Penerbit Akademia Baru

Journal of Advanced Research Design

Journal homepage:
https://akademiabaru.com/submit/index.php/ard
ISSN: 2289-7984

Architecting Robust Connectivity: Unveiling The Blueprint for A Resilient Telecommunication Network Design

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ARTICLE INFO

Article history:

Keywords:
Communication network; design knowledge; network designers; network design knowledge; resilient

ABSTRACT

The telecommunication industry has seen rapid growth over the years. This phenomenon is a result of changes in people's lifestyle, an increase in governmental defence needs as well as in the banking sector and transport control. To ensure all aspects from business to people's lives run smoothly without any disruptions, the communication network must stay efficient at all times. Network designers are continuously faced with the challenge of keeping a communication network running smoothly. The diffusive nature of design knowledge, such that it is scattered among organizations and individual designers because of project-specific variances, makes the task at hand difficult. This distribution creates knowledge silos that pose barriers to access and reuse, therefore the repeated initiation of projects and escalation of costs. These concerns are captured by this study's ambition to systematize and document the knowledge regarding network design in a systematic, easily accessible format, increasing reusability and reducing project duration. The research follows a qualitative approach and focuses on the processes and activities involved in network design. Data gathering included interviews and observations that were interpreted through thematic analysis. The research identifies three knowledge types: definitions of "telecommunication network resilient", "resilient network design knowledge" and "resilient network design process knowledge". This study concludes with a proposed process model for developing a resilient telecommunication network and advice to future users.

1. Introduction

Over 2 million people are connected to the Internet conducting transactions of about USD 8 trillion per annum. The Internet has a major impact on the economic growth of different large and developed economies [1]. Considering the critical importance of computers and information networks to business success, telecommunication networks must ensure constant availability through unending connectivity that will allow businesses smooth operation, and access to applications and services [2,3]. A telecommunication network breakdown can cause massive

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https://doi.org/10.37934/ard.144.1.1020

problems, dealing a blow to communications systems, which triggers economic losses and sometimes leads to the loss of life in severe situations.

In retrospect, one of the worst historical incidents on the Japanese economy was a devastating earthquake that took place on March 11, 2011, and claimed nearly 19,000 deaths and an estimated US$ 210 billion in damage costs were recorded [4,5]. Nippon Telegraph and Telephone (NTT), the largest network operator in Japan had about 15,000 mobile base stations and over 1.2 million fixed telephone lines out of service due to serious damage [6]. In the same manner, in December 2014, a flood in Kelantan of Malaysia blocked telecommunication road access caused almost 80% sector and hampered recovery teams [7,9].

Regardless of the situation, preserving the performance and stability of a telecommunications network is important, especially during crises. Planning a reliable telecommunication network requires detailed preparations [10,11]. The knowledge and experience of network designers and technicians direct the most potent design strategy for networks that is based on customers' needs. The knowledge of these talented people is indispensable for the successful running and general functioning of an organization [12,13]. Concerns about knowledge retention in organizations, especially in an industry where this is a challenge due to high turnover rates, highlight the need for documenting network design knowledge [14,15]. This study aims to create a systematic model of network design knowledge for it to be accessible and reusable. The objective is to improve employee productivity, shorten project duration, and minimize the effect of factors like retirement, layoffs job rotation as well as turnover on essential organizational knowledge.

2. Literature Review

In this section, the literature review delves into the definitions and evolutionary aspects of telecommunication networks, as well as the technologies employed in their development. The discussion also encompasses the taxonomy approach and explores earlier research on criteria for resilient telecommunication networks.

2.1 The Telecommunication Industry

The telecommunications industry is encountering a fundamental strategic challenge, a common occurrence in mature industries and utilities. This sector plays a crucial role in delivering essential services upon which billions of consumers and virtually all businesses depend. The anticipated surge in global data consumption over telecom networks, primarily driven by video traffic, is expected to almost triple from 3.4 million petabytes (PB) in 2022 to 9.7 million PB in 2027. However, due to the apparent lack of pricing power in the increasingly commoditized connectivity and data services, revenues from internet access (used as a proxy for broadband activity) are projected to experience only a modest 4% Compound Annual Growth Rate (CAGR), reaching US$921.6 billion by 2027 [16]. Simultaneously, telecommunications companies (telcos) find themselves obligated to make substantial investments in the expensive infrastructure necessary to serve their customers. With the ongoing transition to 5G and the growing adoption of newer technological standards, telcos are expected to invest a significant sum of US$342.1 billion in their networks in 2027 alone [16].

