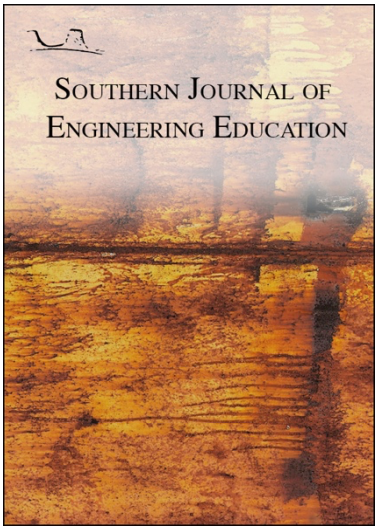

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Leveraging the engineering ecosystem to prepare TVET graduates that the South African manufacturing industry needs

Arnesh Telukdarie[a]
Inderasan Munien[a]

[a]*Department of Digital Business, Johannesburg Business School, University of Johannesburg, Johannesburg, South Africa*

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Leveraging the engineering ecosystem to prepare TVET graduates that the South African manufacturing industry needs

Arnesh Telukdarie*[a]
Inderasan Munien[a]

[a]*Department of Digital Business, Johannesburg Business School, University of Johannesburg, Johannesburg, South Africa*

This study investigates the claims in literature that South African TVET (Technical and Vocational Education and Training) colleges, a key component of the engineering ecosystem, fail to produce graduates who meet industry requirements. A Likert-scale questionnaire was developed and deployed to manufacturing businesses in South Africa. The results confirm the proliferation of negative perceptions of TVET graduates in South Africa. Advanced statistical analysis and simulation techniques applied to the data confirm the key latent variables impacting the sector as graduate capability, technology, curriculum innovation, technical skills, soft skills, business performance, employability, and graduate turnover. Furthermore, a systems dynamics model was developed based on the causal relationships of observable variables constituting the university–TVET–industry nexus of the engineering ecosystem. The simulation results reveal significant potential for growth in new business activity and employment for TVET graduates. This could be achieved by facilitating collaboration across the engineering ecosystem. Thus, business input into curriculum development would be increased, universities would contribute to curriculum innovation and evolution, and soft skills would be enhanced for both new and existing graduates.

Keywords: TVET, engineering ecosystem, systems dynamics, employability, food and beverage sector, skills

Introduction

Research indicates that technology evolution is a key driver of skills requirements for occupations, impacting new entrants to the labour market and mature workers (Bandura & Grainger, 2019). According to Bandura & Grainger (2019), existing education systems in many countries across the world are failing to adequately prepare the global workforce to contend with change. Consequently, a disconnect continues to grow in terms of academic and technical curricula and requisite skills for occupations with education outcomes and employer requirements (Bandura & Grainger, 2019). A rich and extensive literature analysis indicates

*Email: arnesht@uj.ac.za

that the skills development landscape in many countries across the world, South Africa included, is characterised by policies that are not in alignment with the demands of their economic sectors (Brown & Slater, 2018). TVET (Technical and Vocational Education and Training) systems fail to respond to rapid technological advancement, soft skills, and other competencies. In South Africa, the incongruity between supply and demand for skills is intensifying. The existing literature indicates that many young people in the country are languishing in poverty and unemployment arising from an absence of relevant work experience, underdeveloped or inadequate skills, and poor career guidance (Asmal et al., 2020). The TVET system is a critical component of the engineering ecosystem, functioning as a conveyer belt. It creates links between the education system and the labour market. The engineering ecosystem, being complex, depends on all its components to function optimally to generate the requisite outcomes which are to enable, support, and evolve the practices of the engineering discipline wherever they may be relevant or required.

Asmal et al. (2020) find that the unemployment rate among graduates with TVET qualifications has almost doubled from 312 000 in 2013 to 555 000 in 2019. This suggests that there is little or no linkage between TVET institutions and industries, as the skills obtained through these qualifications are not aligned with a developing economy, and fail to produce graduates equipped with the skills demanded by employers. Studies highlight the importance of collaboration between elements of the engineering ecosystem to ensure that students gain the knowledge, skills, and capabilities that employers require (Bandura & Grainger, 2019).

In South Africa, the ineffectiveness of the TVET system is well documented (Badenhorst & Radile, 2018) and characterised by ever-declining uptake rates, low employer satisfaction ratings, and indifference to TVET graduates in the academic sector (Asmal et al., 2020).

Literature review

An overview of the South African TVET sector

TVET played a central role in democratic South Africa's efforts to address persistent unemployment caused by a weak economy. However, the structure, purpose, and accountability of the TVET sector have been significantly altered and transformed by several policy initiatives instituted after the advent of democracy. Currently, there are 677 FET (Further Education and Training) colleges (50 public and 627 private) that operate under the authority of the Department of Higher Education and Training (Needham, 2019).

Public TVET colleges compete with private providers in the marketplace. They are also mandated to provide occupational qualifications, whose funding and quality assurance reside with the Sector Education and Training Authorities (SETAs). To resolve the misaligned technical competence of TVET graduates and to transform the mediocre programmes, which lacked alignment with industry requirements, the government replaced the National Accredited Technical Education Diploma (NATED) qualifications with the National Certificate Vocational (NCV) qualifications (Needham, 2019). The change reduced interest in technical TVET enrolment and the industry failed to support the programme with artisan training. Ultimately the NATED qualifications, with unchanged curricula, were re-introduced into the TVET colleges in parallel with the NCV qualifications, further diminishing the responsiveness of the TVET colleges to the demands of an advanced economy (Terblanche, 2017).

Kraak (2013) likened the South African vocational education system to that of the United Kingdom; both nations adopted a statist and centralised approach lacking industry endorsement and consequently poor employment rates among graduates. The current South African system, according to Allais (2012), contains centralised elements (standards, service delivery regulation, accountability) and decentralised elements (curriculum development, management) which fail to deliver entry-level skills comparable to coordinated systems functioning in Germany and Scandinavia. Studies on skills have found that the South African school and training system has failed to deliver the skills required in the advanced South African economy. McGrath et al. (2019) also found that a TVET qualification offered no advantage in the employment market compared to secondary school leavers. These problems are compounded by high attrition rates in TVET colleges; reports show student attrition of 72% for National Certificate (Vocational) courses offered in TVET colleges (Terblanche, 2017).

Efforts post-1994 were focused on aligning the design and curricula of the TVET colleges to the requirements of the emerging economy. Despite a variety of policy changes, the sector remains besieged by low throughput and poor assimilation of learners into industry. Further, the Human Resource Development Council of South Africa found that funding requirements and uncertainty associated with employment conditions weakened the institutional capacity within the sector to effectively surmount the long-standing challenges, resulting in the TVET colleges persisting with curricula that were acknowledged to be outdated 25 years ago (HRDC, 2014). The diffusion of innovation, which is enabled by institutional investors, is stymied by the absence of agility and relevance in TVET colleges (Vona & Consoli, 2014).

Relationship between the TVET system and employment

Studies have been conducted on employers' views about TVET graduates' employability to determine whether the TVET curriculum is compatible with employers' needs (Kintu et al., 2019). Employers' requirements include a relevant curriculum (implying a process to constantly update and add to the curriculum) and minimal (or zero) nett cost obligations arising from remuneration and training expenditure (Kintu et al., 2019).

Papier et al. (2016) conducted a study across the engineering, retail, wholesale, hospitality, and service sector. They examined employer perceptions of TVET programmes and the graduates produced. The results are quite detailed and demonstrate dissatisfaction among employers with graduate work readiness and attitude. Also, employers in the engineering industry sector highlight an absence of sufficient competence in basic academic knowledge among TVET graduates and maintain that there is a lack of will to remedy the disparity (Papier et al., 2016). Overall, the study found that resolving the following skill gaps is crucial to improving employers' perceptions of TVET graduates across sectors:

- Basic theoretical and practical knowledge;
- Communication skills;
- Computer skills;
- Customer service skills;
- Ability to take initiative;
- An ethic of hard work;
- Self-management skills;
- Willingness to learn;
- Truthfulness/ethics;
- Accountability/taking responsibility;
- Being presentable or well-groomed;
- Respectful attitude;
- Resilience to cope with long hours;
- Punctuality;
- Interviewing skills;
- Professionalism;
- A positive attitude;
- Telephone (mobile phone) etiquette;
- Discipline; and
- Teamwork skills.

The authors reduced these skills to five factors:

- Professionalism;
- Communication skills;
- Workplace understanding;
- Values and ethics; and
- Application of college learning to the workplace.

The authors developed a generic programme and implemented this curriculum enhancement programme in collaboration with selected colleges, SETAs, and employers. The project outcomes revealed that students and employers valued the intervention and showed a positive impact on both employer and graduate experiences and perceptions (Papier et al., 2016).

Conventional ecosystems are biological communities interacting on multiple levels. Applying the analogy to the field of engineering requires an expansion incorporating the interactions between the institutional actors possessing a common interest in the field and the hierarchical relationships between the diverse actors (Klassen & Wallace, 2019). Klassen and Wallace (2019) identified the key challenges confronting higher education institutions (HEIs) within this framework:

1. Pressure to enrol more candidates;
2. Desire to increase research outputs;
3. The oversupply of degreed engineering graduates; and
4. Difficulties of engaging with the private sector due to cultural differences or complex bureaucracies.

