Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Technology

Telecommunication Engineering Graduate Program

Data-Driven QoE Model for Addis Ababa LTE Video Streaming Using Fuzzy Logic Inference System

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Abstract

Nowadays, the video streaming services become the most dominant service as people are more interesting watching online television programs and Video on Demand (VoD). This requires a high speed and high capacity network infrastructure. The Long Term Evolution (LTE) network infrastructure of Addis Ababa has faced this network capacity and data rate demand in order to have a good Quality of Experience (QoE). To takeover this challenge, Ethio Telecom should have appropriate assessment methodology for QoE.

This thesis outlines the means of QoE modelling issue to measure QoE objectively. It proposes a QoE model which is used to measure the QoE from Quality of Service (QoS) parameters using Fuzzy Logic Inference System (FIS). This has been done by collecting end-to-end QoS data from network management system which is used as input for the model and the proposed model has been validated using a dataset collected from customer survey. The Model developed is essential for replacing the subjective measurement techniques which are costly and inefficient being influential to user context, terminal characteristics, application software, user capability, etc.

In addition, the model developed is helpful for business decision making, network planning, optimization and operational support activities in manual systems or system based for self-organizing networks according to the infrastructures implemented. The result of correlation, regression, and Four-way ANOVA show that the Stall Frequency (SF) and the Start Delay (SD) plays the major impact on the LTE video streaming QoE by 33% and 25% respectively. The validation result shows the proposed model is an accurate, consistent and linear compared to the existing models.

Key Words: *LTE, QoE, QoS, KQI, MOS, FIS, Video Streaming, Data-Driven, Model.*

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This is to certify that this thesis has been prepared by Aysheshim Demilie Chekol, entitled: ***Data-Driven QoE Model for Addis Ababa LTE Video Streaming Service Using Fuzzy Logic Inference System*** **and submitted in partial fulfillment of the requirements for the degree of Masters of Science (Telecommunications Engineering–Telecommunication Network Engineering Track) fulfills with the regulation of the University and meets the accepted standards with respect to originality and quality**

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Declaration of Authorship

I, Aysheshim Demilie, declare that this thesis titled, " *Data-Driven QoE Model for Addis Ababa LTE Video Streaming Service Using Fuzzy Logic Inference System*" and the work presented in it are my own. I confirm that, it has not been offered for a degree in this or any other university, and all sources of materials used for the thesis have been recognized.

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This thesis has been submitted for examination with my approval as a university adviser.

Dr. -Eng Yihenew Wondie ——————————

Advisor ... ... Signature

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List of Abbreviations

3GPP	Third Generation Partnership Project
AAiT	Addis Ababa Institute of Technology
ACR	Absolute Category Rating
ANOVA	Analysis of variance
CA	Carrier Aggregation
CDF	Cumulative Distribution Function
CN	Core Network
CSFB	Circuit Switching Fall Back
E2E	End-to-End
EDGE	Enhanced Data rates for GSM Evolution
eNB	Evolved NB
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
EUTRAN	Evolved UTRAN
FIS	Fuzzy Logic Inference System
FR	Full Reference
GPRS	Gateway Packet Routing Subsystem
GSM	Global Communication System for Mobile
Het-Nets	Heterogeneous Networks
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper-Text Transfer Protocol

IMS	IP Multimedia Subsystem
ITU	International Telecommunication Union
KQIs	Key Quality Indicators
LTE	Long Term Evolution
MBMS	Multimedia Broadcast/Multicast Services
MBR	Maximum Bit Rate
MIMO	Multiple-Input Multiple-Output
MME	Mobility Management Entity
MMS	Multimedia Messaging Support
MOS	Mean Opinion Score
MSE	Mean Squared Error
MTC	Machine Type Communication
NB	Node B
NMS	Network Management System
NR	No Reference
OFDM	Orthogonal Frequency Domain Multiple Access
OR	Outlier Ratios
OS	Opinion Score
PCEF	Control Enforcement Function
PCRF	Policy Control and Charging Rules Function
PDF	Probabilistic Distribution Function
PDN	Packet Data Network
PDR	Play Disconnection Rate
PEVQ	Perceptual Evaluation of Video Quality
P-GW	PDN Gateway
PSNR	Peak Signal-to-Noise-Ratio
QoE	Quality of Experience
QOM	Quadrature Amplitude Modulation
QoS	Quality of Service

RDT	Real Data Transport
RR	Residual Reference
RTCP	Real-time Transport Control Protocol
RTP	Real-time Transport Protocol
RTSP	Real-time Streaming Protocol
SAE	System Architecture Evolution
SC-FDMA	Single-Carrier Frequency Domain Multiple Access
SD	Start Delay
SDP	Session Description Protocol
SF	Stall Frequency
S-GW	Serving Gateway
SIP URI	Session Initiation Protocol Uniform Resource Identifier
SON	Self Organizing Networks
SSR	Start Success Rate
STR	Stall Time Rate
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunication Systems
UTRAN	Universal Terrestrial Radio Access Network
VoD	Video on Demand
VoLTE	Voice Over LTE
VQM	Video Quality Model

1 Introduction

Cisco has forecasted in [1] that by 2021, the number of video customers will occupy more than 77% of the total Internet customers, among which mobile video traffic will share 55% of all video traffic. The Addis Ababa Long Term Evolution (LTE) Video Streaming Key Quality Indicators (KQIs) data for the period of Nov 27, 2018 to Dec 27, 2018 analyzed as shown in TABLE 1.1. It has been done with some influential KQIs which have high impact on video streaming service Quality of Experience (QoE) such as: video streaming Start Success Rate (%) (SSR), video streaming Start Delay (ms) (SD), video streaming Plays Disconnection Rate (%) (PDR), video streaming Stall Frequency(times/min) (SF) and video streaming Stalled Time Rate (%) (STR).

By observing the mean, median, standard deviation, minimum and maximum value

TABLE 1.1: Video Streaming KQI Data Analysis result

	SSR (%)	SD(ms)	PDR (%)	SF (times/min)	STR (%)
Mean	75.2234	9712.8115	9.0646	0.4517	12.1665
Median	75.115	9323	8.52	0.35	10.57
Std. Deviation	6.85916	2633.07173	5.38347	0.44486	7.75679
Minimum	45.83	2200	0	0	0
Maximum	100	26177	45.31	4.17	59.85

of this data, it is possible to say good or bad about the Quality of Service (QoS). But this doesn't guarantee the QoE has been achieved or not as far as the impact of each KQI parameter on the QoE is identified and measured. Secondly, there should be some way which able to measure the QoE of video streaming from these KQI data. This thesis proposed solutions for these challenges by identifying the impact of KQI parameters on the video streaming QoE and developing a data-driven video streaming QoE model.

1.1 Quality of Experience and Quality of Service

QoE is defined by International Telecommunication Union (ITU) as the degree of delight or annoyance of the user of an application or a service [3], whereas QoS is defined as the service provider's ability to guarantee a certain level of consistent performance of the network to a data flow, by means of monitoring and controlling. QoE can be evaluated subjectively and objectively. The subjective measurement is the Mean Opinion Score (MOS) of the users' perception. The MOS value is dependent on user factors such as user expectations, security requirements, demographics, contexts, access type, mobility, location, social, task, etc. MOS is a 5-point scale score: 5-Excellent, 4-Good, 3-Fair, 2-Poor, and 1-Bad. On the other hand, the objective QoE measurement estimates the QoE using a parametric model, without requiring the involvement of users. The parametric model is a function of the network-level End-to-End (E2E) QoS parameters [4]. Some of parametric models are: Peak Signal-to-Noise-Ratio (PSNR), Mean Squared Error (MSE), Video Quality Model (VQM), etc.

It is more significant to conduct video quality evaluation from QoE than QoS. The reasons for this are: (1) improving QoS is not the same as improving QoE; (2) only increasing QoS sometimes significantly increases operating expenditure, consequently decreasing the profit of service providers. The main challenge in improving the QoE is measuring QoE appropriately. Because, the subjective measurement has drawbacks such as high cost and insufficient human visual system knowledge. Whereas, the objective measurement requires an advanced model which maps the network level QoS parameters into QoE features. The challenge is due to the different type of the relationships between each KQI parameter and QoE, such as linear, logarithmic, exponential, and power [6].

1.2 Statement of the Problem

Objective measurement of QoE is essential for user-centric service provisioning. User-centric service provisioning delivers a service by considering the interest and satisfaction level of customers. Therefore, a service provider should identify the customers' interest and satisfaction level before delivering a service on market. The objective measurement provides several advantages to both the user and the service provider. Some of them are [9]:

- Through automated real-time QoE monitoring, service providers can control and maintain desired quality levels to the user through the management of controllable QoS parameters, such as video codec, bitrate, signal power, modulation, etc.
- For service charging, QoE could be used as a criterion for quality-based billing that employs differentiated charging schemes in real-time.
- More efficient QoE-based resource utilization can be achieved in terms of bandwidth utilization and power consumption.

Whereas, the subjective measurement of QoE has drawbacks compared to the objective measurements. Some of them are: costly and limited to a certain sample level (impossible to include all customers), insufficient human visual system knowledge, and impossible to take real time measurement.
These drawbacks of subjective QoE measurement enforces to search an objective measurement method which is independent of users' participation. One of the solution for such measurement method is to predict QoE of a specific service from its most influential KQI parameters which is network centric and can be measured objectively. This thesis has done this task using data-driven fuzzy logic inference system model by identifying the impact of each KQI parameter on QoE using correlation and coefficient influence analysis techniques.

1.3 Objective

1.3.1 General Objective

The general objective of this thesis is developing data-driven QoE model for Addis Ababa LTE video streaming service from KQI parameters.

1.3.2 Specific Objectives

To achieve the above mentioned general objective the following specific objectives have been done.

- Extracting Video streaming influential KQI parameters from NMS data collected.
- Mapping the relationships between video streaming KQI parameters with video streaming QoE features.
- Identify the impact of each KQI parameter on the QoE using EXCEL, SPSS and MATLAB.
- Measuring the subjective MOS value using experimental customer survey data.
- Validating the developed model using the subjective test.

1.4 Methodology

The method applied in this thesis includes:

- a survey of literature to grasp the global trend about objective QoE measurements,
- collecting video streaming data,
- extracting and categorizing the KQI parameters from NMS data,

- feature selection and dimension reduction using Pearson correlation,
- identifying the relationship of the KQI parameters with the QoE using coefficient influence analysis,
- determining the impact of each KQI parameter on the QoE with independent weighting method,
- predicting the video streaming QoE using FIS and,
- validating the model using experimental customer survey subjective test.

FIGURE 1.1 shows the flow chart of this methodology steps.

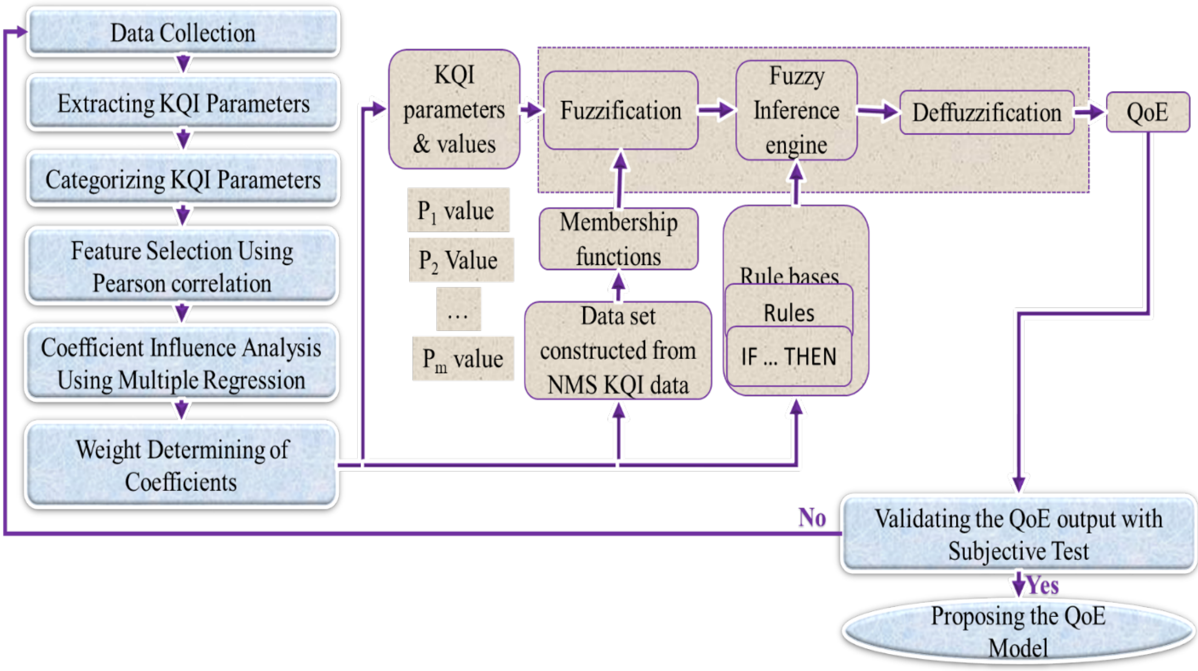

FIGURE 1.1: Flow Chart for the research Methodology

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Data has been collected in two ways; the experimental customer survey data and NMS KQI parameters data. The experimental customer survey data has been collected through internet by inviting individual LTE users to watch online broadcasting television programs and then fill the questionnaires prepared on Google Sheet. The NMS

KQI data collected from QoS monitoring platform in Ethio Telecom QoS monitoring section. Extracting and categorizing of KQI parameters has been done to map the KQI parameters with QoE features. The correlation result used to remove redundancy and to identify the relationship between each KQI parameters and the QoE. The coefficient influence analysis and weighting coefficients used to show the impact of each KQI parameter on the QoE.

