Technology Adoption: Intelligent Agent-based Model for Philippines FTTH Broadband Service Availability

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Abstract—The vast improvement in broadband service delivery has been achieved mainly in the Fiber-To-The-Home (FTTH) technology, which was influential during this pandemic in providing connectivity with everyone, thus ensuring high service availability. The evolution of network monitoring systems has helped achieve this by equipping the network engineers in performing corrective or predictive maintenance. However, minimal research has been conducted to investigate how the adoption of technology and different factors attributes, including organizational culture, have helped or served as the bottlenecks in meeting the set service Key Performance Indicators (KPIs) hinged on the system utilization. This study focuses on measuring, predicting, and simulating technology adoption's interdependence with FTTH network monitoring systems to detect last-mile issues and perform necessary maintenance activities. An agent-based simulation via AnyLogic towards broadband service availability is to be drawn from different works of literature and support the creation of a theoretical model. The goal is to have a simulation tool and quantified outcomes to predict the valued indicators that can help the telecommunications sector to be equipped with proper knowledge in understanding the end-to-end broadband service journey that can benefit not only the business but also the subscribers who rely heavily on broadband service.

Keywords—agent-based simulation, broadband service availability, FTTH maintenance, network monitoring system, technology adoption

I. INTRODUCTION

The adoption of online activities increased due to the Coronavirus (COVID-19) pandemic, which replaced inperson transactions. The implementation of lockdowns to minimize the impact disrupted daily activities, resulting in the dependencies on the Information and Communications Technology (ICT) migrating online activities such as telehealth, e-learning, telework, e-shopping, and video calls through zoom or facetime [1]. The importance of these online activities increased before and during COVID-19, as shown in Fig. 1 in [1].



Figure 1. Online activity comparison [1]

The increase in internet traffic posed a challenge to broadband service providers. Access to the internet was a vital way that helped everyone cope-up with the COVID-19 pandemic. The pressure on each healthcare system to provide immediate patient attention was challenging. However, more pressure was put on the broadband service provider to ensure high network availability to sustain the need to communicate remotely to support economic and business activities affected by the imposed lockdowns. There was an increase in internet usage in all areas until the second quarter of 2022, where an increase of approximately 20% was measured around Europe, as shown in



Figure 2. Internet traffic changes in Europe

The shift of mobile broadband traffic to fixed broadband networks affected each home's bandwidth capacity and service availability requirement. The fixed broadband

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network transport layer has advantages and disadvantages depending on the deployed technology and topology, such as the Fiber-To-The-Home (FTTH).

The Fiber-To-The-Home (FTTH) technology delivers high-speed broadband directly to the homes using optical connectivity compared to other wired technology such as Data Over Cable Service Interface Specifications (DOCSIS) and Asymmetric Digital Subscriber Line (ADSL) technology. The vulnerability of its transmission facility up to the last mile affects the network availability performance of all the services it supports triple-play service through the fiber optic cables. The mean time to repair is also affected by the capability to monitor the service interruption and is often dependent on the subscriber complaint before a technician is dispatched to restore the service [3].

The increase in technology migration is spearheaded by the business organization's aim to optimize the quality of living of their stakeholders. Business needs drive innovations and technology improvements with the primary goal to immediately create valuable service improvement. The readily available processes and strategies aim to increase end-user technology adoption to achieve overall diffusion and business sustainability.

Review existing gaps in technology adoption, challenges, and opportunities and convert them to goals that balance the interdependence of business, technology, and customers' requirements. There is no currently known study in the Philippines that is directly about how FTTH systems are affected by the interdependence of technology adoption with the network monitoring and maintenance activities that measure Broadband service performance.

The studies concerning FTTH systems, technology diffusion, and adoption do not cover how their interdependence impacts the overall broadband service performance. Instead, they only focus on their individual perceived output based on each subject's available theories or processes. There is no known study on the Philippine broadband service that integrates, simulates, and measures how each factor can contribute to successfully achieving the required KPIs.

A study discussed the importance of early detection, failure prediction on the last mile, and implementation of maintenance activities to provide excellent FTTH network performance, ensuring high-quality services [4]. However, their study only focused on the vulnerability of each respective FTTH segment, assuming that each monitoring system end-user would utilize the system effectively. It was seen that monitoring systems are only used locally for hardware supervision and alarm triggers despite numerous studies even before the 21st century [5]. It was also noted that reactive human-based network measurement and management are limiting factors in the evolving optical network, requiring high reliability and efficiency [6].

