Plan, now known as 4IR, and is centred on taking people off the production line. The impact of automation will lead to the loss of blue-collar jobs to robots, which will address the European challenge, but Africa has other challenges that need to be understood in order to share in Africa 4.0. Solutions developed for African problems are potentially exportable to other parts of the world facing similar challenges.

People are involved in the efficient running of a production line, and it is important to try to make everyone involved, from the operator to the manager, more efficient at what they do. It was found that the only requirement for becoming an operator in South Africa was a matric certificate. This assumed that applicants could read and thus build an engine from the instructions provided, which was not the case. Pictures were easier for operators to follow, and animated work instructions customised for the field in which they worked were considered an even better option. A software product was developed for third world operators but is now being sold to mostly first world companies, because everyone follows pictures better than words. This is just one example of a solution to a South African challenge that has become a successful export product.

Augmented reality glasses have been introduced for workers on the production line. The use of these glasses removes the constraint of having to work in a position where the screen with the instructions is visible. Being able to move freely increases the productivity and efficiency of operators.

Important aspects from a human resources perspective include training on the production line and engagement between management and operators. In order to ensure that management can communicate important information to the workforce, software has been developed that provides the ability to communicate via the screen that the workers look at all the time. In this way, interaction can take place between a manager in Germany and operators on a production line in India, and the messages can include training matters.

A virtual reality training machine has been designed and built which, in a simulated environment, allows operators to walk through the process of how to develop parts from design to completion. This facility can be valuable in training and upskilling operators and a new business stream will be created developing content for virtual reality machines. This digital space solution to existing problems on the production line will create a new revenue stream for companies working in this space.

A production line consists of the line itself and above this an enterprise resource planning (ERP) system. There is a bucket above the production line that collects valuable data, which are useless unless analysed by software. The data could, for instance, assist with the ongoing challenge of absenteeism, which currently involves a potentially time-consuming manual intervention. Instead, the system could trigger automatic responses and call up stand-by personnel, thus greatly reducing the downtime of the production line. Production line designers and builders are not best placed to provide the analysis of the data from the bucket system to their customers, so a specialist small start-up company is designing an application to streamline this and other issues. Companies such as this small start-up do not have access to large customers using production lines, but by working with companies such as Jendamark a workable ecosystem is created for all concerned, which becomes a potential export product. South African companies need to work together rather than competing one another, since most opportunities are outside the country.

Problems can become opportunities if viewed differently. The challenges in the South African education system are well known. In an effort to revolutionise education, an entrepreneur in a small start-up company developed an ecosystem bringing together key people in the education domain. By persuading two companies, Huawei and MTN, to invest their corporate social investment (CSI) funds in the provision of tablets and free internet access, an innovative solution has been developed. Furthermore, textbook publishers have been persuaded to load the textbooks currently used in schools on to the tablets provided by Huawei. It costs the government R10 000 to supply textbooks to a learner, whereas through this system the cost over three years is R2 000. The system developer believes that the initiative must not be a charity but a profitable business so as to have the opportunity to succeed and grow. Slots have been allocated to corporates such as banks to use the tablets to disseminate positive useful social messages rather than advertisements to promote their brand. So far, 2000 learners have been issued with tablets.

When artificial intelligence is linked to learning applications, it becomes possible to review individual performance and add courses to develop skills and provide assistance to overcome weaknesses. This solution to an African problem could help change the face of global education. Two interesting and unexpected outcomes were noted during the roll-out of this initiative. The tablets were turned on in the evening, but no interactions were taking place because learners were using the tablets to provide light by which to do their homework. The tablets provide a closed system in which a limited number of some websites are available. A local cell shop owner was requested to crack the system and open the tablet to the whole internet. The shop owner charged a learner R200 for this service. Having learned how to open up access on the tablet, the learner charged his friends R300 each to do this for them. This learner's entrepreneurial spirit will certainly need to be directed.

The importance of materials science in advanced manufacturing (Dr Hein Möller, Senior Lecturer, Materials Science and Metallurgical Engineering, University of Pretoria)

Since everything must be made out of something, materials science could become the most important technology of the next decade. Freemelt, a Swedish 3D metal printing company, contends that the metal 3D printing revolution is governed by materials, and that most future 3D printing applications will require materials that have not yet been developed. Current commercial metal 3D printers use only a handful of different materials, and are not designed to develop new ones. This lack of appropriate materials severely limits the ability to reach new applications.

The materials that are currently in use were developed some time ago using processes such as casting or forging, rather than being developed for additive manufacturing. Freemelt has built a small 3D printer that uses small quantities of powder and allows experimentation to develop new materials. The South African Department of Science and Innovation (DSI) has developed a roadmap for additive manufacturing, which includes the development of new materials. The focus areas for the implementation of the roadmap are the automotive and biomedical sectors. Although the need for new materials has been recognised, there is very little work being done on the development of specialist materials.

Aeroswift, a company formed through collaboration between Aerosud and the CSIR, is involved in building the world's largest 3D printer. Conventional 3D laser powder bed printers have a build volume of 280mm x 280mm and are very expensive to operate. The Aeroswift machine is massive, with a build volume of 800x600x2m. The machine is designed to build large components faster for aerospace applications. Ti6Al4V (titanium6, aluminium, vanadium4), the most widely used alloy in the world, is used in this machine, and components have already been produced. This is an impressive achievement for South Africa.

QuesTek Innovations, a US-based company that is a global leader in integrated computational materials engineering, uses its unique Materials by Design software to optimise alloys for various additive manufacturing processes with a focus on industries such as space exploration, aerospace, automotive, medical, marine and oil and gas. Using software to identify the best material for a particular application and then producing an appropriate alloy cuts down on the time needed for expensive experimentation. The QuesTalloy alloy developed through this process provides better fracture toughness and is especially suitable for 3D printing.

OxMet, a spin-off company from Oxford University established in 2017, is also engaged in the development, licensing and manufacture of proprietary alloys, alloy powders and alloy components for the aerospace, automotive, industrial and biomedical sectors.

Ti6Al4V is currently the alloy of choice for medical implants mainly because it has traditionally been used for this purpose, but it is necessary to develop better new alloys for 3D printing applications. Prof Tshifularo, head of the Department of Otorhinolaryngology in the Faculty of Health Sciences at the University of Pretoria recently performed the world's first inner ear implant surgery. TiAl4V was used to reproduce the tiny bones of the inner ear. The next step in this breakthrough process will be to develop an alloy for use in implants that is closer to human bone in relation to sound transmission.

Another reason for developing new materials is the possible health risks associated with implants manufactured from traditional alloys, particularly vanadium and aluminium. A negative feature of currently used alloys is the elastic modulus, in that osteoporosis or poor osseointegration could result from any significant differences between the stiffness of the bone and the implant, leading to cracking and ultimate failure of the implant. A great deal of work is being done around the world to find solutions to these problems.

It is important to investigate how South Africa's large titanium deposits could be used to the benefit of the country. Vanadium is also plentiful in South Africa. The South African government has invested in titanium beneficiation, but the country still imports all its titanium powder. A project is under way at the CSIR to produce these powders in South Africa. Despite delays and technical difficulties, these powders are being produced in South Africa on a pilot scale.

Scalmalloy® was the world's first material developed specifically for the 3D printing process. It is an aluminium-magnesium-scandium alloy with unique microstructure, strength and ductility compared to other aluminium alloy powders. This second-generation high-strength aluminium powder developed and patented by APWorks, part of the Airbus Corporation works on all powder-bed 3D printing machines currently in use. Using this alloy, APWorks has printed a partition for an aircraft using biomimicry to design the structure, which is 45% lighter than traditionally produced partitions.

The platinum group metals are plentiful in South Africa and a project called PlatForum is producing platinum powders and 3D printing components. These powders are currently used mostly in jewellery making, but in future will also be used in catalytic applications. This joint project between Lonmin, the Vaal University of Technology, Central University of Technology and North-West University is a good example of using minerals produced in South Africa for printing components.

Onyx is a composite material developed by a company called Markforged in the USA. In developing this type of material, it is normal to look not only at the mechanical properties but also at factors such as corrosion, which is important for the aerospace sector, and it is flame retardant. Onyx was found not to be completely flame retardant; this led to the development of Onyx Fr, which does not burn when exposed to a flame. This property of the material opens new markets for Markforged in the 3D printing space.

At the launch of the 4IR centre at the CSIR, Prof Tshilidzi Marwala, vice-chancellor and principal of the University of Johannesburg stated that the areas where South Africa is lagging in terms of 4IR are materials science and gene technology. South Africa needs to focus on materials for additive manufacturing; the country has a policy in this regard, but funding and implementation are required. There are several government departments that play a role in this domain, and it is essential for them to work together to address this problem.

The future of work (Ilse Karg, Chief Director: Future Industrial Production Technologies, Department of Trade and Industry)

The three previous revolutions have been about technologies such as steam, electricity and the development of the internet, but the Fourth Industrial Revolution (4IR) is about people and the role that technology will play in the life of humans. From a policy perspective, 4IR will focus on skills development and the future of work.

The UN Human Development Report of 2016 identified eight area of focus for development, namely good health, access to knowledge, human rights, human security, non-discrimination, a decent standard of living, dignity and self-determination. Development evolves around the capabilities and opportunities for all individuals, and the Human Development Action Agenda requires effective policy planning for inclusive growth.

In defining Industry 4.0 or 4IR, it is important to create common understanding. The German Trade and Investment Association defines Industry 4.0 as connecting embedded system production technologies and smart production processes to pave the way to a new technological age that will radically transform industry and production value chains and business models. Deloitte also refers to smart, connected manufacturing as Industry 4.0. Several commonly known terms such as industrial internet, the connected enterprise, smart manufacturing, smart factory, manufacturing 4.0, the Internet of Everything and the Internet of Things for Manufacturing point towards Industry 4.0, smart production and the connected enterprise in the manufacturing sector. Current mega-trends for industry show a boom in the demand for smart phones; it is predicted that by 2050 there will be 10 billion smart phones and six billion mobile computing devices in use in the world. In Africa there are already more mobile phones than bank accounts.

The list of large corporations in the world is now dominated by technology-based companies. In 2008, only one of the ten largest companies in the world was technology-based (i.e. Microsoft) compared with seven today, three of which are in Silicon Valley. The top technology companies include Apple, Google, Microsoft, Amazon and Facebook.

Industrial robots will replace people, but we need to look at this as an opportunity to work together with robots, and to protect the person rather than the job. The turnover for industrial robots was US$40 billion in 2016, and the top five purchasing countries of robots were China, Germany, USA, Japan and Korea. The stock of robots active in factories is estimated to grow to three billion by 2020. The Department of Trade and Industry (the dti) will shortly issue a report that tracks industrial robots in South Africa.

Another rapidly growing trend is deep tech start-ups and small companies, particularly in sub-sectors that require tangible intellectual property to succeed such as life sciences, robotics and artificial intelligence. Globally, nearly half of all start-ups are in deep tech-related sub-sectors. In this area growth sectors include advanced manufacturing and robotics, agricultural technology, big data and analytics.

Research carried out in the South African retail sector to compare manufacturing output with retail sales shows that the manufacturing sector is flat but there is exponential growth in retail sales. There is also considerable growth in imports through e-commerce. These factors contribute to South Africa getting poorer fast. The South African economy is characterised by ‘jobless growth’, a stubbornly high unemployment rate and low economic growth. From 1994 to 2016, every 1% of economic growth corresponded with a gain of only 0.06% in employment.

