EnPress Publisher

Journal of Infrastructure, Policy and Development 2024, 8(10), 6788.
https://doi.org/10.24294/jipd.v8i10.6788

Article

A 5G competency model based on the fuzzy Delphi method

Mohammad Sadegh Naghipour[1,*], Zulhasni Abdul Rahim[1], Muhammad Saqib Iqbal[2]

[1] Malaysia-Japan International Institute of Technology, University of Technology Malaysia, Kuala Lumpur 54100, Malaysia
[2] NUST Business School, National University of Sciences and Technology, Islamabad 44000, Pakistan
*** Corresponding author:** Mohammad Sadegh Naghipour, naghipour@graduate.utm.my

CITATION

Naghipour MS, Rahim ZA, Iqbal MS. (2024). A 5G competency model based on the fuzzy Delphi method. Journal of Infrastructure, Policy and Development. 8(10): 6788. https://doi.org/10.24294/jipd.v8i10.6788

ARTICLE INFO

Received: 30 May 2024
Accepted: 5 July 2024
Available online: 27 September 2024

Abstract: The fifth-generation technology standard (5G) is the cellular technology standard of this decade and its adoption leaves room for research and disclosure of new insights. 5G demands specific skillsets for the workforce to cope with its unprecedented use cases. The rapid progress of technology in various industries necessitates a constant effort from workers to acquire the latest skills demanded by the tech sector. The successful implementation of 5G hinges on the presence of competent individuals who can propel its progress. Most of the existing works related to 5G explore this technology from a multitude of applied and industrial viewpoints, but very few of them take a rigorous look at the 5G competencies associated with talent development. A competency model will help shape the required educational and training activities for preparing the 5G workforce, thereby improving workforce planning and performance in industrial settings. This study has opted to utilize the Fuzzy Delphi Method (FDM) to investigate and evaluate the perspectives of a group of experts, with the aim of proposing a 5G competency model. Based on the findings of this study, a model consisting of 46 elements under three categories is presented for utilization by any contingent of 5G. This competency model identifies, assesses, and introduces the necessary competencies, knowledge, and attributes for effective performance in a 5G-related job role in an industrial environment, guiding hiring, training, and development. Companies and academic institutions may utilize the suggested competency model in the real world to create job descriptions for 5G positions and to develop curriculum based on competencies. Such a model can be extended beyond the scope of 5G and lay the foundation of future wireless cellular network competency models, such as 6G competency models, by being refined and revised.

Keywords: 5G; competencies; fuzzy Delphi method; technology; workforce

1. Introduction

5G is expected to increase global GDP by $1.3 trillion by 2030, contribute to $13.2 trillion in output by 2035, and create 22.3 million jobs along the way (PricewaterhouseCoopers, n.d.). The job opportunities will encompass a wide range of industries, such as healthcare, manufacturing, telecommunications, and public services. The requirement for network infrastructure development, maintenance, and the development of new 5G-enabled services will be the driving force behind the formation of these new roles (Tăbușcă and Tăbușcă, 2019). This underlines the significance of 5G in the worldwide economy and the demand for workers in industries that implement it. 5G also provides new opportunities for innovation and research in areas such as artificial intelligence, machine learning, and big data analytics, speeding up the progress of creative solutions and technologies (Mistry et al., 2020). While different countries have started to enable 5G use cases at varying rates and priorities since the technology's inception at the beginning of the decade, the process of integrating 5G is hindered by difficulties in aligning communication technology, infrastructure, human resources, and financial resources (Asean, 2022). The swift pace of technological disruption necessitates adjustments across all sectors, particularly in education and policies (Muktiarni et al., 2019).

The rapid progress of technology in various industries necessitates a constant effort from workers to acquire the latest skills demanded by the tech sector. This is an opportunity and an obligation for society to enhance and retrain the workforce to align with the need for emerging jobs resulting from the digital revolution. The successful implementation of 5G hinges on the presence of competent individuals who can propel its progress. Given the rapid and seamless pace of technological progress, it is crucial for the workforce to be prepared to adjust and accommodate automation and software-driven operations (The Edge Malaysia, 2022).

In addition to 5G networks, human capital is a critical driver of digitalization. While technology and financial affairs are vital, the workforce's ability to manage and deploy these technologies has a substantial impact on the success of digital transformation activities (Skrzypek, 2021). 5G highlights the crucial need for continual skill development. This covers not just technical competencies but also non-technical competencies. It is crucial to ensure that the workforce can consistently enhance their skills in order to remain relevant in a quickly changing technology environment (Aluvala and Suryanarayana, 2024). A 5G competency model enhances stakeholder engagement by explicitly defining roles and competencies. It facilitates the assignment of tasks according to individual competencies, enabling more effective oversight and execution (Maman et al., 2021). Keeping abreast of the newest breakthroughs in 5G technology is crucial due to its rapid evolution. A competency model promotes continuous education and training, ensuring that the workforce remains inventive and can effectively capitalize on emerging opportunities (Yrjölä et al., 2018). This model guarantees that both individuals and organizations are adequately prepared to manage the intricacies of 5G technology.

The emergence of 5G technology has sparked a surge in the need for a fresh set of digital and technological competencies. Consequently, there has been fierce competition for skilled employees among technology companies, consulting firms, and start-ups. The success of 5G skilling programs will heavily rely on establishing strategic collaborations with private entities, who will play a key role in designing and developing course content. Establishing a group of skilled experts to oversee the shift to 5G and future technologies could contribute to maintaining a period of economic growth. Technical competencies are essential. However, it is also important to develop and refine soft skills and fundamental human qualities (Observer Research Foundation, 2022).

However, many industries may encounter a pragmatic challenge, which is the absence of an accurate and industry-proven skillset structure necessary for individuals involved in the implementation of 5G. Most of the existing works related to 5G explore this technology from a multitude of applied and industrial viewpoints, but very few of them take a rigorous look at the 5G competencies associated with talent development. Nonetheless, there hasn't been a 5G competency model proposed to encompass the essential skills for working in the 5G environment as of now. The need to accurately determine the ownership of particular competencies and their application is becoming more and more urgent as time goes by (Civelli, 1998). Job performance is only effective when there is a match between an individual's competency, the task requirements, and the environment (Morris and Pinto, 2007). A competency model will help in shaping skills programs and educational activities for the 5G workforce, hence improving workforce planning and performance in complex industrial settings. The aim of this study is to propose a 5G competency model. The competency model supplied through this research identifies, assesses, and introduces the competencies, knowledge, and attributes required for effective performance in a 5G–related job role within an industrial environment. It serves as a substructure to guide hiring, training, and development, ensuring that employees possess the necessary competencies to achieve organizational goals and perform their roles successfully.

The introduction of 5G technology represents a substantial advancement, as it indicates the potential for a digital ecosystem that is more interconnected, efficient, and advanced. However, the success of this innovative technology depends on having the appropriate persons to spearhead its development and growth. With the increasing prevalence of automation and software-driven processes, it is imperative for the workforce to adjust and develop accordingly. The apposite higher levels of management must allocate resources towards implementing methods and technology that improve, broaden, obtain, and safeguard critical skill sets.

The current transformation in the work market demands personnel who are highly competent, exceedingly qualified, and well-educated. Reskilling is essential for future planning, particularly because 5G–related positions require skillsets that span both organizational and technological competencies.

In order to identify and classify the appropriate competencies through this study, a content analysis was conducted by studying the requirements of prominent organizations engaged in the 5G ecosystem. The findings were used to perform the Fuzzy Delphi Method (FDM). This method facilitates the consistent expression of opinions by experts and offers advantages in terms of efficiency and effectiveness when managing questionnaires.

FDM is a technique that enables the systematic collection of expert opinions, thereby facilitating the development of expert consensus, particularly in research domains where expert judgment is essential for decision-making. It incorporates fuzzy logic to address uncertainty and ambiguity, which can more accurately quantify the vagueness of expert opinions. FDM is adaptable and can be used in a variety of fields. FDM improves the reliability and depth of research findings by integrating qualitative expert input with quantitative fuzzy logic. FDM is a potent research tool due to its capacity to comprehensively provide insights across diverse applications, manage uncertainty, and synthesize expert knowledge.

Subsequently, an extensive questionnaire consisting of 50 items was meticulously created and disseminated. This questionnaire encompassed a wide range of topics, including technical skills, soft skills, and complimentary skills. A total of 17 experts were chosen to contribute data. The FDM process involved four phases: creating an appropriate fuzzy spectrum, aggregating opinions, defuzzifying defuzzification of results, and adjudicating verdicts.

Thus, a 5G competency model was presented by way of this approach, with high levels of consensus in all of the studied categories. This competency model is applicable to a wide range of stakeholders, including individuals in charge of education and training specialists in the field of 5G, as well as those overseeing the operations and uses of 5G technology. Organizations and educational institutions can utilize this methodology to construct job descriptions for 5G roles and design educational programs centered around the indicated knowledge, competencies, and attributes. A fascinating new direction for competency model research pertaining to cellular network generations can be opened by expanding and evolving this model for use in the post-5G era.

2. Literature review

2.1. An overview of 5G

Following the introduction of 4G wireless mobile technology, researchers and mobile operators began investigating the technological progress towards 5G communication technology due to several requirements. These include the need for increased data rates, larger capacity, reduced latency, and improved performance (Element14, n.d.). 5G networks surpass 4G networks in terms of greater bandwidth capacity, accelerated data rates, decreased latency, extensive coverage, reduced expenses, and enhanced quality of service (QoS). 5G relies on the fundamental principles of Software Defined Networking (SDN), Network Function Virtualization (NFV), and Mobile Edge Computing (MEC) as its core technologies (Blanco et al., 2017).

The "5G triangle" approved by the 3rd Generation Partnership Project (3GPP) refers to the categorization of 5G applications. It specifies the three primary advantages of implementing 5G, which are:

Ultra Reliable Low Latency Communication (uRLLC), Massive Machine Type Communication (mMTC), and Enhanced Mobile Broadband (eMBB). **Figure 1** represents the domains of 5G applications. This structure serves as an enabler for 5G's new use cases, bringing about several benefits of 5G over the previous generations. The three edges of uRLLC, mMTC, and eMBB are 5G's main application themes.

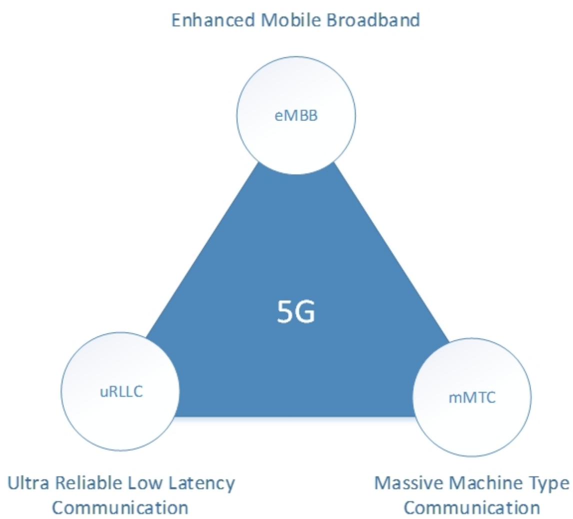

Figure 1. 5G triangle showing the classification of 5G applications. (own work).