The substantial revenues in the telecommunications sector have enticed network engineers and designers to enter this field. However, the intense competition means that only those with skill and experience secure a place in the industry. Despite the demand for skilled and experienced designers, the sector grapples with unmanaged employee attrition. Competitors frequently entice highly skilled network designers with better offers, posing a challenge for organizations. The departure of network engineers is particularly concerning as they take their valuable knowledge and experience with them [17]. Failing to capture the tacit knowledge of network designers becomes a significant issue for organizations, jeopardizing a valuable asset. Finding a replacement is problematic, and the new hire may not possess the same level of skill as the departing employee. Therefore, capturing the tacit knowledge of network designers becomes crucial for the survival of organizations in the telecommunications industry.

2.2 The Knowledge Retention in Telecommunication Industry

Sanz *et al.,* and Ahlrik *et al.,* defines knowledge retention as the ability of an organization or team to preserve essential and distinctive knowledge, whether it is tacit, explicit, or implicit, crucial for the overall functioning of the organization [18,19]. The telecommunication industry grapples with uncontrolled employee attrition, primarily driven by the high demand for experienced network designers. Competitors often lure highly skilled network designers away with better offers due to their invaluable skills and knowledge [20]. When network designers depart from their company, they frequently carry with them valuable skills, experience, knowledge, and wisdom, resulting in a loss for the company. This situation frequently results in what is commonly referred to as corporate amnesia. Corporate amnesia is characterized by the loss of organizational memory, an incapacity to recall experiences, and an inability to communicate lessons from one part of the organization to another [14,21]. It occurs when companies engage in downsizing or frequent staff layoffs without capturing their valuable knowledge and skills. The expertise in building resilient telecommunication networks is cultivated over years of experience by highly skilled network design engineers. In the telecommunications industry, uncontrolled employee attrition is a prevalent issue. The constant demand for network designers from other organizations and competitors, coupled with staff retirements, transfers, and resignations, leads to the loss of valuable network design knowledge every year.

Knowledge is perceived as a cognitive intellectual entity, defined as authenticated and validated information ready for application [22]. Network design knowledge is considered valuable assets for a telecommunications company. However, it is often undocumented, disorganized, and scattered throughout the organization. To ensure that this valuable knowledge remains within the organization, it is essential to capture it before the network design engineer departs. Since network design knowledge is tacit, making it challenging to transfer or exchange, organizations must develop strategies to manage and retain this knowledge effectively.

2.3 A Resilient Telecommunication Network Design Brief

Communication networks are a critical infrastructure that plays an essential role in our everyday lives. In today's interconnected world, reliable and resilient telecommunication networks are essential for the efficient functioning of businesses, governments, and individuals [23]. They enable us to connect, access information, and conduct business efficiently. However, these networks are not immune to various challenges that can disrupt their functioning. Telecommunication networks must provide uninterrupted service, even in the presence of disasters, single-link failures, or malicious attacks. It is well known that telecommunication networks are currently one of the critical infrastructures upon which our society depends and services are expected to be always on [24]. Moreover, disaster-based failures are becoming more frequent in time and wider in scope, degrading drastically the services supported by telecommunication networks.

To ensure the seamless operation of the telecom network, it is imperative to conduct a thorough analysis of the current network infrastructure and assess its capacity to meet the growing demands of data and voice communication [25]. This involves evaluating the existing network topology, bandwidth limitations, and potential points of failure. Furthermore, it is crucial to consider the incorporation of emerging technologies such as 5G, Internet of Things, and cloud-based services into the network design. These advancements have the potential to significantly impact the network architecture and require careful planning to ensure compatibility and optimal performance.

In addition, security measures must be integrated into the design to safeguard against cyber threats and unauthorized access to sensitive data [26]. This involves implementing robust encryption protocols, firewalls, and intrusion detection systems. Scalability is another critical aspect to consider, as the network must be designed to accommodate future growth and expansion without significant disruptions or costly overhauls. By taking these factors into account, a comprehensive and resilient telecom network design can be developed to support the evolving communication needs of the modern world. This resilient design will enable uninterrupted connectivity, facilitate seamless data transmission, improve service reliability, and enhance overall customer satisfaction [27].