Finally, the model has been validated using the experimental customer survey subjective test. The subjective test has been done to identify the relationship between the KQI parameters and QoE with different network performance and customer situations. The test has considered the subjective context, expectation, terminal device performance, network quality and user experience as much as possible. Based on this data and model simulation output, the accuracy and consistency of the model has been verified and proposed.

1.5 Literature Reviews

The work in [10] and [11] show that an E2E QoS and QoE measurement is very important for operators, researchers, developers, regulators and customers. For example, operators use to identify network performance problems, researchers use the measured data for their study, developers use it for predicting the future network, regulators use it to identify the best serving operator and customers can use it to check the quality issue is whether within their own network or within the operators'.

The Authors' in [4] show challenges in subjective QoE measurement and propose objective QoE measurement models based on QoS parameters. They have presented the state-of-the-art on mobile QoE and outline some of the key outstanding challenges. The work done in [12] proposed no-reference novel model for UMTS voice service and LTE data service from QoS parameters. They have used machine learning techniques and the results they obtain show a good correlation and small error variation.

The Author's in [9] present a cross-layer no-reference prediction model for the perceptual quality of 3D video in the wireless domain. The results showed a high prediction accuracy of the proposed FIS-based model with a correlation of 0.943 and RMSE of 0.10907. These works show the challenge in subjective QoE measurement and they propose a QoE model to measure the QoE objectively. But they lack using real-time data. The data they used collected at laboratory level so that their work do not show the real situations.

A survey work done in [13] provides a survey of the state of the art about applying data-driven approach on QoE assessment. The result shows QoE evaluation schemes on data-driven approach has more importance in three reasons. Firstly, with the age of big data, operators can know more about the users' hobbies or interests. Secondly, QoE assessment based on data-driven approach gets the data from real-life environments instead of laboratory. Thirdly, evaluating the QoE from the user in detail without knowing anything about him or her is achieved with this approach. The Authors in [14] proposed a data-driven QoE analysis framework on video streaming QoE data. They found that a small set of QoS parameters play an important role in determining video MOS. The weights of initial buffering latency, stalling times and stalling ratio occupy 69.01%. These works show the possibility of the development of QoE model from real-time data, but their accuracy, consistency and linearity of proposed models can be improved further.

The work done in [15] proposes a fuzzy logic model for assessment of QoS in multimedia transmission. It evaluates the major QoS parameters such as, delay, jitter and packet loss, and use them as inputs to the evaluation system according to the QoS parameters requirements of each network system. The model is used to detect and restore any QoS deterioration in real-time and thus, providing good and efficient QoS for customer satisfaction. The work in [16] presents Modelling user quality of experience from objective and subjective datasets using fuzzy logic. The Authors' used the packet loss rate, the number and duration of packet loss with test subjects'. The Pearson's correlation coefficient for this set of data equals 0.8841. The Authors in [9] show an investigation of the impact of QoS parameters from both encoding and network levels on QoE. They develop a prediction model based on FIS by mapping the chosen QoS parameters to the measured QoE. The correlation between the objective and subjective datasets recorded a Pearson correlation coefficient of 0.92. These works lack considering application layer parameters which are more closer for user perceptions than network layer parameters. So, these works can be improved by considering the most influential application layer parameters on user perception.

1.6 Scope and Contribution

Scope

The scope of the thesis is confined to develop a QoE model for Addis Ababa LTE video streaming service based on the QoS parameters obtained from network side and experimental customer survey data.

Contribution

This thesis proposed a highly accurate, consistent and linear data-Driven QoE model for video streaming service and it evaluated the LTE user satisfaction level subjectively. It has also identified the impact of KQI parameters on the user perception.

1.7 Thesis Organization

This thesis has been organized in five chapters. The first Chapter is completed here by presenting a summary of the whole thesis. The second Chapter describes the overview of LTE video streaming QoE. It describes video streaming protocols and technical background about LTE evolution and architecture. Chapter three discuss about the methodology used to design the QoE model and it gives brief description for each process and method. The results and interpretation has been done in Chapter four and Chapter five concludes the result obtained from this thesis and it recommends future works that are not included in this thesis.

2 LTE Video Streaming QoE Overview

2.1 Quality of Experience

QoE is defined in [9] as "The overall acceptability of a service or an application, as perceived subjectively by the end user". It mainly deals with how the end user is satisfied with the service provided by the operator in terms of usability, accessibility, retainability and integrity of the service. They are defined as:

- Usability stands for the ease of use and learnability of a service.
- Accessibility refers to the quality of being easy to obtain or use.
- Retainability measures service continuity without interruption for specified time.
- Integrity Service aligns attitudes, beliefs and values around the behaviors that are the cornerstone of a customer-focused, problem solving culture.

The QoE considers the E2E service delivery which includes the effects of the client, the overall network and infrastructure of a services. The effect of client considers the user's mood, emotions, physical status, experience, psychology, and cultural influence on the service delivery. The knowledge of the actual user experience is very important for the operator to meet the customers' satisfaction level.

In [14], three main QoE measuring techniques described as; subjective, objective and data-driven measurement. The objective QoE measurement method is based on mathematical models and fast algorithm that produces the results approximately equals to the subjective QoE measurement method and it does not involve any human grading. Examples of objective methods are Mean Squared Error (MSE), Perceptual Evaluation of Video Quality (PEVQ) and the Peak Signal-to-Noise Ratio (PSNR). They are called

Full-Reference (FR) and Reduced - Reference (RR) video quality metrics.
The subjective method is based on human perception. The subjective measurement is considered as accurate way when compared to the objective one. For subjective method, a set of videos are given to the subjects for rating the videos on a scale of five (5) and the grades for quality is taken the average of the participants' evaluation as explained by [17]. The rating given by the subjects are known as MOS. The subjects include expert and non- expert observers.
Data-driven measurement is considered with the no-reference (NR) model which doesn't require the input signal to predict the QoE whereas the FR and RR model needs the input signal to predict the QoE. Unlike the subjective and objective QoE measurements, data-driven analysis is more acceptable as a result of big data found in service providers and the accuracy of predicting user perception while overcoming the challenges of subjective and objective assessments such as high cost and insufficient human visual system knowledge as discussed in [17].

2.2 Video Streaming

A streaming video can be either an integral part of a browser, a plug-in, a separate program, or a dedicated device. Video files may also include embedded players. There are two types of streaming video content distribution: on-demand and programmed-time streaming as explained in [2]. On-demand Streaming is a streaming which has the right for the viewer to choose what content to play at any time. This type of streaming raises bandwidth costs since it is necessary to establish a new network stream for each player. Whereas Programmed-time streaming requires a channel for an audience on a specific time programmed by the streamer. This type of streaming minimizes bandwidth costs as it broadcasts at one time.
There are also two major ways for the transmission of video/audio information over the Internet:

- Download mode: The content file is completely downloaded and then played. This mode requires long downloading time for the whole content file and requires hard disk space.

- Streaming mode: The content file is not required to be downloaded completely and it is playing while parts of the content are being received and decoded. It requires a good buffering capacity for the terminal device for good QoE.

A normal video watching process is shown in FIGURE 2.1 [13]. When a user clicks a video from the webpage or changes channels by the remote controller in Internet Protocol Television (IPTV), the media player initiates a video request and downloads a certain amount of data into the buffer before the video starts playing (start-up state). During playing, the media player reads the data in the buffer; meanwhile, the player requests more data from server and writes them into the buffer. The buffer will be exhausted if the rate of buffer reading exceeds that of writing. Then the player will enter the rebuffer state which will lead the user to experience an interruption until the video player fills its buffer to a certain level before start playing again.

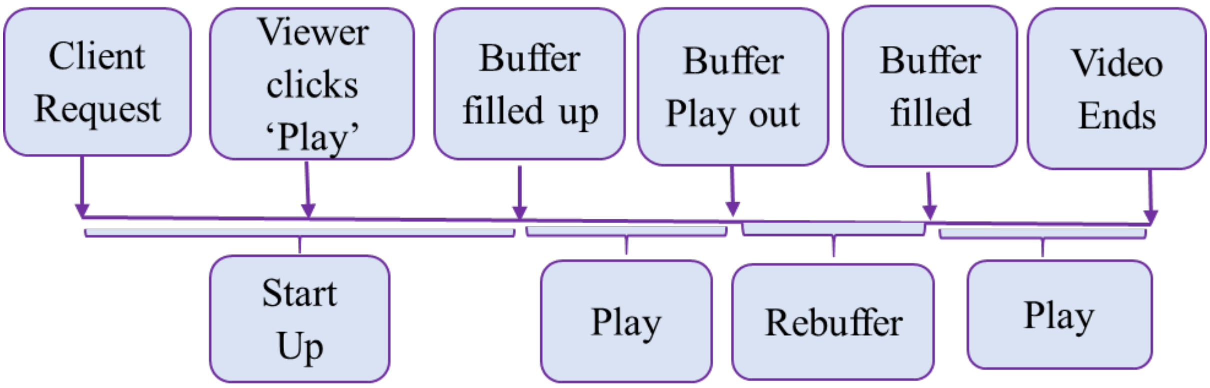

FIGURE 2.1: Streaming watching session [13]

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2.3 Video Streaming Protocols

There are several protocols that support media streaming. Some of the major protocols are [18] Hypertext Transfer Protocol (HTTP), Session Description Protocol (SDP), Real-time Streaming Protocol (RTSP), Real-time Transport Protocol (RTP), Real Data Transport (RDT) and Real-time Transport Control Protocol (RTCP).

Each protocol is used depending on the type of application in that particular point and requirement of the services. For most of the video streaming protocols, Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) serves as the underlying protocol. TCP ensures a reliable and ordered delivery of a stream of bytes from user to server or vice versa. UDP is not dedicated to end to end connections and communication does not check readiness of receiver. UDP used primarily for establishing low-latency and loss-tolerating connections between applications on the internet. UDP is a preferable to TCP in video streaming application because UDP send packets at a constant rate and it doesn't care about the lost packets. But, TCP is also widely used in video streaming because of benefits of streaming with TCP, including its retransmission capabilities, congestion control and flow control. On the same hand, TCP introduces delay due to the retransmission of data whenever data is lost. But in case of UDP, there is no point of retransmission [18]. A sample of video streaming watching protocols is shown in FIGURE 2.2.

A single session can have a client setting up media stream (SETUP), starting the stream with PLAY or RECORD, and closing the stream with TEARDOWN". Referring to FIGURE 2.2 this means that the session starts at (B) and stops at (G) [18]. The client communicates with the web server and media server entities and uses different protocols during the complete procedure, e.g. RTP, RTSP, RTCP, HTTP, etc. It is possible to divide the communication of the client with the server side in two phases: in the first phase the client communicates with the web server in order to get a description of the file to be streamed. The used protocol is HTTP. Starting point is A and ending point is B. In the second phase starts the communication with the media server which is finally

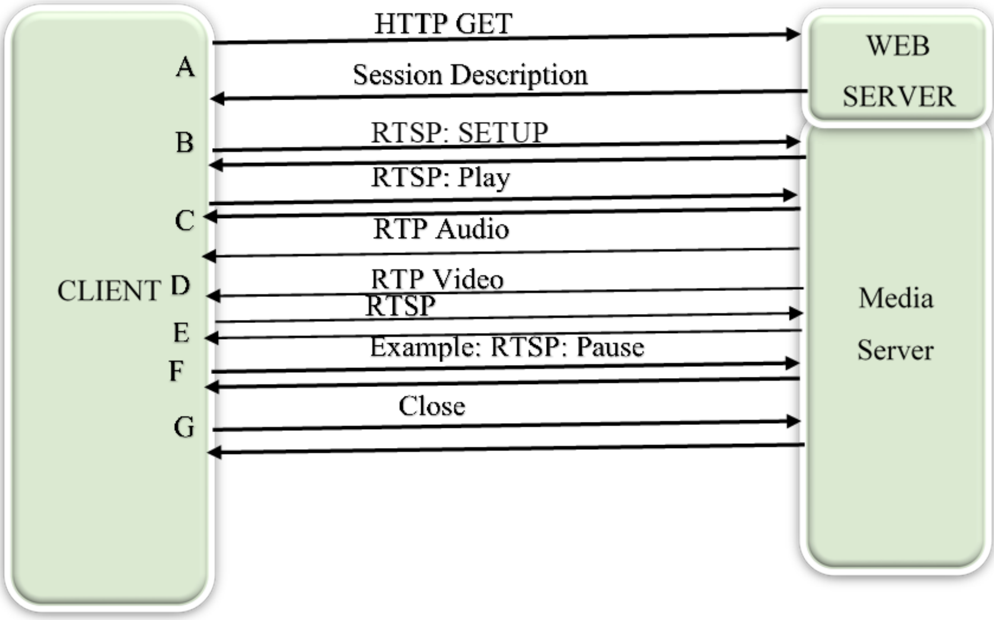


FIGURE 2.2: Generic session signaling flow [18]

delivering the stream. This means that the session starts at B and stops at G. Different protocols are used in this phase (RTSP, RTP, RTCP, etc.) [18].