According to Dangi et al. (2022), eMBB enables high-speed internet connectivity, increased bandwidth, a moderate latency, Ultra-HD streaming videos, virtual reality, and augmented reality (AR/VR) media. uRLLC offers low latency, ultra-high reliability, and rich quality of service (QoS), which traditional mobile network architecture is unable to provide. Industry 4.0, smart grids, intelligent transportation systems, remote surgery, vehicle-to-vehicle (V2V) communication, and other on-demand real-time interactions are all possible with URLLC. mMTC provides low-cost, wide-bandwidth machine-type communication over great distances with minimal power usage. For IoT applications, mMTC offers a high data rate, low power, and wider coverage with less complicated devices through mobile carriers. The IoT sector is predicted to change as a result of this feature being used to connect numerous devices.

5G is expected to bring together numerous existing standards and cut across numerous industries and technologies. A variety of goods, services, and industries appear to be undergoing a transformation thanks to 5G (TWI, n.d.). The way customers live and interact today, in businesses and communities, will change as a result of the development of 5G technology, along with other technologies such as artificial intelligence (AI), the internet of things (IoT), 3D printing, and others (Reply, n.d.). 5G wireless network capabilities offer the potential for transformative applications that go far beyond smartphones and other mobile devices. The integration of the Internet of Things (IoT), connectivity, and intelligent edge into a novel array of 5G use cases and applications will yield interest for everyone, from gamers to governments (Intel, n.d.). The 5G upgrade is anticipated to have a significant positive impact on a variety of industries, including healthcare, retail, agriculture, manufacturing, and logistics, whether their objective is to boost revenue prospects, lower total cost of ownership (TCO), or improve consumer experiences (Intel, n.d.). However, an ample amount of time is required for 5G to be fully settled and reach its summit of advantages throughout the world, since it is being adopted at different paces and policies. Attention to the 5G infrastructure is required during the entire lifecycle of 5G to meet the demands of various stakeholders.

The trilateral structure of 5G applications (**Figure 1**) translates into the key features as in **Figure 2**. This means that uRLLC, mMTC, and eMBB enable the following advantages.

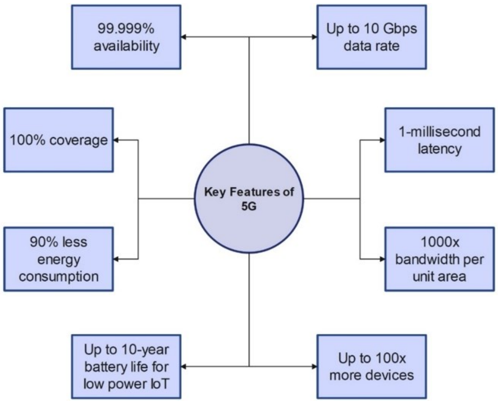

Figure 2. Key features of 5G technology. (Own work).

Companies must attract and employ qualified workers to adopt 5G technology, as the current workforce is regarded as insufficient and job descriptions are outdated. Moreover, the lack of skilled labor might be ascribed to the inherent properties of the technology, as it can operate on a different part of the electromagnetic spectrum compared to the previous 4G standard. Moreover, the introduction of 5G technology has the capacity to greatly influence organizations and their workforce. However, the effective progress of this technology relies on having the right individuals spearhead its development and expansion. The labor force must have the capacity to adapt and evolve in order to respond to the introduction of automation and software-driven processes. Service providers must commit resources to establish methods and technology that increase, diversify, acquire, and preserve skill sets.

The required skills for 5G cover a number of domains, explicitly 5G specific concepts, networking and protocols, signal and transmission, infrastructure and technologies, security and regulation, emerging technologies, as well as management and planning. 5G also necessitates several distinguished skills compared to past technologies. These have come under scrutiny in this research. The main skills that differentiate 5G from its predecessors, notably 4G, is grounded in four elements. These are:

- Understanding of network slicing, in particular network functions virtualization (NFV), as opposed to the traditional network management in 4G.
- Knowledge of edge computing, which is a distributed computing model, contrary to centralized cloud computing in 4G.
- Proficiency in software-defined networking (SDN), which is a networking approach that allows to remotely manage and modify the network. This feature came under a different classification in 4G networks.
- The integration of AI (Artificial Intelligence) and ML (Machine Learning) is more prominent in 5G technology, as compared to 4G.
- Enhanced cybersecurity measures, whereby 5G requires more sophisticated threat mitigation techniques and security protocols in comparison to 4G.

All four elements have been incorporated into the research design of this study. Moreover, this study has evaluated the transferable competencies from the previous generations to the current generation, while investigating the emerging competencies. This assessment has been performed with a specific approach that ensures the competencies are relevant and of current interest to the applicable industries dealing with 5G.

2.2. An overview of competencies

Human competence refers to a network of intricate, self-organized, professional, methodical, social, and personal skills that are developed throughout a person's life (Schmiedinger, 2005). This study took into account the elements of the iceberg model seen in **Figure 3**, including knowledge, skills, and attributes. These three aspects can be used to define a competency model. Developing a competency model that describes the knowledge, skills, and attitudes required for superior job performance is an important step in understanding what organizations are looking for and what they expect in job performance.

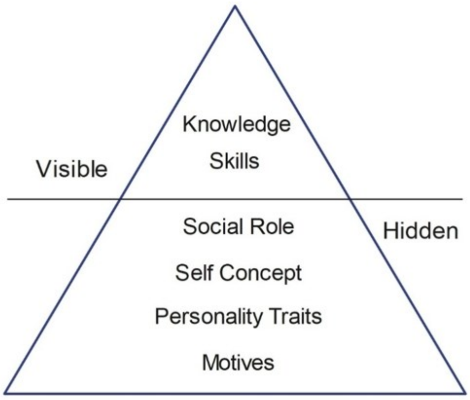

Figure 3. The iceberg model of competence (McClelland, 1998).

A variety of factors, including the source of competence acquisition, substantive scope, availability in an organization, and definition accuracy, can be used to classify competencies (Kowal et al., 2022). Competencies are a set of traits and abilities that enhance a job's effectiveness or performance. They can be classified into organizational and technical competencies, among other classifications. Organizational competencies incorporate the cognitive abilities, practical expertise, attitudes, and conduct required for high performance in a professional setting (Boyatzis, 1982). On the other hand, technical competencies pertain to the ability to apply specialized knowledge and principles in a certain job or position (CCSA, n.d.). Organizational competencies, also referred to as soft skills, comprise personal transversal competences such as friendliness, social aptitudes, language and communication skills, teamwork abilities, and other personality attributes that shape interpersonal connections. Hard skills, another word for technical competence, refer to the specific abilities required to perform a certain task or activity. Soft skills are commonly seen as the complement to hard skills, considering the assessment of an organization's excellence is based on the effectiveness and efficiency of its personnel (Cimatti, 2016; (Mohd Salleh and Sulaiman, 2015).

The dynamic transformation of the job market has necessitated the presence of competent, exceptionally skilled, and well–educated personnel (Ismail and Hassan, 2019). According to McKinsey (2021), the widespread adoption of automation would lead to the inevitable loss of both new and existing jobs. The functions that are most at risk of becoming obsolete are those that are repetitive, manual, or only require the most fundamental cognitive abilities. Therefore, it is essential that reskilling be a key component of future planning. Future-oriented skills that are difficult to replace are those that will be most valued. These include problem-solving abilities, superior cognitive abilities, quantitative and statistical capabilities, and technical skills. The ability to build relationships with different stakeholders is another quality that will become more crucial. Although reskilling a workforce of millions of people is a difficult task, analogous changes in the past have produced fruitful results. 5G requires its own unique skillsets, apart from the basic digital competencies. As opposed to digital competencies, which magnify the skills required for proficient and proactive usage of digital technology in every aspect of life, in the context of this study, 5G competencies primarily and precisely target the accomplishment of the task at hand in an environment applicable to 5G. Both organizational and technological competencies must be considered when discussing 5G-related competencies. The 5G-related skill sets must be comprehensive and explicit and cover a range of knowledge, skills, and attitudes.

Competency models provide employees with a clear understanding of the anticipated level of performance, outlining the specific skills and behaviors that are valued, acknowledged, and rewarded. Competency models are applicable to employers as well as individuals who are seeking work or aiming to progress or change their jobs (Siddiqui et al., 2016). Competency models are crucial instruments for determining desirable abilities for specific activities, distinguishing individual competencies, and evaluating performance and outcomes (Prifti et al., 2017).

Figure 4 below expands on **Figure 3** to include the pragmatic aspect of a competency model, which is the effective completion of a task. Knowledge, skills, and attitudes supply competency. In turn, when competency is evident, an individual will actualize the process of performing a task efficiently. This showcases the purpose of a competency model and the reasoning behind it.

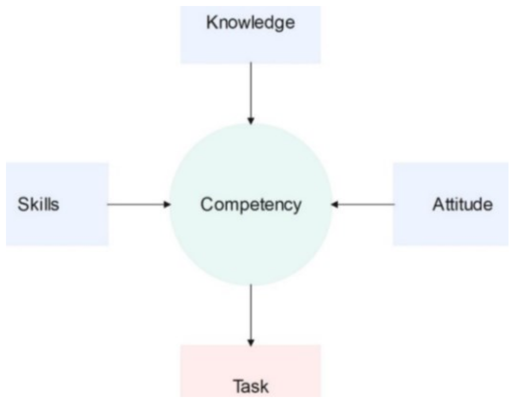

Figure 4. Main aspects of a competency model (Salleh et al., 2015).

Competency models are indispensable tools for improving employee performance and adjusting to market changes. The benefits of developing a competency model include enhanced performance, increased flexibility to respond to market fluctuations, and higher competitiveness in the job market. Competency models have advantages in diverse domains, such as education, training, and lifelong learning. Nevertheless, there is a dearth of comprehensive research on the formulation of competency models in particular industries, and generic competency models are inadequate for the complete utilization of the competency tool (Staškeviča, 2019).

2.3. Literature review findings

Upon recognizing the 5G ecosystem, a number of prominent companies participating in this network were noticed. Following that, a content analysis was performed to gather and categorize the desired competencies by examining the websites of the organizations and extracting information from their job descriptions. **Table 1** provides the findings of the literature review.

Table 1. 5G technical and organizational competencies in line with industry requirements.