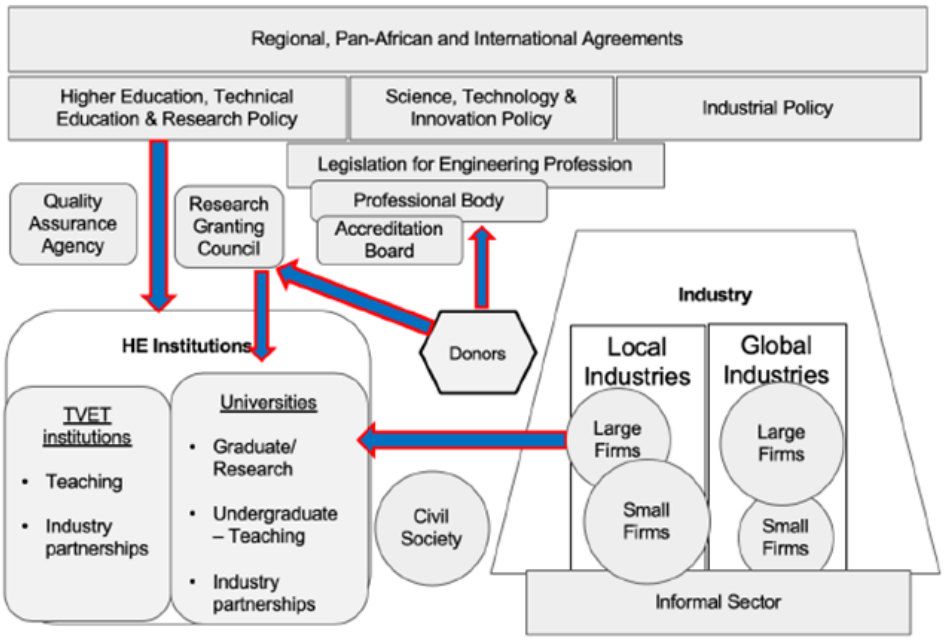

Figure 1: *Engineering ecosystem framework (Klassen & Wallace, 2019)*

Teis (2021) highlighted new challenges for future labour markets initiated by industry digitisation and automation. In response to rapid digitisation, education, and training institutions are now preparing students for evolving and emerging industries instead of outdated occupations. As a result, there is now a concerted effort to align curricula to generate the advanced skills needed for the 4IR. This ongoing effort ensures that students are equipped with the knowledge and skills needed to succeed in the rapidly changing economy of the present and future.

Vocational Education and Training (VET) in the United Kingdom began with a reluctance from the government to participate in the programme, and after a brief period of intervention after World War II when a levy and grant system was legislated, VET in the UK was an employer-led voluntary system. During the 1980s the UK system, being employer-led, was concentrated on company-based skills acquired via National Vocational Qualification skills rather than more generically applicable skills throughout a sector (Terblanche, 2017). The system oscillated between demand and supply control until the present, with the current structure shown in Kraak (2016). The occupational qualification pathway is only followed by 10% of early school leavers. This is primarily due to social and institutional perceptions relating to the prestige and status associated with VET in the UK.

The TVET system in the Netherlands was restructured by merging colleges, adopting outcomes-based education, implementing a National Qualifications Framework, and instituting performance management. Employers play a leading role through sector skills councils in the Netherlands. These councils identify and communicate requirements to an umbrella body which is translated into curricula approved by the government. Employers, who are accredited by sectoral body officials, are the primary training providers in the system. As opposed to the UK system, the Netherlands system is characterised by an institutional alignment between engineering ecosystem actors.

Like the Netherlands, the German system is aligned between the supply and demand components within the engineering ecosystem. The German system consists of a compulsory four years of primary schooling and five years of secondary schooling. Thereafter, learners have the option to enter a dual system, which provides training that alternates between vocational schools and employer sites, and which is accessible to any learner completing the compulsory nine years of education. After three years of vocational training, graduates can enter employment. The German system is facilitated by the government and predicated on

stakeholder consensus, including collectively constructed qualifications that enjoy broad recognition (Terblanche, 2017).

Policy variation in South Africa has resulted in institutional instability (Kraak, 2016), which detracts from the objectives of the TVET system to reduce unemployment, inequality, and the burden on institutions of higher education. Buthelezi (2018) found that TVET graduates in South Africa struggle to find employment and rarely create entrepreneurial activity. Employers have no confidence in the TVET system, primarily due to non-inclusive processes, while Buthelezi (2018) opines that TVET graduates 'have unintentionally been used by the system as subjects for experimentation'.

Currently, obtaining vocational education and training is achieved via NC(V) programmes, NATED programmes, learnerships and apprenticeships, technical schools, and occupational qualifications (Badenhorst & Radile, 2018). Statistics South Africa (2014) reported shortages of artisans, technicians, and engineers, and Field et al. (2014) posit that youth unemployment results from a mismatch between skills and employment opportunities. Recently, the International Institute for Management Development ranked South Africa 61st out of 64 countries for skilled labour availability (IMD, 2023).

Marock et al. (2016) reported that a colleges improvement project conducted in the Eastern Cape and Limpopo provinces between 2011 and 2014 suggested that campus improvement initiatives require broad engagement from all stakeholders (college management, learners, employers, teachers, financers and government) and a focused improvement on teacher development and student support (tutorial programmes). Gewer (2016) posited a framework to effect TVET transformation.

Fannon et al. (2019) propose that TVET lecturers be subjected to mandatory industry-based placements to improve practical skills and comply with a continuous professional development plan to facilitate knowledge transfer. Field et al. (2014) suggested that improvements to the South African TVET system must include: resolving the confusing extant architecture to provide clear vocational pathways; linking the provision of vocational training with employer needs; reviewing skills funding policy and framework; improving teacher and management capacity; and focusing on completion and transition.

The HEI landscape and engineering outcomes

Yokogawa (2021) shows that the extent to which an industrial entity is automated varies between human-controlled processes and technology-mediated collaborative ecosystems operating autonomously. This transition from manual to automatic depends on the availability of skills and knowledge generated by HE ecosystems in their entirety. The engineering outcomes necessary in today's technology-driven economy are determined by the quality of candidates emerging from the HE system. In acknowledgment of the criticality of the quality of the skills and knowledge supplied to a transitioning economy, Teis (2021) noted the South African government's prioritisation of an industry-aligned curriculum presented by lecturers with industrial experience. Further, the Minister of Higher Education, Science and Innovation highlighted the central role of industry in generating the requisite competencies by investing in infrastructure and providing experiential training. The HEI ecosystem remains the primary factor determining engineering outcomes driving technological evolution in the industry.

Kraak (2016) accentuated the importance of the HEI ecosystem to the engineering discipline by pointing out that industrial growth drives innovation evolution, and that work-ready graduates enable growth. The perpetual interplay between these two forces drives the development of the proximal engineering discipline as technology inevitably involves the influx of cutting-edge knowledge in materials, systems, processes, and design.

The gap in the existing literature

Whilst the literature indicates that there seems to be a disjuncture between what is provided by TVET institutions and the needs of the labour market, there is a scarcity of published data peculiar to the South African engineering ecosystem on the topic. The current body of literature identifies several challenges facing the South African TVET system, including a lack of coherence, resulting in fragmentation in the system. According to Badenhorst & Radile (2018), the fragmented TVET system often causes disengagement by students, lecturers, and eventually prospective employers. This is supported by academic scholarship on TVET and skills development that illustrates that generally, TVET institutions are failing to respond to the needs of the labour market effectively (Kruss et al., 2017).

Research illustrates that it is important to provide students with the skills needed to meet the demands of the changing industry (Asmal et al., 2020). Badenhorst & Radile (2018) suggest that TVET colleges' administrative and corporate service functions must be strengthened to

enhance performance. One of the important findings emerging from the existing literature is that the strategies and mechanisms put in place for training and skills development to address the TVET system such as work-based learning, centres of specialisation, the Lead SETA–TVET Project, and TVET College Improvement Project (Kruss, et al., 2017), among others, have failed to achieve the desired results. The extant literature does not address the perspective of manufacturing businesses specifically, nor does it evaluate the potential implications of instituting business-generated reforms on TVET curricula on the wider engineering ecosystem, of which TVET institutions form an integral part.

The primary objective of this study is to address the gap in the literature specifically related to the business–HEI–TVET nexus as key constituents of the engineering ecosystem by identifying the factors businesses in the manufacturing sector view as central to improving the utility of TVET graduates to business success. This is attained by:

- investigating the key insights relating to the TVET system as part of the engineering ecosystem in the manufacturing sector;
- examining the integration of the TVET system into the engineering ecosystem in terms of the adequacy and alignment of TVET outcomes with the needs of the system; and
- evaluating the impact of these integration strategies on the growth of new businesses in the sector using modelling and simulation.

In pursuit of the stated objective, the research addresses questions relating to the adequacy of the contemporary curricula pertinent to the Food and Beverage SETA strategy, the potential for absorption of TVET graduates upon improved integration into the engineering ecosystem, and the key tenets of any new SETA outreach programmes aimed at expediting knowledge evolution in a pervasive manner throughout the food and beverage industry.

Research methodology

Study framework and questionnaire development

The study adopted a mixed methods approach which combines both quantitative and qualitative methods to provide a broader and more complete vision of the problem (Almeida, 2018). A comprehensive global review of existing literature was conducted, and a nationwide (SA) sector-specific research questionnaire, predicated on the literature review and employing

Likert-scale questions, was deployed. A detailed analysis of the questionnaire results was conducted to analyse the current South African food and beverage status. This aimed to provide a current benchmark.

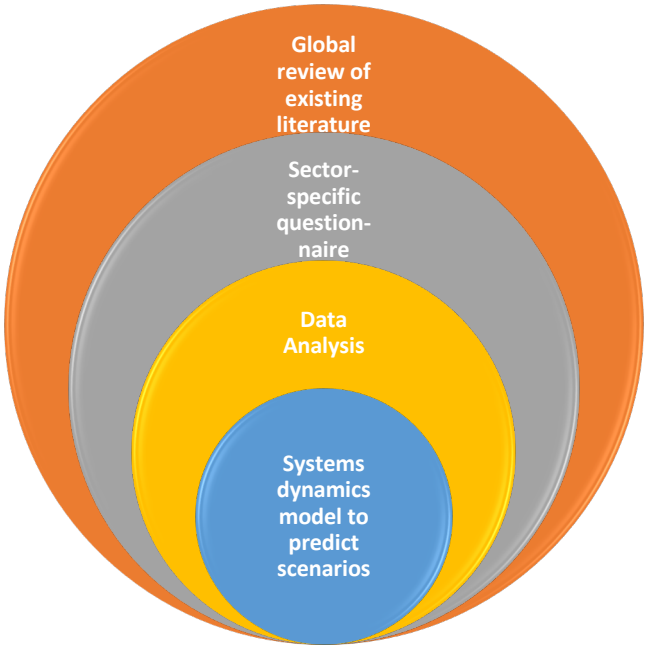

Figure 2: *Research framework*

The literature was also reviewed to determine requirements in terms of skills required for employment, and different TVET curriculum models. The results of the literature review were used to design a questionnaire to determine whether the TVET curriculum in South Africa was appropriate to the skills needed by the food and beverages manufacturing sector.

The themes identified in the literature were analysed into questions designed to validate the findings in the literature and, more importantly, to obtain a detailed understanding of the specifics related to each theme. For example, the need for engineers to be equipped with soft skills was a finding pervasive in the literature. Soft skills are non-technical transferrable skills, and a series of questions was included to validate this finding and to understand the importance that the industry placed on this suite of skills.