2.4 Design Principles for Robust Telecommunication Networks

Design principles for robust telecommunication networks involve the application of key concepts and guidelines to ensure the network's resilience, reliability, and optimal performance. Design principles for robust telecommunication networks are essential for ensuring efficient, reliable, and secure data transmission [28]. Some key design principles include:

i. Robustness Principle: This principle states, “be conservative in what you do, be liberal in what you accept from others”. It is often reworded as, “be conservative in what you send, be liberal in what you accept”. This principle is also known as Postel’s law, named after Jon Postel, who used the wording in an early specification of the Transmission Control Protocol (TCP).
ii. Fault Tolerance: Design networks to handle and recover from faults, ensuring uninterrupted connectivity even if one path faults.
iii. Scalability: A scalable network can rapidly grow to accommodate new clients and applications without affecting performance.
iv. Quality of Service (QoS): In the modern multi-cloud era, networks must prioritize quality of service, ensuring that services are reliable, measurable, and sometimes even guaranteed, with no compromises in quality.
v. Security: Design networks with robust security measures in place, such as network segmentation, least privilege access, and adopting a zero-trust model
vi. Management and Simplification: Simplify network management and minimize the core network breach risk by creating a robust and secure network.

By focusing on these design principles, telecommunication networks can be built to withstand various challenges, provide reliable service, and ensure secure data transmission [26,29].

3. Methodology

This study employed a qualitative research methodology, utilizing a case study approach to explore and gain a comprehensive understanding of the processes and activities inherent in the design of telecommunication networks. Data collection involved conducting semi-structured interviews with experts and practitioners, supplemented by observations conducted by the researchers. The research was organized into four distinct phases, as depicted in Figure 1 below, to effectively plan, structure, and strategize the investigation.

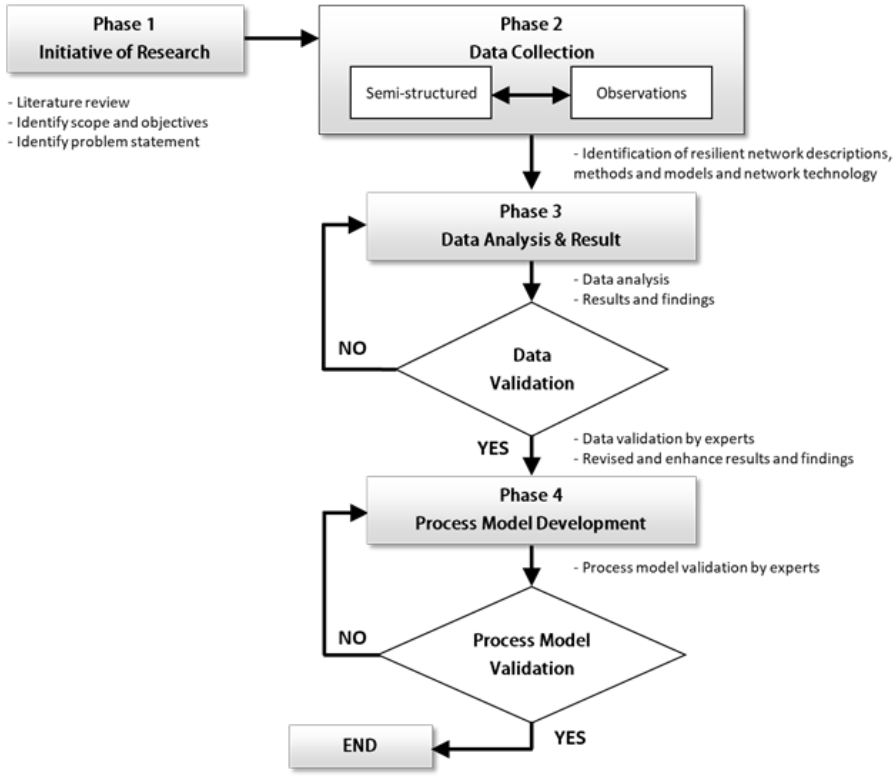

Fig. 1. Flow chart of research design

4. Results And Discussions

This section will describe the findings discovered during Phase 3 of this research which involved the analysis of the data collected using interviews and observation.