The primary objective of this study is to bridge this gap and arrive at a simulation model that could predict the impact of technology adoption in the implementation of maintenance activities whose primary goal is to ensure high broadband service availability. Identifying the interdependence technical parameters, maintenance activities, and agent attributes are translated to an agentbased simulation model using AnyLogic software. The emergent framework and simulation model could assist in creating or improving network service availability based on the identified attributes concerning attitude, behavior, culture, and skill fit. Thus, it could contribute to integrating FTTH programs with operational strategies and business goals to help organizations continuously improve customer experience through high service availability.

Objectives and Deliverable

Technology serves as a process that captures and communicates information that can be used as a tool for decision-makers [7]. It is an omnipresent element that supports creating opportunities supported by different technology-enabled processes that impact each identified stage [8]. They need to understand the organizational position, convert these into possible policies, and maximize technological process improvements to enhance stakeholder experience. It is also empirical to ensure that the stakeholders recognize the technology improvement to help them accelerate the technology adoption and motivate them to use it [9]. However, the adoption would not be successful because of lacking organizational skillset capability and commitment [10].

The study addresses how agent attributes and readily available FTTH monitoring processes and standards policies affect achieving a high broadband service availability.

The following specific questions guide the study:

- 1. What is the impact of technology adoption on the FTTH maintenance activities to ensure high broadband service availability?
- 2. How do individual behavior, attitudes, and culture affect the diffusion of technology in implementing the network monitoring process in the FTTH network?
- 3. What are the issues that affect the usage of the available monitoring system in implementing FTTH maintenance activities?

The study progresses by initially understanding related literature that drives the dependencies and requirements to achieve a paradigm shift for technology adoption. The study aims to develop an analytical framework translated into a simulation model that could help model how technology adoption is affected by several factors and attributes that can improve current Broadband service availability.

II. RELATED LITERATURE

The study in FTTH showed that the availability of remote system monitoring started more than a decade ago, similar to the study of Pfeiffer in 2008, which focused on the remote Optical Time Domain Reflectometer (OTDR) measurement [11]. It was also seen that some of the technologies have evolved from periodic optical encoder remote fault monitoring [12] to machine learning which detected degradation of optical spectrum light path [13].

Most new technologies, theories, and platforms utilize machine learning to provide predictive information even before potential line failure occurs based on the standard parameters. In contrast, some network monitoring systems offer adequate information for service restoration in network outages.

However, one of the issues faced in the deployment of technology is the measurement of how successful such technologies were utilized or adopted. The issue in investigating technology adoption is that not all new processes or innovations are adopted in the form designed or conceptualized [14]. This lack is factor raises a question on the impact of the adoption in the targeted KPIs and what could have been the effect in each case if it implemented in some way different to the level of adoption rate at a given particular time and perception, as shown in Fig. 3 in [15].



Figure 3. Innovation diffusion [15]

Understanding the adoption curve is essential in ensuring critical stakeholders adopt new technology successfully [16]. The low level of innovators and early adopters could cause slow adoption due to a potential lack of awareness and involvement. At the same time, the stagnant value of the early majority also poses a threat to the high adoption since they tend to adopt the technology after seeing the successful implementation of innovators or early adopters.

The study of Cirus focused on understanding the impact of attitude, behavior, and experience in their respective level of adoption[17]. The study found that most Laggards and Late Majority reject adopting because they prefer to continue what they are used to and decline to transition to new technology. In contrast, the behavior of the Early Majority is driven by understanding the improvements and acknowledging the benefit of technology adoption. Some of these individuals participated in evaluating and implementing the new technology. It also discussed the importance of considering building trust in the process or innovation to increase adoption.

Understanding the impact of decision stages such as knowledge, persuasion, decision, implementation, and confirmation concerning adoption is essential in analyzing The result of Celik'studies technology adoption. acknowledged that the decision stages impact the level of each individual, particularly on the timing they decided to transition and utilize the new technology [18]. Usually, the early majority is not the first to use the new system, but they are ahead of the others. In contrast, early adopters immediately tried to learn upon acknowledging that the new system was still at the early stage of diffusion.

Different studies focused on other methods and theories that allow us to understand the intricacies of technology adoption. Most studies discuss the importance of attitude, behavior, and culture in ensuring technology diffusion that leads to adopting the new system.

The prior studies provided an overview of their importance. However, no known research integrated endto-end analysis and measurement of the interdependence of technology adoption with the projected improvements that the new system aims to achieve, particularly in FTTH service availability.