With regard to technological capability, it is very difficult to predict what digital technologies will be employed and how this will impact on jobs. The general feeling is that industry is not interested in expanding into new technologies, which will have an impact on competitiveness in the medium term. The complexity of products manufactured in SA is decreasing, which means that we are manufacturing goods that are not in demand globally. We need to increase the complexity of our products.

A strategic overview of South Africa and 4IR showed that our strengths are that we are an innovative nation with a diverse culture and a good economic infrastructure. The weaknesses that were identified were structural imbalances, poor service delivery, political commitment, poor coordination and policy coherence. Opportunities exist for new companies in the area of leapfrogging into 4IR, which will be difficult for existing manufacturers, the development of talent, investment in education and support to small business. Threats include data management, protection of intellectual property, cyber security, the economy being too open, a large youth population, high unemployment and skills development.

A PricewaterhouseCoopers study identified the top three threats in Africa as social instability, an increasing tax burden and over regulation. In order to make it easier to attract and do business, we need to simplify regulations. A 2018 report by Accenture and the World Economic Forum entitled *Unlocking Digital Value for Business and Society in South Africa* states that digital initiatives hold the key to unlocking R5 trillion of value in South Africa over the next decade.

The number of formal small businesses reported in South African labour market surveys rose from approximately 600,000 in 2010 to 640,000 in 2017. The number of informal businesses grew from 1.3 million to 1.5 million over the same period. Informal small businesses are growing faster than big business. Small business cannot be ignored as a possible solution to the challenge of employment.

The South African manufacturing sector has 300,000 fewer manufacturing jobs in 2019 than in 2008. For every manufacturing job impacted, an estimated three to five indirect jobs are affected. Premature deindustrialisation is a key driver of unemployment in South Africa. Boosting the manufacturing sector would create jobs in the country. The key findings of a Deloitte study on the future of manufacturing work show a widening gap between jobs that need to be filled and the skilled talent pool capable of filling them. This should be considered in the context of the fact that global manufacturing executives ranked skilled talent as the foremost driver of manufacturing competitiveness.

Gender inequality is cause for concern as female employment in the manufacturing sector is low. Over the past decade, the number of women employed in this sector has remained at half the number of men. The changing nature of jobs with the advent of 4IR should mean that more women will be introduced into manufacturing.

The National Integrated Human Resource Development Plan (2014–2018) had five goals: to strengthen basic education, expand access to quality post-school education and training, improve research and technology innovation outcomes, the production of skilled people and the development of a capable state. The goals were recently reviewed and found to still be relevant, so they will remain unchanged, but a 4IR perspective will be incorporated into the higher education curriculum.

There is a growing gap between the demand for and supply of skills. The 730,000 students enrolled at technical and vocational education and training institutions and one million at universities are unlikely to be sufficient to meet the skills requirements for 4IR. A more immediate problem for government is that almost two million students will need to find jobs in the next two to three years. In order to meet the immediate demands of 4IR, upskilling and reskilling will have to be implemented.

The Knowledge Economy Index published by the World Bank lists the four pillars of the knowledge economy. Pillar 1 requires an economic and institutional regime that provides incentives for the efficient use of existing and new knowledge and the flourishing of entrepreneurship. Pillar 2 focuses on education and skills. Pillar 3 is centred on communication and calls for a dynamic information infrastructure to facilitate the effective communication, dissemination and processing of information. Pillar 4 looks at innovation and calls for firms, research centres. universities, think tanks, consultants and other organisations to be capable of tapping the growing stock of global knowledge, assimilating and adapting it to local needs, and creating new technology.

The International Monetary Fund country report No 18/246 investor surveys identified some of the problems of doing business with South Africa as restrictive labour regulations, the inadequately educated workforce and the poor work ethic in the labour force. The aim of structural reforms should be to attract private investment by encouraging product market competition, making labour markets more flexible, addressing skills mismatches, eradicating corruption and leveraging digitalisation. The full potential of a young and growing population should be leveraged. The existing capacity in all economic sectors, and the opportunities provided by digitalisation, could significantly promote growth.

The UN Human Development Report states that the digital skills required for the 21st century include a change in ways of thinking, new tools for working, new ways of working and new skills for living in the world. Talent drives manufacturing competitiveness.

The dti is developing a skills programme for the manufacturing sector. This is a talent-based recruitment programme with a focus on talent retention, which is a weakness in South Africa. The planned talent-driven innovation model will be implemented as a ten-year pilot programme driven by industry in collaboration with the dti. There has been an 80% success rate of employment for the students in the system, compared to the 4–5% employment rate for university graduates. The model could prove to be one of the solutions to creating jobs and skills in manufacturing.

The Digital Industrial Policy Framework that is being developed has four areas of focus, namely smart factories, policies and legislation, digital transformation, and policy coherence and partnerships This will not be an exclusively dti initiative but calls for partnerships with labour and industry, government-to-government partnerships and partnerships with civil society. Collaboration with other African countries and the rest of the world also forms an important part of the policy.

Customised medical applications of 3D printing (Gerrie Booysen, Director, Centre for Rapid Prototyping and Manufacturing, Central University of Technology)

The metal additive manufacturing market is growing exponentially. In 2018, Wohlers Associates reported growth of 875% over the past five years, and 220% growth in the past two years alone. Some of the reported developments in the additive manufacturing sector include the Boeing Corporation, which has 20 sites producing metal parts and over 60,000 additive manufactured 3D printed parts currently in their deployed aircraft. General Electric has over 1,200 sites producing metal parts and more than 60,000 additive manufacturing machines in operation, resulting in 50,000 parts to date. General Electric estimates additive manufacturing and 3D printing as a US$76 billion market opportunity in the next eight years. Stryker have just built a state-of-the-art facility to address the growing opportunities in the medical industry and already have over 100,000 metal additively manufactured implants in patients.

SmarTech Publishing reported that the global additive manufacturing market was worth US$9.3 billion in 2018 and was expected to grow at 18%. Siemens has invested US$30 million in a 3D printing factory in the UK and created more than 50 new advanced manufacturing jobs. This facility is part of Siemens' strategy to build a global additive manufacturing business; the factories will be fully powered by Siemens Digital Enterprise Solutions.

Because not all products are suitable for additive manufacturing, conventional processes will continue to be used. The South African additive manufacturing landscape is difficult to assess as there are many desk-top printers in operation that are not necessarily counted, but it was estimated that there were 4,400 machines in use in 2016, increasing to 5,600 in 2017.

The Centre for Rapid Prototyping and Manufacturing (CRPM) at the Central University of Technology in the Free State was established in 1997. The centre manufactures approximately 15,000 parts annually as part of more than 500 projects, some of which are research based and others contracted by industry. CRPM has 750 commercial clients and supports industry in new product development and in moving from computer-aided design (CAD) to prototypes and end-use products.

The laser melting process used for 3D printing at CRPM starts with CAD that is sliced layer by layer and fed into the machine, which melts powder to 30–50 μm layers. The finer the layers, the more expensive it becomes. At 30-50 μm level, the final product will need post machining. The type of machine used for this process costs between €500,000 and €650,000 for the metal system.

Internationally there are many reports by large corporations showing the benefits of additive manufacturing or 3D printing for healthcare. An important consideration in this regard is to reduce theatre time, which means faster patient recovery. Another benefit is that the customisation of medical devices manufactured by 3D printing improves clinical efficacy through better-fitting implants at lower cost. Large companies such as Smith & Nephew, Lima Orthopaedics and 3D Systems are capitalising on the advantages of additive manufacturing and setting up large 3D printing manufacturing centres that are mass-producing implants and other devices. Currently 95% of all medical devices used in South Africa are imported, which presents an opportunity for localisation and regionalisation, reducing costs and the ability to provide more patients with these devices.

There are many examples of the positive difference that can be made in patients' lives through the use of additive manufacturing and 3D printed implants; for example, a seven-year old girl with a cyst behind her right eye and the possibility of losing her sight within 14 days was successfully fitted with a customised implant inserted using patient-specific guided surgery. Not only was there minimal scarring, but her eyesight was saved without the need for any further reconstruction work.

There has also been considerable success with maxillary and mandibular implants. Patients who require these implants have sometimes waited a long time for treatment, perhaps due to lack of access to appropriate facilities or because the health system has failed patients who require specialist care. The process flow for the creation and implanting of the device includes a computed tomography (CT) scan, a pre-op model (which will in future be produced by planning software) and a cutting guide that is 3D printed. The cutting guide is very complex as the CT scan shows only bone, not nerves and soft tissue. Clinical follow-up is essential. An initiative is under way to convince medical aid companies that this is the way forward.

There has been some evolution in 3D design. The objects were initially unnecessarily strong and solid. It was found that objects with a fine lattice structure and good osseointegration and blood supply were better to work with and could be produced by increasing the elastic modulus.

The demand for implants is high. Gunshot victims wait up to three months for a CT scan, during which time their jaws are wired together and they have to live on a liquid diet. Even conventional corrective operations are not possible in many of the smaller centres as they are complex, high risk and extremely expensive. In state hospitals, tumours are often removed but reconstructive surgery is not performed Clip-on faces that require specialist skills could help these patients. Children are often in need of auricular prostheses. In one success story, a young man born without ears expressed the desire to have ears like his sister. A mould of his sister's ears was used to produce a prosthesis for him.

CRPM produced a custom-designed pelvic implant. It is possible to print large objects as well as smaller implants. All devices undergo a product and process risk assessment process before production can proceed. Spinal cages using a fine lattice structure and high osseointegration are also being produced by CRPM. A new additive manufacturing application is the production of polymethyl methacrylate cranial plates. Titanium was previously used for these plates, but this is not ideal due to scatter if further CT scans are required. The system for producing these plates in theatre to maximise the fit was studied in Brazil and is now being applied in South Africa.

The Collaborative Programme in Additive Manufacturing (CPAM) is the implementation programme for the South African Additive Manufacturing Strategy that has been formally adopted by the Department of Science and Innovation. The programme aims to increase the manufacturing readiness of additive manufacturing, leading to the adoption and utilisation of additive manufacturing as an accepted and viable manufacturing technology. The programme focuses on research, development and innovation support for additive manufacturing of titanium medical implants and aerospace components, polymer additive manufacturing and design for additive manufacturing. Most South African universities, the CSIR and industry are involved in the programme.

CRPM received ISO 13485 certification for 3D printing of medical devices in 2016. ISO 13485 represents the requirements for a comprehensive quality management system for the design and manufacture of medical devices and is only granted after a rigorous audit. This means that CRPM products conform to with International Standards of accreditation, which will open the doors for commercial manufacture of medical devices in South Africa and globally. The scope of the certification includes the design, development and production by means of 3D printing or additive manufacturing of patient-specific custom-made titanium implants, preoperative models, jigs and cutting guides in nylon.

DISCUSSION

What must change with respect to attitudes, legislation/regulations and entrepreneurship in order to work towards realising the potential of new technologies for manufacturing industries?

Panel: Yanesh Naidoo, Hein Möller, Ilse Karg and Gerrie Booysen

Comment: Attitudes are crucially important. We need to work on an outcome in this regard for professional civil engineers. In the USA, 24 outcomes have been identified, but the main focus is on attitude. The number of regulations should be reduced. We need to move from talking about a plan to actual implementation. Outdated approaches should be abandoned so that we can start anew with innovative thinking.

Question: In the opinion of Jendamark and the dti, what could be changed in university curricula to prepare students better for 4IR? Has education been included in the strategy for 4IR that government is developing?