4.1 Data Analysis and Findings

The analysis of the interviews identified three distinct types of knowledge: 1) Definitions of Telecommunication Network Resilience, 2) Knowledge of Resilient Network Design, and 3) Knowledge of Resilient Network Design Processes. The definition of resilient telecommunication networks explores the criteria for resilience as perceived by experts. The knowledge of resilient network design delves into the intellectual understanding of experts regarding the translation of customer requirements and the design approaches employed in proposing solutions. Lastly, the processes of resilient network design unravel the steps involved in designing a resilient telecommunication network. Detailed explanations of each knowledge type are provided below.

4.2 Knowledge of Resilient Telecommunication Network Definition

During the interview session, experts emphasized that crafting a resilient telecommunication network poses considerable challenges. According to these experts, a telecommunication network must exhibit high reliability and availability to guarantee uninterrupted service delivery to customers.

The benchmark for network resiliency is measured by achieving nearly 100% or 99.999%, commonly referred to as five-nine uptime over a year. To attain this 99.999% uptime and ensure resilience, the resilient network must satisfy the following criteria.

i. No failure of network equipment such as routers, switches, or any network devices. These network equipment and devices must stay up all the time (Expert 1, Expert 2, Practitioner 3);
ii. The network equipment must have a protection mechanism either hardware protection or software protection. When network equipment fails, the network equipment should have a mechanism to change over to standby working equipment or components. The failure should not affect the services. For example, if the power supply is cut off, the network equipment shall support a 1+1 power supply source (Expert 1, Expert 2, Practitioner 2, Practitioner 4);
iii. The designed network should have sufficient capacity and be able to cater for unexpected peaks or burst traffic. Intensive traffic planning and design are required because in normal conditions users will not address this issue, but it will give problems to operators when the traffic is burst due to too many users being connected at the same time (Expert 2, Practitioner 2, Practitioner 3, Practitioner 4);
iv. Because the technologies are growing fast, telecommunication networks not only carry data communication but also other services such as Voice over Internet Protocol (VoIP) and Internet Protocol TV (IPTV) for video-on-demand services. A resilient network should be able to carry any ancillary services (Expert 1, Practitioner 1, Practitioner 3);
v. The network equipment also must have security features. The network equipment should protect the data that is transmitted over it and the stored data on the devices that connect it (Practitioner 1, Practitioner 2, Practitioner 3, Practitioner 4);
vi. The designed network must be flexible to adapt to network growth and general business changes. Any changes should not affect or very minimal impact on the services (Expert 1, Expert 2, Practitioner 4);
vii. A comprehensive Network Monitoring System (NMS) is essential to allow engineers to identify the problems efficiently for first-level troubleshooting (Practitioner 1, Practitioner 2, Practitioner 3, Practitioner 4).

Furthermore, in the interview, Expert 1 also discussed potential threats to the telecommunication network. Figure 2 illustrates the taxonomy of conceivable threats to the telecommunication network.