No.	Technical Elements	Organizational Elements
Company 1 (Palo Alto Networks, 2022)	Networking, Programming, Security, Maintenance Activities, Experience with 5G, Telco and Radio Access Network (RAN), Troubleshooting Skills	Time Management, Travelling, Multitasking, Patience, Communication, Writing, Speaking, Building Confidence
Company 2 (Dell, 2022a; Dell, 2022b; Dell, 2022c)	Programming, Linux, Software Development Fundamentals, Networking and Communication Protocols, Source Control (GIT), ARM Architecture, 3GPP (3rd Generation Partnership Project), Open RAN (ORAN)	Positive Attitude, Self-Motivated, Willing to Learn, Enthusiasm, Organized, Meticulous, Time Management, Written and Verbal Communication Skills, Organized, Goal-Oriented, Self-Starter, Team Player
Company 3 (Samsung, 2022)	LTE & 5G RAN, Requirement Analysis, Performance Analysis, Wireless Protocols, Troubleshooting, 3GPP, RAN, Feature Validation, Documentation, Optimization, Network Architecture, (Lab and IoT) Testing	Mentorship, Leadership, Planning, Teamwork, Problem-Solving, Presentation Skills, Travelling
Company 4 (Ericsson, 2022)	Systems Studies, Radio Resource Management (RRM), Radio Access Technologies, Baseband, HW/SW Design or Research, Understanding of 3GPP Specifications, Programming, Troubleshooting	Analytical Mindset, Multitasking, Time Management, Leadership, English, Communication, Building Rapport, Teamwork, Motivated, Self-Starter, Collaboration
Company 5 (Huawei, 2022a)	Linux Operating System, Database, Datacom Network, System Deployment	Team Spirit, Good Communication, Interpersonal Skills, Presentation Skills, Customer-Oriented, Accountability
Company 6 (Verizon, 2022)	Program Management, Technical Presentations, Smartsheets, Google Suite Applications, Networking (CCNA Level or Higher), Development Methodologies, Infrastructure Deployment, Consulting Services, Managing Contracts, SOWs, Cellular Site Surveys, Cloud Computing, Program Management Professional and Project Management Professional Certifications (PgMP and PMP)	Travelling, Effective Leadership, Timely Communication Skills, Time Management, Collaboration, Organizational Skills, Proactivity, Negotiating Skills, Leadership
Company 7 (Accenture, 2022)	Wireless, Network Operations, Consulting, Analytical, Network Engineering	Communication Skills, Interpersonal Skills, Honesty, Integrity, Resilience, Attention to Detail, Team Player, Flexibility, Positive Attitude, Problem-Solving Skills
Company 8 (Viavi Solutions, 2022)	Wireless Networks, Testing, Cloud Computing, MEC Technologies, Product and Solution Positioning, 3GPP, RAN, Fronthaul Architecture, Project Management	Collaboration, Leadership, Presentation Skills, Innovation, Business Acumen, Analytical Skills, Problem-Solving Skills, Oral and Written Communications Skills, Influencing Skills, Time Management, Flexibility, Travelling
Company 9 (ARM, 2022)	RAN, Networking, performance analysis, software optimization, Computer Architecture, Network Packet, Linux	Motivated, Creativity, Independence, Teamwork, Problem-Solving, English, Good Communicator
Company 10 (Intel, 2022)	Specifications Development, Programming, Simulation, Linux, Shell Scripts, Networking	Communication, Leadership, Time Management, Initiative, Innovative, Teamwork, Motivated, Adaptable, Accountability, Integrity, Winning Mindset
Company 11 (Qualcomm, 2022)	Wireless WAN (WWAN), Radio Access Network (RAN), Multi-RAT (Radio Access Technology), Programming, RF, Baseband, Signal Processing, Computer Architecture, Communication Protocols, VLSI, RF SW Design, RFFE Design, HW APIs, IP Architecture	Responsible, Communication Skills, Multitasking, Prioritization, Creativity, Problem-Solving, Adaptable, Collaboration, Timeliness, Proactive, Open-Minded
Company 12 (Nokia, 2022)	Programming, GIT, Jenkins, RF, FPGA, Linux, Agile Practices, Signal Analyzers, Signal Generators, Test Mobiles (UE's)	Self-Driven, Independent, Team Player, Communication Skills, English

Table 1. (*Continued*).

No.	Technical Elements	Organizational Elements
Company 13 (Huawei, 2022b)	• 5G Basic Concepts and Development (Development, Protocols, Types, Application, Networking, Spectrum, Architecture) • 5G Network Capabilities and Key Technologies (Core Network, E2E, Technologies, Massive MIMO, Security) • 5G Use Cases (Business Applications, 5G Cloud X, WTTx, UAV, Smart Manufacturing, Requirements) • 5G Industry Applications and Solutions (IOV, Smart Healthcare, Technical Features, 5G Smart Grid, 5G Smart Education)	-
Company 14 (Cisco, 2022a; Cisco, 2022b)	Networking, Programming, Mobile Packet Core, 3GPP, Docker, Kubernetes, Linux	Leadership, Management, Supportive, Willing to Learn, Team Player, Problem-Solving, Adaptable, Prioritization, Interpersonal Skills, Ambitious
Company 15 (Apple, 2022)	AI/ML, Programming, Communication System Theory, Wireless Systems, Research, Wi-Fi Communication Standards (5G (NR)), Augmented Reality, Virtual Reality, Automotive Applications, Sensing Technologies, Edge Computing	Analytical Thinking, Problem-Solving, Independence, Teamwork, Communication Skills, Presentation Skills, Self-Motivated

Based on the industrial competencies gathered, the table above recognizes these skill sets and sets the tone for evaluation using the Fuzzy Delphi Method (FDM).

3. Research design

3.1. Fuzzy Delphi Method

The Delphi method has certain drawbacks, such as inaccurate and insufficient data accumulation, arbitrary expert judgments, and extensive research required for consensus. To tackle these challenges, it is beneficial to employ FDM, as it reduces redundant iterations and establishes clear priorities. FDM enables experts to consistently express their opinions, and it provides benefits in terms of efficiency and effectiveness while managing questionnaires. The assignment of a huge number of experts is not necessarily required, and the quality of decisions is not directly linked to the number of experts. In order to guarantee precision, it is imperative to select experts from a comprehensive pool of knowledge and experience that covers the entirety of the problem domain.

The FDM combines the traditional Delphi Method with the Fuzzy Set Theory introduced by Zadeh (1965) to address the inherent uncertainty in achieving consensus among the Delphi panel. Fuzzy sets are sets that allow for degrees of membership rather than just a binary value of belonging or not belonging. Fuzzy sets exhibit more compatibility with human linguistic and vague descriptions, rendering them more suitable for practical decision-making in real-world scenarios. The FDM is an enhanced version of the Delphi Method that utilizes triangulation statistics to determine the level of consensus among the expert panel (Shelton and Creghan, 2015). The classic Delphi Method has been enhanced to rectify its shortcomings, which include low convergence in obtaining results, loss of crucial information, and prolonged research (Saffie et al., 2016). The implementation of the FDM strategy helps reduce the possibility of ambiguity, diversity, and discrepancy in the perspectives provided by subject matter experts, hence enhancing the overall quality of the selected items (Manakandan et al., 2017). The FDM offers various benefits, including the ability to gather insights from experts in the field, reach consensus, evaluate the practicality of implementing educational interventions, forecast future advancements, and interact with research participants without temporal or spatial constraints (Ciptono et al., 2019). Below is a flowchart outlining the application of the FDM in qualitative decision-making procedures. **Figure 5** demonstrates the general view of this study's research design.

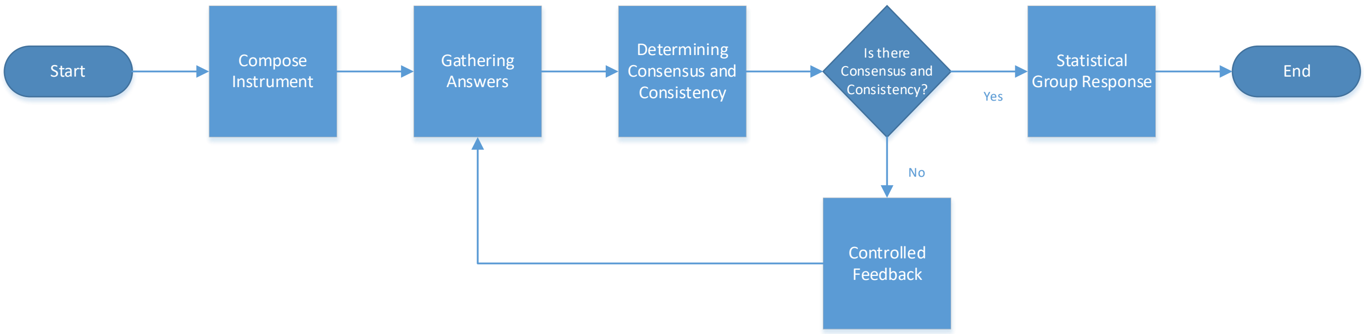

Figure 5. Framework for fuzzy Delphi methodology. (Own work).

3.2. 5G competencies research questionnaire

In order to capture the predominantly subjective views of experts in our subject matter, a 50-item questionnaire under three categories was designed and distributed. These categories were divided into technical skills, soft skills, and complementary skills. The items of the questionnaire are based on the literature review findings, as apparent in **Table 1**. The most significant items have been derived from the table by ranking and synthesizing the elements within the table. Moreover, the basis for categories are the main aspects of a competency model seen in **Figure 4**. The integration of technical and organizational competencies is a critical component of the development of a robust competency model (Podmetina et al., 2018). The technical and soft skills categories included 20 items each, and the complementary skills category was an assortment of 10 skills. The questionnaire also included 10 screening questions to mainly ensure the respondents are experts in 5G. A five-point questionnairewas given to the experts to obtain their consensus. Bar the screening questions, the experts were asked the same question: "How important do you consider these skills, knowledge, or attributes in the context of 5G?" for all the categories mentioned.

3.3. Panel of experts

Many studies have been done using FDM, and there isn't any consensus on the number of experts involved in using FDM. Based on the reviewed works, this number can be anywhere between six and 20 participants. This study selected 17 experts for its data collection, with 10 males and 7 females comprising the expert panel. This panel was selected by careful consideration of both academia and industry-aware people, and the selectees were people directly involved in the implementation and deployment of the 5G network from various backgrounds, including electronics engineering, telecommunications, business administration, management, industrial psychology, economics, and biotechnology. The majority of the respondents were aged 35–54 years. All the respondents were full-time employees in various occupations such as lecturer, engineer, project manager, government and industry relations member, performance and talent manager, marketing, and industry liaison. The key attribute of these individuals is their knowledge of the subject matter. The target group included professionals from telecommunications companies, universities, and government agencies. These experts validated the findings of this study and helped define the necessary competencies for a 5G professional. The study was conducted using questionnaires featuring Likert-style rating scales. The sampling frame was provided by academicians with industry experience from the research institution where this study is being conducted, and expert engagement took place at a conference. **Table 2** below is an overview of their background.

Table 2. Experts' background information.