Implementing maintenance activity in the FTTH network through a monitoring system in the physical layer provides seamless delivery and high availability [19]. Fig. 4 overviews the network segment with high fault vulnerability [4]. A study showed that more than sixty-five percent (65%) of the last mile failure is due to defective passive elements because of cut fiber caused by external factors, high fiber loss due to excessive bending or damaged fiber, and customer premise fiber mishandling [4]. The remaining thirty-five percent (35%) is due to connector issues brought by improper splicing, loose connections, and optical network unit failure.



Figure 4. FTTH Failure Probability [4]

The failure rates in each FTTH segment based on Fig. 5 show the failure diagnosis of the FTTH last-mile segment issues [20].



Figure 5. FTTH Failure diagnosis [20]

The failure occurrence for each customer is predicted to occur twice a year with an interval of six months on the first failure incidence and two months on the second, with a 30% probability that a second incident could happen if Remote Monitoring System (RMS) is not utilized.

The importance of monitoring tools and process plays a significant role in performing maintenance activities based on the physical and optical parameters that triggered the link diagnosis and fault detection [21]. Maintenance activities ensure high systems reliability within optimal performance, including unforeseen repair and restoration activities. Preventive maintenance is planned activities over time to reduce failure probability, and corrective maintenance is carried out to repair or replace network elements or systems to restore service in a short time. In contrast, predictive maintenance is triggered by breached monitored parameters supported by data-driven techniques that alert potential failure or disruption that might not affect service [22]. Table I provides an overview of the maintenance processes and considerations.

Features	Corrective Maintenance	Predictive Maintenance	Preventive Maintenance
Approach	Reactive	Proactive	Proactive
Category	Repair due to failure	Parameter based	Time-based (Periodic)
Downtime	Highest	Least	Less
Failure Probability	Random	Prevents to occur	Age-based
Schedule	Not applicable	Based on parameter	Based on historical failure and standard useful
Action	Detect, inspect, repair, replace (identified parts or segment	Monitor, detect, analyze, isolate, repair, and replace (specified parts or segment	Inspect, replace (based on useful equipment life)
Monitoring	Remote, monitor service downtime	Remote, monitor parameter breach, unstable and on/off connection	Remote, monitor, and previous log activities

TABLE I: MAINTENANCE PROCESS [22]

It is essential to note that the network monitoring system is a type of information system that FTTH engineers use to arrive at a specific decision that could trigger maintenance activities. However, the success of the network monitoring system depends on the adoption to continuously operate and set aside the conventional reactive monitoring process, which can be driven by different influencing factors or attributes [23].

The Network Monitoring System (NMS) monitors the FTTH network status in real time. The monitoring system measures the fiber's physical layer state. It sends feedback to conduct link diagnosis, baseline parameter analysis, and fault detection. The transmission quality measurement of an aging physical fiber layer is vital to ensure high service availability [24]. A closed service monitoring loop is established in each identified network element, as illustrated in Fig. 6.



Figure 6. NMS Loop process [24]

The Network Engineer could perform the maintenance process illustrated in Fig. 7 based on the physical alarm monitored in the NMS in [25].



Figure 7. FTTH Network failure detection and maintenance process flow [25]

The NMS is the agent that enables real-time monitoring and network state identification of the FTTH network that affects service performance. Each alarm identified corresponds with proposed maintenance activities that could affect respective Key Performance Indicators. The study focuses on measuring the network availability of the subscriber network segment, which is just a portion of the end-to-end network service delivery platform. Network availability ensures that the service works when needed and can meet the committed requirement at a defined time with an optimal service experience.

High network availability can be achieved by ensuring the maintenance of network elements to prevent, correct, or restore outages. The restoration of network outages that affect network availability is measured through the Mean Time to Repair (MTTR), the time consumed before the service is restored based on the difficulty level and predicted repair duration of a particular network segment element or equipment.

Network availability is the percentage of the time network is available to meet service requirements. The target of each network provider is to attain "five nines," referred to as 99.999% availability at the core level, which corresponds to 5 minutes of downtime in a whole year [26].

Different availability targets in each network segment vary depending on the design, equipment type, and ease of restoration. The study focuses on the last segment issues, which computes the average subscriber availability based on each service provider's committed turnaround time. For this study, the impact of multiple service premise outages could be simulated with technology adoption in fulfilling maintenance premise activities

The corrective or predictive maintenance fulfillment is affected by each resource's utilization and occupancy rate.