Research sample and questionnaire administration

The target population for this study was the 13 987 companies in the South African food and beverages manufacturing sector. The study used probability sampling to ensure that the characteristics of the sample size reflected those of the larger population. Contact details of all

small, medium, and large companies (levy-paying and non-levy paying) were extracted from the SARS Levy Database (2020). In total, a sample size of 2 628 companies (email addresses extracted from the database) was drawn for the population. All the companies selected for the survey were manufacturing companies whose products can be categorised as baked goods, cereals, confectionary, snacks, beverages, dairy, food preparation products, or processed meat or vegetables. As manufacturing businesses operating in a competitive marketplace, those selected are in a race for productivity, driven primarily by technology and operational improvements. Both technology and operational excellence are enabled by the engineers delivered from the higher education system, which combines with industry in a critical linka in the engineering ecosystem.

The online questionnaire was sent to all the 2 628 companies together with an email explaining the purpose of the study and inviting recipients to click on a link to complete the questionnaire. Following this, reminder emails were sent to those who had not completed the questionnaire to improve the response rate. Moreover, telephonic questionnaires were also conducted to further increase the response rate. 207 responses were received. Responses were received in a format that could be transferred to Microsoft Excel for analysis.

Development of the systems dynamics model

Systems dynamics is uniquely adapted for understanding social, environmental, and systemic interactions due to a top-down, macro focus and a limited need for assumptions (Muravev, 2019). Further, the emergent behaviour arising from complicated cause-and-effect interactions is readily reproduced by systems dynamics models (Nielsen, 2018). Klassen and Wallace (2019) viewed the engineering discipline as being part of a complex ecosystem evolving under the influence of dynamic forces including technological change and knowledge and skills

Current studies encounter the persistent challenge of predicting the impact of systemic and other changes on improvement initiatives. To remedy this shortcoming, the research team developed a systems dynamics model predicated on the qualitative survey feedback. The questionnaire responses were evaluated using confirmatory factor analysis to establish the latent impact of the following five constructs on the integrated engineering ecosystem:

- TVET training qualifications;
- SME uptake;
- Industry uptake;

- SETA;
- Higher education; and
- External factors.

These factors were selected based on the study objectives, together with Klassen & Wallace's (2019) engineering ecosystem framework, and the various causal loops were integrated to form a coherent systems structure commensurate with extracts from international best practices. The factor loadings quantified the impacts of the key constructs on the system and generated the dynamic profiles of the system variables resulting from the complex reciprocal interactions over time.

The integrated systems structure (see Figure 7) was evaluated using algorithmic techniques to establish the long-term impacts of various scenarios on the engineering ecosystem and its constituent systems.

Results

The research identifies the key facets for prospective engagement between operating entities in the food and beverage sector in South Africa and the TVET institutions which exist to deliver skills to the industry. The key parameters necessary for the appraisal of a TVET system as elucidated in the literature were the relevance of the curriculum, the familiarity of graduates with contemporary technology, the hard and soft skills, the employability of graduates, and perceptions of industry actors regarding the prospective value of TVET graduates.

The research instrument (questionnaire) was developed to specifically illuminate the key issues accentuated in the literature and to address the gap in the literature relating to identifying perceptions necessary to leverage the engineering ecosystem in service of manufacturing in South Africa. Importantly the literature review and subsequent questionnaire were structured to align with a systems approach. This is detailed in the methodology above, with the systems focusing on the SETA, skills, and business cycles. The results from the questionnaire are presented below followed by the systems construct and the systems dynamics model. The research study was structured to deliver on the individual variables affecting skills delivery, the factoring of these variables into systems, and finally the interaction of the collection of systems as an ecosystem.

The profile of the sample was established based on two categories: size, and SETA chamber. The respondents submitted the requisite information with the data (shown in Table 1) showing the comparable participation levels between the different categories of business in the sector.

Table 1: *Participation levels in business category*

Respondent business category	
Large	42%
Medium	31%
Small	27%

The distribution of respondents among the five chambers of the food and beverage manufacturing sector is shown in Table 2. The majority of the respondents are from production, processing, and preservation of meat, fish, fruit, vegetables, oil, and fats (28%), followed by the manufacture of food and preparation products (25%).

Table 2: *Response rate of the various chambers*

To which food and beverage SETA chamber does your business belong?	
Manufacture of Breakfast Products	15%
Beverage Manufacturing	17%
Dairy Manufacturing	15%
Manufacture of Food Preparation Products	25%
Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetables, Oil, and Fat	28%

The first section of the questionnaire focused on industry perceptions relating to the ability of the TVET system to fulfil the skills requirements of the food and beverage industry sector. Various researchers have alluded to a skills mismatch between industry and TVET graduates, and the questionnaire was designed to investigate this perception within the food and beverage sector in South Africa. The responses (as shown in Figure 3) highlight a general dissatisfaction with the graduates' capabilities in all disciplines relevant to the manufacturing sector, with the best response achieved by administration TVET graduates (30% of respondents dissatisfied).

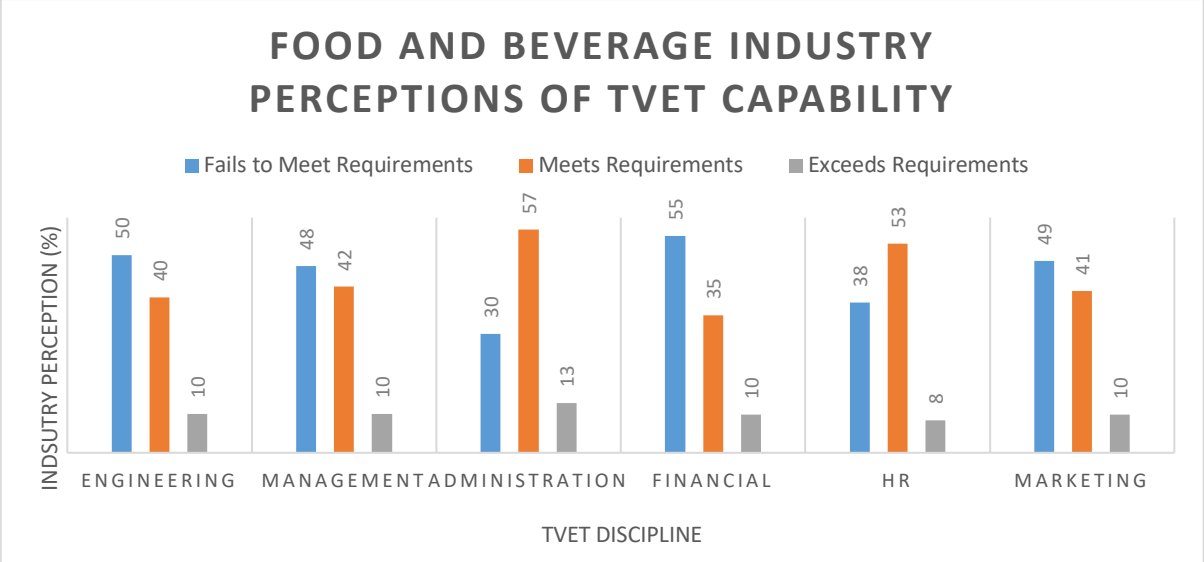

Figure 3: *TVET graduate capabilities as viewed by the employers*

The results indicate that all qualifications assessed by respondents had large proportions failing to meet industry requirements. 50% of engineering graduates from TVET institutions failed to meet employer requirements. This is similar to the perceptions relating to TVET graduates undertaking other fields of study. This result confirms the disconnect between the two key components of the engineering ecosystem, highlighted extensively in the literature, namely industry and TVET institutions.

In the literature, the failure of the South African TVET system to respond to the need for soft skills is cited as a key limitation. This research investigated the perceptions within the food and beverages (FoodBev) employer community relating to soft skill requirements amongst TVET graduates in the South African food and beverages sector. Figure 9 in Appendix A illustrates that the overwhelming majority (84%) of employers in the food and beverages sector indicated that soft skills should be included in the TVET curriculum with the need expressed as 'moderate' amongst 48% of the respondents, 'major' amongst 18% and as 'must have' amongst 19% of the respondents.

The employers were requested to propose the portion of the TVET curriculum that should be dedicated to soft skills. Figure 10 in Appendix A illustrates that 29% of employers indicated that a 'significant' portion of the curriculum should be devoted to soft skills, 9% indicated major and 45% indicated minor. The inclusion of soft skills in the TVET curriculum is thus supported by 83% of employers, including 29% indicating that a 'significant' portion of the curriculum should be devoted to soft skills (see Figure 10, Appendix A). In addition, 88% of

the sample of food and beverages employers believed that soft skills would improve graduate effectiveness in the workplace, with 36% predicting a 'significant' improvement and 9% anticipating a 'major' improvement.

Pervasive in the literature (Terblanche, 2017) is the culpability of the antiquated curriculum in generating graduates lacking acceptable levels of proficiency in technology-related disciplines. Respondents in the food and beverage sector concurred with the literature that TVET graduates' proficiency in engineering and technology-related disciplines is lacking, as demonstrated in Figures 4 and 5.