Level of Education	
Level	**Count**
Doctorate degree or higher	3
Master's degree	4
Bachelor's degree	10
Associate degree	0
High school degree or equivalent	0
Total	17
Working Experience	
Duration	**Count**
Over 20 years	3
16–20 years	2
11–15 years	5
6–10 years	4
1–5 years	3
Total	17
Workplace	
Industry|Organization	**Count**
ICT/Telecommunications	8
Manufacturing	0
Government	2
Academia	6
Other	1
Total	17

Note: Statistics are based on the data collection of this study.

3.4. Fuzzy Delphi instrument

As stated by Habibi et al. (2015), the FDM method consists of the following subsequent phases:

1) Identification of a suitable spectrum for the fuzzification of linguistic expressions.
2) Fuzzy aggregation of the fuzzified values.
3) Triangular Fuzzy Numbers and the Defuzzification Process.
4) Selection of the threshold and item acceptability criteria.

3.4.1. Fuzzification spectrum

The initial step in the FDM algorithm for screening is to create an appropriate fuzzy spectrum that will help convert the linguistic terms given by the respondents into fuzzy values. For this purpose, fuzzy spectrum creation methods, or commonly deployed fuzzy spectra, can be utilized. The triangular fuzzy number representing a 5-point Likert scale used in this study is provided in the form of **Table 3**.

Table 3. Triangular fuzzy numbers for a 5-point Likert scale.

Linguistic Expressions	Fuzzy Number
Very Important	(0.75, 1, 1)
Important	(0.5, 0.75, 1)
Neutral	(0.25, 0.5, 0.75)
Unimportant	(0, 0.25, 0.5)
Very Unimportant	(0, 0, 0.25)

Note: The table is constructed based on triangular fuzzy numbers for a five-point scale.

3.4.2. Fuzzy aggregation

The second step entails the fuzzy aggregation of opinions. Expert opinions are collected and undergo a process of fuzzification. The aggregation of experts' opinions is a pivotal stage in the process. Several methodologies have been proposed to aggregate fuzzy opinions from experts. When presented with an expert's opinion in the form of triangular fuzzy numbers (l, m, u), the most direct technique is to compute the fuzzy mean of the experts' opinions, as suggested by Habibi et al. (2015) below.

Equation (1) is the notation for the fuzzy aggregation of opinions.

$$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n} \tag{1}$$

where, l = the fuzzy number of each answered item assigned to each expert for the first element of the fuzzy set;

m = the fuzzy number of each answered item assigned to each expert for the second element of the fuzzy set;

u = the fuzzy number of each answered item assigned to each expert for the third element of the fuzzy set;

n = the number of experts.

3.4.3. Triangular fuzzy numbers and defuzzification

To complete the process of aggregating experts' opinions using fuzzy logic, it is essential to carry out defuzzification of the resultant values. Mohamed Yusoff et al.

(2021) state that the utilization of the FDM technique necessitates the inclusion of the triangular fuzzy numbers and the defuzzification process as essential components. Triangular fuzzy numbers have two specific criteria that must be met. The first condition is that the value of threshold (d) must be less than or equal to 0.21. When the result is 0.21 or lower, the experts reach a consensus. The formula is as stated:

Equation (2) is the formula for the calculation of the threshold (d) value.

$$d\ (M, m) = \sqrt{\frac{1}{3}[(M1 - m1)^2 + (M2 - m2)^2 + (M3 - m3)^2]} \quad (2)$$

where,
M = the mean value of a fuzzy number,
m = represents a fuzzy number assigned by each expert for each item.

The second criterion for the triangular fuzzy number is the necessity of obtaining a level of agreement among experts, expressed as a percentage. In accordance with the traditional Delphi process, a suggestion is deemed acceptable if the consensus among the expert group exceeds 75%. This formula is utilized for this objective.

$$[(\Sigma \text{ Experts} \times \Sigma \text{ Items}) - (\text{Total Responses} > 0.2 / (\Sigma \text{ Experts} \times \Sigma \text{ Items})] \times 100\% \quad (3)$$

Equation (3) is the formula for the calculation of the consensus percentage.

In addition, the defuzzification process calculates the fuzzy (A) score value by applying a 0.5 α-cut value. The measured item is deemed acceptable if the fuzzy score value (A) is greater than or equal to 0.5; otherwise, it is rejected (Mohamed Yusoff et al., 2021). The formula utilized for computing A is as follows (Mohamed et al., 2019):

Equation (4) is the formula for determining the defuzzification value.

$$A = 1/3 \times (m1 + m2 + m3) \quad (4)$$

where, *m* = mean.

After acquiring the values of the aforementioned equations, the overall threshold value (d-construct) is determined using the following formula:

Equation (5) resembles the formula to obtain the threshold value (d-Construct) for the constructs during data analysis.

$$Threshold\ Value\ (d - Construct) = \frac{\Sigma\ Threshold\ Value,\ (d) for\ each\ item}{Total\ Experts\ \times Total\ Items\ in\ the\ Construct} \quad (5)$$

where, *d* = the threshold value for each item.

3.4.4. Threshold and item acceptability criteria

As indicated in the above explanations, this research has chosen the threshold value (d) of less than 0.21 and the expert consensus percentage of greater than 75% as its criteria for adjudicating the verdict of the expert panel. **Figure 6** is a summary of the FDM prerequisites for carrying out the study. **Figure 6** acts as a summary of the prerequisites for carrying out the FDM by summing up the previously mentioned equations.

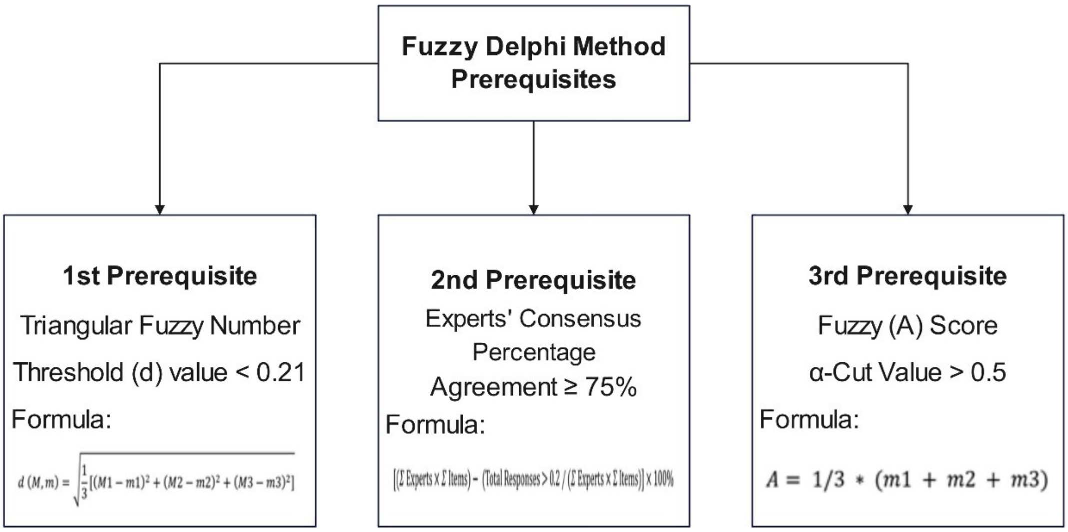

Figure 6. Fuzzy Delphi method prerequisites. (Own work).

4. Data analysis

After the data collection, the responses were tabulated in the Microsoft Excel 2019 version. The items were spread across the sheet and analyzed accordingly. Firstly, they were fuzzified using the aforementioned spectrum, and then the average of the fuzzy numbers was calculated. **Figure 7** shows how the fuzzification looks like after the data has been tabulated.

1	**Construct**									
2		Networking			Programming			Project Management		
3			Item 1			Item 2			Item 3	
4	**Triangular Fuzzy Numbers (n)**	**n1**	**n2**	**n3**	**n1**	**n2**	**n3**	**n1**	**n2**	**n3**
5	Expert 1	0.75	1	1	0.5	0.75	1	0.75	1	1
6	Expert 2	0.75	1	1	0.5	0.75	1	0.5	0.75	1
7	Expert 3	0.75	1	1	0.75	1	1	0.5	0.75	1
8	Expert 4	0.75	1	1	0.75	1	1	0.5	0.75	1
9	Expert 5	0.75	1	1	0.75	1	1	0.75	1	1
10	Expert 6	0.75	1	1	0.75	1	1	0.75	1	1
11	Expert 7	0.75	1	1	0.75	1	1	0.75	1	1
12	Expert 8	0.75	1	1	0.75	1	1	0.75	1	1
13	Expert 9	0.75	1	1	0.25	0.5	0.75	0.5	0.75	1
14	Expert 10	0.5	0.75	1	0.25	0.5	0.75	0.5	0.75	1
15	Expert 11	0.75	1	1	0.5	0.75	1	0.5	0.75	1
16	Expert 12	0.5	0.75	1	0.5	0.75	1	0.75	1	1
17	Expert 13	0.75	1	1	0.75	1	1	0.75	1	1
18	Expert 14	0.75	1	1	0.75	1	1	0.25	0.5	0.75
19	Expert 15	0.5	0.75	1	0.5	0.75	1	0.5	0.75	1
20	Expert 16	0.75	1	1	0.75	1	1	0.5	0.75	1
21	Expert 17	0.5	0.75	1	0.75	1	1	0.5	0.75	1
22	**Average Fuzzy Numbers (m)**	**0.691**	**0.941**	**1**	**0.618**	**0.868**	**0.971**	**0.588**	**0.838**	**0.985**
23		**m1**	**m2**	**m3**	**m1**	**m2**	**m3**	**m1**	**m2**	**m3**
24	**Defuzzification Process**	**0.877**			**0.819**			**0.804**		
25	**A = 1/3 * (m1 + m2 + m3)**									
26	**Item Ranking**	**1**			**10**			**14**		
27										

Figure 7. General view of the fuzzification.

Note: The figure is a screenshot of Microsoft Excel.

After that, the defuzzification process was performed by calculating the fuzzy score (A). Thereafter, the items were ranked using the "RANK" function in Microsoft Excel. **Figure 8** exhibits how an item is ranked based on the defuzzification value.

B24 | f_x =1/3*(B22+C22+D22)

	A	B	C	D
1	**Construct**			
2		Networking		
3			Item 1	
4	**Triangular Fuzzy Numbers (n)**	**n1**	**n2**	**n3**
5	Expert 1	0.75	1	1
6	Expert 2	0.75	1	1
7	Expert 3	0.75	1	1
8	Expert 4	0.75	1	1
9	Expert 5	0.75	1	1
10	Expert 6	0.75	1	1
11	Expert 7	0.75	1	1
12	Expert 8	0.75	1	1
13	Expert 9	0.75	1	1
14	Expert 10	0.5	0.75	1
15	Expert 11	0.75	1	1
16	Expert 12	0.5	0.75	1
17	Expert 13	0.75	1	1
18	Expert 14	0.75	1	1
19	Expert 15	0.5	0.75	1
20	Expert 16	0.75	1	1
21	Expert 17	0.5	0.75	1
22	**Average Fuzzy Numbers (m)**	**0.691**	**0.941**	**1**
23		**m1**	**m2**	**m3**
24	**Defuzzification Process**		**0.877**	
25	**A = 1/3 * (m1 + m2 + m3)**			
26	**Item Ranking**		**1**	

Figure 8. The defuzzification process.