Panel Response (1): With regard to changes to the curriculum, government has had discussions with the Engineering Council of South Africa (ECSA) regarding a possible degree in automation. Implementing a degree of that nature would be difficult since it spans several disciplines and faculties at universities. In the strategy, eight areas have been identified which will form a chapter each, one of which is education.

Panel Response (2): Production engineering programmes of the future will be skills based rather than qualification based, and students will finish the course when the required skills have been achieved. There also needs to be a change of attitude in the perspective of private companies. In the past, universities have been blamed for their lack of skills training, but private organisations also need to be involved in developing the talent that they require and invest in upskilling.

Question: Are there any plans to formalise the informal business sector of the South African economy?

Panel Response: From the government perspective, one of the most difficult issues is to incorporate the informal sector into the tax system. There is resistance from the informal sector to paying taxes, but small businesses also need to contribute to the tax base.

Question: Are there any efforts to communicate with the general public to create awareness of new technologies and the skilling of unemployed youth?

Panel Response (1): Communication is critically important, and could be achieved by giving each student a tablet. There are opportunities to introduce digitisation to the informal sector, including payment transactions.

Panel Response (2): Communication is a big problem. The NSTF addresses this need through its discussion forums and there is considerable interaction with scholars at universities, but communication could be improved.

Panel Response (3): Improving digital communication from government would entail addressing issues such as the cost of data, access to the internet and cloud services. Government is working towards reducing the cost of data and improving digital infrastructure.

Panel Response (4): Social media and websites could be more effectively used to address the needs; for example, to create public awareness, communicate with patients and assist in mobilising crowd funding.

Comment: In the past, civil engineers produced a successful video to raise awareness of the profession. Engineers and scientists should consider the possibility of moving into this domain. Communication is important, and outreach is critical.

Chair: proSET is a distinct and important part of the NSTF membership. proSet has a long-term project to develop the STEMulator interactive cartoon, which is a landscape with clickable items that provide detailed descriptions of aspects of technology in everyday life with the aim of educating children. The next step in the project will be to build a demonstration model and to request contributions; for instance, a modern assembly line could be included.

Comment: In the private sector, large businesses that should be reaching out to small businesses tend to swallow them instead. Large and small businesses need to work together to develop the right technologies for the African market.

Comment: Esivinni News is a small media house based in Gauteng that is covering the issues of 4IR in indigenous languages and is available to assist in conveying this message to grassroots communities.

Final comments from panel members:

- While it is important to talk about the challenges that we face, we need to go further, open doors and collect clinical evidence for medical aids.
- With regard to the environment, a great deal of effort must be made to coordinate future work. There is a need to consult with social partners and to make government more effective. It is also important to review the education system from the perspective of science and innovation and to consider how students could be better supported.
- From the university perspective, technology is advancing at a faster pace than the curriculum can be updated. There is a need to educate students to solve problems rather than just reacting.
- 4IR not only entails changes in technology, but a central aspect is how people respond to the technology, move out of their silos and collaborate with one another.

Microelectronics in manufacturing (Dr Trudi-Heleen Joubert, Acting Director: Carl and Emily Fuchs Institute for Microelectronics, University of Pretoria)

The discipline of microelectronics began when Bell Laboratories unveiled the first transistor on 23 December 1947. It was a rough sample and not well manufactured, but essentially did the same things as sophisticated modern-day examples. The three people involved in the development of the transistor (John Bardeen, Walter Brattain and William Shockley) were awarded the 1956 Nobel Prize in Physics. The next important invention was the integrated circuit by Jack Kilby in 1958, for which he received the 2000 Nobel Prize in Physics, followed by the planar integrated circuit invented by Robert Noyce and built by Fairchild in 1959, which was built of silicon layers with masking to remove some layers based on the design of the circuit. This method of production has been used for decades and is still in use.

A single crystal silicon ingot is used in integrated circuit processing. The ingot is sliced into wafers with a diamond saw, and the integrated circuit is then fabricated on the surface of the wafer. The required chip is embedded and then the device is packaged. Each stage of this process represents an industry all on its own.

In 1965, Gordon Moore (Director of Research and Development at Fairchild), noted that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented and predicted that this trend would continue for the foreseeable future. This is known as Moore’s law and has become a target for industry.

Some enabling factors in technology development and in line with Moore’s law include the 1963 development by Frank Wanlass of the complementary metal oxide semiconductors (CMOS) process; the 1967 dynamic random-access memory technology of Robert Dennard of IBM; the 1982 UV excimer laser and the 2006 deep UV excimer laser, both from IBM; the 2008 memristor from Hewlett Packard Laboratories; the silicon germanium (SiGe) supercooled transistor from IBM, the nanowire transistor from Tyndall National Institute; and the single atom transistor in 2012. Another relevant aspect of Moore’s law is that it was envisaged that in order to manufacture such devices, larger and more expensive manufacturing facilities would be required. There are currently only two facilities in the world that can produce these sophisticated products. There is no need for South Africa to participate at the leading edge of technology development, but there is no reason that we cannot become a design house, which is the role played by many big companies in other countries.

CMOS has been the dominant fabrication technology since its invention in the 1960s, and trillions of chips have been produced using this process. CMOS is now increasingly being developed for sensing applications. Trends in the field of integrated circuits include the development of heterogeneous components, which are integrated hybrids using different technologies that provide additional functionalities such as sensing and actuating. The biggest future application growth areas are expected to be in wearable devices, medical diagnostic devices and the Internet of Things.

South Africa needs to use of appropriate technology, which may not necessarily be the very best but is the right technology for the purpose. We need to apply low-cost solutions and devices to solve local problems such as the monitoring of rivers in poorer areas, waiting periods at hospitals and access to healthcare in rural areas. In considering the challenges and opportunities facing the microelectronics industry in South Africa, there is a need to straddle the innovation chasm and manage the process from basic research to spin-off. Interdisciplinary work is essential. Whilst technology push is important, new things do not always solve local problems, so technology push needs to be balanced with demand pull.

The Carl and Emily Fuchs Institute for Microelectronics (CEFIM) was founded in 1982. The focus areas of the institute include mixed signal integrated circuit design, novel electronic devices, radio frequency microelectronics, micro-electrical mechanical systems, silicon photonics and optoelectronics.

The current key areas in microelectronics include 5G communications, radiometry, cloud radar, automotive radar, airport security screening, radio astronomy, synthetic-aperture radar imaging, seeker heads and naval fire control. There is also a move from subtractive processes to additive processes using materials for the production of printed circuits that are more green than traditional materials.

Printed point-of-need sensor system microelectronics is smart, simple, low-cost and green. It is used in devices that are portable, flexible, low power using, stable, durable and refreshable. Non-standard inkjet printers are used, but technology is being developed to go bigger for production purposes. It is possible to print with gold, silver and conductive polymers. The circuits are printed on paper and can be fitted to various shapes. The vision for the future is that microelectronics could be printed not only on paper or plastic but could include a printed battery, display and antennae for communications. These devices could include processing capability or a whole electronics system.

The DSI’s South African Research Infrastructure Roadmap includes the establishment of a nano and micro manufacturing facility. This is currently being established and will work on a hub-and-spoke design, with the CSIR as the hub and organisations such as CEFIM at the end of spokes. This process will facilitate the move from research and prototypes to commercialisation.

Microelectronic components are being manufactured in a decreasing number of global facilities. South Africa does not need to compete in that arena, but we do need to invest in research and development, and skilled workers. There is a need to acknowledge the changes that are happening, such as additive manufacturing, microelectronics with heterogeneous integration and printed electronics. There is also a need for the establishment of a low-cost small-scale automated fabrication facility for rigorous design and process modelling, and it is important to stay geographically close to grassroots communities.

The role of an industry association in revolutionising the South African manufacturing industry (Johan McEwan, CEO, Production Technologies Association of South)

An industry association is an organisation founded and funded by businesses that operate in a specific industry and work together for the mutual benefit of the members and for the economy as a whole.

The Production Technologies Association of South Africa (PtSA) is an industry association with the mission of promoting, protecting and supporting the collective interests of the production technologies industry of South Africa. Its vision is to be a centre of expertise for the production technologies industry in the country. Production technologies used to be called tool making. The current definition is that production technologies provide the means to manufacture any manufactured goods. Typical manufacturing technologies include dies for metal pressing, stamping, punching and forming; injection and compression moulds; jigs and fixtures; assembly systems and robotics; gauging and measuring systems; and precision components

The PtSA has a partnership agreement with government which forms the basis of the Intsimbi Future Production Technologies Initiative through which some 2,500 people have been trained, 95% of whom have been employed in the manufacturing industry.

The PtSA owns a project management company called the National Technologies Implementation Platform (NTIP) which focuses on skills and entrepreneurial development and has an international footprint through membership of the International Special Tooling and Machining Association (ISTMA). The PtSA currently holds the chairmanship of this association. ISTMA aims to help national industry associations and their member companies to achieve business success in the global economy through advocacy, networking and information services. Membership includes 29 associations from around the world with a total membership of some 8,000 companies in Russia, China, the USA and other countries, including South Africa.

According to Bob Williamson, the international president of ISTMA, 4IR will be disruptive to some companies if they allow it to be disruptive. It is more a case of actually embracing it and looking for opportunities that emerge as a consequence of the new technologies. 4IR is not a technology but an environment in which disruptive technologies and trends are changing the way we live and work.

It is essential that we understand the potential impacts of 4IR on the manufacturing industry and how we should adapt. This is a complex environment in which South Africans should stand together and compete with the rest of the world rather than with fellow South Africans.

Dr Harry Teifel of Progressus claims that 4IR is fundamentally driven by a digital network effect and requires a shift to a cyber-physical way of working. Cyber networks and the Internet of Things are becoming increasingly important, but physical networks remain important. In this space, the PtSA facilitates the networking of people, companies, governments and institutions, locally, regionally and internationally. The PtSA also brings experts together and assists manufacturing companies to link up with capabilities, technologies and skills in order to enhance production on the shop floor.

Constructive engagement between government and industry is essential and should be aimed at creating a climate for growth and industry as well as being actively involved in policy development. Through Intsimbi, and other programmes, the PtSA forged strong links with government. Through its international footprint, the PtSA can assist the manufacturing industry in becoming more export orientated so as to stimulate growth. There are already a number of South African success stories such as the blocks for Mercedes trucks that are made in Cape Town, but there is a pressing need to grow the export business.

'Coopertition' is a neologism coined to describe cooperative competition. This concept describes the approach taken by the tooling industry in Portugal, where a centre of excellence has been created for the production of bumpers, dashboards and interior trim for the automotive industry. There is still competition between companies in the country, but they have worked together to build a facility that serves the whole world. This approach of simultaneously cooperating and competing with one another is driven by a strong industry association.

An industry association can guide its members towards a better understanding of 4IR, its potential impact on the production technologies industry and how its members should adapt.

South Africa must increase its export potential, make use of existing international connections and market internationally, and must adapt to 4IR in order to grow. An industry association assists, facilitates and drives all these essential functions.

Networks and networking are vital for growth, and constructive engagement between industry and government is essential. Manufacturing companies have to continuously improve efficiencies and productivity to stay in business and to grow. As South Africans, we must believe in ourselves, pass on skills and knowledge, and focus on making things happen.

DISCUSSION

What does the ecosystem look like that would enable the implementation of advanced manufacturing and automation?

Panel: Dr Trudi-Heleen Joubert, Johan McEwan

Comment: In order to get the ecosystem up and running, it is important to grow additive manufacturing companies in South Africa. Metal additive machines are expensive, but they are becoming available outside of universities. Private companies require trained operators for their machines. Hands-on training starting as early as possible would help in developing an understanding of the technology.