2.4 An Overview of LTE

2.4.1 Evolution of LTE

The modern society is becoming rapidly dependent on high speed mobile networks and instant information access. The customer needs a fast application process such as banking, multiplayer, on-line gaming, downloading music, watching live news and sports, IPTV and so on over the Internet. There is a great need for high speed and high quality networks required to meet the need of the above applications. To have a solution for this requirement, the 3rd Generation Partnership Project (3GPP) developed LTE to have higher data rate network. 3GPP, as explained in [19], is a collaboration agreement that was established in December 1998 and it was formed by six telecommunication standards that came together on an agreement from different countries known as the Organizational Partners. 3GPP has developed different mobile technologies and those technologies are differentiated by releases. 3GPP releases are evolved as Releases 99 or Release 4, Release 5, Release 6, etc.[19].

The naming of LTE originated from the development of the UMTS radio access through the Evolved Universal Terrestrial Radio Access Network (EUTRAN) and the evolution of core network known as System Architecture Evolution (SAE). The developed new architecture provides higher data rate delivering capacity to the LTE network. By this LTE is able to support different types of services including High Definition (HD) video streaming, Voice over Internet Protocol (VoIP), Multi user online gaming, Video on demand, Push-to talk and Push-to-view. The main features and capabilities of LTE as explained in [19] are :

- The downlink speed is up to 100 Mbps and the technique used is Orthogonal Frequency Division Multiplexing (OFDM), a technique for digital multi-carrier modulation using many closely spaced subcarriers - a previously modulated signal modulated into another signal of higher frequency and bandwidth..

- The uplink speed is up to 50 Mbps and the technique used is Single Carrier Frequency Division Multiplexing Access (SC-FDMA), a technique that has similar performance and essentially the same overall structure as those of an OFDMA system, which utilizes single carrier modulation at the transmitter and frequency domain equalization at the receiver.

- The user plane latency offered in LTE is less than 10 ms and the control plane latency is less than 100 ms.

- LTE supports higher flexibility in carrier bandwidths, the set of bandwidths actually supported are 1.25, 2.5, 5, 10, 15, and 20 MHz.

- LTE is capable of delivering optimum performance in a cell size up to 5 km but it still can deliver its effective performance up to 30 km. Whereas with its limited performance, it can deliver up to 100 km radius.

2.4.2 Architecture of LTE

The enhancement features like higher packet data rates and significantly lower-latency of LTE cannot be possible without the evolution of SAE [19]. This includes the Evolved Packet Core (EPC) network. The (Evolved Packet System) EPS consists of LTE and SAE. EPS is defined to support only packet-switched traffic. It uses the concept of EPS bearers to direct the IP traffic from a gateway in the Packet Data Network (PDN) to the User Equipment (UE). EPS bearer is a virtual connection provides transport service with specific QoS attributes between the gateway and the UE. The LTE architecture divided into two networks as radio access network and a core network as shown in FIGURE 2.3.

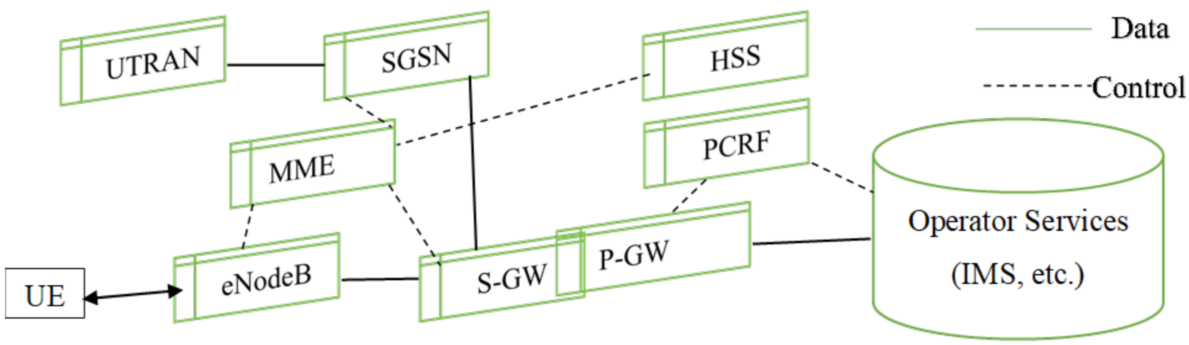


FIGURE 2.3: LTE/EPC Architecture

The nodes contained in the core network [19] are:

- **Policy Control and Charging Rules Function (PCRF)**: It provides the service management and control of the LTE services. It is responsible for policy control decision making besides regulating the flow based charging functionalities in the Control Enforcement Function (PCEF). It helps to have dynamic control over QoS in turn help operators, to provide customers with a variety of QoS and charging options when delivering for a service.

- **Home Subscriber Server (HSS)**: It is the master database, it contains the user subscription data to support call control and session management entities. This includes the subscribed QoS profile and restrictions to access, when the subscriber is in roaming. It provides the authentication and authorization of subscribers. It holds the information related to the location of subscriber and the information about the PDN to which the subscriber is connected. HSS also supports multi-access, multi domain networks, which provides E2E traffic handling facilities for the subscribers moving between LTE and WLAN.

- **PDN Gateway (P-GW)**: It is responsible for allocating the dynamic IP addresses to the subscriber and routes the user plane packets. It provides the QoS enforcement and flow based charging as per the policies in the PCRF. PCRF gives the instructions on how to deal with a particular service data flow by keeping in mind the QoS terms of priority as per the subscriber profile. It acts as an anchor for mobility between 3GPP and non-3GPPP technologies.

- **Serving Gateway (S-GW)**: It directs data packets to all subscribers, which acts as a local mobility anchor for data bearer that moves between eNB hand overs. It also acts as the anchor between LTE and 3GPP technologies. It gets the information about the bearer when the UE is in an idle state. S-GW terminates the Downlink data path and triggers paging when DL data arrives for the UE.

- **Mobility Management Entity (MME)**: It is the key control node for LTE access network that processes the signaling between UE and the CN. It is responsible for choosing the S-GW for a UE at the initial registration process and also for intra-LTE handover including CN node relocation. The main functions that are carried by the MME are related to the bearer management and connection management. Bearer management includes maintaining, establishment and release of the bearers. And the connection management includes establishment of the connection as well as security between the network and UE.

The E-UTRAN manages the radio communication between the UE and the EPC by using one component called evolved Node B (eNB) [19]. Unlike normal NB, eNB does not have centralized controller system and hence the E-UTRAN is regarded as a unified architecture. eNB is responsible for radio resource management which includes radio bearer control, scheduling and dynamic allocation of links to UE for uplink and downlink. Also it compresses the IP packet header for efficient use of resources. Encrypted data is sent over the radio interface for better security.

3 Method Deployed for Modeling

Most of multimedia operators obtain huge data from customers. With these data, they can know more about the users' hobbies or interests. Second, QoE modelling based on data-driven approach usually gets the data from real-life environments instead of laboratory. Operators are not only interested in the QoE metrics but also interested in the factors influencing QoE metrics. Several researches classify such Influence Factors (IF) into three classes[13]; Human IFs, System IFs, and Context IFs.
The definition of Human IFs is any variant or invariant properties or characteristics of a human user. Many researchers use video sensors to perceive human IFs like psychical activities. System IFs refer to properties and characteristics that determine the technically produced quality of an application or service. Context IFs are factors that embrace any situational property to describe the users' environment. In the evaluation process of data-driven based QoE, influence factors and QoE metrics are taken as input and output of the QoE model respectively to predict users' QoE.
There is no standard dataset for QoE assessment [13]. Existing related dataset can be divided into three categories: ISP dataset, subjective experiment dataset and objective experiment dataset.

- ISP dataset means a large number of data coming from ISP.
- Subjective experiment datasets denotes that the data obtained from public datasets using customer survey and get MOS values from participants response.
- Objective experiment dataset means that the data obtained from public dataset using customer survey and get MOS values by some models like PSNR-to-MOS and VQM.

The data for this thesis obtained from experimental customer survey (Subjective Experiment datasets) and Ethio Telecom QoS monitoring system (ISP datasets). The data analysis has been done with application layer influential KQI parameters which have high impact on video streaming service QoE such as: video streaming Start Success Rate (%) (SSR), video streaming Start Delay (ms) (SD), video streaming Plays Disconnection Rate (%) (PDR), video streaming Stall Frequency(times/min) (SF) and video streaming Stalled Time Rate (%) (STR). This datasets has the unique characteristics which make difficulties to use it directly such as:
1) Heterogeneous data types, (Having different units and characters)
2) Positive/ negative correlations with the QoE and
3) Dependence of features (different impact on the QoE);
In order to coup up with these challenges, this research work has analyzed the data into different stages as follows.

3.1 Data Collection and Extraction

The first stage of the research is collecting the Addis Ababa LTE video streaming data in two ways. 1) KQI data collection from the network QoS monitoring NMS system and 2) performing experimental customer survey through subjective test. The NMS system collected datasets has an average value of an hour of KQI parameters measured all over Addis Ababa LTE video streaming service. An eight-month data, starting from October 05, 2018 upto July 05, 2019, which is equal to 8*30*24 = 5,760 datasets have been collected. The customer survey data has been collected using subjective test of a streaming video on Addis Ababa LTE network. These datasets have been explained in detail within in this section as follows.

3.1.1 Video Streaming Start Success Rate

SSR indicates the rate at which video streaming files are successfully played on a web page after a user clicks the play button. It is the ratio of video streaming start success to

video streaming start request. It is affected by TCP connect success rate, get response success rate and initial buffer success rate. Each of them is defined in [21] as :
TCP connect success rate, which is the rate that data is successfully delivered over a TCP connection, is an important metric to measure the quality of a network connection. It is bounded by two mechanisms, flow control, where receiving hosts can limit the rate of incoming data to what they are able to process, and congestion control, where transmitting hosts limit their outgoing data rate to moderate their negative impact on the network.

$$\text{TCP Connect Success Rate} = \frac{\text{TCP Connection Successful Times}}{\text{TCP Connection Requests}} \tag{3.1}$$

Get response success rate the rate of the requested server successful response with respect to total requests as:

$$\text{Get Response Success Rate} = \frac{\text{Get Response times}}{\text{Get Request times}} \tag{3.2}$$

Initial buffer success rate is rate of successful initial buffering. The time one spends buffering when a video begins is really important. It helps to understand the duration of time a user waits before a certain video actually starts to play. If a user stares at the buffer rotating icon for a moment longer than usual, they will abandon watching the video before it even starts. The initial buffer success rate is expressed as:

$$\text{Initial Buffer Success Rate} = \frac{\text{Initial Buffer Success Times}}{\text{Initial Buffer Request Times}} \tag{3.3}$$

3.1.2 Video Streaming Start Delay

SD is the amount of time a user waits until a video streaming file is played after clicking the play button on a web page. It is the sum of video Streaming Response Delay, DNS Query Delay, TCP Connection Delay, Get Response Delay and Initial Buffer Delay as defined in [21].

$$SD = \text{Response delays} + \text{Query Delay} + \text{Connection Delay} + \text{Buffer Delay} \quad (3.4)$$

This KQI parameter depends on the E2E delay or latency which is defined as the delay of point-to-point data transfer which depends on transfer routes or distance involved, speeds of some service networks. If the one-way E2E delay level is over 10 seconds, the network standard is regarded as below ITU standard.