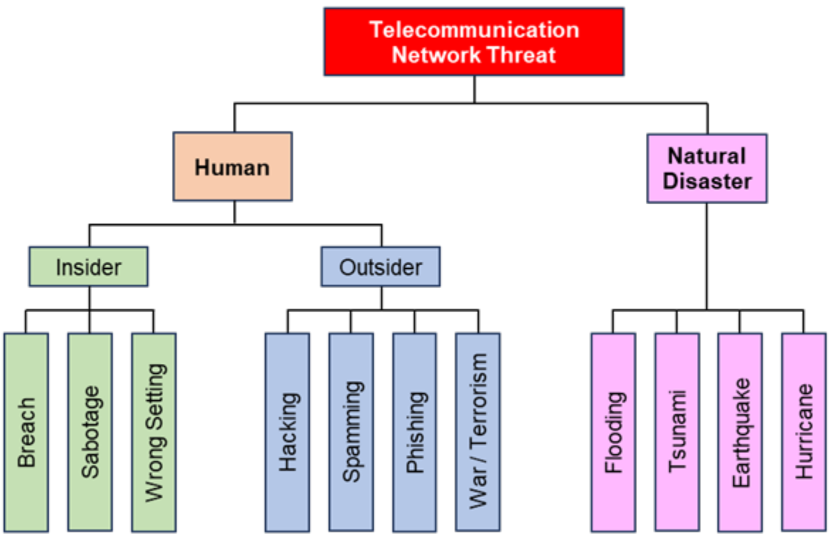

Fig. 2. Taxonomy of possible threat to telecommunication network

There are two primary categories of major threats to telecommunication networks: human causes and natural causes. In terms of human causes, Expert 1 highlighted that threats may originate from insiders or outsiders. Insider threats, such as breaches of conduct by internal employees, can expose the telecommunication network to external risks. Outsider threats encompass hackers with intentions to steal information or data transmitted through the telecommunication network. Insider sabotage can result in telecommunication network outages, as per Expert 1 experience. Instances of insider sabotage often occur when an individual disagrees with management decisions, leading to the operator incurring costs to replace faulty equipment. Common human errors, such as incorrect equipment settings, frequently impact operators and have repercussions on customers. Examples of outsider threats include spamming and phishing, orchestrated by IT experts exploiting their skills. These activities aim to steal user information for fraudulent purposes. The most significant impact on telecommunication networks from outsider threats is posed by war or terrorism threats, which can lead to a complete breakdown of the communication system, requiring billions of dollars for infrastructure and service recovery. Another major threat category is natural disasters. Natural disasters, such as floods, earthquakes, tsunamis, and hurricanes, affect all sectors, including telecommunication, power lines, and the economy. According to the World Disaster Report 2014, these disasters can devastate everything, including telecommunication infrastructure, buildings, and residential areas. The aftermath of natural disasters incurs costs in the billions of dollars, and thousands of lives are lost.

4.3 Resilient Telecommunication Network Design Knowledge

The second category of knowledge gathered pertains to resilient telecommunication network design. All respondents emphasized that crafting a resilient telecommunication network requires an in-depth understanding of translating customers' requirements into technical knowledge. With this knowledge, designers can propose optimal and cost-effective solutions to customers. The translation of customer requirements into technical knowledge is deemed challenging, involving tacit knowledge. Expert 1 and Expert 2 asserted that this process demands abstract knowledge gained through years of experience in network design.

In the context of large telecommunication network projects, Expert 1 highlighted the importance of modularity and scalability. Modularity architecture enables the addition of adjunct processors, such as voice processing equipment and data communication gateways, without modifying application interfaces. According to Expert 2, scalability entails designing a network capable of adapting to future expansion with minimal upgrading costs. Practitioner 2 and Practitioner 3 underscored the significance of scalability features for network operators to control costs during future expansions. All experts and practitioners recommended a modular approach with three layers, employing hierarchical models for enhanced ease of management. This model divides networks into the core, metro, and access layers.

4.4 Resilient Network Design Process Knowledge

Throughout the interview, experts and practitioners outlined that network design is essentially segmented into four major phases. These phases include 1) Requirement Analysis, 2) Development of Conceptual Design, 3) Installation, Testing, and Optimization Planning, and 4) Documentation. Each phase encompasses specific processes required to finalize the design. The initial phase, Requirement Analysis, necessitates designers to identify network objectives and goals, whether for constructing a new telecommunication network or upgrading an existing one. During this phase, designers must also pinpoint the technical requirements essential for achieving the network objectives and goals.

The second phase involves developing a conceptual design, incorporating tasks such as proposing network topology, selecting technologies, devising management strategies, outlining project scopes of work, creating schedules and timelines, and finally reviewing the design for ultimate approval. If any modifications are required, the design proposal must be adjusted and resubmitted to the customer. Moving on to the third phase, Installation, Testing, and Optimization Planning, designers are required to plan installation works according to the project schedule and timeline defined in the second phase. This phase also involves strategizing for network optimization, encompassing VLAN planning, bandwidth planning, and switching and routing to ensure comprehensive network optimization. The concluding phase is Documentation, where designers meticulously document all phases and processes of the project, presenting them to the customer as a comprehensive network design proposal.

4.5 Developing a Process Model for the Knowledge of Designing Resilient Telecommunication Networks.

Drawing insights from the findings of this study, it can be deduced that network design is delineated into four primary phases. Moreover, each phase encompasses several processes leading to the culmination of the final design proposal. Through an analysis of the techniques and knowledge employed by experts and practitioners, the study puts forth a process model designed for future endeavours in crafting resilient telecommunication networks. The illustrated process model is presented in Figure 3 below.