Note: The figure is a screenshot of Microsoft Excel.

Subsequently, the threshold value (d) was calculated for each item and each expert one by one. Afterward, the average threshold value and the sum of the average threshold values were identified. These enabled the calculation of the overall threshold value (d-construct). **Figure 9** displays how the threshold value is calculated for each item.

B29 | f_x =SQRT(1/3*(((B21-B4)^2)+((C21-C4)^2)+((D21-D4)^2)))

	A	B	C	D	E	F	G	H	I	J
1										
27										
28	Expert/Item	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9
29	Expert 1	0.048	0.098	0.132	0.105	**0.220**	0.132	0.073	0.049	0.145
30	Expert 2	0.048	0.098	0.073	0.105	0.217	0.072	0.073	0.049	0.062
31	Expert 3	0.048	0.109	0.073	0.149	0.044	0.072	0.073	0.049	0.062
32	Expert 4	0.048	0.109	0.073	0.105	0.044	0.072	0.073	0.049	0.062
33	Expert 5	0.048	0.109	0.132	0.149	0.044	0.132	0.132	0.185	0.145
34	Expert 6	0.048	0.109	0.132	**0.328**	**0.220**	0.132	0.132	0.185	0.145
35	Expert 7	0.048	0.109	0.132	0.149	0.044	0.132	0.132	0.049	0.145
36	Expert 8	0.048	0.109	0.132	**0.328**	**0.220**	0.132	0.132	0.185	0.145
37	Expert 9	0.048	**0.326**	0.073	0.105	0.044	0.072	0.073	0.185	0.062
38	Expert 10	0.156	**0.326**	0.073	0.105	0.217	0.072	0.073	0.049	0.145
39	Expert 11	0.048	0.098	0.073	0.105	0.044	0.072	0.073	**0.250**	**0.293**
40	Expert 12	0.156	0.098	0.132	**0.354**	**0.467**	0.072	0.073	**0.497**	0.062
41	Expert 13	0.048	0.109	0.132	**0.328**	**0.220**	0.132	0.132	0.185	0.145
42	Expert 14	0.048	0.109	**0.308**	**0.354**	0.217	0.072	**0.308**	0.185	**0.293**
43	Expert 15	0.156	0.098	0.073	0.149	0.044	0.072	0.132	0.185	0.062
44	Expert 16	0.048	0.109	0.073	0.105	0.044	0.072	0.132	**0.250**	0.062
45	Expert 17	0.156	0.109	0.073	0.105	0.044	0.072	0.073	**0.250**	0.062
46	Average Threshold Value (d)	0.073	0.131	0.111	0.184	0.141	0.093	0.111	0.167	0.124
47										
48	Σ Average Threshold Value (d)	**6.193**								
49	Threshold Value (d-Counstruct)	**0.007**								
50										
51–52	Frequency of items with Threshold Value, (d) for each item ≤ 0.21	17	15	16	12	12	17	16	13	15
53–54	Percentage of items with Threshold Value, (d) for each item ≤ 0.21	100%	88%	94%	70%	70%	100%	94%	76%	88%

Figure 9. The mechanism for attaining threshold values.

Note: The figure is a screenshot of Microsoft Excel.

4.1. Results

Out of the 50 items that were specified in the questionnaire, 46 passed all the criteria and were deemed acceptable by the panel of experts. Items 4 (Linux), 5 (3GPP Specifications), and 15 (Consulting) were rejected, respectively, since there was less than 75% consensus for these items, while item 24 (Travelling) was rejected as the threshold value (d) was above the 0.21 condition for this item. Items 1 (Networking), 26 (Teamwork/Collaboration), 27 (Problem-Solving), and 33 (Analytical Mindset) were the top rankers with an α-Cut Value of 0.877 each. The three rejected items were all in the technical skills category, while all items from the soft and complementary skills categories were accepted. **Table 4** depicts the final result of the data analysis.

Table 4. The ranks and verdict of the 5G competencies items.

No.	Item	Average Likert Score	Threshold Value (d)	Fuzzy Score Value (A)/ Defuzzification Value	Experts Consensus Percentage (%)	Ranking	Verdict
	Technical Skills						
1	Networking	4.76	0.073	0.877	100%	1	Accepted
2	Programming	4.47	0.131	0.819	88%	10	Accepted
3	Project Management	4.35	0.111	0.804	94%	14	Accepted
4	Linux	3.47	0.184	0.603	70%	25	Rejected
5	3GPP Specifications	3.94	0.141	0.716	70%	23	Rejected
6	Troubleshooting	4.35	0.093	0.809	100%	12	Accepted
7	Specifications Development	4.35	0.111	0.804	94%	14	Accepted
8	Communication Protocols	4.12	0.167	0.745	76%	21	Accepted
9	Requirement Analysis	4.29	0.124	0.789	88%	17	Accepted
10	Performance Analysis	4.65	0.093	0.858	100%	4	Accepted
11	Wireless Systems	4.47	0.148	0.814	88%	11	Accepted
12	Radio Access Network	4.29	0.185	0.775	82%	18	Accepted
13	Hardware/Software Optimization	4.35	0.129	0.799	88%	15	Accepted
14	System/ Infrastructure Deployment	4.41	0.132	0.809	88%	13	Accepted
15	Consulting	3.94	0.159	0.711	70%	24	Rejected
16	Computer Architecture	4.18	0.128	0.765	82%	20	Accepted
17	Cloud Computing	4.59	0.099	0.848	100%	5	Accepted
18	Testing	4.53	0.115	0.833	94%	7	Accepted
19	Database	4.47	0.131	0.819	88%	10	Accepted

Table 4. (*Continued*).

No.	Item	Average Likert Score	Threshold Value (d)	Fuzzy Score Value (A)/ Defuzzification Value	Experts Consensus Percentage (%)	Ranking	Verdict
20	Cellular Site Surveys	4.24	0.179	0.765	76%	20	Accepted
	Soft Skills						
21	Communication Skills	4.47	0.131	0.819	88%	10	Accepted
22	Time Management	4.59	0.099	0.848	100%	5	Accepted
23	Leadership	4.47	0.131	0.819	88%	10	Accepted
24	Travelling	4.06	0.211	0.725	76%	22	Rejected
25	Motivation	4.59	0.111	0.843	94%	6	Accepted
26	Teamwork/ Collaboration	4.76	0.073	0.877	100%	1	Accepted
27	Problem-Solving	4.76	0.073	0.877	100%	1	Accepted
28	Presentation Skills	4.59	0.111	0.843	94%	6	Accepted
29	Accountability/ Integrity	4.47	0.116	0.824	94%	9	Accepted
30	Interpersonal Skills	4.47	0.148	0.814	88%	11	Accepted
31	Multitasking	4.71	0.085	0.868	100%	2	Accepted
32	Flexibility	4.59	0.111	0.843	94%	6	Accepted
33	Analytical Mindset	4.76	0.073	0.877	100%	1	Accepted
34	Organized	4.71	0.094	0.863	94%	3	Accepted
35	English	4.24	0.176	0.770	82%	19	Accepted
36	Positive Attitude	4.53	0.115	0.833	94%	7	Accepted
37	Independence	4.59	0.111	0.843	94%	6	Accepted
38	Prioritization	4.35	0.147	0.794	82%	16	Accepted
39	Creativity/Innovation	4.47	0.116	0.824	94%	9	Accepted
40	Adaptability	4.53	0.129	0.828	88%	8	Accepted
	Complementary Skills						
41	5G Security	4.53	0.130	0.828	94%	8	Accepted
42	Cellular Networks Fundamentals	4.53	0.115	0.833	94%	7	Accepted
43	Telecom Regulations	4.47	0.116	0.824	94%	9	Accepted
44	Mobile Edge Computing	4.53	0.129	0.828	88%	8	Accepted
45	Network Function Virtualization	4.53	0.129	0.828	88%	8	Accepted
46	Spectrum	4.53	0.129	0.828	88%	8	Accepted
47	Software-Defined Networking	4.53	0.115	0.833	94%	7	Accepted

Table 4. (*Continued*).

No.	Item	Average Likert Score	Threshold Value (d)	Fuzzy Score Value (A)/ Defuzzification Value	Experts Consensus Percentage (%)	Ranking	Verdict
48	AI/ML (Artificial Intelligence and Machine Learning)	4.53	0.115	0.833	94%	7	Accepted
49	Blockchain	4.53	0.129	0.828	88%	8	Accepted
50	Internet of Things (IoT)	4.65	0.093	0.858	100%	4	Accepted

Note: The table is the outcome of the data analysis performed by the authors.

The results table has been graphically represented in the following figures to delineate a visualization of this study's outcomes. **Figure 10** shows the 'Average Likert Score' for all 50 items through a line chart. In **Figure 10**, the point markers (items 4, 5, 15, and 24) below the value of 4.1 have resulted in a rejection after the data analysis.

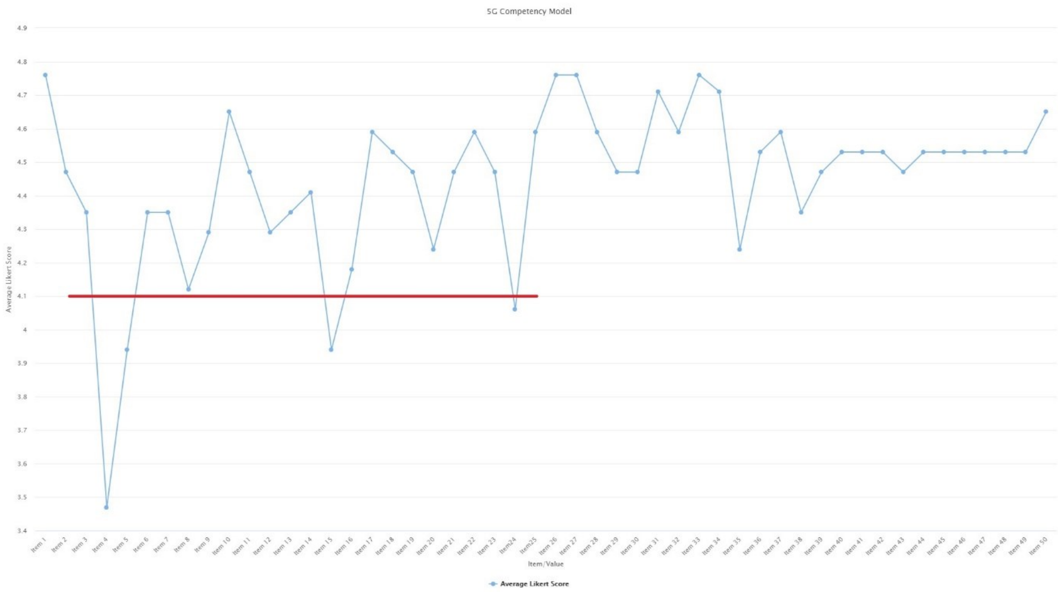

Figure 10. Line chart of the average Likert scores.