3.1.3 Video Streaming Stalled Time Rate

It indicates the percentage of the total stall time out of the total length of the played video streaming file as described in [21]. This KQI depends on the TCP download retransmission rate, the stalled duration (min), play times, video streaming download throughput and average download delay.

$$\text{STR} = \frac{\text{stalled duration}}{\text{Play times} * \text{Avg DL delay}} \quad (3.5)$$

3.1.4 Video Streaming Plays Disconnected Rate

This KQI indicates the rate at which the downloading of a video streaming file stops or restarts before the video buffer is fully occupied, because the client or server fails to process the video service efficiently or the network transmission quality is poor [21].

$$PDR = \frac{\text{Number of watched videos with interruptions}}{\text{total watched videos}} * 100 \quad (3.6)$$

3.1.5 Video Streaming Stalled Frequency per Minute

SF is the number of times a video streaming file stalls within one minute when the file is being played. It depends on the stalled count, play times, video streaming download throughput (kbps), TCP download retransmission rate (%), and average download delay (min) [21].

$$\text{SF} = \frac{\text{stall count}}{\text{play times} * \text{Avg DL delays}} \tag{3.7}$$

3.2 Categorizing KQI Parameters

Categorizing KQI parameters used to map the impact of each parameter on the QoE features. This thesis maps 5 KQI parameters with 15 video streaming QoE features as shown in TABLE 3.1.The video streaming QoE determined from these five KQI parameters: SSR, SD, PDR, SF and STR.

TABLE 3.1: Categorization of features

KQI Parameters	Features	Variables
PDR	Play Disconnections	x1
	Plays	x2
	Download throughput(kbps)	x3
SSR	TCP Connect Success Rate (%)	x4
	Get Response Success Rate (%)	x5
	Initial Buffer Success Rate (%)	x6
SD	Response Delay (ms)	x7
	DNS Query Delay (ms)	x8
	Get Response Delay (ms)	x9
	Initial Buffer Delay (ms)	x10
STR	Play Times	x11
	Average Download Delay (min)	x12
	Stall Durations (min)	x13
SF	Stall time per minute	x14
	TCP Download Retransmissions	x15

Then, the linear regression result of these data is used to identify the relationship between the subjective MOS value and the KQI parameters. Linear regression is used to analyze the relationship between two or more independent variables and one dependent variable. The KQI parameters are considered as independent input variables and the QoE as dependent output variable for the regression. TABLE 3.2 shows the multiple linear regression result of the customer survey data. From TABLE 3.2, the linear relationship is as shown in Equation 3.8:

$$MOS = 0.809 + 0.113SSR - 0.216SD - 0.081PDR - 0.189SF - 0.114STR \quad (3.8)$$

TABLE 3.2: Multiple Regression result for the Subjective Test

Model		Unstandardized		Standardized	t	Sig.
		B_i	Std. Error	Beta		
1	(Constant)	0.809	0.028		28.388	0
	SSR	0.113	0.031	0.167	3.615	0
	SD	-0.216	0.028	-0.352	-7.777	0
	PDR	-0.081	0.023	-0.149	-3.528	0.001
	SF	-0.189	0.04	-0.265	-4.753	0
	STR	-0.114	0.038	-0.166	-3.027	0.003

3.3 Feature selection

Pearson correlation is used to find the linear relationship between KQI parameters and QoE. Pearson correlation can be directly adopted to reduce the dimension of the dataset by removing the redundant parameters. Let r represent the Pearson linear correlation and n denote the number of samples in the dataset. Moreover, let x and y denote the mean of KQI parameters and QoE, respectively. The calculation of correlation r is defined in [13] as:

$$r = \frac{\sum_{i-1}^{N}(X_i - x) * (Y_i - y)}{\sqrt{\sum(X_i - x)^2} * \sqrt{\sum(Y_i - y)^2}} \quad (3.9)$$

3.4 Coefficient Influence Analysis

Coefficient influence analysis is used to analyze the impact of each feature on the QoE of video streaming using Four-Way ANOVA method and multiple regression. Before ANOVA analysis, the KQI parameters should be normalized to have zero mean value and a standard deviation of one. Therefore, to do normalization of the dataset, feature scaling is used to bring all values into the range zero and one. This is also called unity-based normalization. Also known as Min-Max scaling or Min-Max normalization, is the simplest method and consists in rescaling the range of features. Selecting the target range depends on the nature of the data. The general formula is given by [14] as:

$$x = \frac{x - Min(x)}{Max(x) - Min(x)} \tag{3.10}$$

Where, x is the data value, $Min(x)$ is the minimum value of the datasets and $Max(x)$ is the maximum value of the datasets.

Independent weighting method can be used to determine the weight of each coefficient of KQI parameter and to identify the impact of each KQI parameters on the QoE features. The independent weighting method can be calculated as follows [14]:

$$w_i = \frac{zita(i)}{\sum_i^m zita(i)} \tag{3.11}$$

Where, $zita(i)$ is calculated by:

$$zita(i) = \sqrt{\frac{B_i}{\sum_i^m B(i)}} \tag{3.12}$$

Where, B_i refers the correlation coefficient and w_i stands for the weighted coefficient of each KQI parameter.

3.5 System Model for Video Streaming Prediction

The system model for LTE video streaming QoE has been designed on the Fuzzy Logic toolbox on MATLAB using Fuzzy Inference System (FIS). The data-driven FIS technique has been selected for this purpose. Fuzzy Logic [22] is a computational paradigm that is based on how humans think. Fuzzy Logic looks at the world in imprecise terms, in much the same way that our brain takes in information (e.g. temperature is hot, speed is slow), then responds with precise actions. The human brain can reason with uncertainties, vagueness, and judgments. FIS is a precise problem-solving methodology. It is able to simultaneously handle numerical data and linguistic knowledge. It is a technique that facilitates the control of a complicated system without knowledge of its mathematical description.

Computers can only manipulate precise valuations. Fuzzy Logic differs from classical logic in that statements are no longer black or white, true or false, on or off. In traditional logic an object takes on a value of either zero or one. In Fuzzy Logic, a statement can assume any real value between 0 and 1, representing the degree to which an element belongs to a given set. Fuzzy Logic enables low cost microcontrollers to perform functions traditionally performed by more powerful expensive machines enabling lower cost products to perform advanced features [22]. More detail about FIS can be found at Appendix $A2$.

To compute the output of FIS given the inputs, one must go through five steps as described in [22]:

- Fuzzification of the input variables,
- Application of the fuzzy operator (AND or OR) in the antecedent,
- Implication from the antecedent to the consequent, Inference Rule,
- Aggregation of the consequents across the rules, and
- Defuzzifying the output distribution.

The system model developed for the video streaming QoE model is as shown in FIGURE 3.1. It incorporates a FIS with membership functions developed from the dataset prepared using multiple regression and weighted coefficient's. The details of each block explained as follows.

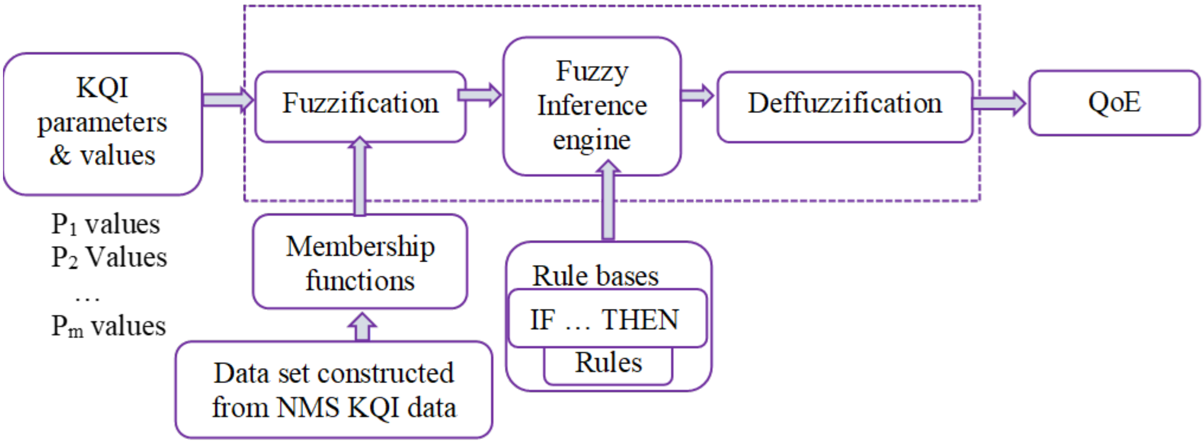


FIGURE 3.1: System model for developing Video Streaming QoE Model

3.5.1 Fuzzification

Fuzzification translates input into truth values i.e., KQI parameters; P_1, P_2 upto P_m values into fuzzy sets. The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In Fuzzy Logic Toolbox software, the input is always a crisp numerical value limited to domain of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1). Fuzzification of the input amounts to either a table lookup or a function evaluation. Example, KQI parameters p_1, p_2, p_m, to their values p_1 value, p_2 value ... p_m value.

3.5.2 Apply Fuzzy Operator

After the inputs are fuzzified, we know the degree to which each part of the antecedent is fulfilled for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number is then applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. In the toolbox, two built-in AND methods are supported: min (minimum) and prod (product). Two built-in OR methods are also supported: max (maximum), and the probabilistic OR method [22].

3.5.3 Apply Implication Method (Inference Rules)

Before applying the implication method, the rule's weight must be determined [22]. Every rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. After proper weighting has been assigned to each rule, the implication method is implemented. Each rule transfers the antecedent into a consequent.

A consequent is a fuzzy set represented by a membership function, which weights appropriately the linguistic characteristics that are attributed to it. The consequent is reshaped using a function associated with the antecedent (a single number). The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Implication is implemented for each rule. Two built-in methods are supported, and they are the same functions that are used by the AND method: min (minimum), which truncates the output fuzzy set, and prod (product), which scales the output fuzzy set.

3.5.4 Aggregation of All Outputs

Because decisions are based on the testing of all of the rules in a FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. As long as the aggregation method is commutative (which it always should be), then the order in which the rules are executed is unimportant. Three built-in methods [22] :

- max (maximum)
- probor (probabilistic OR)
- sum (simply the sum of each rule's output set)

3.5.5 Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. Perhaps the most popular defuzzification method is the centroid calculation, which returns the center of area under the curve. There are five built-in methods supported: centroid (Center of mass), bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, and smallest of maximum [22]. In this thesis work the centroid is used.

Center of mass - This technique takes the output distribution and finds its center of mass to come up with one crisp number. This is computed as follows:

$$z = \frac{\sum_{j=1}^{q} z_j u_c(Z_j)}{\sum_{j=1}^{q} u_c(Z_j)} \tag{3.13}$$

Where, z is the center of mass and u_c is the membership in class c at value Z_j.

3.6 Validation of the Model with Subjective Test

Subjective test directly measures user QoE by petitioning users' evaluation scores under the laboratory environment or in normal situations. Users are given a series of tested video sequences, original ones and processed ones included, and then required to give scores on the video quality. Apart from distortions, there are other factors that will affect QoE. These external factors, some of which may not have direct impact on the video quality, influence users' experience by affecting viewing environment.
Some typical external factors as explained by [20] are video service type (whether the video is live streaming video or VoD), viewer demography, viewer geography, video length, video popularity (viewers tend to be more tolerant of bad QoS for popular videos), device type, time of the day and day of the week, connectivity (here, the major concern is usually the last-mile connection, for example, fiber, cable, DSL, 3G/4G, etc.). Therefore, subjective test directly measures QoE by asking human assessors to give their scores for the quality of the video sequences under test. Subjective test results are often used as the ground truth for validating the performance of the objective quality model.
An objective model is not expected to predict an average subjective opinion more accurately than an average test subjects. The output of the objective quality model should be well correlated with the subjective results, which are regarded as the ground truth for user QoE. Subjective methods are more accurate in gauging the user opinion when compared to the objective ones. A variety of subjective techniques are available and a proper one should be chosen based upon the time available and application requirement. For time critical conditions, generally Absolute Category Rating (ACR) method is preferred [20].
ACR method: here the distorted test sequences are presented one at a time and the users give opinion scores (typically on a scale of 1 to 5), which are averaged into a

MOS. TABLE 3.3 shows the MOS scale as described in [20]. ACR is easy, fast to implement, and hence commonly used.

The main aspects of subjective testing as explained by [20] are:

TABLE 3.3: MOS scale [20]

Rating	Meaning
5	Excellent
4	Good
3	Fair
2	Poor
1	Bad

- Voters are recommended to be trusting subjects representing normal subscribers whose perception is estimated by the objective quality models.
- The number of voters per sample should meet the subjective testing requirements as described in the appropriate Recommendations, (ITU-R BT 500-13).
- The experiments performed could contain an anchor pool of samples that best represent the particular application under evaluation.