Question: The idea of an industry association seems to be an excellent driver. How long does it take to get an association up and running and to enable the rest of the ecosystem?

Panel response: It is difficult to answer that question. The Production Technology Association, for example, was established in 2006 but lacked capacity until a decision to build capacity was taken in 2018. The issue is how long it would take to build capacity and get people involved, and the value proposition of becoming a member of an association. The value of being a member is difficult to quantify in financial terms. For members of the Production Technology Association, the benefits are worth the cost. We need to move away from being prepared to contribute only if there is a direct return and start to realise that making a contribution benefits everyone in the industry.

Comment: One of the biggest technological changes in recent history was from the horse-drawn carriage to the automobile and the internal combustion engine. The example of having managed that transition successfully should demonstrate that there is no need to fear new technology. An important part of the process is to gain knowledge of new technology without being frightened of it.

Comment: Another part of the ecosystem is getting to know other parts of the professional landscape and what they can do. Many projects are multidisciplinary and could potentially include civil engineers together with professionals from other disciplines. Membership of proSET could assist in this regard, since proSET is a networking entity that is mapping its members to determine their various capacities. This information forms the basis of the ecosystem and could be invaluable to government and other decision-makers.

Comment: Collaboration between industry and higher education is driven by individuals, and this kind of networking takes time. Given the many demands on professionals' time, networking tends to take place in people's limited private time. Very few professional associations have full-time employees. If more members were to become involved in the task of running the associations, it would make a big difference.

Comment: The University of Pretoria works closely with industry. Most projects are industry related and involve an industry partner, so networking takes place automatically.

Comment: Most of the projects in the electronic engineering department of the University of Pretoria are approved by ECSA, which requires that undergraduate projects are not linked to industry partners, and there are often issues of intellectual property.

Chair: It is difficult for industry to work with government, because this kind of cooperation seems to depend on passionate individual public servants rather than on an ecosystem that can be accessed.

Comment: For industry to work with government depends on people and programmes, but project memory is often lost when the people in government positions change. Communication is an important part of networking, especially communicating stories about success and progress.

Comment: The National Metrology Institute of South Africa (NMISA) provides support to manufacturing through advanced material characterisation techniques and the calibration of tools and sensors used in the automation process. NMISA is also the custodian of the national standards.

Comment from proSET: It is difficult for industry to form relationships with government as there are very few technocrats in government and it is difficult to speak to ministers. proSET has a relationship with DSI, but there might be a need to convene a meeting of representatives of relevant government departments to inform them about what proSET can offer.

Comment: Engagement with government is fragmented. Departments seem to operate almost as separate entities rather than as part of a national government. There is a need for unity with respect to what the departments represent. Many of the drivers identified in the White Paper on Science, Technology and Innovation have changed radically from the past, which makes it difficult for industry to align with what government requires. Government should assist industry in meeting its needs.

Comment: There should be a focus on making South Africa globally competitive. South Africa has some pillars of excellence that need to be supported so that they can improve even further, thereby strengthening Brand South Africa. South Africa cannot be strong in all areas and therefore needs to focus on areas of excellence. If quality standards are maintained, prices can be negotiated. We need to agree on what quality is and skill up accordingly. With the right technology, the right specifications and a process for upskilling, South Africa can move towards becoming globally competitive.

Comment: Skilling is a challenge for higher education. Historically 4IR has meant the loss of jobs, but different new jobs have been created. We need to overcome the fear of job loss, encourage the development of highly skilled people, and fix the school system.

Comment: As South Africans, we tend to underestimate ourselves. We do have undereducated people but once they are trained, they are more than competent to become part of the production process. Women are becoming involved in the tool-making industry, which was previously male dominated.

Chair: How can we mobilise young people to develop ideas for the new world? How do we allow creativity to flourish?

Comment: South Africans are multi-skilled and have a ‘can do’ attitude that must be used to advantage. There is a difference between skilling and education, and we need to ensure that we do the right things in the right way. Government is introducing robotics and coding as school subjects, which need to be properly implemented and require teachers who are qualified to teach these subjects.

Chair: We need to start by addressing identified needs and consider how this could be done through an ecosystem approach. What needs to be done to identify the needs and link them to people that can address them?

Comment: It helps to work from a set of common goals as described in the DSI’s White Paper on Science, Technology and Innovation and the UN Sustainable Development Goals, for example.

Comment: Teamwork is required. Since no single entity can do everything required for networking, there is a need to know who can do what.

Comment: Establishing an ecosystem requires building up a database of who can do what. To that end, it is important to work across organisations to capture the available information.

Comment: In establishing the ecosystem, we need to be realistic. There are many people in South African society who lack food and other basic necessities. As scientists and engineers, we need to ask whom we are serving. Are we serving those who are well off, or those without clean water and sewerage systems? We need to take those people with us and make them part of the solution, not the problem.

Question: The issue of job losses was difficult to address in the context of the turnaround strategy for mining, and is further complicated by the need to serve labour unions. How can the unions be involved in building an ecosystem to enable the implementation of advanced manufacturing and automation?

Panel response: Unions often tend to be confrontational, but they should be approached to find solutions rather than taking a hard management line towards them. Taking the underprivileged along with us on the ecosystem journey is important. An example of how this can be done is the work of two young engineers from the University of Johannesburg who have developed a vertical hydroponics system that is nearing implementation and production. Industry assisted in the development of this idea.

Question: Commercialisation policies are hampering and affecting state-owned enterprises and enterprise development. How does the national system of innovation support indigenous knowledge?

Question: In the national system of innovation, everyone is pushed towards producing spin-offs. In government, whose mandate is it to lead the push towards enterprise development?

Chair: DSI is responsible for research and innovation. The role of the Department of Trade and Industry in relation to the DSI is not altogether clear, and there seems to be a disconnect with the Department of Small Business Development that was created to work with SMEs.

Question: The Saldanha Bay Industrial Development Zone acknowledges the importance of research and is therefore establishing an innovation campus focusing on the oil, gas and marine domains. Companies that are exploring offshore deposits need technology in order to innovate. The economic zones need to be sustainable. The establishment of research and education facilities will assist local communities and encourage investment.

Chair: This example illustrates the importance of geographical ecosystems.

Panel response: The White Paper on Science, Technology and Innovation emphasises that grassroots communities can contribute towards innovation.

DAY TWO

Automation education and training (Johan Maartens, Director and Chief Operating Officer, Society for Automation, Instrumentation, Measurement and Control)

The Society for Automation, Instrumentation, Measurement and Control (SAIMC) is a voluntary association of ECSA that aims to promote the automation industry in Africa. The vision of SAIMC focuses on education and training, and a large proportion of the membership fees is devoted to work with the youth.

The automation industry faces a number of challenges including customer demands for customisation, graduates who do not want to spend time learning how to operate automation equipment, and cost cutting to increase profits, which impacts on on-the-job training.

The major 4IR factors causing industrial upset and change include big data, augmented reality, simulation and digital twins, the Internet of Things, cloud computing, cyber security, systems integration, additive manufacturing, autonomous systems and cryptocurrencies.

It takes a great deal of time for graduates to gain the understanding of automation required to be effective on the shop floor. Industry has unfortunately removed itself from involvement in tertiary education, and is not demanding the skills required in industry or providing education institutions with equipment and train-the-trainer programmes. Most international companies have been forced to set up their own training facilities, and technical development and research tend to be conducted by individual companies.

In the past, education institutions relied on industry to provide equipment for training purposes. Industry is now proposing to assist in developing the curriculum and course materials as a pre-requisite to supplying equipment. Industry is willing to be involved in train-the-trainer initiatives and provide expert input in order to fulfil the need for suitably skilled graduates.

Education has adopted a silo approach without integration across disciplines, which is an industry requirement. South African industry supported local education for many years, but this support has dwindled and industry is focusing on narrowing profit margins and stiff competition. This trend has meant that equipment in the laboratories of tertiary institutions has become outdated, forcing lecturers to teach the basics rather than increasing students' knowledge of the machines that would be used in industry. Education institutions are largely government funded, with the level of funding determined by throughput. There is no check on whether industry can actually use the skills being taught, and little or no follow-up of what happens to graduates once they complete their studies.

The South African president has enjoined us "to reimagine and build the South Africa we yearn for, a South Africa of our dreams". In this regard, the dreams of the Department of Basic Education are to improve the foundational skills of literacy and numeracy, and to implement a curriculum with skills and competencies for a changing world (4IR) and a world-class assessment system. This is a commendable vision, but the question is whether these were compiled in consultation with industry and whether industry's needs have been taken into account.? The Minister of Higher Education, Science and Technology has announced that the Department of Higher Education and Training (DHET) is developing a skills master plan in response to the known skills demands associated with 4IR. The plan will be complemented by a national list of occupations in high demand and a critical skills list. Through the National Skills Fund, DHET has made R150 million available to upgrade workshops at Technical and Vocational Education and Training (TVET) colleges to meet industry requirements. SAIMC represents more than 31 companies that supply automation equipment and is not aware know of anyone that was contacted to assess industry needs.

The Automation Federation in the USA, which has 130 country members, is working towards establishing automation as a separate discipline. As part of this process, South Africa has been tasked with looking at factory and process automation. A competency model and a qualification framework have been built for the various areas of automation. The competencies that have been identified as essential to the automation industry are advanced control engineer, automation network engineer, automation sales-marketing professional, automation technician, control software engineer, control systems engineer and enterprise integration engineer. A description and performance domains have been provided for each qualification, together with skills, tasks and source material on how to educate. In developing a curriculum for South Africa, it will first be necessary to establish what already exists, after which it will be possible to add recognised programmes that have been developed in the USA. Two recognised programmes in the USA could be used for this purpose, one for certified automation professionals and the other for certified control systems technicians.

By consulting industry for input into the development of courses, many of industry's needs could be met and many of the current problems could be avoided. Many recent graduates have never seen a pipe and instrumentation diagram; they have very little knowledge of equipment sizing and equipment limitations; and their knowledge of project management does not include risk management based on financial calculations. Incorporating these into courses would assist both industry and graduates.

The South African Manufacturing Industry and 4IR (Dirk van Dyk, CEO, National Technologies Implementation Platform)

Due to the changes brought about by 4IR, traditional skills are no longer adequate and there is a need to look at future skills required for production systems. The idea of a machine producing something is no longer new; highly automated integrated systems have been implemented, with direct links to customers through an enterprise resource planning (ERP) system. Times have changed, and the pace of change has caught South Africa by surprise. South Africa is still contemplating what 4IR is, but it is already ten years old and racing ahead.

In a recent report published by Accenture on creating South Africa's future workforce, it is predicted that the disruptive technological environment created by 4IR will place one in three jobs at risk by 2025, which represents 5.7 million jobs. The manufacturing skills gap is widening globally, with more than ten million jobs unfilled. There are many people that are painting a gloomy picture of job losses, but the manufacturing sector in South Africa has decided to approach this problem differently and look at what we need to do to stop the manufacturing sector from shrinking. We need to learn from Germany, China, Korea and the USA whose manufacturing sectors are growing.

The future will entail cooperation between humans and technology and hybrid systems. The manufacturing sector believes that the human element cannot never be de-coupled from the process because of human's innovation capacity. Creativity and consciousness are not inherent in machines. It is important to understand the partnership between humans and technology in order to move from present curricula, which will produce unemployable students without any understanding of modern dynamics.

Industry associations such a PtSA, the Manufacturing Circle, SAIMC and smaller organisations such as the Welding Association have agreed to support an industry-led programme. A formal partnership has been formed between industry and the dti, called the Intsimbi Future Production Technologies initiative.