Note: The figure is produced by feeding data to RapidMiner Studio.

Figure 11 depicts the 'Threshold Value (d)' for items 1 to 50 through a line chart. The point marker at the peak (item 24) that is circled red has a value above 0.21 and indicates a rejection after the data analysis has been performed.

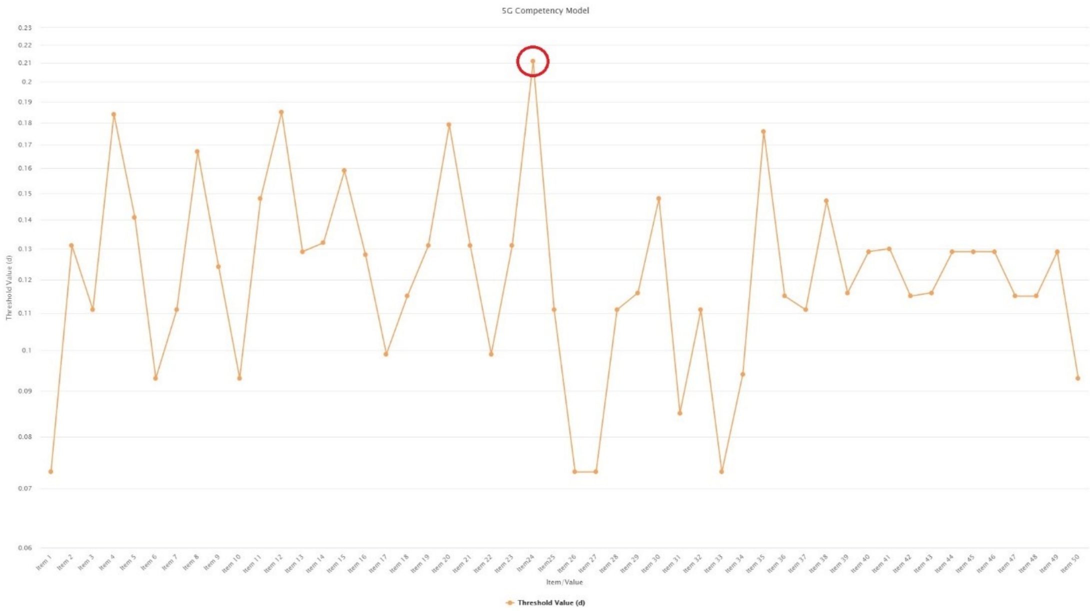

Figure 11. Line chart of the Threshold Values (d).
Note: The figure is produced by feeding data to RapidMiner Studio.

Figure 12 illustrates the 'Fuzzy Score Value (A)' for all of the items through a line chart. The four point markers at the peak (items 1, 26, 27, 33) that are circled red point to an exact value of 0.877 and designate the top-ranking items, while the four point markers (items 4, 5, 15, 24) fall below the red line that holds a value of 0.725 and separate these rejected items from the remaining items that were accepted after the data analysis.

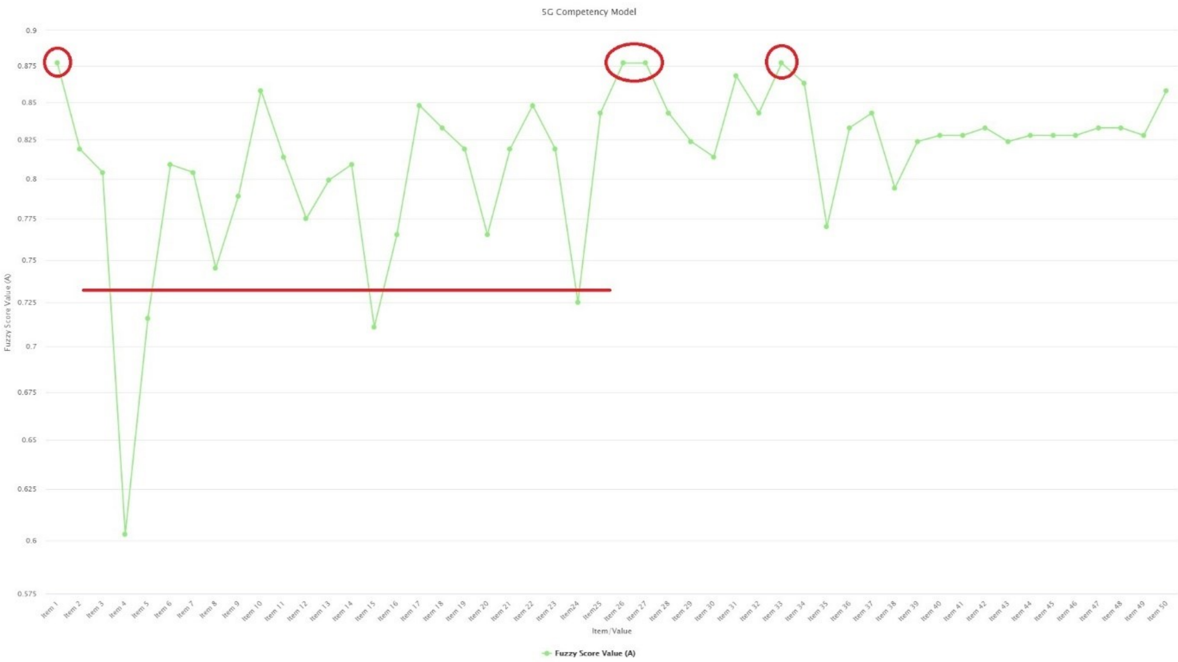

Figure 12. Line chart of the Fuzzy Score Values (A).
Note: The figure is produced by feeding data to RapidMiner Studio.

Figure 13 portrays the 'Ranking' for each of the 50 items through a line chart. The Y-axis has been reversed, with the lowest ranking on the bottom and the highest ranking towards the top of the chart. The point markers (items 1, 26, 27, and 33) at the highest that are circled red are all ranked 1 and indicate the items with the most consensus among the experts revealed by the data analysis.

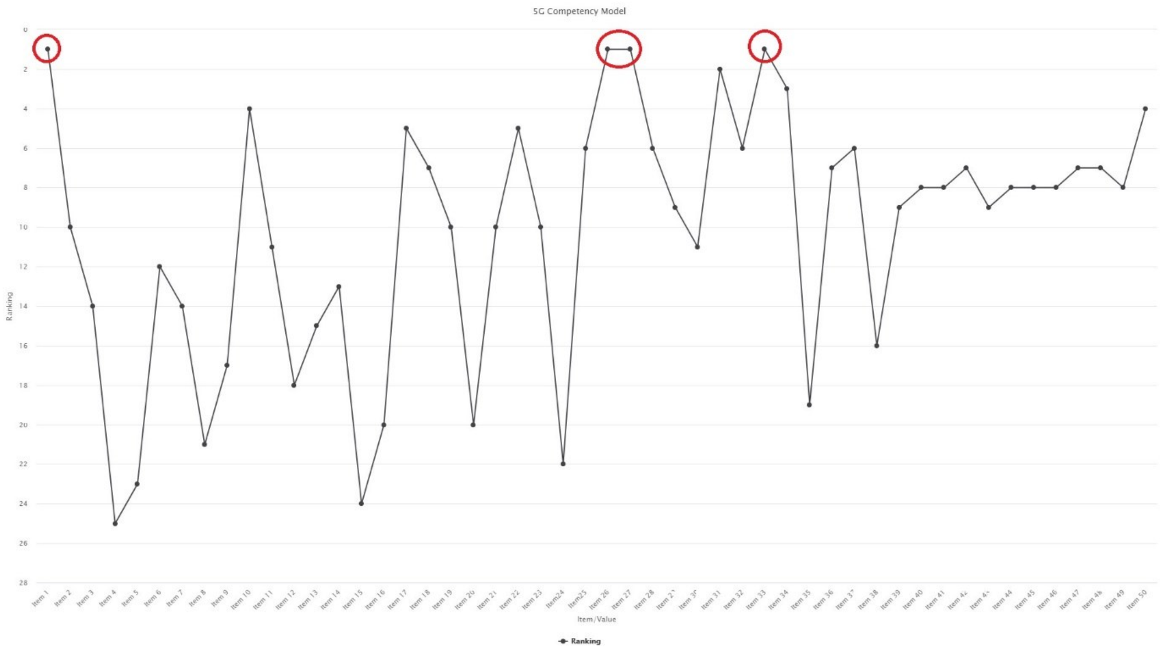

Figure 13. Line chart of the rankings.
Note: The figure is produced by feeding data to RapidMiner Studio.

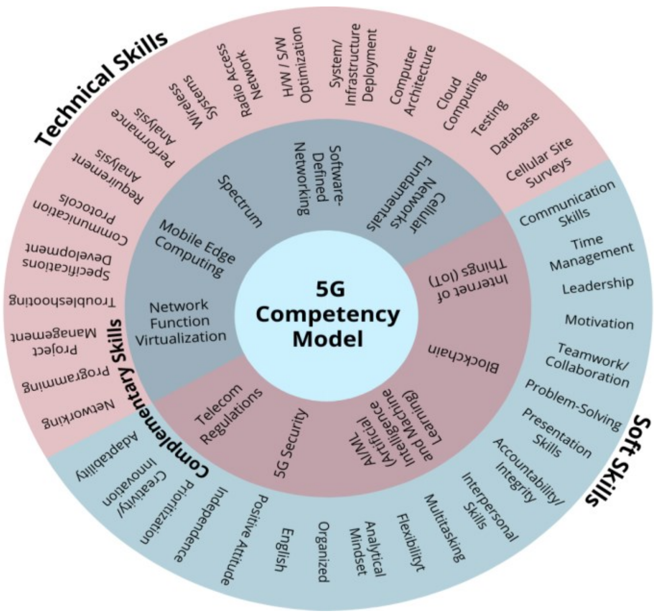

Figure 14. The 5G competency model. (Own work).

Based on the results of **Table 4**, the 5G competency model has been proposed by this research, as visually represented in **Figure 14**. There are 17 items approved under the technical skills category, while 19 items have been accepted and constitute the soft skills category. Additionally, another set of 10 recognized items falls under the complementary skills category. Overall, the technical skills category had an 85% consensus among the experts. The consensus rate was 95% for the soft skills category. The items in the complementary skills category achieved 100% consensus and were altogether deemed acceptable by the experts. All these items, along with their categorizations, form the 5G competency model. **Figure 14** reveals the 5G competency model as the deliverable of this research.