The snowball (chain-referral) sampling technique is used since samples are rare and difficult to find. Snowball sampling is a non-probability sampling method used when characteristics to be possessed by samples are rare and difficult to find. This sampling method involves primary data sources nominating another potential primary data sources to be used in the research. Therefore, when applying this sampling method members of the sample group are engaged via chain referral as explained in [6].

Let OS be the individual opinion score, i be the participants index (a total of I participants), j be the test condition index (a total of J test conditions), k be the video streaming index (a total of K video streams). Then MOS and standard deviation defined in [20] as follows:

- Mean Score. The mean score for the j^{th} test condition and k^{th} video sequence is

$$MOS_{jk} = \frac{1}{I}\sum_{i}^{I} OS_{ijk} \tag{3.14}$$

- Standard Deviation. The standard deviation of MOS_{jk} is

$$S_{jk} = \sqrt{\sum_{i} \frac{(MOS_{jk} - OS_{jk})^2}{I-1}} \tag{3.15}$$

The recommended statistical metrics for objective quality assessment need to cover three main aspects: accuracy, consistency and linearity against subjective data. The prediction error can be used for accuracy, the outlier ratio or the residual error distribution for consistency and the Pearson correlation coefficient for linearity. The accuracy of the objective metric is evaluated using the RMSE evaluation metric. The difference between measured and predicted MOS is defined as the absolute prediction error. The RMSE of prediction error is calculated in [20] as:

$$RMSE = \sqrt{\frac{1}{N-1}(|MOS_{(measured(i))} - MOS_{(predicted(i))}|)} \tag{3.16}$$

where N denotes the number of samples.

To calculate the residual error distribution, the use of the Cumulative Distribution Function (CDF) of the residual error is recommended. The probability of exhibiting residual errors below a pre-established threshold is easily determined based on the CDF.

$$p_{th} = \frac{N_{th}}{N} \tag{3.17}$$

Where, N_{th} denotes all samples for which the residual error remains below the imposed threshold and N represents the total number of samples used for the analysis. Therefore, the probability P_{th} represents the proportion of samples exhibiting errors below the threshold in the total number of samples N. The outlier ratio (OR) represents the number of "outlier-points" to total points N.

$$OR = \frac{\text{Total No. Outliers}}{N} \tag{3.18}$$

where an outlier is defined as a point for which the error exceeds the 95 percent confidence interval of the mean MOS value.

4 Result Analysis and Interpretations

This thesis work has addressed two main results using KQI data analysis and by simulating the proposed Data-Driven video streaming QoE model. The data analysis result shows the relationship between KQI parameters and their influence on the user perception. Whereas, the proposed model has obtained a model with high accuracy, consistency and linearity compared to the existing models.

4.1 Data collection

Data has been collected into two ways: Subjective data and objective data. The subjective data has been collected using experimental customer survey and it has considered the subjectivity of the user perception as could as possible. It includes user's expectation, usage experience, educational background, age, job occupation, geographical location, time of the day, network KQI parameters, etc. The objective data has been collected from Ethio Telecom LTE video streaming QoS monitoring system. It has an hour average KQI parameter value which includes all over Addis Ababa geographical area.

4.1.1 Subjective data analysis result

The subjective test accomplished on home based experiment on live streaming television programs. The target population for the subjective test are Addis Ababa LTE video streaming customers. The sampling technique selected for this work is chain referral sampling technique. The chain referral continued till the required sample full filled. There are three criteria usually will need to be specified to determine the appropriate sample size: the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured [6]. The level of precision, sometimes called sampling error, is the range in which the true value of the population is estimated to be.

The risk level or confidence level is based on ideas of Central Limit Theorem. The key idea in the Central Limit Theorem is that when a population is repeatedly sampled, the average value of the attribute obtained by those samples is equal to the true population value. The degree of variability in the attributes being investigated, refers to the distribution of attributes in the population. The variables with more homogeneous population, the smaller the sample size required. If the more heterogeneous population, the larger the sample size required to obtain a given level of precision. For example, a proportion of 50% indicates a greater level of variability than either 80% or 20% as described in [6]. Cochran (1963, 1975) developed a representative sample for proportions of large sample as:

$$n_0 = \frac{z^2 * p * q}{e^2} \tag{4.1}$$

Where, n_0 is sample size, Z^2 is the abscissa of the normal curve, e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and q is $1 - p$. The value for Z is found in statistical tables which contain the area under the normal curve. With Equation 4.1 the number of samples required at 95% confidence interval, p=85% and e=5% is:

$$n_0 = \frac{1.96^2 * 0.85 * 0.15}{0.05^2} = 195.21 \tag{4.2}$$

Therefore, the minimum sample size is 196 Addis Ababa LTE video streaming customers. The sample size determination techniques provide the number of responses that need to be obtained. Many researchers commonly add 10% to the sample size to compensate for persons that the researcher is unable to contact. Thus, the number of mailed surveys or planned interviews can be substantially larger than the number required for a desired level of confidence and precision. Therefore, considering about 10% compensation, the minimum sample size increased to 216 and the experimental customer survey has been accomplished with this sample size.

The questionnaire has been created using Google Forms and distributed through Email using referral chain sampling techniques because of the challenge faced to get LTE video streaming customers. The survey covers all over Addis Ababa by distributing the questionnaire within the ten sub-cities by selecting focal persons within each sub-city. The participants has been invited to select the subjectivity among choice using Likert Five scale mechanism [23].

A Likert Five scale method invites the participant to select the level of satisfaction among the given choice as shown in TABLE 4.1. The survey invites the participant to watch live video streaming session and requested to give response for the questionnaire immediately. The questionnaire contains 22 questions which collects the user's expectations, usage history, context, E2E KQI parameters, geographical location, educational back ground, task engaged, service satisfaction level, company wise expectation, etc.

TABLE 4.1: Likert Five scale subjective data measurement [23]

Rating	Meaning
5	Extremely satisfied
4	Moderately satisfied
3	Slightly Satisfied
2	Neither satisfied nor dissatisfied
1	Dissatisfied

The experimental customer survey consists of four parts and the detail of the survey and the questionnaire can be refereed for further information in Appendix $A1$. The first part is an introductory about the survey and it gives a short briefing how to give response for each question. It also invites to watch a video streaming program by posting the web address of the most common online streaming programs. Then, based on the streaming watched, the participants expected to respond the survey.

The second part of the survey deals with the participant's profile. It includes about eight questions and it contains the survey participants' profile. The third part of the survey deals with evaluating the video streaming scenario which are the most important part of the survey. Because, this part used to collect the KQI parameters of the streaming which is supposed to verify the model. It includes questions from Q9 to Q13. Each of them measures participants' perception about each KQI parameters such as SSR, SD, PDR, SF and STR.

The fourth part of this questionnaire discuss about the service delivery processes and their impact on user perception. It includes nine questions starting from Q14 to Q22. They discuss about the service price, call center support, usefulness of the service, customization of the service, first top factor and second top factor of the services provided. The last question invites the participant to express his/her own opinion about the service delivery process.

The MOS value for subjective measurement obtained using Equation 3.14 and from the subjective opinion scores (OS) collected through experimental customer survey data is as follows:

$$MOS = \frac{1}{216} * \sum_{i=1}^{216} OS_i = 3.92 \tag{4.3}$$

Therefore, a 3.92 MOS value is approximated to a Good satisfaction level on MOS scale rating as shown in TABLE 3.3. This result shows the LTE video streaming service in Addis Ababa has a satisfaction level of Good which implies Ethio Telecom should do further analysis to increase the satisfaction level to be Excellent and to identify the reasons for the degradation.

4.1.2 Objective Data Analysis Result

The objective data has been collected from Ethio Telecom QoS monitoring department. This QoS monitoring platform measures an hour average value of each KQI parameter for all Addis Ababa LTE video streaming service. An eight-month data has been collected starting from October 05, 2018 up to July 05, 2019. The data includes the main KQI parameters such as SSR, SD, PDR, SF and STR. These data have been analyzed and processed using correlation and regression techniques and used as input to the development of the model. The sample of the data collected is as shown in TABLE 4.2.

TABLE 4.2: The sample objective data collected.

Current period	SSR (%)	SD(ms)	PDR (%)	SF (times/min)	STR (%)
7/7/2019 19:00	78.05	7743	5.37	0	0.1
7/7/2019 20:00	83.61	13332	1.77	0.01	0.1
7/7/2019 21:00	84.78	10108	2.79	0.02	0.7
7/7/2019 22:00	74.5	11970	5.57	0.07	1.08

TABLE 4.2 shows that, the collected data is a dataset measured at the same time in different units. SSR, PDR and STR are measured in percentage as they are rates of their performance whereas SF and SD measured in times/min and ms respectively. The statistical analysis result of the collected data is shown in TABLE 4.3. It shows the mean, median, mode, standard deviation, minimum value and maximum value of the datasets. But it doesn't show weather the customers are satisfied or not. Therefore, there should be a model that correlates this KQI data with customer satisfaction as this thesis work tried to propose.

TABLE 4.3: The statistical analysis of the objective dataset

	SSR(\%)	SD (ms)	PDR(\%)	SF (times/min)	STR(\%)
Mean	75.7215	9576.13	7.8828	0.3045	8.9121
Median	75.87	9382.5	7.26	0.25	7.89
Mode	75	8912	0	0	0
Std. Deviation	7.5681	2408.157	4.60408	0.28305	6.92022
Minimum	35.43	2200	0	0	0
Maximum	100	48874	50.75	3.68	54.82

FIGURE 4.1 (a) to (e) show the histogram for SSR, SD, PDR, SF and STR respectively. The histograms show the mean and the standard deviation of the Addis Ababa LTE video streaming KQI dataset collected for eight months. The SSR as shown in FIGURE 4.1 (a) has an average value beyond 75%; whereas, 4.1 (b) to (e) show an average value of below 10ms, 8%, 0.3$times/min$, and 9% respectively.

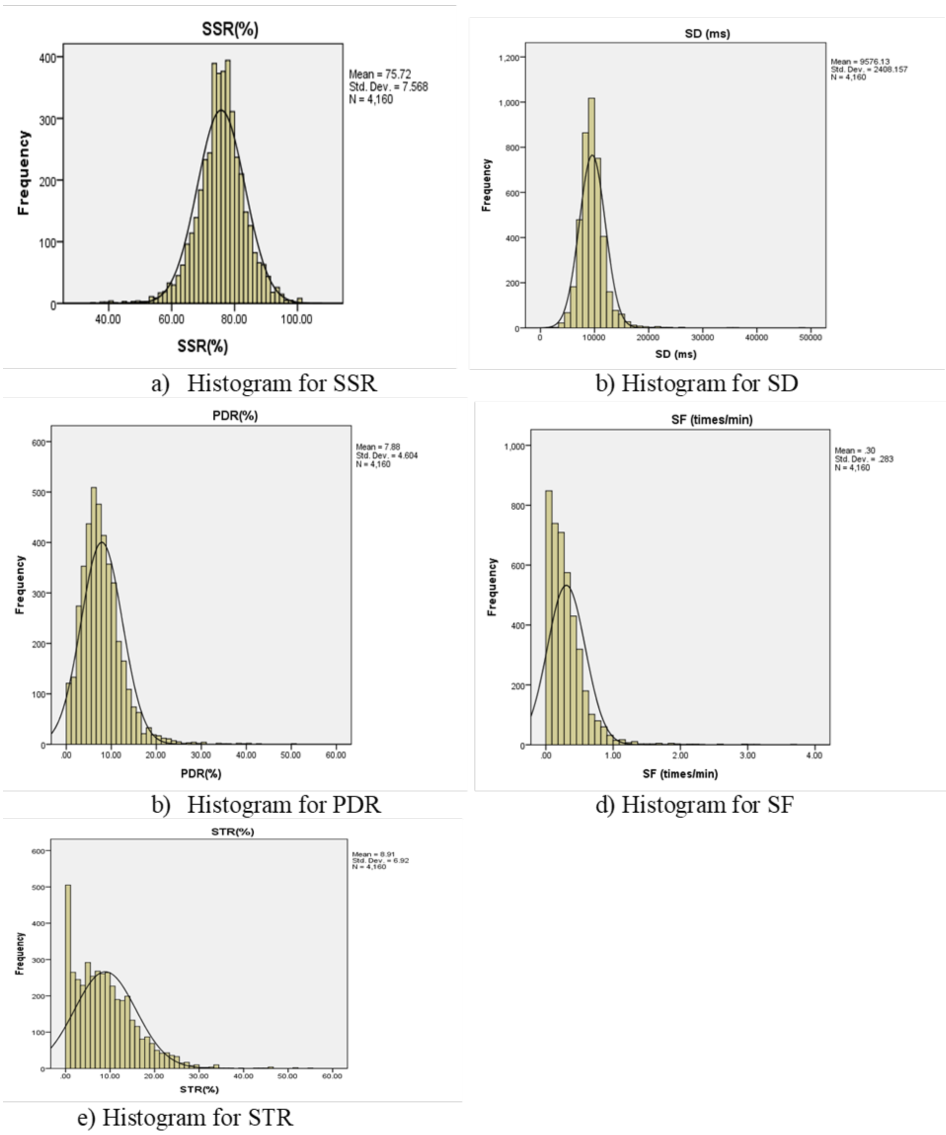


FIGURE 4.1: Histogram for SSR, SD, PDR, SF and STR respectively.