The technology adoption concept focuses on the technology spread rate in society. Technology diffusion in the population and social networks is the same as the transmissibility of the "spreading of infectious disease" towards targeted areas—the decision to adopt the technology made by individual users through first-hand experience and learning. Adopters focus on knowledge acquisition and a significant push from the social system. At the same time, non-adopters are concerned with performance improvements [27].

The technology implementation push from the executive and management is a rigid approach that forces users to adopt. The need to learn and experience the initial technology adoption is essential to benefit the users, considering several factors such as compatibility, trialability, complexity, and observability [28].

Fig. 8 shows Roger's adoption curve theory that can be used to identify individual stages in [29]:



Figure 8. Roger's adoption curve [29].

The following factors affect users' adoption rate, including the market and other stakeholder reactions. The modeling process has long been used to understand the adoption process and hypothesis confirmation based on observed phenomena. However, some prior models were inefficient since they only obtained adopters at a limited time, which does not consider the population homogeneity and communication dynamics due to diffusion [30]. The discussion of different modeling systems provides an overview of how to maximize the understanding of technology adoption.

The development of Agent-Based modeling focuses on individual uniqueness and interactions between them and their immediate environment. Agent-based modeling simulates real-life systems, a type of artificial intelligence that brings a new paradigm for conceptualizing, designing, and implementing a software system [31]. It allows system behavior simulation based on several agents interacting in a particular environment. The agent-based system also represents behaviors, interactions, and impacts within their respective environment [32]. Agents represent actors or contributors in the design, which can be products, vehicles, ideas, behaviors, or processes. The limit of a single agent is based on its perspective, knowledge, and computing resources. At the same time, a multi-agent system consists of more than one agent aimed at a problem-solving organization [31]. Agent-Based Modelling (ABM) is used to address the following concerns [33]:

- Local interaction
- Heterogenous and time-varying environment
- Behavior adoption based on the current or projected environment state

Applying ABM provides a broader range of behavioral or process phenomena that could address empirical or theoretical issues [34]. An increase in new users in the past years, as shown in Fig. 9 in [35].



Figure 9. ABM Historical User [35]

The recent use of ABM with different data and model integration has sustained the increased popularity used in interdisciplinary settings, disciplines, and knowledge [36]. Fig. 10 shows the publications from various scientific branches concerning formal systems such as statistics, information theory, theoretical computer science, game theory, decision theory, system theory, and technical applications [35].



Figure 10. ABM Publications [35]

The Agent-Based Model bottom-up approach enables the explanation of complex, emergent, and non-linear macro to micro dynamics. The advantage of allowing social science computation provides the capability to explore how key factors are shaped by diffusion phenomena that are not generally represented by systems of differential equations [37]. Agent-based modeling aims to aid researchers, management, and regulatory bodies decide on a business, education, or evaluation of behavior in the market, medicine, and technology [38]. An Agent-Based model can also be applied in influence diffusion, as shown in Fig. 11.

The application of ABM is growing in the consumer energy choices facilitated by the agent heterogeneity modeling wherein the agent's decision-making is proactive and autonomous. The interaction with diverse and multiple stakeholders is enabled in the application, influenced by human behaviors [39].



Figure 11. Influence diffusion agent-based model [38]

Human behavior is addressed in ABM through human behavioral theories such as the Theory of Planned Behavior (TPB) which is used in modeling behaviors of consumers for diffusion model application, as shown in Fig. 12 [39].



Figure 12. Theory of Planned Behavior [39]

The requirement of a common language in an agent system increases the accuracy of messages between each agent. Agents' main goal is to collaborate and interact toward a particular purpose. A multi-agent system aims to break down the complex system into smaller and similar objectives and create agents for each sub-group, reducing complexity and improving model flexibility using different computational modeling software.

In 2002, the simulation using agent-based modeling started to change from an academic topic to an actual application to provide a deeper perspective on system simulation not fully covered by traditional modeling. The rapid improvement in the modeling technology brought by the advancement of computer systems has given way to different software that supports agent-based modeling by further understanding how a system behaves based on the interaction of dependencies and key variables or how individual objects act as a whole process flow.

Agent-based modeling does not use a standard programming language. However, it differs in how a model is created through graphical or scripts, depending on the software. Each software has been designed to be flexible and supported by any computing machine. Conventional programming languages such as Java, Smalltalk, and C are not required for users compared to the previous process [40].