The programme has three main focus areas, namely skills, education and funding, and is systemic rather than curriculum-based. It is a sustainable system involving enterprises that need to change and absorb new skills. Industry has requested changes in the funding system as it is felt that the current system of Sector Education and Training Authorities (SETAs) is unsuitable. This is a solutions-based approach to developing the competitiveness of industry, encouraging the creation of new businesses, and facilitating the deployment of talent and skills and the creation of innovation capacity in the sector. This systemic cycle of development will have to inform the education system of future.

The education process based on a proprietary ICT platform comprises nine components in a blockchain-controlled environment, starting with global industry standards, followed by learning frameworks and then student networks leading to modular knowledge and competency. The process then moves to practical learning, the factories network, localisation and the possible creation of incubator and new business development. Customised training programmes, based on industry needs, are compiled from existing modules developed internationally.

Modular components are loaded on to the system and made available free of charge. Technology companies will provide the modules developed for their own equipment. If they do not participate, there will be no training on their specific equipment. The programme is being piloted in South Africa and has a national footprint with well-equipped modern training facilities for basic training, advanced training and advanced manufacturing training aligned to the needs of industry. Most colleges and university in the country have outdated equipment, aged laboratories and facilities that are not conducive to training. In the Intsimbi programme, students have pleasant places to learn; the programme includes personal skills modules; and social workers are available to assist students with problems and barriers to learning. Trade tests have been included in the facilities provided because the national system cannot offer this service. The system has a nine-year track record and is very successful. Industry has developed a solution that works, but it is unfortunately not the mainstream system. There is now a need to work with colleges and universities in order to encourage them to adopt such a system.

Industry regards the system as a solution to unemployment and the decline in the manufacturing industry. South Africa is the innovator of this system and has an opportunity to leapfrog the rest of the world as we believe that this is the way of the future. The system does not exclude the need for teachers. Students requiring assistance can book time with teachers to help with particular difficulties. There is a need for mentors, facilitators and highly skilled and trained engineers to consult on the practical side of the programme. Theory is also important, but students have shown that if they are provided with the technology, they can work their way through it by using applications and receiving additional help through technology. Artificial intelligence running in the background of the system will track areas of difficulty, and help will be provided through additional tools.

A national pipeline of students is managed based on the needs of industry in terms of numbers and skills and linked to all member companies. Big data are collected on all students, and information on students' progress is available to member companies. Students do not belong to a company but to a national pipeline owned collectively by all the member companies. Students can only move to a company contractually after they have qualified. Where the current system does not produce suitable people for employment by industry, the Intsimbi process makes it possible for companies to employ people who have already-demonstrated competence.

The factories of the future are expected to be dark places without people, operated by cloud computers, robots and machines, but on the periphery there will be people dealing with outputs, data, installation, applications and software development. These peripheral activities present the opportunities of the future. Baskets of competences need to be developed to serve these areas that will surround smart factories. In order to attract investors, South Africa needs to package the skills supply train more efficiently than other countries, and to become appliers of technology. South Africa has a talented youth pool but there are barriers to entry, and the country is stuck in an outdated system of education.

Maintenance and repair are also essential parts of the smart factory, and people need to be trained with skills for these activities. Low-end skills will be overtaken by applications and devices, but people will still be an essential part of the smart factory.

There are good things happening in South Africa with support from aboard, but support from the mainstream in the country is necessary. 4IR is disruptive, and life in the future will be very different from the past because of the rapid deployment of technology.

I2P, a strategic technology catalyst for community intervention: augmenting emerging technologies for South African further education and training school curricula (Sarel Havenga, Vaal University of Technology)

The Idea to Product (I2P) laboratory at the Vaal University of Technology was developed by Prof Deon de Beer in 2011 with the aim of contributing to poverty alleviation. Various models are being developed and tested in an effort to see what can be done with what is already available, rather than coming up with something completely new.

Additive manufacturing is a disruptive innovation system that is key to change in South Africa. According to the latest Wallace reports, there is an annual increase of 6,000 desktop 3D printers per year, 90% of which are for educational institutions. There is funding available, but a lack of reskilling or upskilling in order to take advantage of the opportunities that this equipment offers.

The technological revolution will disrupt all sectors, including education. The needs have changed from technology transfer to adoption by industry, but there is a lack of skills to manage such adoption. Quality depends on the skill and expertise level of operators rather than the technology used. The lack of skills is due to the lack of systemic education platforms, very little comprehensive training and few certified programmes.

The first I2P model was based on the premise that technology transfer did not create a system or platform for reskilling, and that for sustainable development it is important not to just dump technology on learners. The educational system needs to change the way in which curricula are updated to cope with changes such as 4IR. Basic education largely ignores technological developments due to insufficient funding, time constraints and outdated assessment methods. Overworked and underpaid educators lead to a lack of interest and skills.

Based on the Advanced Manufacturing Roadmap for South Africa, the I2P team decided that pre-university was the best place to focus interventions. There are many programmes running at university level, but initiatives at school level fall outside of the formal system and are not integrated into the school curriculum.

I2P has two main streams, namely a technology transfer model and an accredited model. The technology transfer model is based at academic locations and training is conducted through government-funded initiatives using open source software. The programme is adaptable and successful, but has limited general public exposure and is not focused on reskilling. Only 10–20% of participants developed prototypes after undergoing training, which was very basic without formal assessment criteria.

The accredited model can be based anywhere with work placement approval and is SETA verified, uses open source or proprietary software, and may be either government or privately funded. The course is accredited and designed to train 3D printing operators and facilitators, who can then train others. Service centres aim to incubate. Unfortunately, this process is time consuming.

The I2P research methodology is an interventionist research concept based on pragmatic functionalism. Limitations were identified. Through collaboration with the Department of Basic Education, specific educators were identified and became involved in the strategies that were developed on how to intervene in the education system. The current models were investigated, and a pilot programme based on learning and teaching support materials was developed. The participating teachers were trained over a two-year period, and a learner programme was constructed. During the process, workshops were held and surveys were conducted to identify fears and barriers. It is encouraging that the schools that participated are now introducing their own systems.

The I2P process is underpinned by several educational foundations under the banner of the technological pedagogical content knowledge (TPACK) model in which technological knowledge, pedagogical knowledge and content knowledge are combined. The final model places I2P at the hub, with all information systems feeding into the middle. This includes information from school learners, TVET or university students or the community at large. The focus is on reskilling educators.

Seventy-two teachers were nominated for possible inclusion in the first phase of the I2P programme, of whom 16 teachers of technology, mathematics or science from 11 schools took part. The teachers have completed the training and are implementing the process with 3D printers in their schools. Eleven schools have been identified to participate in the second phase of the project. This project would not have been possible without the support of the educators.

Participants were surveyed on completion of the course and most felt that the practical work had benefited them most and that they would be able to use what they had learned in their classrooms. Forty per cent of the participants believed that they would use the learning for practical demonstrations, and 60% believed that they were more likely to use the learning and teaching support materials. They were aware of time constraints in introducing new objects or concepts. Most participants felt that digital fabrication would benefit science, technology, engineering and mathematics (STEM) education in South Africa. It is a matter of concern was that the educators did not believe that 3D printing could be introduced into classrooms as a teaching aid or method. This stigma will need to be addressed.

Most teachers felt that the current curriculum is already overloaded but that it should be updated to include 3D printing. Most participants felt that educators rather than learners should use the 3D printing system in the classroom, but it was acknowledged that time could be saved through the new system and that learners could increase performance and understanding through the introduction of digital fabrication.

When questioned on whether open source or proprietary CAD software should be used in the classroom, the majority of educators preferred proprietary software. This outcome could have been influenced by the fact that in the last decade schools have been given proprietary software by the government, which has set the standard. Identified constraints included limited available time and possible failure of the technology.

There is a need for increased funding and collaboration and the development of more formal pedagogical models under the TPACK system of cross pollination. Essential requirements for the system to succeed include curriculum reform, reskilling of teachers and moving away from the so-called ‘key chain system’, which relates to an experiment in the USA where the introduction of 3D printers resulted in people using the technology to produce key chains for friends and family. It is important to decide what we want to achieve and align the objectives of industry and the education sector.

“If we teach today’s students as we taught yesterday’s, we rob them of tomorrow” (John Dewey).

DISCUSSION

What are the priority skills needs related to industry 4.0? What progress is being made on such skills training?

Panel: Johan Maartens, Dirk van Dyk, Sarel Havenga

Chair: Are learners being taught the content that they require, or are they being taught to find the information they need and figure out for themselves how things work?

Panel response: The principle is firstly to teach people navigation skills to enable them to find information. In order to internalise information, one has to explore it. The idea is therefore to let students find their way and develop their understanding. Teachers need to be able to interpret their students' journeys and understand their progress in interpreting or applying information. The student needs to be in control by removing control from the teacher and overturning the current classroom situation in which the teacher as the superior party relates to the student as inferior. In this way, we can create an environment in which students are allowed to test, stress and break the system and where innovation happens.

Panel response: Engineers are supposed to be able to deal with complex problems that go beyond the narrow confines of the engineering discipline. Engineering is not a single discipline. The basics can be explained in the classroom, but working in the laboratory with the latest technology is a better way of learning to solve complex problems.

Chair: Is there a sense of the level at which this process is taking place. Ideally, the teacher should find learners at a place where they are ready to explore, but many children in our society are not there. With learners in the TVET band, how do you build bridges between where they are and where you expect them to be?

Comment: There are differences in readiness not only between grades but also between geographical locations. Collaboration can be of great value in providing access to artificial intelligence (AI), virtual reality and tablets. A solution has been found in teaming up with universities. Basic skills are loaded on to AI goggles, which allows students to move through the subject matter at their own pace. The teacher acts as a facilitator to ensure safety in the classroom. Students work through the content, take the tests and can repeat the process until they have mastered the content. This is a successful means of learning, but in large schools and classrooms it is generally not possible to have an educator or facilitator who manages this kind of system rather than just conveying knowledge. It is important to empower educators to understand emerging new technologies and gain the confidence to use these in the classroom.

Comment: School education is a numbers game. A certain number of learners have to be put through the system, which means large class sizes in which it is difficult to focus on quality. A way of profiling young people was developed, which provided a means of assessing which learners constituted a good investment in the post-school mathematics and science environment. In this approach, talent profiles are matched to industry needs, and endurance and staying power are also tested. This system has been successful in producing competences that will get students a job at the end of the course. It is a modular, self-regulating system based on industry needs and standards and supported by industry.

Comment: We do not want to eliminate the teacher, especially in the early stages. In order to change the way in which technology is taught, professional artisans and engineers with at least 15 years' experience would have to be employed, but this would be beyond the financial reach of universities and TVET colleges. Advanced engineering cannot be taught by educators alone, but requires highly experienced industry personnel who are also aware of the pedagogical aspects of learning.

Comment: In one particular university environment, students were given a project and provided with the tools to build something. The outputs were then evaluated together with industry partners. The aim was to stimulate creativity.

Comment: That is a sound approach. The only thing that is missing is the commercial aspect in order to teach technical people how to start a business or market a product.

Question: Technology is still at the fringes of society. When is the factory of the future manned only by machines, with human beings working behind the scenes, likely to become a reality?

Comment: Motor manufacturers and large-scale bottle manufacturers already operate their factories in this way. The only people in the plant are the maintenance crews and a person in the control room. There is no longer any manual labour in large-volume production in South Africa. Systems are now becoming even smarter, so the few remaining jobs such as in warehousing are quickly being mechanised to avoid the high cost of labour. The demise of the mining industry can be attributed to the cost of labour. The new mining industry will use drones and other automation without putting people down the mines.