4.2 Correlation Analysis Result

The correlation analysis has been done for feature selection in order to reduce the dimension size if there is redundant KQI parameter. Secondly, the correlation result used to identify the impact of each KQI parameter on the user perception. It has been done using Pearson correlation techniques as expressed with Equation 3.9.

4.2.1 Subjective Data Correlation Result

For subjective data, correlation has been done between KQI parameters obtained from participants' response among themselves and with individual's opinion score. Among KQI parameters used to identify redundant parameter and within individuals' opinion score used in order to identify the relationship between the KQI parameter and user's satisfaction level. Based on the result shown in TABLE 4.4, SF and STR are correlated 80.8% and they are redundant. Therefore, one of them should be ignored. STR should be ignored since it is less correlated with MOS with its magnitude value. The SD and SF have higher correlation magnitude value which means that they have high influence value on the customer satisfaction.

TABLE 4.4: Subjective KQI parameters Correlation Result

	SSR	SD	PDR	SF	STR	MOS
SSR	1	-0.672	-0.622	-0.562	-0.53	0.733
SD	-0.672	1	0.555	0.546	0.59	-0.79
PDR	-0.622	0.555	1	0.571	0.499	-0.683
SF	-0.562	0.546	0.571	1	0.808	-0.77
STR	-0.53	0.59	0.499	0.808	1	-0.75
MOS	0.733	-0.79	-0.683	-0.77	-0.75	1

4.2.2 Objective Data Correlation Result

Similar to the subjective data, the objective data correlation result used to identify the relationship between the KQI parameters and QoE and to reduce the dimension by removing redundancy. Since there is no MOS value from objective dataset, it is obtained from subjective data by regression as shown in Equation 3.8. The result of the objective data correlation is as shown in TABLE 4.5. It shows similar relationship as the subjective data. The SF and STR are redundant as they are correlated at 76.4% and STR which is less correlated with MOS should be ignored. The SD and SF has higher correlation magnitude which is interpreted as they have higher influential factors on user satisfaction level.

TABLE 4.5: Correlation Result of Objective data

	SSR	SD	PDR	SF	STR	MOS
SSR	1	0.276	0.243	0.042	-0.045	0.15
SD	0.276	1	0.193	0.048	-0.103	-0.436
PDR	0.243	0.193	1	0.142	0.118	-0.355
SF	0.042	0.048	0.142	1	0.764	-0.795
STR	-0.045	-0.103	0.118	0.764	1	-0.729
MOS	0.15	-0.436	-0.355	-0.795	-0.729	1

4.3 Coefficient Influence Analysis Result

Coefficient influence analysis has been done using Four-way ANOVA and multiple regression in order to analyze the relationship between two or more independent variables and one dependent variable. The dependent variable is the MOS value and the independent variables are the KQI parameters. Before we have applied the regression on the data, it should be normalized using MIN-MAX scaling normalizing techniques as expressed in Equation 3.10. A sample of the normalized data is shown in TABLE 4.6.

To statistically establish the relationship between QoE and these four KQI parameters, a Four–way ANOVA test was carried out on the dataset. This is to determine the impact of all four KQI parameters on QoE, as well as the interactions in between the parameters, i.e., their combined effect on QoE. TABLE 4.7 shows the results obtained from the ANOVA analysis. A small p–value (p less than or equal to 0.01) indicates

TABLE 4.6: Sample Normalized objective data

SSR	SD	PDR	SF	STR	QoE
0.568375	0.679448	0.797666	0.837748	0.722802	0.420323
0.441691	0.566961	0.704784	0.824503	0.752235	0.437069
0.487378	0.593524	0.713186	0.721854	0.701751	0.460961
0.609416	0.631375	0.649242	0.880795	0.687779	0.443372
0.686232	0.697119	0.740723	0.864238	0.663376	0.436261
0.582933	0.616212	0.770362	0.831126	0.658346	0.446466
0.561406	0.700274	0.637106	0.701987	0.459575	0.48387
0.582624	0.556244	0.551925	0.857616	0.685358	0.46921
0.575809	0.739264	0.843174	0.92053	0.826192	0.377079
0.664705	0.715095	0.860677	0.923841	0.845939	0.388033
0.634041	0.702744	0.823804	0.937086	0.856185	0.386588
0.602602	0.68188	0.722754	0.880795	0.806259	0.412158

that QoE is significantly affected by the corresponding parameter. This implies that all four parameters (p-value = 0) have a significant effect on video streaming QoE. Furthermore, there are interaction effects between each pair of parameters, and 2–way, 3–way, and 4–way interaction have also impacts on QoE as p less than or equal to 0.01 for all combinations.

FIGURE 4.2 shows a sketch of Four–way ANOVA analysis of KQI parameters with QoE. SSR vesus QoE shows an increasing exponential relationship whereas SD, PDR, and SF has a decreasing logarthmic relationship with QoE as shown in FIGURE 4.2 a, FIGURE 4.2 b, FIGURE 4.2 c, and FIGURE 4.2 d respectively.

The result of multiple regression is as shown in TABLE 4.8, TABLE 4.9 and TABLE 4.10. The model summary in TABLE 4.8 shows R, R square and adjusted R square are 0.969, 0.94 and 0.94 respectively and standard deviation error is 0.0093841. This mean that the regressed data has consistent and accurately estimated. The ANOVA result in TABLE 4.9 also shows a zero significant value, zero residual mean square and a high F value which mean that the regression estimates accurately.

TABLE 4.10 shows coefficient of the regressed dataset and a zero significant value and high t value interpreted as the regression result shows the dependent variable is highly influenced by the input independent parameters. Therefore, we can conclude

TABLE 4.7: Four-Way ANOVA Analysis Result

Source	Type II	df	MSE	F	Sig.
Corrected Model	1250.170a	321	3.895	36.75	0
Intercept	33633.643	1	33633.643	317366.851	0
SSRB	61.955	4	15.489	146.152	0
SDB	180.239	4	45.06	425.184	0
PDRB	86.69	4	21.673	204.502	0
SFB	423.297	4	105.824	998.557	0
SDB * PDRB	6.586	16	0.412	3.884	0
PDRB * SFB	5.432	16	0.339	3.203	0
SSRB * PDRB	3.897	15	0.26	2.452	0.001
SDB * SFB	13.529	16	0.846	7.979	0
SSRB * SDB	4.194	15	0.28	2.638	0.001
SSRB * SFB	3.468	12	0.289	2.727	0.001
SDB * PDRB * SFB	14.405	44	0.327	3.089	0
SSRB * SDB * PDRB	10.011	42	0.238	2.249	0
SSRB * PDRB * SFB	7.508	36	0.209	1.968	0.001
SSRB * SDB * SFB	8.077	29	0.279	2.628	0
SSRB * SDB * PDRB * SFB	9.898	58	0.171	1.61	0.002

TABLE 4.8: Model Summary of Regression Result

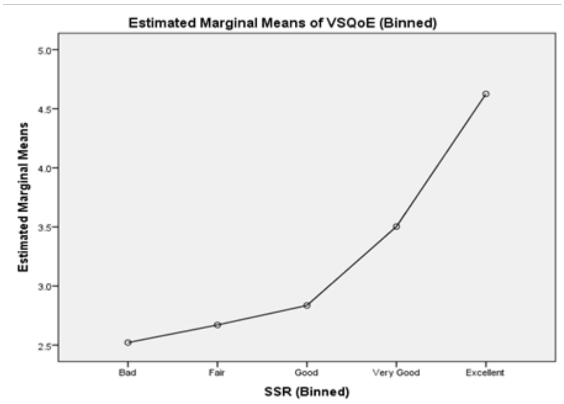
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.969	0.94	0.94	0.0093841

that, the output MOS is determined by the input KQI parameters. The average value of the standard deviation is less than or equal to 0.002, which mean that the distribution of the data has less variation. The linear model from objective data would be as shown in Equation 4.4.

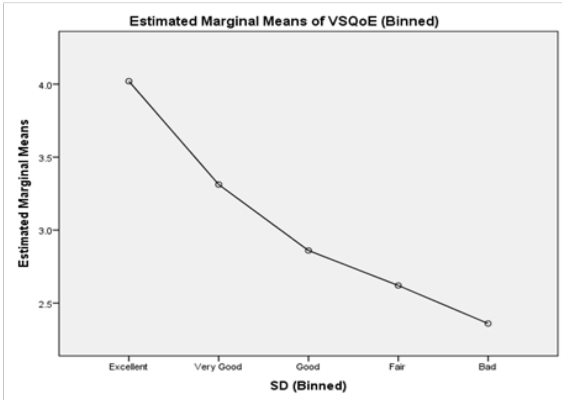
$$MOS = 0.811 + 0.12 * SSR - 0.193 * SD - 0.089 * PDR - 0.314 * SF \tag{4.4}$$

TABLE 4.9: ANOVA Result of the regressed objective dataset

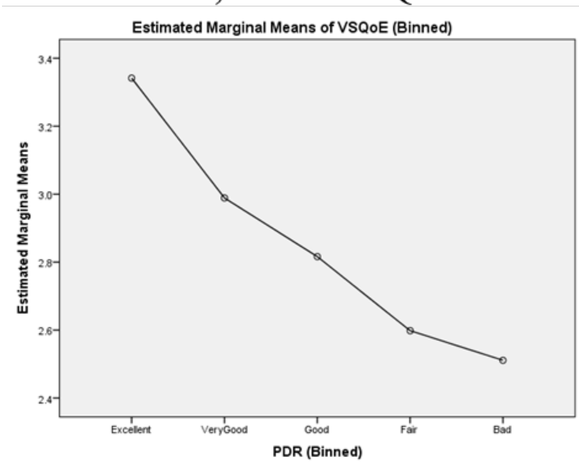
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.372	4	1.343	15251.685	0
	Residual	0.345	3914	0		
	Total	5.717	3918			



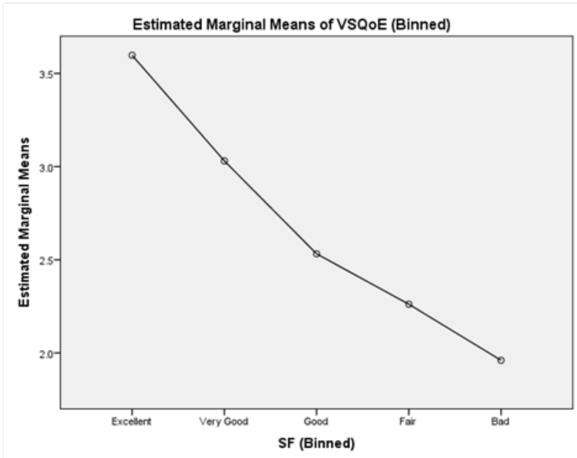
a). SSR versus QoE



b). SD versus QoE



c). PDR versus QoE



d). SF versus QoE

FIGURE 4.2: The impact of each KQI parameter on QoE

TABLE 4.10: Coefficients of the regressed objective dataset

Model		Unstandardized.		Standardized	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.811	0.002		400.465	0
	SSR	0.12	0.001	0.367	88.045	0
	SD	-0.193	0.002	-0.453	-109.945	0
	PDR	-0.089	0.001	-0.249	-60.499	0
	SF	-0.314	0.002	-0.753	-189.957	0

TABLE 4.11: Weight of coefficients of the KQI parameters

Variables	SSR	SD	PDR	SF
Coeff.	0.23	0.25	0.19	0.33
Rank	3	2	4	1

4.4 Weight Determining

Independent weighting method have been used to determine the weight of each coefficient of KQI parameter. This helps us to identify the impact of each KQI parameter on the user perception (MOS value). This have been done by applying the independent weight method on the magnitude of Beta coefficients in TABLE 4.10 using Equation 3.11 and Equation 3.12. The result of the analysis is as shown in TABLE 4.11. Therefore, the influence of the KQI parameters are ranked as SF is first by 33%, SD is second by 25%, SSR is third by 23% and PDR is fourth by 19%. This result is also assuring the result obtained during correlation.