The study uses AnyLogic software since it supports innovation analysis, telecom networks, and complex adaptive dynamic/discrete-event systems. The AnyLogic software is a platform that enables engineers, analysts, and managers to optimize and gain insights into complex systems. It supports the discrete event, agent-based, and system dynamics methods to develop simulation models. It can combine any technique to create a digital replica of a real-world scenario. Simulation of system behavior, performance metrics tracking, and prediction of potential system maintenance or downtime is also supported.

The consideration of individual agents, behaviors, rules, and interactions in a defined environment is supported by AnyLogic through its Agent-Based Modeling multiparadigm software simulation feature. The simulation is done in a single computer system that enables all agents to share a common ontology, eliminating the need to use a communication language for Agents.

III. METHODOLOGY

This chapter discusses the assumptions, processes, and guidelines to achieve the projected output of the study. The first Sec. focuses on defining and identifying keyagent parameters that provide the interdependence between the fixed broadband service availability and the different factors that can influence each identified stakeholder's adoption-the second and third focus on previous studies and actual field data. Integrating the data with the available organizational framework aims to calibrate, analyze and validate the generated model. The section forms the theoretical framework based on the synthesized and validated model, which could be the foundation of the agent-based model simulation using AnyLogic. The last portion discusses the validation of simulation results showing each agent attribute's impact on achieving acceptable fixed broadband service availability.

The final calibration of the theoretical model through the simulations aims to provide a technology adoption model that can improve quick and accurate restoration of fixed broadband service, resulting in high service availability. However, possible process changes in the steps of each objective can still be done based on the actual output, which can improve the overall simulation performance. Fig. 13 shows the process flow methodology of the study.

The process deals with understanding all parameters, specifications, and considerations needed to create the model and simulate the impact on service availability and mean time to restore service concerning technology adoption of utilizing network monitoring system. The following are included in the model:

- Define FTTH topology, components, and standard parameters attributed to the network monitoring system, network segment, and service availability parameters affected by maintenance activities.
- 2. Model all processes process flow concerning network monitoring, maintenance activities, and service failure.
- 3. Define model output and scope expected for the study
- 4. Identification of critical stakeholders affected or involved in the current and simulated scenarios.
- 5. Determination of interdependence of each process that could determine the relationship affecting the service availability and mean time to restore
- 6. Identification of potential vital issues and uncertainties



Figure 13. Study process flow methodology

The study proposes to focus on corrective and predictive maintenance of the FTTH last mile, which is the most vulnerable segment due to degradations caused by passive elements, high fiber loss, cut fiber cable, improper splicing, loose connections, and optical network unit failure. The remote monitoring system plays a significant role in identifying the degradations which trigger maintenance activities based on ITU-T G.984.3 Monitoring System Physical Layer Alarm that could trigger necessary maintenance actions. Fig. 14 integrates all technical dependencies and processes identified in the end-to-end maintenance process.



Figure 14. Considered FTTH attributes agent parameters

High service availability is achievable through predictive and corrective activities driven by the remote network monitoring system. However, multiple agents can affect the effectiveness of implementing both activities, even with a sophisticated and accurate network monitoring system. The system acceptance and adoption vary based on individual attitudes and behaviors driven by internal or external factors such as user training, efficient new policies and norms, and the individual's skill set. Fig. 15 aims to identify and analyze the impact of these factors and uncertainties by identifying and knowing their interdependence on each other.



Figure 15. Considered attributes agent parameters

The agents in the model represent the different system elements that interact to carry out the maintenance activities, which can be correlated with the other identified variables that impact the technology's adoption, resulting in either high or low broadband service availability. The model is composed of the primary agent, which is the toplevel object that defines the process and dependencies, the FTTH network with associated maintenance activities that are driven by the network monitoring, and network technicians that are affected by behaviors, attitudes, and actions towards the adoption of available technology which can affect the availability of the broadband service.

Multiple parameters are considered used in monitoring the physical fiber layer, which is essential in fulfilling broadband service Service Level Agreements (SLA). The degradation in the optical network results in packet losses or transmission errors that affect service availability. It is critical to note that the network monitoring system is a type of information system that network engineers use to arrive at a specific decision that could trigger maintenance activities. However, the success of the network monitoring system depends on the adoption to continuously operate and set aside the conventional reactive monitoring process, which different influencing factors or attributes can drive.

Understanding the functions, involvement, and different attributes of each agent involved in the FTTH maintenance process could breach this gap. They could help in building a model to simulate each defined process. The model for the maintenance multi-agent system is presented in Fig. 16.