Chair: It sounds quite bleak, but disruptive innovation means that old jobs will fall away and new ones will be created. The shortcomings of human beings will be eliminated.

Comment: Advertisements for jobs for farmers on Mars can be expected in the near future. There will be new opportunities with the advent of anti-gravity and cheap electricity devices. The technology already exists for many of these technological breakthroughs, but changing from existing systems is very expensive and the technology cannot be made public because of the maturity of society.

Question: There has been much talk of including a topic such as megatronics, for example, in higher education curricula. How is this regarded in industry?

Response: Industry is suggesting that universities and colleges should stop worrying about curriculum content. Industry should put forward the curriculum and methodology required to be taught. It will be necessary for teaching staff to learn new methodologies, which will need to be regularly updated as often as every six months in alignment with industry needs. Courses should comprise flexible modules that can be plugged in and out. Industry will have to assist universities and colleges in being ready for change, as slow upgrading will no longer be sufficient.

Question: Universities are expected to pursue the three pillars of teaching, research and community outreach. Where should the main focus be?

Comment: Since universities are expected to train, the biggest focus must be on knowledge although specific applications are also required (e.g. how to build transistors). Much of the research done in higher education institutions is not applied to products in industry. It is important for this to change and for universities do research with commercial applications that would create jobs.

Comment: Most South African universities conduct research based on available capabilities. In Germany, the Fraunhofer Gesellschaft invites big business to tell them what research they require to be done, and this research is funded by business. The research from our universities is seldom implemented. Industry has lost faith in academia and generally does its own research.

Comment: The academic world tends to be inhabited by thinkers and industry by doers. It is important for industry and academia to collaborate, but policies and processes often to change too slowly for industry.

Chair: We definitely need academia for the purposes that it serves, but we need many more doers than thinkers. Young people need to understand and appreciate what can be gained by being on the factory floor.

Comment: We need ‘thinking doers’!

Comment: We are now involved in third-generation education: first-generation education involved only teaching; second-generation education involved teaching and research; and third-generation education involves teaching, research and innovation. Ideally, innovation should be included in the curriculum in all fields, but curriculum change takes a long time. In Europe, technically orientated non-degree courses have been developed to fill this space.

DAY THREE

Critical raw materials in southern Africa: research from the perspective of the DSI–NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis (Prof Paul Nex, Associate Professor, Economic Geology Research Institute, University of the Witwatersrand)

The Department of Science and Innovation–National Research Foundation Centre of Excellence for Integrated Mineral and Energy Resource Analysis (CIMERA) is hosted at the University of Johannesburg and co-hosted at the University of the Witwatersrand. CIMERA supports research at 11 South African universities involving 45 academic staff, 35 PhD students, 41 MSc students and two research fellows. The centre has graduated 31 MSc, 8 PhD, 22 honours students and supported ten postdoctoral fellows since 2015. CIMERA has eight research areas. The presentation will focus on base and critical metals, gold and other deposits.

There is a serious answer to the question of what critical or strategic raw metals or materials are, but there is also a cynical view. The serious answer is that critical metals are those whose availability is essential for high-technology, green and defence applications, but which are vulnerable to politically or economically driven fluctuations in supply. Any definition depends on the particular country, the technology or industry in which one is interested, the perceived risk of future supply and perceived demand, all of which are subject to change.

The cynical view is that critical or strategic raw metals or materials are any that can be so declared in order to enhance the ‘spin’ produced by a junior exploration company, or to increase the chances of obtaining research funding in the academic environment, or to enable producing companies to increase prices or to justify in-depth studies by government departments.

There is nothing new in the concept of critical metals, since it is very likely that the Romans invaded Britain as far back as 55 BC to obtain tin. During the Second World War, tungsten was a critical/strategic metal for munitions, and Panasqueira in Portugal was the main producer for both sides of the conflict. Dependency on raw materials was highlighted by the oil crisis of 1973 when the Organisation of Arab Petroleum Exporting Countries (OAPEC) proclaimed an oil embargo. Currently the most prominent use and discussion of critical raw materials is related to conversion to a low-carbon economy. Renewable energy and changing from internal combustion engines to electric vehicles and fuel cells is driving the new manufacturing and the exploitation of mineral deposits.

In 2010 a European Union report identified 14 critical materials – rare earth elements (REEs), platinum group metals (PGM), niobium, germanium, magnesium, gallium, antimony, indium, tungsten, fluorine, beryllium, cobalt, tantalum and graphite – out of 41 that were defined as critical based on economic importance and supply risk. This analysis changes over time and with redefined needs. Antimony and PGM were high on the list in 2011, but by 2015 these slipped down to near the bottom. The list reflects the supply risk of Western countries, and it is possible that China has a very different list.

In 2013, an EU review of the original 14 critical metals was undertaken, and 20 critical materials were identified out of 54. The additional metals that were included were REEs split into light and heavy, borates, chromium, coking coal, magnesite, phosphate rock and silicon metal, and graphite was changed to natural graphite. Lithium was not listed as it was not as important then as it is today.

The world contains enough energy and mineral resources needed to sustain 10.5 billion people (the level that the world population is expected to reach by 2100) at a European standard of living for hundreds of centuries, but most of these resources are under the sea. There is not a lack of resources, but limited economic and technological capability to retrieve and concentrate them.

It is difficult to make accurate predictions with respect to critical raw materials, but it is important to consider which of these raw materials could potentially be supplied by Africa. Many critical raw materials do not occur in sufficient concentrations in a single deposit, and there are for instance no tellurium germanium deposits since these elements are extracted as accessory deposits with other mineral deposits. There is a big difference between the occurrence of a mineral and a deposit that can be mined economically.

The research that we could and should be involved in is establishing the occurrence and distribution of the various critical materials, and understanding the cycling of critical materials in the Earth system, and the genesis and mineralogy of the different critical materials and the implications for extraction and processing. We should research what is critical, what might become critical, and what we have in the ground. We must work with stakeholders to improve the efficiency and value of the extractive industries. We should not be involved in exploration to find new critical material deposits, evaluating and quantifying critical materials in any particular deposit, or making financial assessments of deposits. Companies mine deposits, not academics or governments.

It is a popular misconception that the 4IR risks running out of steam because of a shortage of the essential elements needed to run it, and that there are shortages of the minerals required to provide elements for 21st century civilised life. It is also feared that the 4IR will reduce mining activity. Renewable energy will in fact require more rather than less raw materials, at least in the short term.

The need for critical raw resources is determined by China, the USA, Europe and other manufacturing countries but what are the critical raw materials with respect to Africa? Water and energy resources would be high on the list. Bulk construction materials for infrastructure development such as bauxite, cement, iron, steel and wood, and minerals for agriculture such as phosphates and potash are also extremely important. Africa produces raw materials for other countries, but it is critical also to consider the continent's own needs.

Africa is underrepresented in recent literature. We need to focus on critical metals but it is impossible to know what the next generation of batteries will require. Manufacturers will decide on priorities according to the availability of resources. The platinum industry will decline with the advent of electric vehicles, but given the massive deposits of PGMs in South Africa it would make sense to focus on fuel cells. The decision will have to be made regarding which is more important, the 4IR with artificial intelligence, the Internet of Things, digitisation, disruptive technology and a fundamental change in the way we do things, or a carbon-free or low-carbon economy characterised by electronic vehicles, renewable energy sources and fuel-cell energy.

Critical raw materials research needs to be multidisciplinary. We must continue to understand and examine the genesis of all ore deposits, their mineralogy and the trace elements that occur within them. Synergy between researchers, industry and government must be maintained and increased, along with greater sharing and transparency.

As a global community we are depleting the Earth's resources, and there is increasing division between rich and poor people and nations. Climate change is certain to affect us all; it is not selective with respect to income. Unfortunately, political instability and increasing nationalism and intolerance are not conducive to solving these issues.

Platinum group elements: minerals to metals and beyond (Prof David Reid, Department of Geological Sciences, University of Cape Town)

The platinum group elements (PGE) and metals occur in close bands on the periodic table and are classified as precious, noble, heavy, siderophilic and chalcophilic. It is important to understand the distribution of these elements in the Earth's crust and the uses for the PGEs.

At a fundamental and primordial level, the formation of nuclei and atoms produced minerals 1.0 and rocks 1.0. In the planetary formation stage of development, rocks 1.0 became magmas 1.0 and crystallised minerals 2.0. Rocks 2.0 were also formed in this phase and also the core mantle of the Earth. Planetary convection resulted in the formation of rocks 2.2, magmas 2.9, minerals 3.0 and rocks 3.0, which formed the crust of the Earth. Our mining efforts take place in the Earth's crust. It required a super nova to generate PGEs. Only palladium and platinum occur in large deposits. Many siderophiles or iron-rich PGEs were lost to the core.

Automotive applications and the jewellery industry are the largest users of platinum, but in 2018 use by the investment sector grew from 0% to 10% with bullion (real or crypto) using platinum as support. Cryptocurrencies could be the future in the fourth industrial revolution, which would impact the demand for platinum. The current drivers of demand for platinum are the automotive sector at 41%, industry at 21%, jewellery at 38% and investment at 11%.

There have been some efforts at localisation in the jewellery sector, but South African currently tends to export metals and import jewellery. The investment sector is of potential interest to platinum producers, but this emerging area needs to be fully understood. The World Platinum Investment Council, established in 2014, is investigating whether cryptocurrencies are relevant to platinum's' investment case, whether it is possible or likely to have a cryptocurrency backed by platinum, and the implications of cryptocurrencies and blockchain technology for commodity ownership. South Africa is the world's major supplier of PGEs with 95% of the world's resources, and the world is watching South Africa in relation to the cryptocurrency potential.

PGEs are used in a variety of applications, which are affected by changing technologies. Europe is the main market for platinum, while palladium is more important for other countries. The two elements are similar in price. Effective recycling is taking place. As the production of platinum increases, the platinum recycling industry should also be growing, but it seems that there might be some constraints. Current supply and demand are roughly equivalent, but possible increase in demand by the investment sector could affect the future of PGEs. In order for South Africa to profit from PGEs, it is important to manage production costs.

Investment in resources in the platinum sector will not come from the financial houses as this is not their business. It will be more important to consider productivity and reduce the costs of mining. PGEs are also available in Zimbabwe, Russia and North America, but only in the form of small palladium deposits. South Africa has the largest deposits of reefs that are rich in platinum and palladium and suitable for reef mining. Although the ore-bearing horizon might be 100 g per ton, the final amount could be as low as 4-5 g per ton. Perhaps 4IR robots could assist in improving recovery. Because of relatively high operating costs, not many of the mines are very profitable.

Research is required to better understand the mineralogy of the reefs, as well as research into processing and improved recovery. There is considerable potential in relation to exploration targets and interesting methods of finding scope for stakeholders in the industry, including the use of big data.

South Africa has 95% of the known world reserves of PGEs, but the difficult mining processes to extract PGEs require huge investment. Platinum and palladium are the two most important PGEs. A negative aspect of the platinum industry is that it consumes a great deal of electricity, and in South Africa 90% of this electricity is generated by burning coal. The platinum industry needs to get back to basics. The world is watching us, and we cannot let them down.