4.5 Simulation Result of Data-Driven FIS Model

We have proposed a Data-Driven FIS model which take KQI parameters as input and a MOS value as a model output using FIS on MATLAB Fuzzy Logic toolbox as shown in FIGURE 4.3. It shows that, the model has four input parameters; SD, SSR, SF and PDR. The FIS deployed here is a Mamdani type inference system which has 81 inference rules. The output for the model is QoE of the video streaming service.The model used the input KQI parameters at three stages. Firstly, it has used the input KQI parameters for membership function design. Secondly, the weighted coefficients have been used to develop the fuzzy inference rules. As they are 'IF...THEN' statements, the antecedents are the KQI parameters operated by 'AND' and the consequences are MOS values resulted from the sum of fuzzy scores multiplied by the weight of KQI parameters. Thirdly, the model has been simulated with the normalized KQI parameters. The next step will be developing the model with this data as follows.

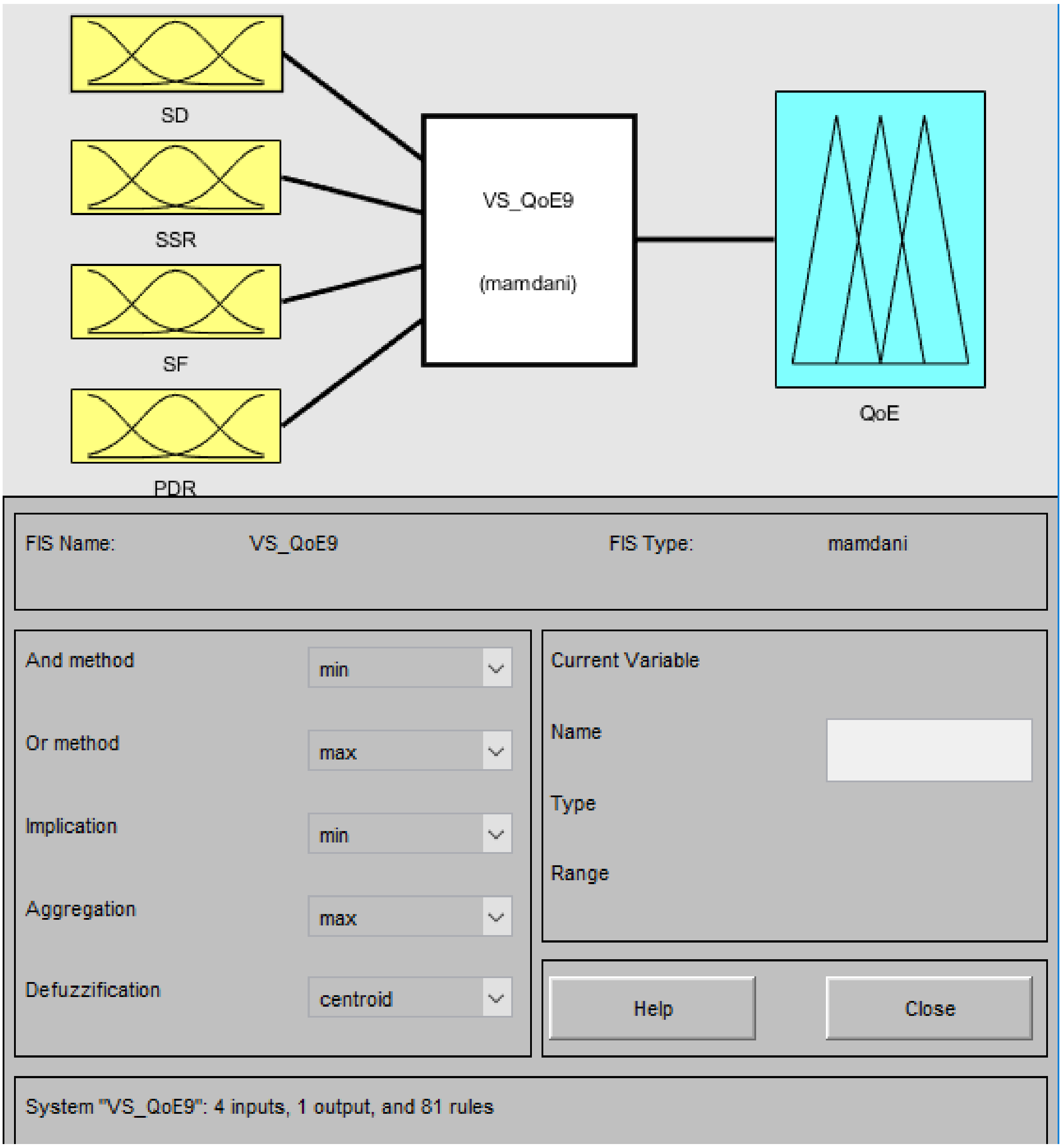


FIGURE 4.3: Data-Driven FIS Model for Video Streaming

4.5.1 Design of Membership functions

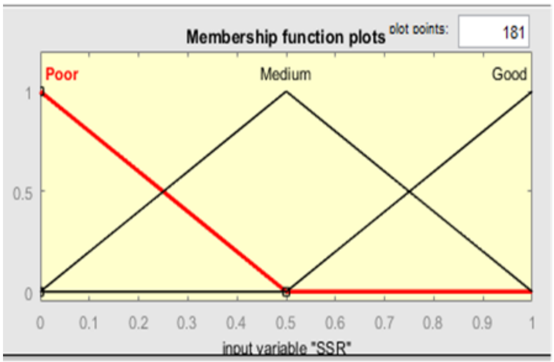
Here, the KQI parameters and video streaming QoE has been transferred into fuzzy membership functions. The membership functions obtained from the Probabilistic

Distribution Function (PDF) of the input and output relationship. The PDF can be triangular, trapezoidal, Gaussian, bell curves or any other shape as long as those shapes accurately represent the distribution of information. For this thesis, the input and output parameters selected to be the triangular PDF based on the shape of the relationship between the KQI parameters and the output MOS values. The triangular curve is a function of a vector, x, and depends on three scalar parameters a, b, and c, as given by [22]:

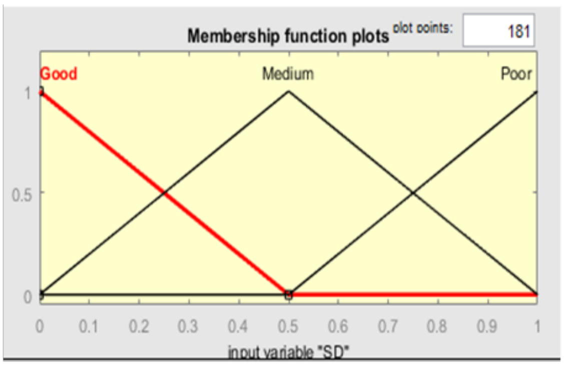
$$f(x;a,b,c) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \tag{4.5}$$

Different PDFs are built for every KQI parameters' fuzzy set. The probabilistic information was changed into a fuzzy set by dividing the PDF by its peak. As shown in FIGURE 4.4 a to d, three fuzzy sets (Poor=1, Medium=2, and Good=3) are assigned to each of the fuzzy input variables. The value of membership function runs from 0 (less membership value) to 1 (high membership value). Similarly, in FIGURE 4.4 e for the output, five fuzzy sets were assigned based on the video streaming QoE scores (Bad=1, Poor=2, Fair=3, Good=4 and Excellent=5). The fuzzy set is converted into an equivalent form (shape) of the membership function by using a curve fitting method. The curve values of the membership functions represent the degree to which a particular KQI parameter value belongs to different video streaming QoE scores.

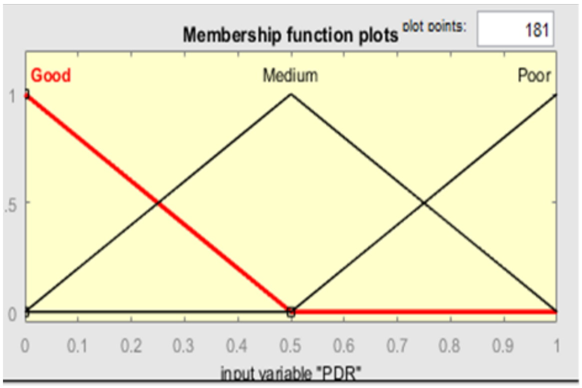
Membership functions have been designed to be a triangular PDF defined as Equation 4.5. The input MFs maps the numerical KQI parameters into fuzzy sets depending on its magnitude of input output relationship. The value of the fuzzy set at a particular point represent the degree of membership in the input-output relationship. There is a 50% overlap ratio for the input fuzzy sets whereas the output fuzzy set has 0% overlap ratio. For example, in FIGURE 4.4 a, a SSR of 0.5 results a membership value of 0% Poor, 100% Medium and 0% Good. Similarly, a SSR of 0.75 results a membership



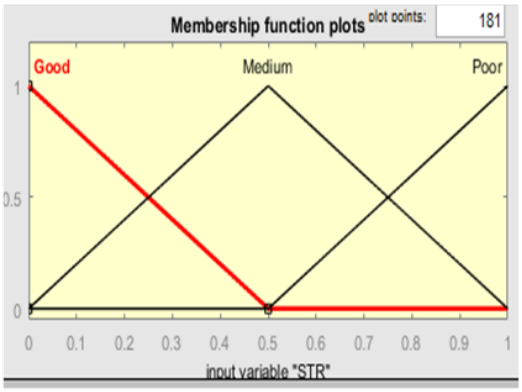
a). SSR Membership functions



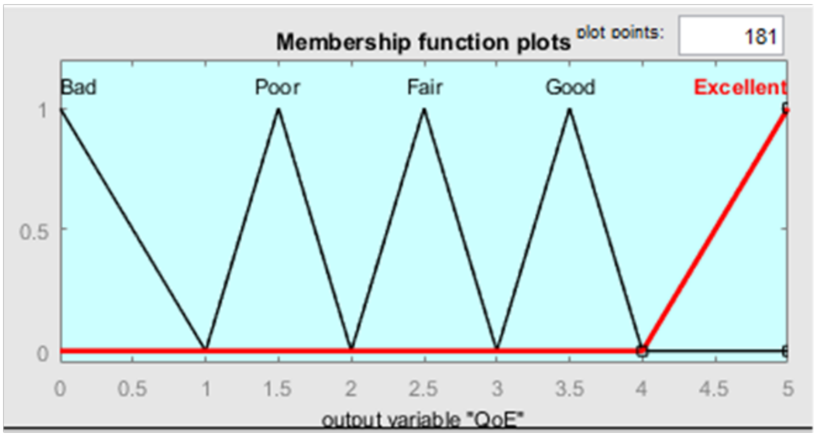
b). *SD membership functions*



c). PDR membership functions



d). STR membership functions



e). QoE Membership functions

FIGURE 4.4: MFs for the input and output fuzzy sets

value of 0% Poor, 50% Medium and 50% Good. Similarly, FIGURE 4.4 b, FIGURE 4.4 c, FIGURE 4.4 d and FIGURE 4.4 e show the degree of membership of the SD, PDR, SF and the output video streaming QoE respectively.

The score of each fuzzy set is assumed to be increased in a regular way in ascending or descending order. The input fuzzy sets run from one to three. By starting one for Poor, two for Medium and three for Good. The output fuzzy sets run from one to five and one for Bad, two for Poor, three for Fair, four for Good and five for Excellent. Therefore, the value of each input parameter would be mapped to each fuzzy set according to the range specified in FIGURE 4.4. Then the output fuzzy set would be determined by logical AND operator of all the four input parameters and it would result a single output fuzzy set with the inference rule as explained in the next section.

4.5.2 FIS Rules Development

The development of the inference rules in this work are a Mamdani-type. The FIS Rule is constructed to control the output variable with the input parameters. These rules are simple IF-THEN statements which depends on the combinations of KQI parameters and their impact on video streaming QoE. A value of estimated video streaming QoE required for each inference rule based on the constructed dataset and expert knowledge. For example:

IF (SD is Medium) AND (SSR is Medium) AND (SF is Medium) AND (PDR is medium) THEN (QoE is Good).

The fuzzy rules are generated by assigning weights to the KQI parameter values. For each combination, the rule weight is calculated as the sum of the weights of the KQI parameter values. Every input variable is assigned a weight number, and the sum of all weight numbers from input variables is equal to 1. Next, the score for antecedent-part of IF-THEN rule is added up by every product of fuzzy set score and corresponding input variable weight. The weight of each KQI parameter is obtained from independent weighted method calculation result.

The generation of the greatest possible number of rules is formed as:

$$\text{Max. No. Rules} = X^n \tag{4.6}$$

Where X is the number of fuzzy sets and n is the number of input variables. So, the maximum number of rules that can be extracted with three KQI parameters and three fuzzy sets for each input KQI parameter is $3^4 = 81$ possible rules. If a rule predicts more than one QoE class, then the QoE class with the highest accuracy is considered to resolve the conflict between the rules.