The Network Analytics agent defines required resources to perform the task, determines the duration of each activity based on defined SLAs, and schedules priority activities concerning the ongoing task. The Network Engineer monitors each resource's utilization and occupancy rate.

The effectiveness of the existing workflows depends on the willingness of agents to utilize or follow the defined process, similar to the ABM application in smart metering, which is dependent on the changes in their daily routine simultaneously, with little effort from their end.



Figure 16. Maintenance multi-agent structure

All the identified technical parameters, processes, information, and scenarios are crucial in arriving at the consolidated model shown in Fig. 17, which integrates the interdependence of FTTH network monitoring, agent attributes, and technology adoption that affects broadband service availability.

The proposed model is simulated using AnyLogic software based on identified scenarios and dependencies affecting broadband service availability.

The activity of the Network Engineer is based on the identified values in the Maintenance parameters. The trigger of the maintenance activity starts with the NMS alerts. It is analyzed by Network Analytics which is dispatched to the Network Engineer. The model simulation also considers the Network Engineer state defining the capacity requirement based on the projected volume of identified network fault and duration. The simulation focuses not only on the FTTH technical and individual attributes but also on the direction and culture of the identified organization. It aims to analyze how organizational culture affects inclination towards adoption considering the readily available local and international standards, policies, processes, programs, initiatives, and advocacies. Fig. 18 shows the integrated FTTH technical and individual attributes to meet the required service availability of 98.6%.



Figure 17. FTTH service technology adoption simulation model



Figure 18. Interdependence of technical and adoption attributes

The agent-based model could allow the study to focus directly on the technical attributes that drive the Network Availability performance while separating the Agent attributes through identified interactions, similar to the analysis of Telecommunication Equipment Maintenance Efficiency. The opportunities to arrive at an Agent-Based simulation model that could predict the impact of technology adoption in the implementation of maintenance activities could assist in creating or improving technical attributes to achieve high network service availability backed up by the identified attributes concerning attitude, behavior, culture, and skill fit.

The initial model derived from the integration of concepts, technical standards, processes, studies, and actual field data aims to validate the impact of agent attributes on FTTH broadband service availability with the aid of the network monitoring system, which is dependent on technology adoption by identified stakeholders that could be simulated using AnyLogic Software that utilizes a combination of system dynamics and agent-based. The defined goals are supported by all the information discussed in the previous chapters, which considers the required parameters and variables assigned for each defined entity.

Technical	Adoption	
<u>NMS</u>	<u>NMS</u>	
Isolation Time (I _{Time}): Endorsement (Et) – Detection(Dt)	Internal Influence(Iinf): $\frac{dN(t)}{dt} = g(t) (m - N(t))$	
Dispatch Time(D _{TIME}):		
Onsite (Os)		
– Endorsement (Et)		
<u>MAINTENANCE</u>	<u>MAINTENANCE</u>	
Utilization Rate (Urate): Operation Time (Ot) Openning Time (OpenT)	External Influence(Einf): $\frac{dN(t)}{d} = p (m - N(t))$	
Occupancy Rate (Orate) : <u>Utilized Resource (Ur)</u> Total Resource (Tr) Mean Time To Restore(MTTR): <u>Repair Time (Rtime)</u> Nbr Failure	Mixed Influence(Minf): $\frac{dN(t)}{d} = [p + \frac{q}{m}N(t)]$	
KPIs	KPIs	
Network Availability (NA): Uptime (UT) Downtime (DT) + Uptime (UT)	$\frac{Technology Adoption (TA):}{\frac{dN(t)}{d}} = g(t) (m - N(t))$	

The derive simulation model aims to mimic the output of the existing system, which requires verification and validation if it meets the initially perceived outcome and is within the standard technical parameters. Table II shows that the measurable Technical and Adoption attributes supported by computational formulas are integrated with the proposed simulation model to achieve a comparable broadband service availability of 98.6%.

The study proposed using the data validation model shown in Fig. 19 to verify and validate the output of the AnyLogic Model in [41].

Three identified methods are used in the verification and validation process. The first method is the Historical Data Validation which utilizes historical information from other research to create the simulation model and validate the model output on the remaining data. The second method is the sensitivity analysis which focuses on how the model responds while changing the input data and uses parameters or agents' behavior to determine its impact on the perceived model results. The last method is the Turing Test Validation, which involves knowledgeable individuals that can bench-mark the perceived model output with the real-world operational system



Figure 19. Data validation process [41]

IV. DISCUSSION OF RESULTS

Multiple identified factors affect the FTTH service performance, both technical and adoption. The interdependence between the Network Monitoring System, Maintenance activities, and Technology Adoption is essential in achieving high quality of services and high performance of a reliable and efficient optical network. The conversion of the following factors to a simulation model is critical in analyzing the issues affecting FTTH service availability performance.