The relevance of rare earths to South Africa (Brent Jellicoe, Principal consulting Geologist, Merkara Exploration and Resource Consultants)

The rare earth elements (REEs) comprise 15 elements that are collectively termed lanthanoids. The REEs tend to have similar chemistry but are distinguished by different optical and magnetic properties. These elements are not 'rare,' with a total abundance on Earth of 220 ppm compared with carbon at 200 ppm. REEs are widely distributed in low concentrations but typically occur together due to having ionic chemistries dependent mostly on the size of the M+3 ion. REEs are very reactive and not very noble. They are easy to dissolve and easy to precipitate, but are difficult to chemically reduce and separate. They are characteristically trivalent with a strong ionic character that allows them to readily form salts with anions.

Of the 15 REEs, the focus is in the five most useful of these elements. REEs occur in over 250 minerals, but it is important to focus on high abundances and ease of separation. This occurs mostly in three minerals, namely bastnaesite, monazite and xenotime, although others are economically mined in some places. All REEs have to be mined together, and then time and money are needed to separate the elements. The REEs are classified in two streams, light REEs and heavy REEs. In general terms, light REEs are in greater abundance than heavy REEs, which is pertinent to the economics of REEs.

There are at least 800 rare earth deposits in the world, but only 49 of these have code-compliant resource estimates and only a few deposits can be mined economically. The exploration process includes area selection, mapping and drilling, resource definition and process development. The requirements include a pilot plant, environmental impact assessment studies, product certification and most importantly financing for construction and production. Light REE concentrations are known, and the focus for targeting rare earth deposits now is mostly focused on heavy REEs and yttrium.

There is a fairly equal distribution of REEs across the world. Many for the deposits that have been developed since 2011 are in Russia. China has 35% of the world's known resources, which is considerably more than any other country. Resources do not occur in an equal split between light and heavy. The light REEs are more abundant, but the really good REEs are the heavy ones. There are reasonably sized deposits in southern Africa, mostly in carbonite and phosphate areas with both light REE and heavy REE mineral potential. Steenkampskraal mine in the Western Cape is currently the highest-grade deposit in the world. Other deposits range from low-tonnage high grade to high-tonnage low grade.

REEs have many high-tech uses in the defence, energy, industrial and military domains. They are also widely used in a wide range of consumer products such as iPods, wind turbines, hybrid vehicles, fibre optics and energy-efficient light bulbs. The use of REEs in magnets is a rapidly increasing application. The global production of REEs in 2016 was 126,000 metric tons valued at US$1.5 trillion. China supplies 95% of the world's REEs. There is a need to increase production of critical REEs to meet current and future needs.

The mining and extraction of REEs is very expensive. Mining requires testing for feasibility as well as authorisation. Specialist studies of hydrogeology, as well as environmental, archaeological and infrastructure assessments are required. It is also essential to plan for the safe disposal of the radioactive material that is always associated with REE deposits to some extent. Other important considerations in planning a mine are power, transport and skills availability.

Ore processing is a complex operation, particularly for the high dollar worth commodities. The processing of the ore begins with crushing the rock and grinding it to a finer consistency. The rare earth-bearing minerals are removed and then the separation process of individual elements takes place. These elements are made into a powder, which is combined with other metals to form alloys. Every mine has a unique mineralogy and process flow based on the particular characteristics of the ore, REE mineralogy, deleterious elements and extractive needs.

The domination of China in the global REE market makes it difficult for other countries to compete. Over several decades, China has developed a fully integrated mine-to-market value chain from the mining of the ore through the physical and chemical processes to the delivery of an industry-ready product. This value-add chain is a prerequisite for success in the market. Even though there are opportunities for other companies and countries in this market, it is not easy to take the process from conceptualisation to reality.

In the domain of REEs, basket pricing is important and is based on the selection of which critical REEs can be put in a basket. Projections can be made on demand drivers and changing supply dynamics over the life of a mine, but it is not possible to put a price to all the REEs that are produced in a mine, but only on those that are commercially viable and in demand. The more value that can be added to the end product, the higher the price that will be achieved. There are price differentials between light and heavy REEs. The existence of agreements with potential customers is critical and can influence the REE basket makeup, price and marketing policy of a mining company. Having a long-term fixed pricing list on customer-specified products (either oxides or mix concentrates) will define the feasibility prospects of the REE project in a more secure manner.

There are four main challenges in relation to the supply chain, namely a broken REE supply chain, the rare earth oxide balance problem, environmental impacts, and the China issue. The problem of a broken supply chain is the absence of a robust and fully integrated value chain with sufficient capacity to translate the ore into value end-products, which can jeopardise the future of a company through the loss of control and revenue. Chemical separation of individual rare earth oxides can be accomplished only by China and a handful of non-Chinese service providers.

The issue of balance between heavy and light REEs occurs because it is necessary to mine large quantities to extract the required REEs, which results in sacrificial over-production of some other REEs. This over-production results in stockpiling and flooding of the market and consequently lower prices for non-critical rare earths.

There are two main issues associated with the environmental impacts of REE mining. REE mines are associated with naturally occurring radioactive materials, which must be handled correctly in order to avoid damage to people and the environment. Mine waste from REE mining is generally fairly benign without any threat of acid mine drainage, but the use of dangerous chemicals and toxic compounds during the processing of REEs can result in negative environmental effects. In China, lax compliance with regulations has resulted in severe environmental consequences as well as illegal mining, which is now costing China a great deal to clean up. The environmental challenges can be alleviated through the diversification of supply, recycling and the use of rare earth production to develop better green energy solutions.

China has had the monopoly in the REE market since the mid-1980s. As part of the current trade war between the USA and China, rare earth exports have become part of the tool that can be used by China to bludgeon the USA. China sells products that are less processed to their own industry and high-value products to the rest of the world. China’s strategy is based on making enough money to strengthen their economy by adding value and raising prices, but this has severe consequences for countries without rare earth deposits. Until the rest of the world starts investing in the critical downstream linkages upgrade rare earth outputs into market-desired materials, end-users outside China will remain reliant on and vulnerable to China’s monopoly into the foreseeable future.

There is no reason why South Africa could not spearhead, develop, build and support a full supply and value chain for African REE mines based on providing separation and metal-making services. South Africa has three decent REE deposits, and there are numerous others in southern Africa. Mining companies struggle to raise capital to build processing plants without involving China. A centralised facility could research what China has done and perhaps improve on the processes to provide a facility that could be used by all the mines in southern Africa. A centralised facility would convert the rare earth concentrate into oxides, purify these and convert them to metals. These metals could then be incorporated into customised processes for the production of REE alloys. The facility would need to be world class and would require the support of government, industry and the nuclear regulator. International agreements and mechanisms for knowledge sharing would have to be developed.

The issues that would have to be dealt with include complex technical requirements, supplies of feedstock, financing, transport, disposal of radioactive waste and possible direct competition with China. The benefits include the possibility of attracting world-class experts, avoiding capex investment, improved viability of mining companies and the creation of a major manufacturing centre of excellence in South Africa.

Identifying critical raw materials in South Africa (Davis Cook, Minerals Council of South Africa; CEO, Research Institute for Innovation and Sustainability)

The conversation is not just about raw materials but the broader role of mining and manufacturing and the implications for the rest of Africa.

From the point of view of Minerals Council South Africa, there are several policy instruments and longer-term instruments for strategic decision-making that need to be put in place to address the issues surrounding mining and manufacturing, starting at macro-economic level by defining the trade profile and trade partners for both manufacturing and minerals.

There are expected to be big shifts in the needs for metals and minerals over the next 20 years. There is a push in the rest of world for a circular-type economic model based on the existing economic structure especially in Europe. In Europe the pressing questions revolve around how to recycle infrastructure, whereas Africa faces different problems, such as how to move from 50% urbanisation to 80% urbanisation over the next three to five decades. This is equivalent to building the entire cities of Europe. Africa does not have infrastructure available to recycle and will have to build with new minerals and products. The issues in Africa are very different from other parts of the world, which will affect the minerals and commodities that will be in demand in the future and the potential need to reclassify the critical elements, perhaps so that they are slanted more towards development needs than in developed countries. The list would then include base infrastructure minerals, aggregates and steel. The new infrastructure will create new opportunities that will have to be filled, and South African has the manufacturing capability to support mining across the continent.

Ten to 20 years ago, South Africa produced most of the mining equipment used on the continent, but this is no longer the case and equipment is largely imported from across the world. Two significant opportunities exist in this domain, namely to produce the big trucks used in the mining industry, which are currently imported, and to provide the embedded components in equipment, which currently use software developed in Japan, China, Germany and the USA. The costs of big data and communications are not always obvious, but represent revenue that could accrue to South Africa.

There are a number of trade questions that will determine how minerals and raw materials issues are managed in future. Although it is not necessarily obvious, South Africa is a third party in the middle of a form of trade war between equipment suppliers and African mines. Once a particular product has become established in an area, it is difficult to make changes, and there are challenges of become bound to equipment suppliers. It is important for South African companies to develop products that will remain relevant for the rest of Africa. If the Chinese monopoly in rare earth elements is to be broken, mines will have to be opened up. Questions related to raw materials and manufacturing are dependent on trade economics and broader mining systems.

There is very little greenfield exploration for locally mined minerals in South Africa, which is a potential barrier to investment. A favourable policy environment is another prerequisite for exploration, but the South African policy environment is uncertain as the Mining Charter is still being debated.

The South African manufacturing sector has not been able to scale up to the level of production of international original equipment manufacturers (OEMs). Markets in the rest of Africa need to be opened up for the growth of the South African manufacturing sector. Developing a bigger market to boost manufacturing would also lead to more efficient mining and the reduction of capital costs to the mines.

The Minerals Council has been focusing on building clusters that involve a range of participants including industry, universities, government and public–private consortia to deal with problems in the mining and manufacturing domain. This approach is linked to the suggestion to develop a centralised facility for REEs. We need to work together to find solutions.

The Minerals Council is concerned not only with technology and economic issues, but also takes a people-centred approach to the mining industry and the role of mining in society. The mining industry recognises the threat of climate change and the challenges of transitioning to green technologies without causing societal damage in the country. South Africa is very dependent on fossil fuels, and regions such as Mpumalanga are dependent on the mining of these fuels. In the transition from old to new energy sources, livelihoods in the areas where fossil fuels are mined have to be taken into account. It will be important to manage migration patterns and avoid the creation of ghost towns when mines are closed.

Building infrastructure across Africa will not only at an environmental cost but also at a human cost, which will need to be managed correctly in order to obviate further problems. The issue of critical raw materials is rooted in consumer demand for appliances such as cell phones and low cost power, which need to be satisfied preferably by South African industry, and if not by our competitors. South Africa has the skills set, infrastructure and policy under development to be a major player in the critical raw material domain.

The demise of advanced manufacturing (Johan Kriek, Marketing Manager, Tshipi é Ntle Manganese Mining)

When the material recovered from the wreck of the Titanic was analysed, it was found that the steel used to build the ship did not contain enough manganese. This made the material that was used very brittle and unable to withstand the collision with the iceberg. A modern ship hitting the same iceberg would not be damaged. Manganese is an essential mineral.

Manganese is the twelfth most abundant mineral in the Earth’s crust and occurs in economically viable quantities in the middle of the Amazon basin in Brazil, in Gabon, on an island north east of Darwin in Australia and in the Northern Cape, which has 85–90% of the world’s reserves. Manganese is not a scarce commodity and cannot be used directly in steel production, but first has to be made into an alloy. Between the 1960s and 1990s, South Africa had the most up-to-date alloy production facilities, but these have been transferred to Sarawak in Malaysia where there is cheap labour and a guaranteed supply of electricity. There is only one alloy producer left in South Africa, but rising electricity costs threaten to drive that company out of business. South Africa used to have sophisticated manufacturing facilities, but these have gone. The country needs more relaxed labour laws and guaranteed supply of electricity to grow the manufacturing facility again, and these are unlikely.