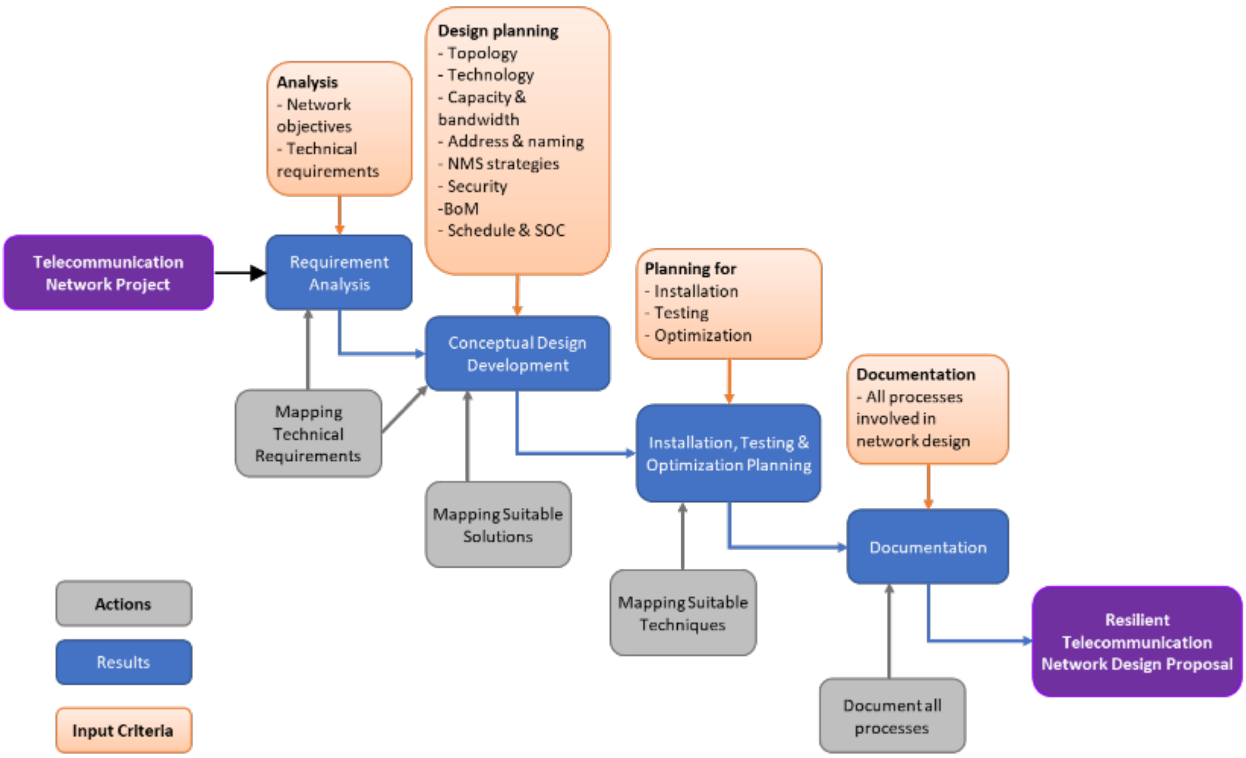

Fig 3. Proposed process model for resilient telecommunication network design

Figure 3 illustrates the proposed process model for the design of a resilient telecommunication network, derived from the research findings. This model delineates the relationship between design phases and processes essential for crafting a resilient telecommunication network. The telecommunication network design commences with the requirements analysis phase, initiated during the initial project meeting and customer discussions. Input criteria for network objectives and technical requirements are defined at this stage. Designers then align these technical requirements with the customer's network objectives.

Moving on to the second phase, the development of conceptual design, input criteria include topology and technology selection, capacity and bandwidth planning, naming and addressing planning, network management system (NMS) and security strategies, bill of material, schedule, scope of works, and design review. Designers map suitable solutions and strategies based on these criteria, ensuring alignment with the technical requirements identified in the requirements analysis phase. This guarantees that the designed network meets customer objectives and goals. The third phase, installation, testing, and optimization planning, employs the input criteria to plan for installation, testing, and optimization. Designers map suitable testing or proof-of-concept testing and optimization techniques to ensure the designed network is functional and fully optimized, as discussed in the previous section.