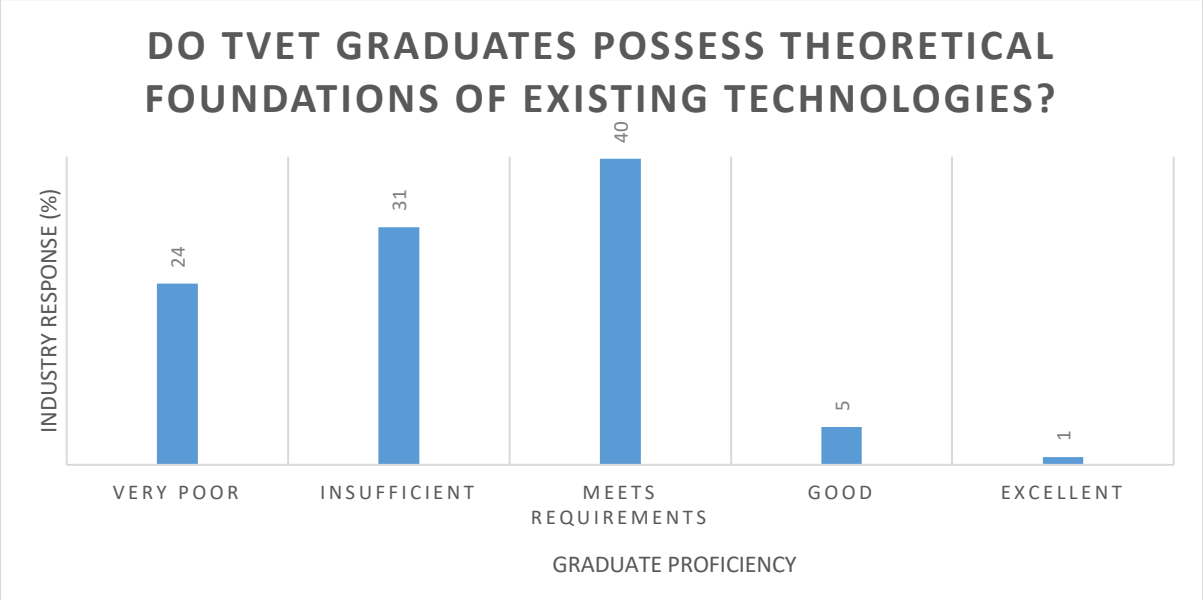

Figure 4: *TVET graduates' theoretical foundation in technology-based disciplines*

A minority (39%) of food and beverage sector respondents were satisfied with TVET graduates' theoretical foundations. Only 5% rated TVET graduates' engineering and technology proficiency as 'good' and 1% as 'excellent'. The majority of respondents (55%) rated the TVET graduates either as 'very poor' (24%) or 'insufficient' (31%) concerning technical knowledge. As an integral component of the engineering ecosystem, the levels of dissatisfaction with TVET engineering graduates reflect the lack of cohesive and integrated action within the engineering ecosystem and highlight the necessity for coordinated action amongst higher education, industry, and government policy to ensure the smooth functioning of the entire ecosystem. The implications of such coordinated action are investigated in subsequent sections.

As the proliferation of innovative technologies driven by the Fourth Industrial Revolution (4IR) increases in the food and beverage sector specifically and manufacturing in general, the capacity of TVET graduates to work with innovative technologies becomes critical to the sector's ability to remain competitive in a globalised economy.

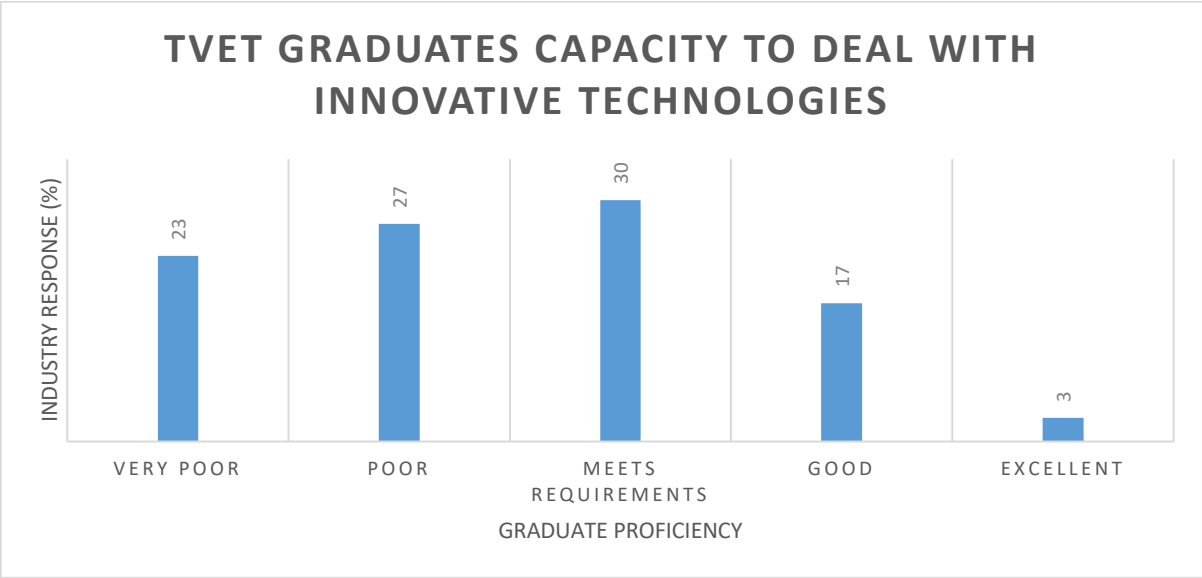

Figure 5: *TVET graduates proficient with innovative technologies*

Only 50% of respondents rated current TVET graduates as capable of meeting the challenges of the 4IR, of which the majority (30% of the total sample) indicated that the graduates just 'meet requirements'. The remaining respondents rated the TVET graduates' ability to contend with innovative technologies as either 'poor' (27%) or 'very poor' (23%). Having been identified as central to South Africa's competitiveness going into the future, industry initiatives to implement 4IR strategies are constrained by the availability of the requisite skills in South Africa. The response from this questionnaire suggests that the majority of industries in manufacturing in South Africa have poor confidence in TVET graduates' capability to give effect to 4IR investments, thus minimising commitments to 4IR strategies in South African manufacturing. Here again, the imperative of coordinated action from all components of the engineering ecosystem is shown to be critical to achieving strategic outcomes essential to ensuring the sustainability of the South African economy.

The vast majority of respondents (81%) indicated that appropriately skilled TVET graduates would positively affect business performance, with 46% anticipating a 'significant' improvement and 19% expecting a 'major' enhancement in business performance (refer to Figure 11, Appendix A). As per the literature (Papier et al., 2016), TVET-trained employees

can significantly contribute to businesses. The ongoing disjuncture between the key elements of the engineering ecosystem manifests in material losses for the manufacturing sector. The extremely high proportion of responses indicating significant and major improvements that would arise from properly skilled TVET graduates highlights the lost opportunities which are ultimately borne by society at large.

Further, nearly all the respondents (96%) indicated that they would increase their complement of TVET graduates if the graduates were appropriately skilled, with 45% of business projects employing an additional 6 to 10 TVET graduates (refer to Figure 12, Appendix A). The total potential for employment exclusively restricted to the cohort of respondents (n = 202) at the low, midpoint, and high levels within the ranges reported suggest additional opportunities for 1 009 (low end of the range), 1 516 (midpoint of range) or 2 235 (high end of the range) TVET graduates. That the overwhelming majority of respondents would increase the uptake of suitably skilled TVET graduates is a strong indicator of the immediate need for TVET skills, the opportunity cost currently being suffered by the economy, and the imperative for coordinated action from the engineering ecosystem. The results also suggest a potent opportunity for employment and economic growth within the food and beverage sector if the sample projections are extrapolated to the population.

The perception that the TVET programme curriculum should be improved by evolution innovation is affirmed by 84% of the respondents from the Dairy Manufacturing Chamber and 93% of the respondents from the Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetable, Oil and Fats Chamber. In the beverage manufacturing chamber, only 26% of respondents believe that innovation evolution should constitute a ‘major’ portion of the TVET curriculum renewal (Figure 13, Appendix A).

Figure 6 illustrates that 81% of respondents from the Manufacture of Breakfast Products Chamber and 98% of respondents from the Production, Processing, and Preservation of Meat, Fish, Fruit, Vegetables, Oil, and Fat Chamber believe that innovation evolution content would improve TVET graduate workplace performance. A full 60% of the respondents believe that inclusion of innovation evolution in curriculum development will have either a ‘significant’ or ‘major’ impact on TVET graduate workplace performance. Innovation evolution is best affected by high levels of integration between the components of the engineering ecosystem as well as higher levels of knowledge dissemination between the universities, which are research-focused institutions operating at the leading edge of knowledge, and the TVET colleges.

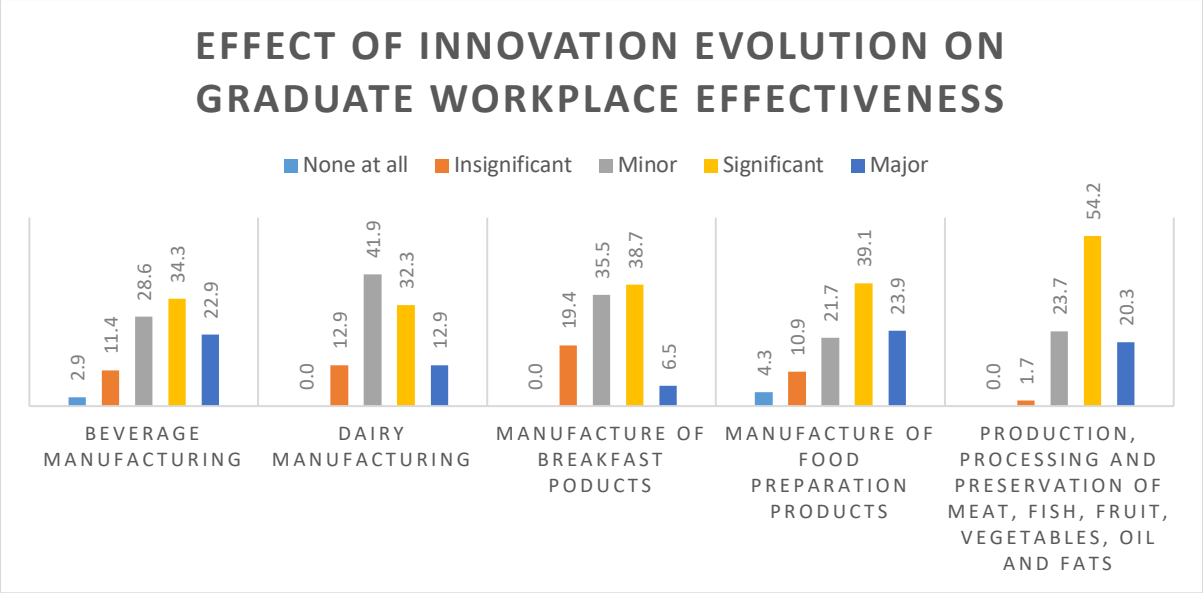

Figure 6: *Innovation evolution and workplace effectiveness*

The results presented in this section confirm that respondents' in the food and beverage sector experiences of TVET graduates are compatible with the findings in the literature, primarily about the skills gap, and the respondents' expressing a strong sentiment that sector involvement in curriculum development and soft skills education will have a transformative impact on TVET graduate workplace effectiveness. A distinctive finding from the sample is the strong expression of the need to incorporate innovation evolution as a critical component of the curriculum development process.