The system manages the service requests "service dispatcher" function driven by the configurations and assumptions indicated in FTTH Agent and Maintenance workflow. The system organizes the task process according to intervention requirements for restoration and corrective or proactive maintenance activities. In contrast, the action of the Network Crew is based on the identified values in the Maintenance parameters. Fig. 20 illustrates the service request handling



Figure 20. Service request handling

The integration of the technical attributes and the application of identified technology adoption scenario was successfully translated to an agent model that aims to measure Network Availability performance dependent on the following technical parameters shown in

The identification of several workflows triggered by the transition of each respective statecharts that are timedriven and dependent on the spent time in each statesupported AnyLogic's probabilistic conditions based on each scenario has successfully simulated the impact on the performance of technical parameters such Dispatch Time and Travel Time which measures the total Detection to Dispatch Duration, the Crew utilization response with adoption level and the overall impact on MTTR which affects Service Availability.

The overall response of each technical attribute and technical parameters are crucial in ensuring that a realworld situation is achieved through interdependence. This setting provides flexibility to focus on scenarios based on the experience or behaviors of identified participants. The capability of the ABM simulation model to simulate the impact of the agent attributes in the implementation of maintenance activities has provided an additional opportunity to convert the attributes such as attitude, behavior, culture, and skill fit to measurable values through the individual and overall response of the technical parameters based on the scenario variations.



Figure 21. Interdependence of technical and agent attributes

The simulation model would predict the impact of technology adoption in implementing maintenance activities to ensure high broadband service availability by adding variables in the AnyLogic simulation model. The integration of the technical attributes and the application of identified technology adoption was successfully translated to an agent model that aims to measure Network Availability performance dependent on the following technical parameters shown in Fig. 21.

The simulation model was validated using three different methods. The first method used sensitivity analysis based on the model response while changing the identified values based on the scenarios to determine their impact on the standard output process. The simulation input/output accuracy results met the expected range of 99.94% to 99.97%, as shown in Figs. 22-23.



Figure 22. Subscriber unit process accuracy validation



Figure 23. Network crew process accuracy validation

The model response was also validated compared with baseline research data for response and dispatch time. The results show consistency in the Network Crew travel duration regarding the dispatch to arrival time for each endorsed activity between 1hr to 1.75hrs. However, the Detection to Dispatch duration depends on the queue service request, and the transition duration is inversely proportional to the Adoption Rate value of each scenario.

The validation of the historical baseline information verifies the impact of each transition duration on the Network Crew utilization for a 12hrs working shift. The identified scenarios for 2000 subscribers show that the network crew utilization is also inversely proportional to the transition duration.

The sensitivity analysis results in Fig. 24 show the MTTR and Service availability compared to the adoption rate for the 1,750 Subscribers count, and 11 Network Crew shows that the intensity of NMS utilization and Maintenance implementation can improve the MTTR, thus increasing Service Availability performance. The results are also consistent with the crew utilization and dispatch duration based on their impact on adoption. However, we can see that the utilization does not immediately go below 100% since it still depends on the work order volume that needs to be fulfilled.

Adoption Rate vs Service Performance 1750 Subscriber Count @ 11 Network Crew



Figure 24. MTTR and availability correlation

The multimethod simulation feature of AnyLogic was achieved to simulate the complex process, allowing it to reflect the average workforce working hours and process duration. It also resulted in an overall average accuracy output of 99.30%, while Scenario 5, with 1,750 Subscribers, had the lowest accuracy, 94.91% in Fig. 25.

Scenario 5, with 1,750 subscribers with an accuracy of 94.91%, has the highest recorded average MTTR at 132hrs, the lowest average Service Availability of 81.96%, and the highest peak Network utilization of 120%. The output is

aligned with the expected simulation because it has the 6% Adoption Rate for Corrective Maintenance, the lowest across all the ten scenarios. Fig. 26 shows its simulation output compared to the other scenarios having the same number of subscribers and Network Crew count, which shows the output consistency aligned with the Historical Data Validation and Sensitivity analysis. However, the result also shows a notable difference in Detection to Dispatch duration, where it has the highest peak and average value of >100hrs compared to all the remaining scenarios with <100hrs, which can also be correlated with the Network Utilization Rate.