The final phase involves project documentation, where all phases, from requirements analysis to conceptual design, installation, testing, and optimization, along with the processes within each phase, are documented. The comprehensive project document is then submitted to the customer as a resilient telecommunication network design proposal for evaluation. This proposed process model aims to assist organizations and emerging designers in crafting resilient telecommunication networks in the future.

5. Conclusion

This study was conducted to capture and analyze the tacit knowledge held by experts and practitioners in the design of resilient telecommunication networks. The goal is to create a well-documented model of network design knowledge, fostering accessibility and reusability, and ultimately reducing project turnaround time. The research identified three types of knowledge: Telecommunication Network Resilient Definitions, Resilient Network Design Knowledge, and Resilient Network Design Process Knowledge. The findings indicate that a resilient network remains operational consistently, even in the face of component failures, ensuring uninterrupted services. Additionally, the study emphasizes the importance of incorporating security features, such as firewalls and intruder prevention, to safeguard transmitted data. Resilience, in this context, extends beyond security and encompasses scalability and manageability, both critical factors in ensuring network robustness. Scalability is essential for accommodating future growth, impacting an organization's return on investment, while manageability allows users to efficiently oversee the network. A resilient network must also support a comprehensive Network Monitoring System (NMS), facilitating efficient problem identification by engineers.

For future research, it is suggested that investigators explore additional segments not covered in this study, specifically enterprise networks and campus networks. These segments may possess distinct network design knowledge and involve different technologies, potentially contributing to the development of more resilient networks in the future.

Acknowledgements
The authors would like to express their deepest appreciation and gratitude to Universiti Teknologi MARA, colleagues and all those who have contributed with stimulating suggestions, and encouragement and helped to coordinate this research to its completion.

References
[1] Hjort, Jonas, and Lin Tian. "The economic impact of internet connectivity in developing countries." *Annual Review of Economics* 17 (2021). https://doi.org/10.2139/ssrn.3964618
[2] Beqiri, Edmond. "The implications of information networking at the pace of business development." *International Journal of Knowledge* 27 (2018): 17-22.
[3] Trimintzios, P. "Measurement frameworks and metrics for resilient networks and services." *Discussion Draft. European Network and Information Security Agency* (2011).
[4] Hirata, K. "The Great East Japan Earthquake." *GIM International* 25, no. 9 (2011): 1-3.
[5] Matanle, Peter. "The Great East Japan Earthquake, tsunami, and nuclear meltdown: towards the (re) construction of a safe, sustainable, and compassionate society in Japan's shrinking regions." *Local Environment* 16, no. 9 (2011): 823-847. https://doi.org/10.1080/13549839.2011.607160
[6] "International Telecommunication Union." *International Organization* 15, no. 1 (1961): 195–97. https://doi.org/10.1017/S0020818300024668
[7] Baharuddin, Kamarul Aryffin, Shaik Farid Abdull Wahab, Nik Hisamuddin Nik Ab Rahman, Nik Arif Nik Mohamad, Tuan Hairulnizam Tuan Kamauzaman, Abu Yazid Md Noh, and Mohd Roslani Abdul Majod. "The record-setting flood of 2014 in Kelantan: challenges and recommendations from an emergency medicine perspective and why the medical campus stood dry." *The Malaysian journal of medical sciences: MJMS* 22, no. 2 (2015): 1.
[8] Bahar, Arham Muchtar Achmad, Marinah Muhammad, Mohammad Muqtada Ali Khan, and Noor Janatun Naim Jemali. "Statistical and Spatial Analyses of the Kelantan Big Yellow Flood 2014." In *IOP Conference Series: Earth and Environmental Science*, vol. 549, no. 1, p. 012014. IOP Publishing, 2020. https://doi.org/10.1088/1755-1315/549/1/012014
[9] Aisha, Tengku Siti, Saodah Wok, Aini Maznina A. Manaf, and Rizalawati Ismail. "Exploring the use of social media during the 2014 flood in Malaysia." *Procedia-Social and Behavioral Sciences* 211 (2015): 931-937. https://doi.org/10.1016/j.sbspro.2015.11.123
[10] Cisco Systems. "Design Overview: Smart Business Architecture, International Technical Report," 2010.
[11] de Sousa, Amaro. "Improving the connectivity resilience of a telecommunications network to multiple link failures through a third-party network." In *2020 16th International Conference on the Design of Reliable Communication Networks DRCN 2020*, pp. 1-6. IEEE, 2020. https://doi.org/10.1109/DRCN48652.2020.1570613461
[12] Massingham, Peter Rex. "Measuring the impact of knowledge loss: a longitudinal study." *Journal of Knowledge Management* 22, no. 4 (2018): 721-758. https://doi.org/10.1108/JKM-08-2016-0338
[13] Al-Dalahmeh, Maha Lutfi. "Talent management: a systematic review." (2020). https://doi.org/10.47535/1991ojbe102
[14] Sumbal, M. Saleem Ullah Khan, Irfan Irfan, Susanne Durst, Umar Farooq Sahibzada, Muhammad Adnan Waseem, and Eric Tsui. "Knowledge retention in oil and gas industry–the case of contract workforce." *Kybernetes* 52, no. 4 (2023): 1552-1571. https://doi.org/10.1108/K-06-2021-0458
[15] Durst, Susanne. "How far have we come with the study of knowledge risks?." *VINE Journal of Information and Knowledge Management Systems* 49, no. 1 (2019): 21-34. https://doi.org/10.1108/VJIKMS-10-2018-0087
[16] PricewaterhouseCoopers. *Perspectives from the Global Telecom Outlook 2023–2027: The Future on the Line.* 2023.
[17] Sabri, Sabiroh Md, Haryani Haron, Nursuriati Jamil, and Emma Nuraihan Mior Ibrahim. "A Conceptual Review on Technological Intergenerational Knowledge Transfer." *J. Comput.* 9, no. 3 (2014): 654-667. https://doi.org/10.4304/jcp.9.3.654-667
[18] Sanz, Rocio, and John Hovell. "Knowledge retention framework and maturity model: Improving an organization or team's capability to retain critical knowledge." *Knowledge Management for Development Journal* 16, no. 1 (2021): 8-27.
[19] Ahlrik, Alma, and Hertha Kamras. "Knowledge Retention in Practice: How organizations avoid knowledge loss through proactive and reactive knowledge retention processes." (2023).
[20] Field, E., D. Mendelsohn, N. Rainone, and B. Schaninger. "The Great Attrition: Same turnover, but the "why" differs by industry." *McKinsey & Company* (2021).