Systems modelling

This investigation ultimately evaluated the implications of enhanced cooperation strategies between the elements of the engineering ecosystem, with government policy represented by the FoodBev SETA. The key variables evaluated were:

- Curriculum innovation evolution;
- SME maturity;
- Employment;
- Impact of technologies;
- Soft skills;
- Hard skills;
- Graduate turnover within the sector.

Questions intended to ascertain perceptions relating to each of the aforementioned parameters were included in the questionnaire and the appropriateness of the questions to the related magnitudes was evaluated using confirmatory factor analysis (CFA) conducted with the Quantec Stata statistical package. The results of the factor analysis confirm the correlation of the observable variables with the aforementioned dimensions, thus confirming the validity of the questionnaire.

Quantification of the Likert scale raw data obtained from the measuring instrument was used on all questions to facilitate statistical analysis and comparison. A Cronbach coefficient alpha of 0.911 demonstrated a strong alignment of the questions to the factors being measured and the internal consistency of the data. The sample consisted of 207 randomly selected respondents from a population of 1 000 businesses. The margin of error for the data was calculated to be 6.2%, validating the samples representative of the population.

A systems dynamics model was created based on the investigation dimensions verified by the CFA, using the relative factor loadings. The model arises from the structure of the causal relationships inherent in the integrated TVET and food and beverage system and is constituted of the observable variables identified in the questionnaire. The integrated causal loop diagram developed in Figure 7 is based on Klassen and Wallace's (2019) engineering ecosystem framework. The pool of graduates in the system (Graduate Pool in the model) is a key response variable in the system together with the FB New Business Growth and Entrepreneurial Activity.

The various sub-systems account for the education and qualification of graduates into the system, ingress of graduates in the food and beverage sector from other industrial sectors, movement of graduates out of the system, and SETA-mediated industry input into TVET curricula upskilling of graduate soft skills and hard skills, and insemination of innovation evolution into the TVET programme.

The questionnaire feedback and the results arising from the subsequent statistical analysis provided the input quantities to define the key dimensions of the model. The integration of the various reinforcing and balancing loops produced by the component systems was effected by linking the common variables between the systems. The selection of the variables and constituent systems was guided by Klassen and Wallace's (2019) engineering ecosystem framework.

The accumulation variables in the integrated system were formulated to provide insight into the key aspects under investigation in the system of systems. A key benefit of systems dynamics is that the temporal profile of the variables was obtained in a manner that included the reciprocating effects of the variable on the elements within the system, and the effect of the system on the variable. As such, dynamic equilibria and unconstrained growth of accumulated quantities provide insight into the fundamental structure of the model during the validation and calibration processes.

The system crucially includes the implications of curriculum improvement on graduate workplace effectiveness and the corresponding implications for food and beverage business performance. The combination of the entrepreneurial activity in the sector and the manifestation of the system structure on business performance is presented as New Business Growth in the model. The model accommodates the feedback loops inherent in the system, providing a more realistic representation of the TVET–FoodBev system.

The model provides the predictive capacity to establish the effects of changes to the observable variables on the research dimensions and the key response factors within the food and beverage industry sector, viz., workplace efficiency, TVET graduate uptake, the pool of TVET graduates available to the sector, food and beverage business performance, and new business growth in the sector. The emergent characteristics inform decision making and resource allocation in constrained environments.

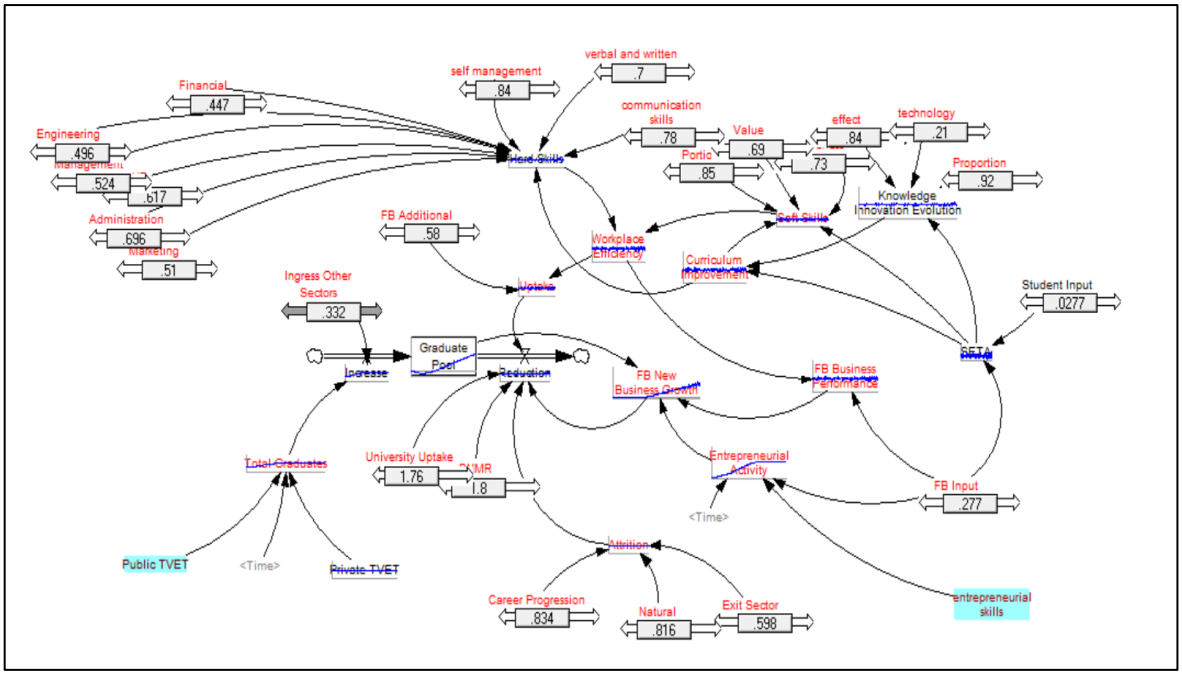

Figure 7: *Systems dynamics model*

The systems dynamics model (Figure 7) developed following the questionnaire data indicates that any TVET curriculum improvement propelled by innovation evolution will improve the hard and soft skills of TVET graduates, resulting in increased graduate effectiveness in the workplace. This will contribute in turn to improved food and beverage business performance, ultimately leading to growth within the sector. The growth of business will deplete the pool of graduates which will constrain growth until the pool is replenished at higher levels from the TVET system and other industrial sectors refuelling the cycle of growth. The model facilitates strategy development by evaluating the deployment of initiatives on the key variables driving growth in the sector. The key value of the model is in using the systems dynamics methodology to simulate integrated inputs with feedback mechanisms to predict tactical and strategic outcomes.

The baseline model was set up on Vensim, a specialty systems dynamics simulation software package. Systems dynamics models reflect systems behaviour at a strategic level which manifests over extended periods; hence the model was set up to run over 240 months (with monthly iteration intervals). The structure of the model was laid out as per the causal relationships discussed above. The baseline scenario (Figure 14, Appendix B) was established on the results of the questionnaire feedback and the relative interactions between the observable variables within dimensions was obtained from the confirmatory factor analysis. The

mathematical relationships between the variables were designated following the relative interaction between the variables, as obtained from the measurement questionnaire and the CFA results indicating the relationship between the system dimensions. The results obtained from the baseline simulation were used to ascertain the impacts of changes in observable variables on the two key response variables in the system, the Graduate Pool and New Business Growth. Graduate Pool is the only accumulation variable in the system, and it monitors the changes in the pool of available graduates over time. The baseline inputs for each variable are shown in Figure 14, Appendix B.

The baseline model reflects the hypothetical scenario constructed exclusively from FoodBev sector respondents' perceptions of the impacts of observable variables which are primarily related to TVET graduate quality and the impact of curriculum changes on the overall TVET–FoodBev system. The model was first run to illustrate the baseline scenario which served as the basis for comparison for subsequent changes enacted to investigate specific scenarios. The results obtained for the two key response variables in the baseline scenario are shown in Figure 14, Appendix B. The comparisons with the data in the subsequent scenarios were conducted based on indexes, with Graduate Pool initially at an index value of 100 and FB New Business Growth at a value of 0. In the figure, the Graduate Pool shows an initial decline arising from the increase in demand for graduates stimulated by the improved curriculum. The system does not initially possess the capacity to supply the required number of graduates; however, lower graduation reduction rates allow the accumulation of a pool of graduates over the system requirements.

The Graduate Pool and FB New Business Growth variables reached maximum index levels of 1 200 and 0.15 from initial values of 100 and 0 respectively. The Graduate Pool achieved a minimum value after 58 months, while the FB New Business Growth reached a minimum value after 45 months. In terms of the model, the baseline profiles of the variables were driven by the improved curriculum creating demand for more graduates. These graduates had a significant positive impact on company performance due to improved workplace effectiveness, ultimately driving new business growth in the food and beverage sector (FB New Business Growth).

To investigate the effect of the food and beverage sector input into the TVET curriculum, the level of FB Input into the TVET curriculum development was doubled to 0.6, from the baseline value of 0.3 in the first scenario (Figure 15, Appendix B). The Graduate Pool assumed a similar profile as the baseline profile of the variable; however, the maximum value reached

was 688, almost half the final graduate pool relative to the baseline. The FB New Business Growth variable also reached a final level double that of the baseline value. The number of graduates in the pool declining indicates higher employment rates arising from the twofold increase in new business growth in the sector. This result shows that if the system behaved in accordance with respondents' perceptions, input from the food and beverage sector into the curriculum development could translate into proportionate new business growth in the sector.