4.2. Discussion

Although previous studies have vastly discussed the technological aspects of 5G, this research has put emphasis on the competencies required for the 5G workforce to thrive at their workplace. Thus far, Oberländer et al. (2020) have presented a definition and a framework consisting of 25 dimensions for digital competencies in the workplace, specifically concentrating on white-collar workers. However, they have clearly mentioned that their study findings cannot be applied universally to all types of workers and businesses. Moreover, Iqbal et al. (2023) have recognized technical and organizational competencies along with several extended levels in the form of a conceptual framework for 5G competencies. Even so, their study offers a holistic concept rather than an in-depth model of 5G competencies. Additionally, Abdul Rahim et al. (2023) have suggested a conceptual framework consisting of super-system, system, and sub-system levels for developing strategic competency and skill sets for 5G technology applications using the system-based theory of inventive problem solving (TRIZ). They have also recognized technical and organizational components in their framework. However, this framework does not thoroughly examine the deeper elements of the two key components and their validity since it possesses a panoramic view of a complete system rather than delving into individual parts of 5G skill sets. The previous studies lacked the detailed granularity required for practical application. The “5G Competency Model” fills this void by providing a comprehensive and validated set of competencies that can be applied directly in both educational and professional settings. This specificity renders it a more practical tool for immediate use in the development of the 5G workforce.

In order to achieve maximum efficiency in 5G applications, the most viable solution is to have a competency model for boosting 5G workforce performance. By thoroughly scrutinizing the sought-after skillsets of several leading companies in the ICT field and putting them under investigation to attest their relevance from the perspective of pertinent experts, a competency model including a total of 46 skills under three categories was obtained. The “5G Competency Model” is beneficial for pedagogical usage for teaching and training 5G professionals and at every stage of employment, aiding in the identification and expression of job needs and the establishment of work instructions. The development of a comprehensive “5G Competency Model” will have a number of important effects on the ICT industry. It first tackles the pressing need for an organized strategy for growing and improving the skill sets needed for 5G technology applications. This model offers a clear path for educational institutions and training programs to match their curricula with industry demands. The workforce will be well-equipped to handle the demands of the rapidly changing technological landscape thanks to this alignment. It is a useful tool for human resource management at work, helping to streamline the hiring process by specifying exact job specifications and performance indicators. Additionally, it promotes ongoing professional growth by assisting managers and staff in establishing precise performance benchmarks. Because they have a clear path for career advancement and skill development, employees may be more productive and satisfied at work as a result. It can be utilized to define performance objectives, set goals for completing the assignment, and aid supervisors in delivering feedback.

Since 5G is an iteration of cellular technology and an incremental step from 4G despite its disruptive qualities, there isn't an abrupt transformation in terms of competencies among these two generations. When it comes to its competencies, we should view 5G as a new generation rather than a new phenomenon, as it carries many competencies from its predecessors, in addition to some that are unique to itself. The passed-down set of competencies are transferrable to 5G, given that individuals upskill and reskill aspects of their existing skills. Clearly, some of the skills are entirely new to this generation, but the overall skill sets are a combination of existing and emerging skills. For example, computer programming is a skill that was required in previous generations and remains a sought-after skill in the 5G era; however, learning a new programming language may be required this time around.

There are multiple reasons for this study's observed results. A plausible rationale could be found in the meticulous approach utilized in this research, which comprised examining the highly sought-after skill sets of top ICT companies and verifying them with feedback from relevant specialists. The identified competencies are both relevant and useful thanks to this careful approach. The dynamic nature of the 5G technology landscape, which demands a constant evolution of skill sets to keep up with technological advancements, could be another factor. The fact that a broad range of skills are included in three categories speaks to the fact that 5G technology is complex and involves organizational, technical, and strategic competencies. This all-encompassing strategy guarantees the competency model's resilience and adaptability to different use cases and changing industry standards.

In addition to meeting present needs, this model can be extended and evolved for the 6G era and open an exciting new avenue for future research involving competency frameworks and models pertaining to cellular network generations. Subsequent investigations may concentrate on expanding and improving the model to encompass new technologies and skill needs.

In the area of ICT workforce development, the creation of the "5G Competency Model" is a noteworthy development. By providing a detailed and validated set of competencies, it addresses the immediate needs of the 5G workforce and sets the stage for future research and development in competency frameworks for subsequent generations of cellular network technology.

5. Conclusion

Based on the findings of this study, a competency model consisting of a variety of elements is presented for utilization by any contingent of 5G. This model is relevant to various 5G stakeholders, specifically those who are responsible for teaching and training 5G professionals and those who deal with the operations and applications of 5G technology. Companies and academic institutions may utilize the suggested competency model in the real world to create job descriptions for 5G positions and to develop curriculum based on competencies. However, supplementary research is required to investigate additional facets of competencies and establish how the model may be implemented in practical settings. Additional competencies should be identified and scrutinized, as the list of competencies acknowledged in this study is not exhaustive and the competencies may need to be altered or updated from time to time. Subsequent studies should verify the framework's validity and expand its utilization to encompass areas beyond recruitment and performance assessment, such as conducting training needs analysis and implementing personal development initiatives. The research is also hampered by its rapidly changing nature, as 5G is intimately related to technological advancement. Such a model can be extended beyond the scope of 5G and lay the foundation of future wireless cellular network competency models, such as 6G competency models, by being refined and revised. In the meantime, this study's effort is to establish a model that can be used primarily for the preparation of telecommunications workers in the context of 5G. By taking these competencies into account for policies and practice, a more accurate and pin-pointed approach can be maintained by those who aim to witness an efficient path to a 5G-ready workforce. A more comprehensive and sophisticated skill set is needed for 5G technology than for prior generations. Professionals must have strong cybersecurity, strategic planning, and customer-centric solution abilities in addition to being well-versed in new technologies, software tools, and methodologies. To remain relevant in the rapidly changing 5G environment, it is crucial to engage in continuous learning and demonstrate flexibility and adaptability. Unquestionably, both technical and soft skills need to be considered when forming a competency model with regards to the current industry requirements. Moreover, certain competencies are becoming discipline-independent and should be noticed almost regardless of the area of study.

Author contributions: Conceptualization, MSN and ZAR; methodology, MSN; software, MSN; validation, MSN, ZAR and MSI; formal analysis, MSN; investigation, MSN; resources, MSN; data curation, MSN; writing—original draft preparation, MSN; writing—review and editing, MSN; visualization, MSI; supervision, ZAR; project administration, ZAR. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

Abdul Rahim, Z., Iqbal, M. S. Abdul Rahim, N. A. & Ohshima, N. (2023). Sustainable Industrial Revolution Competency Framework for 5G Technology Applications using TRIZ. Journal of Advanced Research in Applied Sciences and Engineering Technology, 31(3), 336–344. https://doi.org/10.37934/araset.31.3.336344

Accenture. (2022). Wireless 5G Networks & Technologies Tech Delivery Subject Matter. Available online: https://www.accenture.com/in-en/careers/jobsearch?jk=5G&sb=0&pg=1&vw=1&is_rj=0 (accessed on 16 October 2022).

Aluvala, R., & Suryanarayana, A. (2024). Monumental Transition From 5G To 6G: Skill Development Needs And Workforce Evolution Imperative. Educational Administration: Theory and Practice, 13699–13706. https://doi.org/10.53555/kuey.v30i5.5986

Apple. (2022). AI/ML Research Engineer - Wireless 5G/6G. Available online: https://jobs.apple.com/en-us/details/200307911/ai-ml-research-engineer-wireless-5g-6g (accessed on 16 October 2022).
ARM. (2022). 5G Performance Software Workload Engineer (Non-RF). Available online: https://careers.arm.com/job/austin/5g-performance-software-workload-engineer-non-rf/33099/31412330368 (accessed on 16 October 2022).
Asean. (2022). Development of Best Practice Guides for 5G Ecosystem Development in ASEAN. ASEAN Main Portal. Available online: https://asean.org/wp-content/uploads/2022/02/03-ASEAN-5G-Ecosystem-Best-Practices-Guide_Final-Report_SG_ASEC_TL_PH_MY.pdf. (accessed on 16 October 2022).
Blanco, B., Fajardo, J. O., Giannoulakis, I., et al. (2017). Technology pillars in the architecture of future 5G mobile networks: NFV, MEC and SDN. Computer Standards & Interfaces, 54, 216–228. https://doi.org/10.1016/j.csi.2016.12.007
Boyatzis, R. E. (1982). The Competent Manager: A Model for Effective Performance. Available online: http://ci.nii.ac.jp/ncid/BA25462247 (accessed on 16 October 2022).
CCSA. (n.d.). Technical Competencies. Canadian Centre on Substance Use and Addiction. Available online: https://www.ccsa.ca/technical-competencies (accessed on 12 January 2024).
Cimatti, B. (2016). Definition, Development, Assessment of Soft Skills and Their Role for the Quality of Organizations and Enterprises. DOAJ (DOAJ: Directory of Open Access Journals). https://doi.org/10.18421/ijqr10.01-05
Ciptono, A., Setiyono, S., Nurhidayati, F., et al. (2019). Fuzzy Delphi method in education: A mapping. Journal of Physics: Conference Series, 1360(1), 012029. https://doi.org/10.1088/1742-6596/1360/1/012029
Cisco. (2022a). Senior Software Development Engineer - C, C++ | Linux | 3GPP | Packet Core. Available online: https://jobs.cisco.com/jobs/SearchJobs/5G (accessed on 16 October 2022).
Cisco. (2022b). Senior Technical Leader. Available online: https://jobs.cisco.com/jobs/ProjectDetail/Technical-Leader/1380245 (accessed on 16 October 2022).
Civelli, F. (1998). Personal competencies, organizational competencies, and employability. Industrial and Commercial Training, 30(2), 48–52. https://doi.org/10.1108/00197859810207652
Dangi, R., Lalwani, P., Choudhary, G., et al. (2021). Study and Investigation on 5G Technology: A Systematic Review. Sensors, 22(1), 26. https://doi.org/10.3390/s22010026
Dell. (2022a). 5G NR L1 Embedded Linux Senior Developer. Available online: https://jobs.dell.com/job/ottawa/5g-nr-l1-embedded-linux-senior-developer/375/34531698144 (accessed on 16 October 2022).
Dell. (2022b). Principal 5G Layer-1 Digital Signal Processing at Dell Careers. Available online: https://jobs.dell.com/job/ottawa/principal-5g-layer-1-digital-signal-processing/375/34531691168 (accessed on 16 October 2022).
Dell. (2022c). Software Developer I, 5G RAN Platform at Dell Careers. Available online: https://jobs.dell.com/job/ottawa/software-developer-i-5g-ran-platform/375/27200135952 (accessed on 16 October 2022).
Element14. (n.d.). 5G - What is 5G, Capabilities and its Applications. Element14 Malaysia. Available online: https://my.element14.com/5g-what-is-5g-capabilities-and-its-applications (accessed on 12 January 2024).
Ericsson. (2022). 5G RRM System Developer Available online: https://jobs.ericsson.com/job/Stockholm-5G-RRM-System-Developer-Stoc/751334102/ (accessed on 16 October 2022).
Habibi, A., Jahantigh, F. F., & Sarafrazi, A. (2015). Fuzzy Delphi Technique for Forecasting and Screening Items. Asian Journal of Research in Business Economics and Management, 5(2), 130. https://doi.org/10.5958/2249-7307.2015.00036.5
Huawei. (2022a). CBS/AICC/RBT/5G Message Engineer – GSRC. Available online: https://www.jobstreet.com.my/en/job/cbs-aicc-rbt-5g-message-engineer-gsrc-5038476?jobId=jobstreet-my-job-5038476§ionRank=1&token=0~4bb1d60c-08e7-4cef-9868-d0725fb3f7b9&fr=SRP%20View%20In%20New%20Tab (accessed on 16 October 2022).
Huawei. (2022b). Huawei Certified ICT Associate - 5G. Available online: https://e.huawei.com/en/talent/#/cert/product-details?certifiedProductId=203&authenticationLevel=CTYPE_CARE_HCIA&technicalField=IIC&version=1.0 (accessed on 16 October 2022).
Intel. (2022). 5G IP Solution Engineer. Available online: https://jobs.jobvite.com/ip-infusion/job/ovWfmfwM (accessed on 16 October 2022).
Intel. (n.d.). Top Use Cases for 5G Technology. Available online: https://www.intel.com/content/www/us/en/wireless-network/5g-use-cases-applications.html (accessed on 12 January 2024).