[21] Sadat, Andi Muhammad, and Mei-Lan Lin. "Organizational amnesia: the barrier of value creation and organizational performance in small and medium sized enterprise." *Journal of Business and Behavioural Entrepreneurship* 2, no. 1 (2018): 1-8. https://doi.org/10.21009/JOBBE.002.1.01
[22] Alsaleh, Saad, Sabiroh Md Sabri, and Haryani Haron. "Research Knowledge System Model for Higher Learning Institutions." In *2021 IEEE 11th International Conference on System Engineering and Technology (ICSET)*, pp. 36-39. IEEE, 2021. https://doi.org/10.1109/ICSET53708.2021.9612572
[23] Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway. *Resilience of Telecommunications Networks.* 2022.
[24] Alashaikh, Abdulaziz, Teresa Gomes, and David Tipper. "The spine concept for improving network availability." *Computer Networks* 82 (2015): 4-19. https://doi.org/10.1016/j.comnet.2015.02.020
[25] Tipper, David. "Resilient network design: challenges and future directions." *Telecommunication Systems* 56, no. 1 (2014): 5-16. https://doi.org/10.1007/s11235-013-9815-x
[26] Aziz, Mohd Zafran Abdul, and Koji Okamura. "A security trending review on software define network (SDN)." *Journal of Advanced Research in Computing and Applications* 6, no. 1 (2017): 9-19.
[27] Insights Desk. “Mastering Network Architecture Design – from Concept to Reality | TechDemand.” TechDemand, August 21, 2023.
[28] Ahmed, Moustafa Abdelrahman Mahmoud, Syahril Anuar Idris, Nur Arzilawati Md Yunus, Fazlina Mohd Ali, and Hazrina Sofian. "CyberShield Framework: Attacks and Defense Modelling for Cybersecurity in Internet of Things (IoT)." *International Journal of Advanced Research in Computational Thinking and Data Science* 4, no. 1 (2024): 30-39. https://doi.org/10.37934/ctds.4.1.3039a
[29] Expert Panel. “17 Key Strategies for Designing a Secure, Efficient Network.” *Forbes*, November 28, 2023.