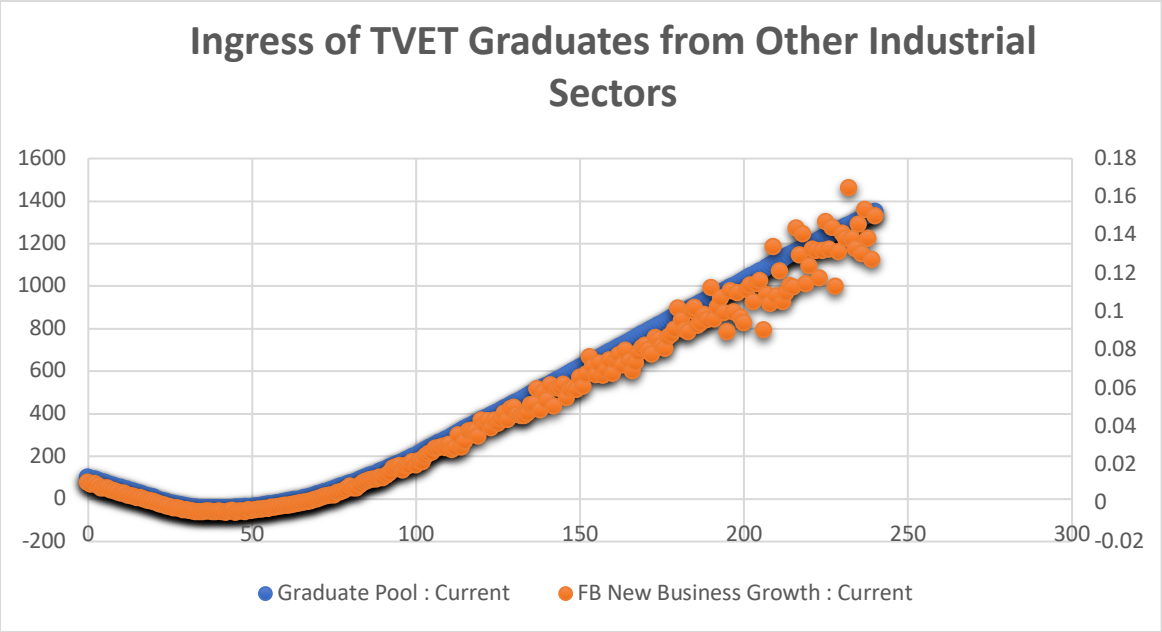

Figure 8: *System dynamics model ingress of graduates*

The minimum levels reached by the Graduate Pool when the number of TVET graduates from other sectors into the food and beverage sector doubled was higher than the baseline minimum value for this variable. However, at 1 348, the Graduate Pool surpassed the baseline maximum, demonstrating that graduate ingress is not a desirable situation. An excessive accumulation of graduates leads to unemployment and dissatisfaction in the sector. Irrespective of the availability of graduates in the available pool, the New Business Growth remains at the same levels as the baseline conditions. This result indicates that well-qualified graduates possessing the requisite skills to function effectively in the workplace obviate any need for inter-sector movement of TVET skills.

In Figure 16, Appendix B, the effect of doubling the attrition rate of graduates from the FoodBev sector on the Graduate Pool and New Business Growth is shown. The deficit in the Graduate Pool (–162) does not exceed the deficit achieved when the food and beverage sector

provides input in the TVET curriculum development (–177). FB New Business Growth only reaches a maximum of 0.09, which was the second lowest maximum in the scenario analysis. Losing key skills through attrition has a severe impact on business performance to the extent that business growth is significantly subdued.

The results presented in this section are based on the hypothesised impacts on the observable variables of the respondents' perceptions as predicted by a systems dynamics model of the system. The severity of outcomes on the Graduate Pool and the New Business Growth could also be interpreted as the importance with which the industry representatives view the effect of an escalation of the TVET failure rate and loss of graduates to universities. Also, the impact on the system of returning graduates with improved qualifications is not considered.

It is evident from the results that innovation evolution affected by technology updates and skill requirements from industry and research from universities will increase graduate effectiveness and growth in the sector. The mechanisms facilitating innovation evolution across the engineering ecosystem is an area for future study. However, curriculum improvement through innovation evolution is shown to be a significant medium to integrate the knowledge across the engineering ecosystem.

Conclusion

The results obtained from the deployment of a measuring instrument (questionnaire) to random businesses from the five chambers constituting the Food and Beverage SETA confirm the findings from the literature (Terblanche, 2017) relating to the skills gap between employer expectations and TVET graduates entering the marketplace. Except for graduates pursuing administration qualifications, the industry response showed that 50% of TVET graduates from fields relevant to the FoodBev SETA in South Africa failed to meet industry requirements. Further, also supporting the literature (Papier, 2016), 84% of respondents highlighted a need for the inclusion of soft skills education in TVET curricula, and a greater proportion of respondents, 88%, felt that soft skills will improve graduate workplace performance.

The respondents also articulated dissatisfaction with the graduates' technical knowledge, and the point is highlighted by a strong expectation amongst 96% of the cohort of respondents that graduate employment in the sector would improve considerably should this shortcoming be addressed. The respondents are most concerned about issues relating to innovation

evolution, employment, business performance, and technology capacity of graduates, which are well correlated with findings in the literature.

A key finding in this study is the respondents' prominent consideration of innovation evolution as critical to the success of devising a successful TVET curriculum, with 60% of the respondents across all the chambers indicating that innovation evolution will have a 'significant' or 'major' impact on graduate workplace effectiveness. This suggests that research-based knowledge from universities and technology skills from industry are important inputs to the TVET curriculum.

The respondents in this study have clearly articulated dissatisfaction with the existing TVET outputs; and the research identifies opportunities for improvement and presents a systems dynamics model capable of evaluating system impacts when changes are introduced into the food and beverage and TVET integrated system.

The contention that the TVET institutions are a key element of the engineering ecosystem is supported by research findings showing the extent of latent growth potential in the manufacturing sector attributed to inadequately skilled TVET graduates, and the industry responses establishing an absence of cohesion between the engineering ecosystem elements. The respondent's eagerness to employ graduates deemed suitable by industry standards exposes the cost currently being suffered by the economy at large by the poor quality of TVET graduates. The results indicate that the graduate quality issue is an outcome of a poorly integrated engineering ecosystem. The systems dynamics modelling shows that in all scenarios, the outcomes for business and employment in the sector are significant when the components of the engineering ecosystem, as articulated by Klassen and Wallace (2019), function in a coordinated manner to generate a defined outcome.

The higher education–policy–industry nexus has proven incapable of resolving the crisis in technical skills befalling South Africa, with each element pursuing an agenda in isolation. The findings of this research show that the necessary outcomes to realise the 4IR in South African manufacturing emerge from the engineering ecosystem in its entirety, functioning as a single system operating with constant feedback between the components. Innovation evolution is a key attribute of the engineering ecosystem which is made possible by the guidance of industry facilitated by policy and with intensive engagement between the universities and TVET institutions.

Further innovation evolution facilitated by TVET curriculum alignment predicated on industry and research institution input was found to be a key factor in integrating the disparate components of the engineering ecosystem to deliver growth. This could be accomplished by producing graduates with the skills required by industry. The results show that integration of the engineering ecosystem could facilitate innovation evolution by the transfer of knowledge and skills through reinforcing and balancing feedback mechanisms characteristic of an integrated ecosystem.

Most importantly, this study emphasises the interdependent nature of the engineering ecosystem and demonstrates that fulfilling the objectives of the economy cannot be achieved with singular action by individual components within the engineering ecosystem. Delivering the objectives of the economy necessarily entails integrated action from the various sub-systems constituting the engineering ecosystem. This result also accentuates the principle that the engineering ecosystem is not a figurative construct, but an essential system required to deliver outcomes that are unavailable from either its components or other systems within the economy. The emergent properties arising from the integration of the components of the engineering ecosystem are vital to the economy and society in general.

References

Allais, S. M. (2012). Will skills save us? Rethinking the relationship between vocational education, skills development policies, and social policy in South Africa. *International Journal of Education Development*, 32(5), 632–642. https://doi.org/10.1016/j.ijedudev.2012.01.001

Almeida, F. (2018). Strategies to perform a mixed methods study. *European Journal of Education Studies*, *5*(1), 137–151.

Asmal, Z., Bhorat, H., Culligan, S. Hofmeyr, H., Monnakgothla, J., Oosthuizen, M. & Rooney, C. (2020). *Skills supply and demand in South Africa.* Labour Market Intelligence Partnership, Human Sciences Research Council.

Badenhorst, J. W. & Radile, R. S. (2018). Poor performance at TVET colleges: Conceptualising a distributed instructional leadership approach as a solution. *African Education Review*, 15(3), 91-112. https://doi.org/10.1080/18146627.2017.1352452

Bandura, R. & Grainger, P. (2019). Rethinking pathways to employment: Technical and vocational training for the digital age (pp. 55-63). In *Realizing education for all in the digital age*. Asian Development Bank Institute.

Brown, E. K. & Slater, L. (2018). *The future of work in Africa: Implications for secondary education and TVET systems*. African Centre for Economic Transformation.

Buthelezi, Z. (2018). Lecturer experiences of TVET college challenges in the post-apartheid era: A case of unintended consequences of educational reform in South Africa. *Journal of Vocational Education & Training*, 70(3), 364-383. https://doi.org/10.1080/13636820.2018.1437062

Department of Higher Education and Training. (2019). National Skills Development Plan 2030. *Government Gazette, No. 43390*, 2 March.

Fannon, A. M., Pop, C. & Pretti, J. T. (2019). A review of South Africa's draft curriculum framework for industry-based and work-related work-integrated learning in TVET teacher education (pp. 31-40). In K.E. Zegwaard & M. Ford (Eds.), *Refereed Proceedings of the 3rd International Research Symposium on Cooperative and Work-Integrated Education, Stuttgart, Germany.* World Association for Cooperative Education (WACE).

Field, S., Musset, P. & Álvarez-Galván, J. (2014). *OECD reviews of Vocational Education and Training: A skills beyond school review of South Africa*. OECD Publishing.

Gewer, A. (2016). Unfinished business: Managing the transformation of further education and training (pp. 23–46). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

HRDC. (2014). *Strengthening & supporting TVET colleges for expanded access & increased programme quality - A synthesis report*. Pretoria: Human Resource Development Council of South Africa.

International Institute for Management Development (IMD). (2023, November 21). *World Talent Ranking 2023.* https://www.imd.org/centers/wcc/world-competitiveness-center/rankings/world-talent-ranking/

Kintu, D., Kitainge, K. M. & Ferej, A. (2019). An exploration of strategies for facilitating graduates' transition into the world of work: A case of vocational, technical education and training graduates in Uganda. *International Journal of Vocational Education and Training Research*, 5(1), 1–9. http://41.89.164.27:8080/xmlui/handle/123456789/634

Klassen, M. & Wallace, M.L. (2019). Engineering ecosystems: A conceptual framework for research and training in sub-Saharan Africa. *7th African Engineering Education Association International Conference. Lagos, Nigeria.* https://www.researchgate.net/publication/336681167_Engineering_ecosystems_A_conceptual_framework_for_research_and_training_in_sub-Saharan_Africa

Kraak, A. (2013). State failure in dealing with the NEET problem in South Africa: which way forward? *Research in Post-Compulsory Education*, *18*(1–2), 77–97. https://doi.org/10.1080/13596748.2013.755819

Kraak, A. (2016). Three decades of restructuring in further education colleges: Divergent outcomes across differing global vocational education and training systems (pp. 1 –22). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

Kruss, G., Petersen, I., Fongwa, S., Tele, A., & Rust, J. (2017). *Synthetic analysis on the skills development and economic responsiveness of education and training institutions in South Africa: towards an integrated public private partnership strategy for skills development in the TVET college system*. Labour Market Intelligence Partnership, Human Sciences Research Council.