DISCUSSION

To what extent can South Africa mine and manufacture the required materials?

Panel: Prof Paul Nex, Prof David Reid, Brent Jelllicoe, Davis Cook, Johan Kriek

Question: Is CIMERA a multidisciplinary initiative? A previous similar initiative at the University of Cape Town included a wide range of skills, including law.

Panel response: CIMERA currently comprises mostly geoscientists, and involving other disciplines would be valuable. Greater interaction between the various centres of excellence would be useful, since they tend to be established around single disciplines. Another possible solution might be to establish a school of mines, either virtually or at a physical location.

Comment: The University of the Witwatersrand's Centre for Sustainability in Mining and Industry, and the University of Pretoria's Mining Resilience Research Centre share similar goals with CIMERA related to the sustainable utilisation of Earth's mineral and fossil energy resources. The Mandela Mining Precinct has several projects in various disciplines, mostly in engineering.

Comment: Apart of engineering and science, other occupations make downstream contributions to mineral exploitation. With respect to the concept of a facility for rare earths, a broader spectrum is required from start to finish, which makes the concept of a school of mines very attractive. The schools in the USA and UK have produced generations of people who have made significant contributions. For initiatives such as CIMERA, there is a need to focus rather than dilute the initiative with other disciplines. A multidisciplinary approach would be particularly useful in mine-to-market applications.

Comment: Academia is struggling with multidisciplinarity. Research tends to be done in silos, and students can only register for one faculty at a time. Government is also struggling with multidisciplinarity. The terrain is difficult to negotiate because of ring-fencing and the personalities involved.

Comment: It is important to break down the ring-fencing of funding that causes silos and to push for a multidisciplinary approach. China has benefited from the mine-to-market concept, and so have fluoride mines in South Africa and Namibia owned by foreign companies. Critical raw materials lend themselves to a mine-to-market approach.

Comment: From the perspective of industry, it is important to consider the return on investment. Chinese is able to control the price of rare earth elements. It is difficult for a private-sector company to match this without considerable backing, and government lacks the will and competency to deal with the challenges. Considering the broader geopolitical issues, perhaps it would be better to start at the processing end rather than the mining end of the continuum.

Comment: The concept of a collaborative effort with possible equity investment by miners would save investment in capital expenditure and other mining costs. In order to operate in the same market as China, there is a need for a united front of smaller companies or countries with some support from the USA. Such an initiative would allow broad participation in value addition.

Chair: What possibility is there of producing the powders such as titanium used in additive manufacturing in South Africa. What is the status of the titanium powder manufacturing initiative of the DSI and CSIR?

Comment: The powders need to be identically formed, which is difficult. There are interesting processes under way, but it is not easy to scale up. The second challenge is that the range of uses is still relatively limited. This is a technology of the medium- to long-term future, not the short term.

Chair: What is the feasibility of establishing a centre for the processing of rare earths in South Africa, as outlined by Mintek?

Comment: Mintek has spent many years assessing the needs with respect to rare earth deposits and looking at rare earth material to concentrate stage. Mintek is skilled at removing impurities from the concentrate. The concept of a centralised facility is rather vague. A centre for the processing of rare earths would not necessarily provide an international facility, but would provide services to companies in southern Africa. It seems that many of the mines will not be productive without a collaborative effort.

Chair: How would robots and general automation change the mining industry, and would it make mining economically viable again?

Comment: South African industry needs to improve productivity, and in deep-level operations the use of modern equipment is critical. Given the nature of South African mines, it is not possible to introduce automated equipment. Some of the newer mines would be more fully automated, but people will always be involved in mining in South Africa. Technologies using big data will be integrated, but there is no need for concern that mining in South Africa will be overtaken by robots.

Comments: It is difficult to make technological improvements, but planning is in place to introduce efficiencies in new mines. Where radioactivity is an issue, remote control will be applied to reduce the adverse effects on peoples' health.

Chair: Is there enough research being done on extraction?

Comment: The NRF Chair of Excellence in Materials is involved with Skorpion Zinc mine in Namibia. The technology for processing this deposit is recent, even though it was identified some time ago. Electricity supply is essential and was previously a bottleneck. Improved recovery and smarter processing can overcome previous poor practices.

Comment: With regard to big data, large companies have huge databases that could assist in increasing efficiency, but there is a need for people to process and analyse the data. Are universities training people to fill this gap? The mining houses need technical expertise to run the expensive sophisticated equipment in which they have invested.

Chair: Are these records digitised, and is Mintek working in this domain?

Comment: One of Mintek's roles is to provide a centralised location for map data. Vast amounts of data are available, but there may be issues related to data from different agencies, and problems of coordinating a range of different data types and formats.

Comment: More mine data have been lost than the amount of data currently in existence due to poor record-keeping, the passage of time and accidents. It is laborious and difficult for small companies to do the basic work to develop a digital database.

Chair: South Africa has enormous manganese deposits, but it seems that the industry is constrained by problems of transporting the deposits from the mines to the ports.

Comment: Manganese is required to make steel.

Chair: Is it profitable to recycle objects made of metals that are still useful?

Comment: It is difficult to retrieve small amounts of any particular element. Europe is trying to ensure that the production of goods is done with recycling in mind. Even though recycling is increasing, it will not be sufficient to replace mining as a source of minerals.

Comment: The biggest producers of platinum at the moment are scrapyards in the USA.

Comment: There is an interesting correlation between the amount of production and the volume of recycling. The heavy constraints on the amount of recycling could perhaps be the result of pressure from industry. In the case of the platinum group metals, the quantity of recycling appears to be constant and production is also constant, which could indicate that the constraints are artificially imposed.

Comment: In the rare earth industry, there is concern regarding current recycling efforts with a very low recovery rate, which is partly due to the problems of separation from alloys. Rare earths could be compartmentalised in the construction of products, which would make recovery easier.

Comment: Japan and China hold investment reserves of platinum that could be used to control the price. Recycling is a multidisciplinary issue, but there is a need for collaboration across the entire cluster.

APPENDIX 1: LIST OF ACRONYMS

3D	Three dimensional
4IR	Fourth Industrial Revolution
5G	Fifth generation cellular network technology
AI	Artificial intelligence
Al	Aluminium
CAD	Computer-aided design
CEFIM	Carl and Emily Fuchs Institute for Microelectronics
CEO	Chief executive officer
CIMERA	DSI–NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis
CMOS	Complementary Metal Oxide Semiconductors
CRPM	Centre for Rapid Prototyping and Manufacturing
CSIR	Council for Scientific and Industrial Research
DHET	Department of Higher Education and Training
DSI	Department of Science and Innovation
dti	Department of Trade and Industry
I2P	Idea to Product
ICT	Information and communications technology
ISTMA	International Specialist Tooling and Machining Association
NSTF	National Science and Technology Foundation
NTIP	National Technologies Implementation Platform
PGE	Platinum Group Elements
PtSA	Production Technologies Association of South Africa
REE	Rare Earth Elements
SAIMC	Society for Automation, Instrumentation, Measurement and Control
SETA	Sector Education and Training Authority
SME	Small and medium enterprises
Ti	Titanium
TPACK	Technological pedagogical content and knowledge
TVET	Technical and vocational education and training
UK	United Kingdom
UN	United Nations
UP	University of Pretoria
USA	United States of America
V	Vanadium
Wits	University of the Witwatersrand

APPENDIX 2: LIST OF DELEGATES

Delegate	Organisation
Julia Rantani	
Oria Herma	
Chanwari Ketano	4IRI
Alessandra Forsti	Amabo GMBH
Jona Kinghill	Clockwork
Bryn Lake	Clockwork
Gerrie Booysen	Central University of Technology
Julia Ranzani	Creative Communications
Earnest Dada	DSE Innovations
Ceck Masoka	Department of Science and Innovation
Thabisile Mkhize	Department of Small Business Development
Nontombi Marule	Department of Trade and Industry (the dti)
Ilse Karg	the dti
Ilse Kanra	the dti
Nonkululeko Majaja	the dti
Nkuli Shinga	the dti
Sindi Buthelezi	Esivinni News
Dintwe Africa Teiseho	Geek Electronics Fab
Mandla Dlamini	GIP
Viwe Sigeni	Human Sciences Research Council (HSRC)
Stevens Moaheki	HSRC
Anele Slater	HSRC
Corrie de Jager	Hydrox Holdings
Jason Cuomo	Hydrox Holdings
Shabier Jacobs	IMA Medis Africa
Mohlolo Katsanae	Independent IT Consultant
Yanesh Naidoo	Jendamark Automation
Sahil Shah	KBG
Titus Maina	KBG
Andrea Bohmert	Knife Capital
Orion Herman	Liquid Gold
LG Moqoshi	LLS Consulting
Angel	LOGOS
Lusapho Thabeni	Lukhanyolwethu Technology
Dave Pons	Mangosuthu University
Brent Jellicoe	Merkara Exploration and Resource Consultants
Sereme Maphaka	Methano Group
Davis Cook	Minerals Council South Africa
T Mthoba	MTL
Patrick Masina	National Metrology Institute of South Africa (NMISA)
Dirk van Dyk	National Technologies Implementation Platform

Delegate	Organisation
Sergio Carvaldo	NIIPB
David Mutebi	Parliament of Uganda
Sueneil McLeod	Private-I Corp
John McEwan	Production Technologies Association of South Africa
Sahar Mohy-Ud-Din	Research and Development Africa (RADAF)
Berharel Heyer	Robotixlab
Nokwanda Mkhize	Saldanha Bay Industrial Development Zone
Vuyolethu Towelekile	South African Broadcasting Corporation
Mmakgabo Maluya	South African Bureau of Standards
Ina Maartens	Society for Automation, Instrumentation, Measurement of Control (SAIMC)
Johan Maartens	SAIMC
Kwanele Makeleni	SB Connect SA
Mali Mashinini	Skylight IT Centre
Prof Kristiaan Schreve	Stellenbosch University
Wessel van Wyk	Smit & Van Wyk
Tholofelo Lesati	Technology Innovation Agency (TIA)
Mokete Ratlabala	TIA
Marebodi Kaotsane	TIA
Tieho Tsiane	TIA
Patricia Mathabe	TIA
Thabiso Tiro	TIA
Reabetswe Matuna	Transnet
Tshifhiwa Ravele	Transnet
Kgomotso Gafela	Transnet
Brendan Booysen	TRYAD
Johan Kriek	Tshipi é Ntle Manganese Mining
Thomas Kgatle	Tshwane University of Technology (TUT)
Thembeka Ncata	TUT
Moeketsi Tsholoane	TUT
Prof David Reid	University of Cape Town (UCT)
Riyad Daningo	UCT GSB
Karla Rocha Liboreiro	University of Minas Gerais
Jasper Bhaumick	UMa Soft GmbH
Banels	Uniconne
Darely	Uniconne
Dr Abrie Oberholster	University of Pretoria (UP)
Dr Hein Möller	UP
Dr Trudi-Heleen Joubert	UP
Mariza Costa Almeida	University of Rio de Janeiro
Prof Paul Nex	University of the Witwatersrand
Leonard Nhlapo	University of the Western Cape
Georg Oliver	VDS
Sarel Havenga	Vaal University of Technology

Delegate	Organisation
Sibdsalwe Sondlo	Woke Network
Angel Selebano	ZADNA
Zoe Amin-Akhlaghi	ZAMSTEC Academy of Science and Technology