Iqbal, M. S., Rahim, Z. A. & Ohshima, N. (2023). Enhancing Workforce Performance and Applications Toward Industry 5.0 with the 5G Conceptual Framework in Malaysia. Journal of Advanced Research in Applied Sciences and Engineering Technology, 31(3), 282–289. https://doi.org/10.37934/araset.31.3.282289

Ismail, A. A., & Hassan, R. (2019). Technical Competencies in Digital Technology towards Industrial Revolution 4.0. Journal of Technical Education and Training, 11(3). https://doi.org/10.30880/jtet.2019.11.03.008

Kowal, B., Włodarz, D., Brzychczy, E., et al. (2022). Analysis of Employees' Competencies in the Context of Industry 4.0. Energies, 15(19), 7142. https://doi.org/10.3390/en15197142

Maman, M., Calvanese-Strinati, E., Dinh, L. N., et al. (2021). Beyond private 5G networks: applications, architectures, operator models and technological enablers. EURASIP Journal on Wireless Communications and Networking, 2021(1). https://doi.org/10.1186/s13638-021-02067-2

Manakandan, S. K., Rosnah, I., Ridhuan, J. M., & Priya, R. (2017). Pesticide Applicators Questionnaire Content Validation: A Fuzzy Delphi Method. PubMed, 72(4), 228-235.

McClelland, D. C. (1998). Identifying Competencies with Behavioral-Event Interviews. Psychological Science, 9(5), 331–339. https://doi.org/10.1111/1467-9280.00065

McKinsey. (2021). Tackling Asia's Talent Challenge: How to Adapt to a Digital Future. McKinsey & Company. Available online: https://www.mckinsey.com/featured-insights/asia-pacific/tackling-asias-talent-challenge-how-to-adapt-to-a-digital-future (accessed on 16 October 2022).

Mistry, I., Tanwar, S., Tyagi, S., et al. (2020). Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges. Mechanical Systems and Signal Processing, 135, 106382. https://doi.org/10.1016/j.ymssp.2019.106382

Mohamed Yusoff, A. F., Hashim, A., Muhamad, N., et al. (2021). Application of Fuzzy Delphi Technique Towards Designing and Developing the Elements for the e-PBM PI-Poli Module. Asian Journal of University Education, 17(1), 292. https://doi.org/10.24191/ajue.v17i1.12625

Mohamed, S., Ismail, N. K., & Hamzah, M. I. (2019). The Application of Fuzzy Delphi Technique in the Aspect of School Connectedness as Preventive Measure of Preschool Children Delinquency. International Journal of Academic Research in Progressive Education and Development, 8(4). https://doi.org/10.6007/ijarped/v8-i4/6783

Mohd Salleh, K., & Lisa Sulaiman, N. (2015). Technical Skills Evaluation Based on Competency Model for Human Resources Development in Technical and Vocational Education. Asian Social Science, 11(16). https://doi.org/10.5539/ass.v11n16p74

Morris, P. W. G., & Pinto, J. K. (2007). The Wiley Guide to Project Organization and Project Management Competencies. Available online: https://www.wiley.com/en-us/The+Wiley+Guide+to+Project+Organization+and+Project+Management+Competencies-p-9780470226834 (accessed on 16 October 2022).

Muktiarni, M., Widiaty, I., Abdullah, A. G., et al. (2019). Digitalisation trend in education during industry 4.0. Journal of Physics: Conference Series, 1402(7), 077070. https://doi.org/10.1088/1742-6596/1402/7/077070

Nokia. (2022). 5G Integration Engineer in Oulu, Finland, Finland. Available online: https://careers.nokia.com/jobs/5g-integration-engineer-9902 (accessed on 16 October 2022).

Oberländer, M., Beinicke, A., & Bipp, T. (2020). Digital competencies: A review of the literature and applications in the workplace. Computers & Education, 146, 103752. https://doi.org/10.1016/j.compedu.2019.103752

Observer Research Foundation. (2022). 5G: New Skills for a New Era. ORF. Available online: https://www.orfonline.org/expert-speak/5g-new-skills-for-a-new-era/ (accessed on 16 October 2022).

Palo Alto Networks. (2022). Senior Professional Services Consultant - 5G Specialist. Available online: https://my.jora.com/job/Sr-Professional-Services-Consultant-ad0d23187316380fd308d49c6eee0ad2?from_url=https%3A%2F%2Fmy.jora.com%2F5G-jobs-in-Malaysia&sl=Malaysia&sol_srt=44ff59a2-45b3-4806-8c04-1b5ecd63cd7c&sp=serp&sponsored=false&sq=5G&sr=1&tk=9zSxxIJUSynaf3Qve7cw-WXNwkrxP3b6ix3rRuCO8 (accessed on 16 October 2022).

Podmetina, D., Soderquist, K. E., Petraite, M., et al. (2018). Developing a competency model for open innovation. Management Decision, 56(6), 1306–1335. https://doi.org/10.1108/md-04-2017-0445

PricewaterhouseCoopers. (n.d.). The Global Economic Impact of 5G. PwC. Available online: https://www.pwc.com/gx/en/industries/technology/publications/economic-impact-5g.html (accessed on: 10 January 2024).

Prifti, L., Knigge, M., Kienegger, H., & Krcmar, H. (2017). A Competency Model for "Industrie 4.0" Employees. ResearchGate. Available online: https://www.wi2017.ch/images/wi2017-0262.pdf (accessed on 16 October 2022).
Qualcomm. (2022). Embedded Software Engineer - 5G. Available online: https://qualcomm.wd5.myworkdayjobs.com/en-US/External/job/San-Diego-USA/Embedded-Software-Engineer---5G_3038066 (accessed on 16 October 2022).
Reply. (n.d.). 5G Technology: Mastering the Magic Triangle. R. Available online: https://www.reply.com/en/telco-and-media/5g-mastering-the-magic-triangle (accessed on 12 January 2024).
Saffie, N. A. M., Shukor, N. M., & Rasmani, K. A. (2016). Fuzzy delphi method: Issues and challenges. In: 2016 International Conference on Logistics, Informatics and Service Sciences (LISS). https://doi.org/10.1109/liss.2016.7854490
Salleh, K. M., Khalid, N. H., Sulaiman, N. L., et al. (2015). Competency of Adult Learners in Learning: Application of the Iceberg Competency Model. Procedia - Social and Behavioral Sciences, 204, 326–334. https://doi.org/10.1016/j.sbspro.2015.08.160
Samsung. (2022). 4G/5G System Test Engineer. Available online: https://sec.wd3.myworkdayjobs.com/en-US/Samsung_Careers/job/6655-Excellence-Way-Plano-TX-USA/XMLNAME-4G-5G-System-Test-Engineer--Ref-597_R65354 (accessed on 16 October 2022).
Schmiedinger, B. (2005). Competence Based Business Development - Organizational Competencies as Basis for Successful Companies. Available online: https://www.semanticscholar.org/paper/Competence-Based-Business-Development-Competencies-Schmiedinger-Valentin/ee409b350b548938b73210e6139cac6660675a42 (accessed on 16 October 2022).
Shelton, K., & Creghan, K. A. (2015). Demystifying the Delphi Method. Advances in Knowledge Acquisition, Transfer, and Management, 375–395. https://doi.org/10.4018/978-1-4666-7409-7.ch019
Siddiqui, A., Qureshi, S. M., & Fahad, M. (2016). Building on Technical Competencies. ResearchGate. Available online: https://www.researchgate.net/publication/315488511_Building_on_Technical_Competencies (accessed on 16 October 2022).
Skrzypek, E. (2021). Digitalization along with 5G and 6G Networks – Determinants and Consequences. Annales Universitatis Mariae Curie-Skłodowska, Sectio H – Oeconomia, 55(1), 51. https://doi.org/10.17951/h.2021.55.1.51-66
Staškeviča, A. (2019). The Importance of Competency Model Development. Acta Oeconomica Pragensia, 27(2), 62–71. https://doi.org/10.18267/j.aop.622
Tăbușcă, A., & Tăbușcă, S.-M. (2019). Impact of 5G Technology in Global Economy. Cybersecurity and Legal Issues. Journal of Information Systems & Operations Management, 177-179.
The Edge Malaysia. (2022). Talent: Developing a 5G Workforce for the Future. Available online: https://theedgemalaysia.com/article/talent-developing-5g-workforce-future (accessed on 16 October 2022).
TWI. (n.d.). What is 5G Technology and How Does it Work? TWI-Global. Available online: https://www.twi-global.com/technical-knowledge/faqs/what-is-5g.aspx (accessed on 12 January 2024).
Verizon. (2022). Technical 5G Project Manager. Available online: https://www.verizon.com/about/work/search/jobs?q=5G (accessed on 16 October 2022).
Viavi Solutions. (2022). 5G Solutions Marketing Manager. Available online: https://viavisolutions.wd1.myworkdayjobs.com/en-US/careers/job/Home-Office-USA/XMLNAME-5G-Solutions-Marketing-Manager_220000720 (accessed on 16 October 2022).
Yrjölä, S., Ahokangas, P., & Matinmikko-Blue, M. (2018). Novel Context and Platform Driven Business Models via 5G Networks. In: 2018 IEEE 29th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC). https://doi.org/10.1109/pimrc.2018.8580819
Zadeh, L. A. (1965). Fuzzy Sets. Information and Control, 8(3), 338-353. https://doi.org/10.1016/s0019-9958(65)90241-x