Marock, C., Hazell, E. & Bina, A. (2016). What will it take to turn TVET colleges around? Evaluation of large-scale college improvement programme (pp. 103–120). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

McGrath, S., Ramsarup, P., Zeelen, J., Wedekind, V., Allais, S., Lotz-Sisitka, H., & Russon, J. A. (2020). Vocational education and training for African development: A literature review. *Journal of Vocational Education & Training*, *72*(4), 465–487. https://doi.org/10.1080/13636820.2019.1679969

Muraveva, D., Hu, H., Rakhmangulov, A., & Mishkurov, P. (2020). Multi-agent optimization of the intermodal terminal main parameters by using AnyLogic simulation platform: Case study on the Ningbo-Zhoushan Port. *International Journal of Information Management, 57,* 102133. https://doi.org/10.1016/j.ijinfomgt.2020.102133

Needham, S. (2019). TVET policy in South Africa: Caught between neo-liberalism and privatisation? *Journal of Vocational, Adult and Continuing Education and Training, 2*(2), 82–101. https://hdl.handle.net/10520/EJC-1ba524e12a

Nielsen, H.E., & Nielsen, S. (2018). System Dynamics Modelling, its concept of causality and particular relevance for providing the Balanced Scorecard thinking with a dynamic analytical framework. https://pure.au.dk/ws/files/129904811/SDMcausalityDOC_final_WP_July_2018.pdf

Papier, J., Needman, S., Prinsloo, N. & McBride, T. (2016). Preparing TVET Graduates for the workplace: Employers' views (pp. 83–1 02). In A. Kraak, A. Paterson & K. Bok (Eds.), *Change management in TVET colleges: Lessons learnt from the field of practice*. African Minds. http://www.africanminds.co.za/wp-content/uploads/2016/06/JET-TVET-text-and-cover-web-final-1.pdf

Statistics South Africa. (2014). *National and provincial labour market: Youth. Statistical release P0211.4.2.* http://beta2.statssa.gov.za/publications/P02114.2/P02114.22014.pdf

Teis, N.J.P. and Els, C.J. (2021). Knowledge, competencies and dispositions of lecturers in technical engineering in the context of advancing 41R technologies. *Journal of Vocational, Adult and Continuing Education and Training, 4*(1). https://hdl.handle.net/10520/ejc-jovacet_v4_n1_a6

Terblanche, T.E. (2017). Technical and Vocational Education and Training (TVET) colleges in South Africa: A framework for leading curriculum change. PhD thesis, University of Stellenbosch, Stellenbosch.

Vona, F. & Consoli, D. (2014). Innovation and skill dynamics: a life-cycle. *Industrial and Corporate Change*, *24*(6), 1393–1415. https://doi.org/10.1093/icc/dtu028

Appendix A

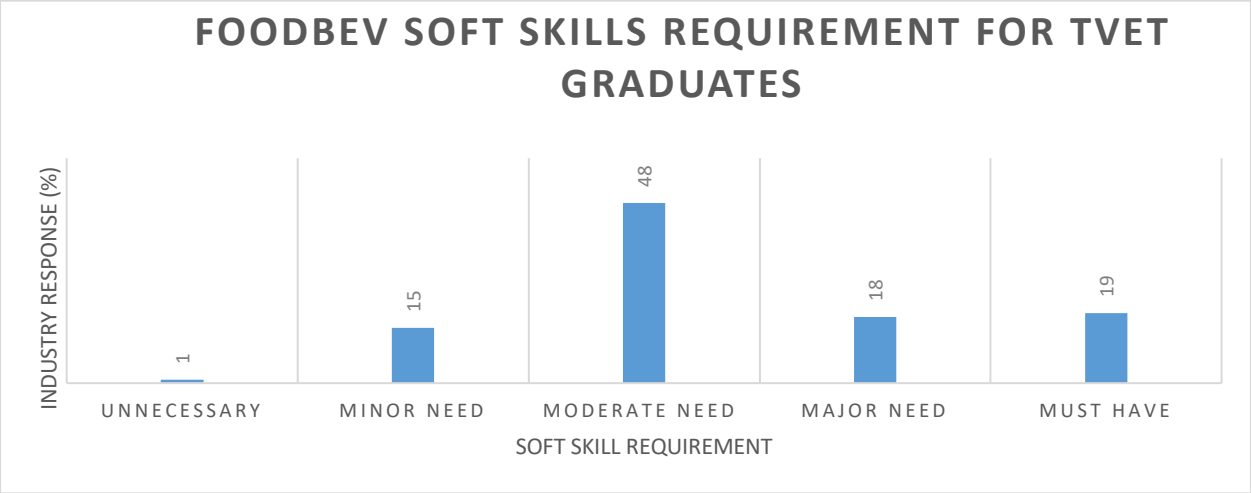

Figure 9: *Soft Skills requirement for TVET curriculum*

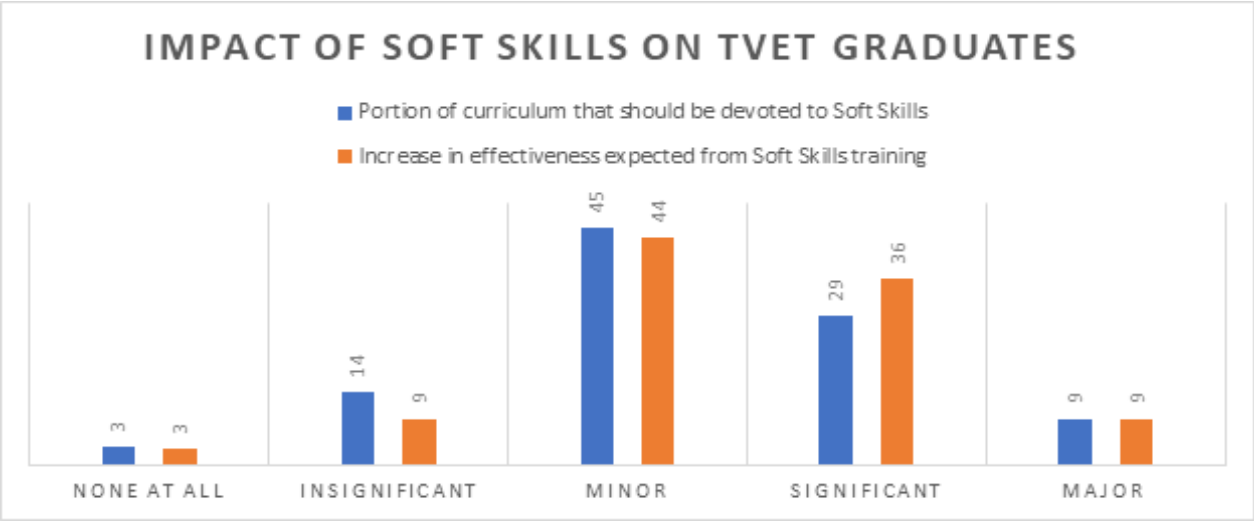

Figure 10: *Soft Skills training input and impact*

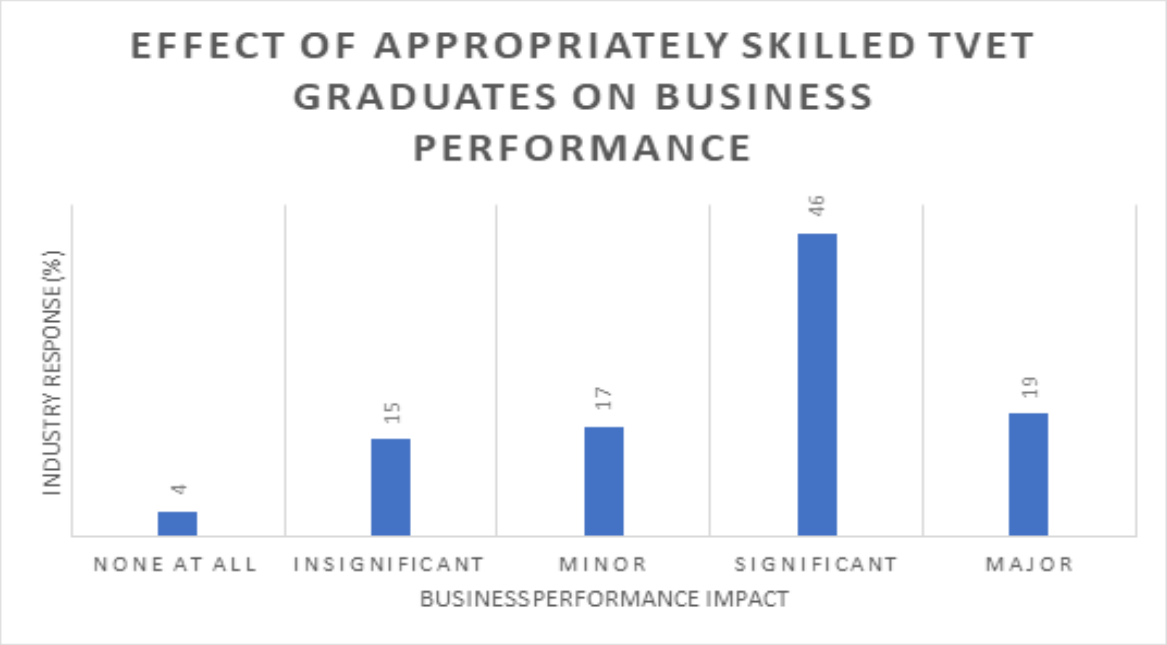

Figure 11: *Impact of appropriately skilled TVET graduates on business performance*