Figure 25. Availability accuracy

Figure 26. Scenario 5 (1,750 Subscriber) performance KPIs

The 5.09% difference has resulted in a longer average restoration time of 7.06hrs, which has a substantial customer impact due to the high dependency on Broadband Service but still does not affect the overall measurable impact between the effects of Technology Adoption and Maintenance activities. The contribution of the model performing simulations is still significant due to its ability to correlate these two factors. It can also give the user the liberty to change other variables, such as Network Crew count, to verify the impact immediately on the overall performance.

The average accuracy result of the simulation model demonstrated 99.31% accuracy. The variability in the Proactive Detection, Dispatch, Restoration, and Maintenance duration in line with Proactive and Corrective Maintenance has shown the importance of adoption in ensuring that available technologies similar to the Network Monitoring System are efficiently utilized.





Figure 27. Service availability results per scenario

As shown in the results, the high adoption rates have yielded a better than target service availability of 98.60%, as seen in Scenario 4, Scenario 9, and Scenario 10, with a peak value of 98.98% at 7.2hrs MTTR. Fig. 27 shows the Service Availability per identified scenarios.

The 72hrs MTTR has also been simulated, which resulted in a Service Availability of 89.92% with a 50% NMS adoption (Internal) rate and 16% Corrective Maintenance adoption (External), which is also comparable to the actual industry experience as validated by the Resource Experts.

The achieved accuracy level of the simulation model is significant compared to the reference value of the peak accuracy value of 89.37% from the prior study, which focuses on the application of Machine Learning in analyzing the factors that affect users' adoption. However, the principal significance of the model does not only focus on its accuracy but on its capability to simulate multiple technical attributes and adoption scenarios. The numerical accuracy comparable to the real-world system can help the telecommunications industry immediately identify areas to focus on, achieving the industry target of 98.6% service availability.

V. CONCLUSION

In this study, the results show the capability of the model to simulate the impact of the technical and adoption factors concerning FTTH service performance. The specific questions were addressed throughout the study.

The first question that focuses on the effects of technology adoption on the FTTH maintenance activities has shown that service failure performance is indirectly proportional to the adoption rate of the Network Crew, and the adoption of NMS capability affects service restoration and maintenance.

The second specific question, the impact of behavior, attitudes, and culture in implementing the network monitoring process in the FTTH network, was simulated using adoption values in previous studies.

The use of the agent-based simulation software AnyLogic helped to bridge the gap and provide an initial overview of the interdependence of each aspect through the simulation results. The relationship of the adoption rate concerning service performance has been validated, including the impact on the operational efficiency such as Network Crew Utilization, Dispatch Duration, and the number of Network Crew count that can either improve or degrade the overall service experience.

Lastly, the last specific question on the impact of successful adoption of technology implementation affects service improvement mean time to restore and predictive maintenance activity. The study shaped by the simulation model's initial results validated the need to consider the end user's level of usage, utilization, and adoption concerning the overall KPIs such as broadband Service Availability by achieving a peak of 98.98% availability compared to the industry standard 98.6% while also measuring the impact of attaining a 72hrs MTTR in comparison with the corresponding availability of 89.97% which is 8.8% lower compared to the optimal availability level. The gap in measuring the impact of network crew and adoption level, both internal and external, is already simulated through this model.

Predicting the impact of technology adoption in implementing maintenance activities ensures the simulation model has achieved high broadband premise service availability.

Several prospects may be extended for further studies that aim to continuously simulate and analyze the interdependence of FTTH technical attributes with Technology adoption. The following topics are suggested:

- The integration of the AnyLogic Agent-Based Simulation model with NMS and Service Dispatch system to conduct a simulation of actual field data could continuously improve the output based on actual performance
- To combine with other AI technologies such as Reinforcement Learning to provide intelligence based on learned data, which optimizes assumed parameters concerning actual operational performance
- Integration of the AnyLogic system with an external database that can handle efficient processing of higher simulation data
- To extend the Model simulation in measuring operational and business efficiency through training interventions based on the measured individual performance of actual Network Engineers deployed in the field

The simulation model enables the organization to pinpoint the gap that can still be improved: technical efficiency, service handling time, maintenance implementation, or the engineer's adoption in maximizing available technology to enhance FTTH broadband service availability.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

R. J. M. Licup conducted the work, gathered the data, and ran the simulations under the supervision of L. Materum. The authors had approved the paper.

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