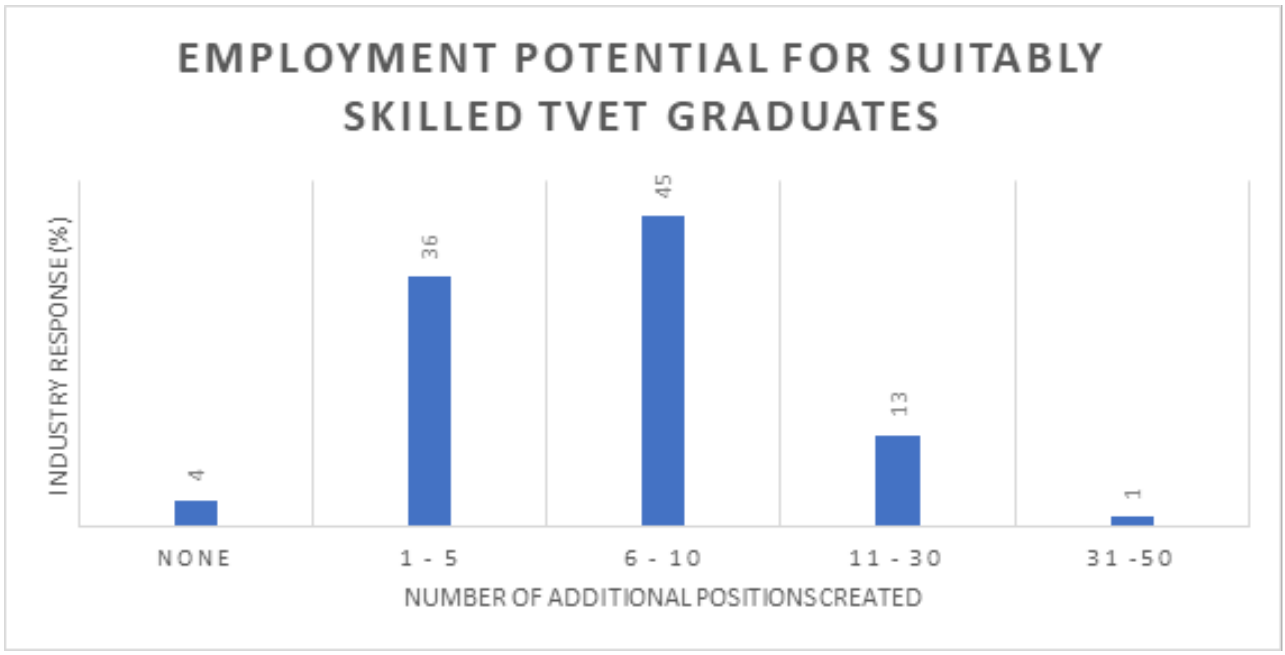

Figure 12: *Employment potential of appropriately skilled TVET graduates*

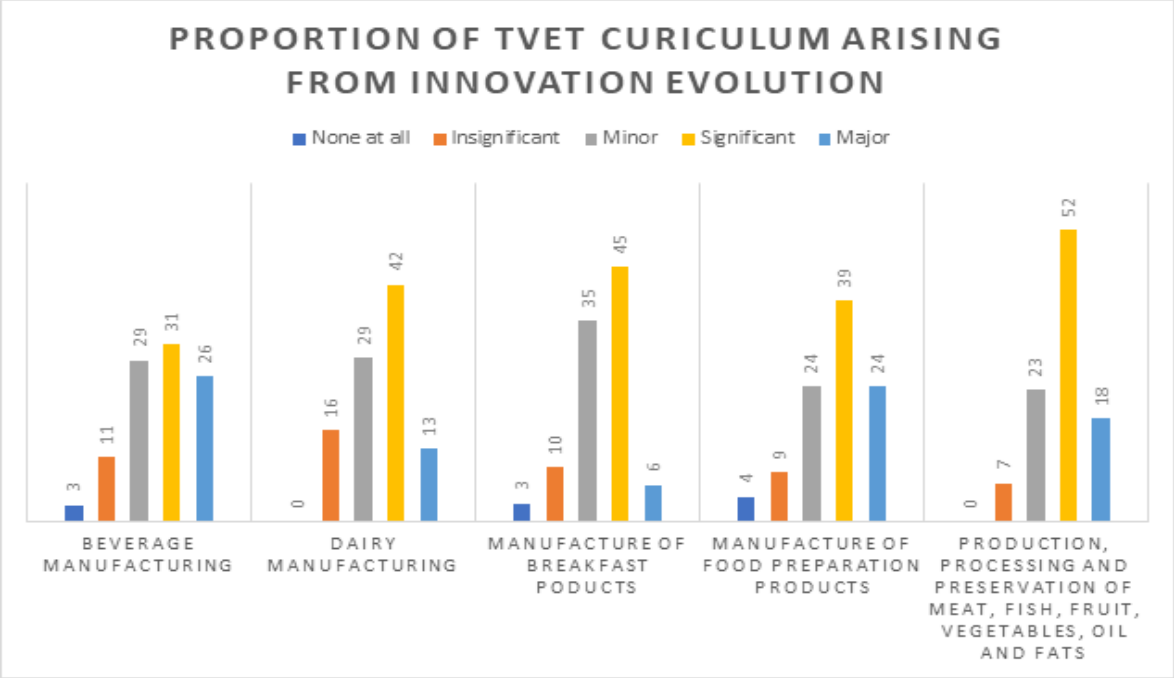

Figure 13: *Respondents recommendation for TVET curriculum proportion of innovation evolution.*

Appendix B

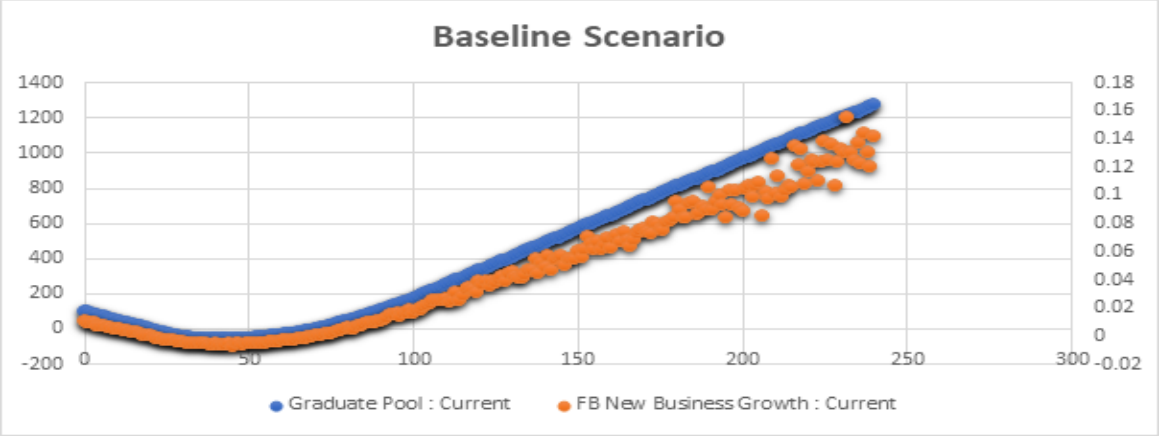

Figure 14: *Systems Dynamics baseline scenario*

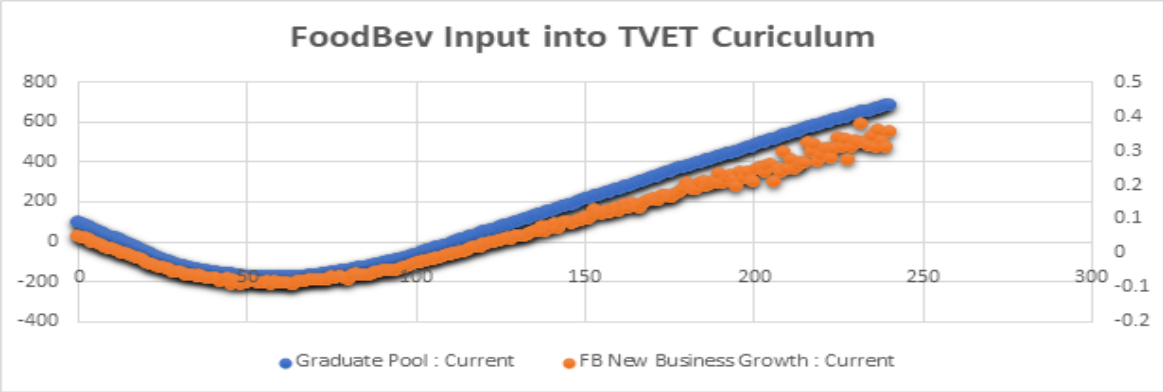

Figure 15: *Systems Dynamics FoodBev input into curriculum*

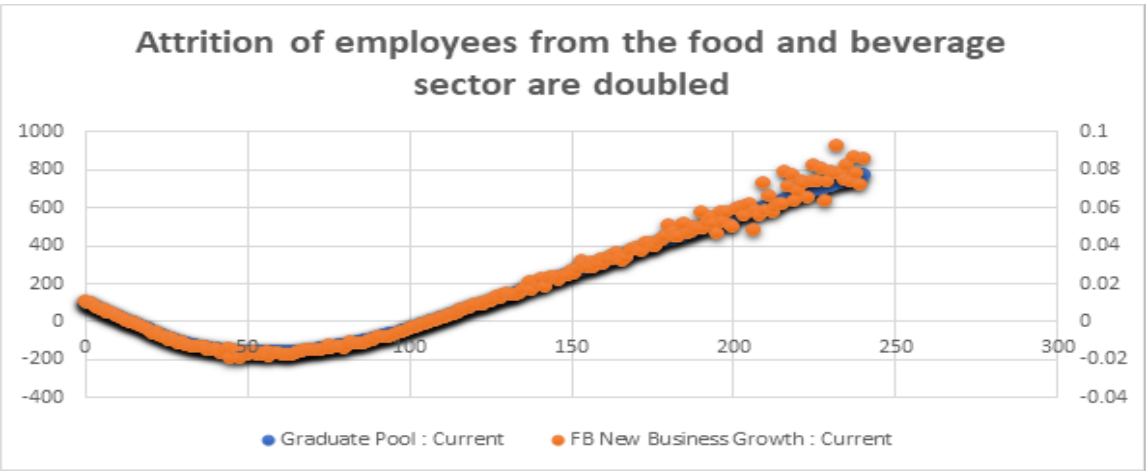

Figure 16: *Systems Dynamics model attrition of graduates*