The FIS rules are an 'IF ... THEN' statements which maps the input fuzzy sets into an output fuzzy set. The input fuzzy sets are operated by a logical 'AND'. The result of the logical operation would determine the output fuzzy set. The weight of each KQI parameter coefficients has been considered in order to include their influence. Therefore, the output fuzzy set determined by the sum of the product of each KQI parameter fuzzy score with its coefficient weight as shown in Equation 4.7, where, Weight of coefficients for $SSR = 0.23$, $SD = 0.25$, $PDR = 0.19$ and $SF = 0.33$ as can be referred from TABLE 4.11.

$$MOS = 0.23 * SSR + 0.25 * SD + 0.19 * PDR + 0.33 * SF \tag{4.7}$$

This means the MOS score for the antecedent of "IF (SD is Medium) AND (SF is Medium) AND (PDR is Medium) AND (SF is Medium)" will be:

$= 0.23 * 3 + 0.25 * 3 + 0.19 * 3 + 0.33 * SF = 3$

Which belongs to Good in the output fuzzy set as can be seen in FIGURE 4.4 e. TABLE 4.12 shows the combinations of the input parameters using logical AND operator and result of the consequent scores.

4.5.3 Aggregated Output

The result of each inference rule would be aggregated with the maximum rule (logical OR operator) and it would be ready for defuzzification. During executing the model, all the rules determine the result with the minimum rule and aggregate the final output with the maximum rule and a final crisp value obtained after defuzzification. This result can be displayed in two ways. 1) It can be viewed using Rule Viewer and 2) It can be viewed in Surface Viewer.

The Rule Viewer shows the result in vertical columns as shown in FIGURE 4.5. It has a vertical red line on each input parameter and by moving this line to the left and right, it shows the impact of each parameter on the output MOS value. Except SSR, all inputs increase the QoE when the red line moves to the left (towards zero). This means, they are inversely correlated with the QoE. Whereas the SSR increase as the red line moves to the right (towards one) which means it is positively correlated with the QoE. For example, the values shown in FIGURE 4.5 shows QoE equals 3.87 where $SD = 0.129, SSR = 0.838, SF = 0.189$ and $PDR = 0.1$. The yellow shaded triangular PDF within each input parameter show the value of the fuzzy score and their operation result transferred for aggregation as discussed above. The QoE would be obtained from the defuzzification of the aggregated fuzzy scores.

The surface Viewer displays the result in three-dimension view. It displays the variation of the two KQI parameters when the other two being constant. It shows the simulation result of the whole dataset by different color with blue color worst MOS value and yellow color best MOS value as shown in FIGURE 4.6. The constant values used preferred for the KQI parameters during simulation was a good value which are $SSR = 0.95, SD = 0.1, SF = 0.1$ and $PDR = 0.1$.

In FIGURE 4.6 (a), SSR and SD has been displayed where PDR and SF being constant. The result shows video streaming QoE increase as the SSR increase and it decreases as SD increases. The maximum value of QoE ($MOS = 4$) scored at $SSR = 1$ and $SD = 0$. When the SSR become less than 0.6 and the SD above 0.5, the QoE is below 2.5 which is poor on MOS scale and unacceptable as a service.

In FIGURE 4.6 (b), SD and SF has been displayed where SSR and PDR being constant. Here, the result of both are inversely related to the video streaming QoE and the maximum value of QoE scored at $SD = 0$ and $SF = 0$. The QoE score below 2.5 which is poor result on MOS scale when the SF and SD become above 0.5. In the opposite, as

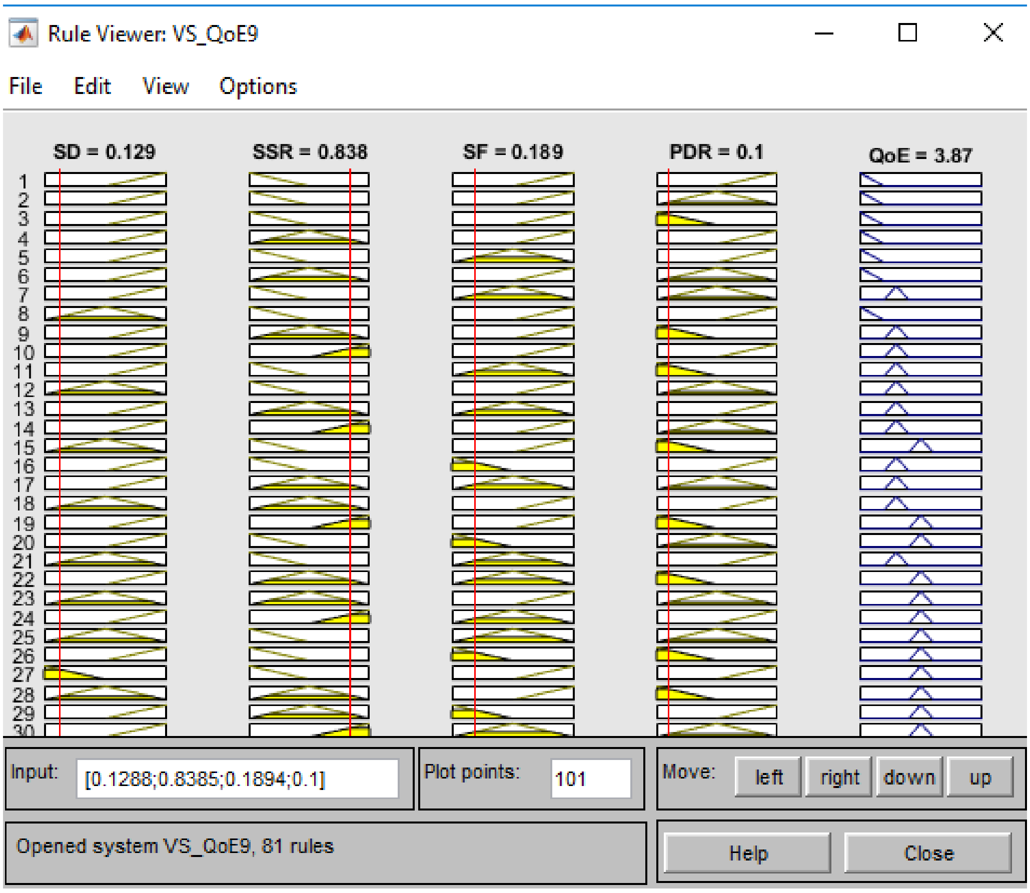
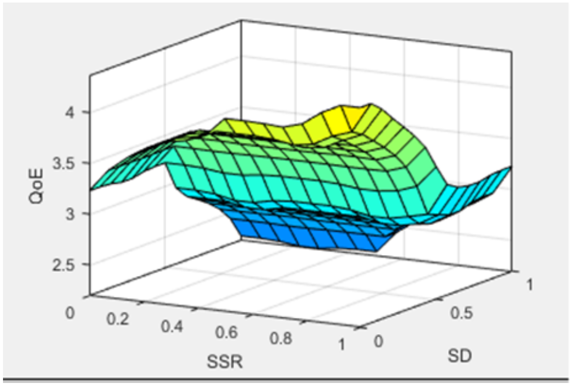


FIGURE 4.5: Partial part of Simulation Result on Rule Viewer

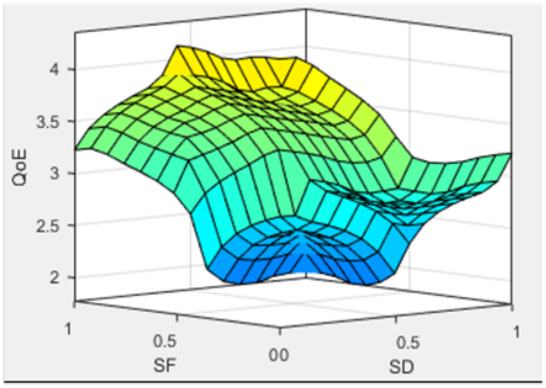
SD and SF become below 0.1, the QoE become above 3.5 which is good service on the MOS scale.

Similarly, 4.6 (c) shows the relationship of SF and PDR when SD and SSR being constant. The best user perception score when SF and PDR became below 0.1 and its value would be above 3.5 which is a good service value on MOS scale. The perception scored zero when both SF and PDR goes to zero.

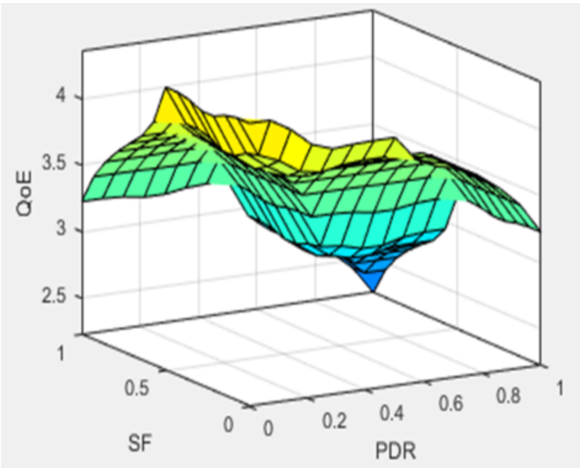
Lastly, 4.6 (d) shows the SSR and PDR relationship, where the other two parameters SD and SF being constant. It scores the highest MOS value, which is beyond 4.5. This result scored at $SSR = 1$ and $PDR = 0$. Again, the QoE is below 1 on the MOS scale, when the SSR is below 0.5 and the PDR is above 0.5. This show the user perception is more sensitive with SSR and PDR. If these parameters degraded highly, the user perception would be considered as no service delivered. This result obtained from the simulated data behavior. As it can be seen in the histogram at FIGURE 4.1 there is no recorded data for SSR below 0.5 and for PDR above 0.5.



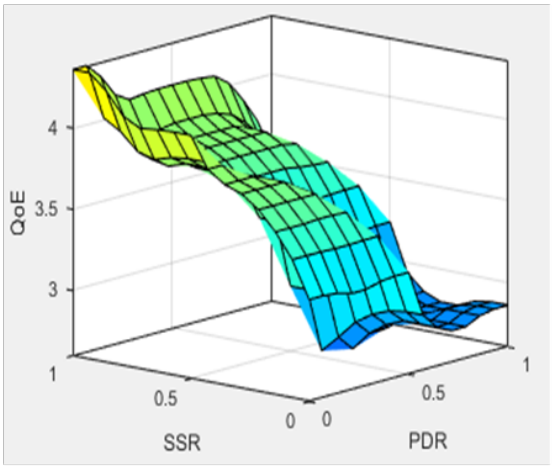
a). SD and SSR versus VSQoE



b). SD and SF versus VSQoE



c). SF and PDR versus VSQoE



d). SSR and PDR versus VSQoE

FIGURE 4.6: Simulation Result on Surface Viewer

4.6 Validation of the Model

The model has been validated using the experimental customer survey data. The survey considers the overall user perception of LTE video streaming in Addis Ababa which have a similar coverage as the objective data collected from the KQI parameters monitoring system. Since the model developed from this objective data, evaluating the model with the customer survey data collected from the same coverage area would make the validation more accepted and logical. The model has been validated with respect to its accuracy, consistency and linearity.

The accuracy of the model has been evaluated with RMSE as shown in TABLE 4.13, TABLE 4.14 and TABLE 4.15. TABLE 4.13 shows the model has a good accuracy with R, R square, adjusted R square and RMSE of 0.932, 0.869, 0.869, and 0.03175 respectively. An R value above 0.68 is accurate for linear regression as explained in [9]. The RMSE value 0.03175 also shows a good accuracy relatve to the existing models.

TABLE 4.14 shows the ANOVA analysis result of the subjective and simulated MOS value. The result shows a residual mean square error of 0.001 which is acceptable and it shows the model is highly consistent. The consistency implies the variation relative to the input parameters variation and it measure the outlier ratio of the datasets.

In TABLE 4.15, the linear regression coefficients of the subjective MOS and the simulated MOS displays their relation can be approximated linearly. The linear curve fitting result is as shown in FIGURE 4.7. The linear curve fitting presents the simulated and the subjective MOS have linear relationship with very small variation. The Equation of the linear line is:

$$\text{Simulated MOS} = 0.192 + 0.772 * \text{Subjective MOS} \tag{4.8}$$

The result of Pearson correlation of the subjective MOS and the simulated MOS shows as they are more than 93.2% correlated as shown in TABLE 4.16. This mean that their relationship is linear by this percentage amount which is also a good value.

Therefore, the validation of the model shows at best level with all the three metrics. The accuracy is high as RMSE = 0.03175 and the consistency is highly consistent as the residual mean square is 0.001. The linearity of the model achieved 93.2% correlation

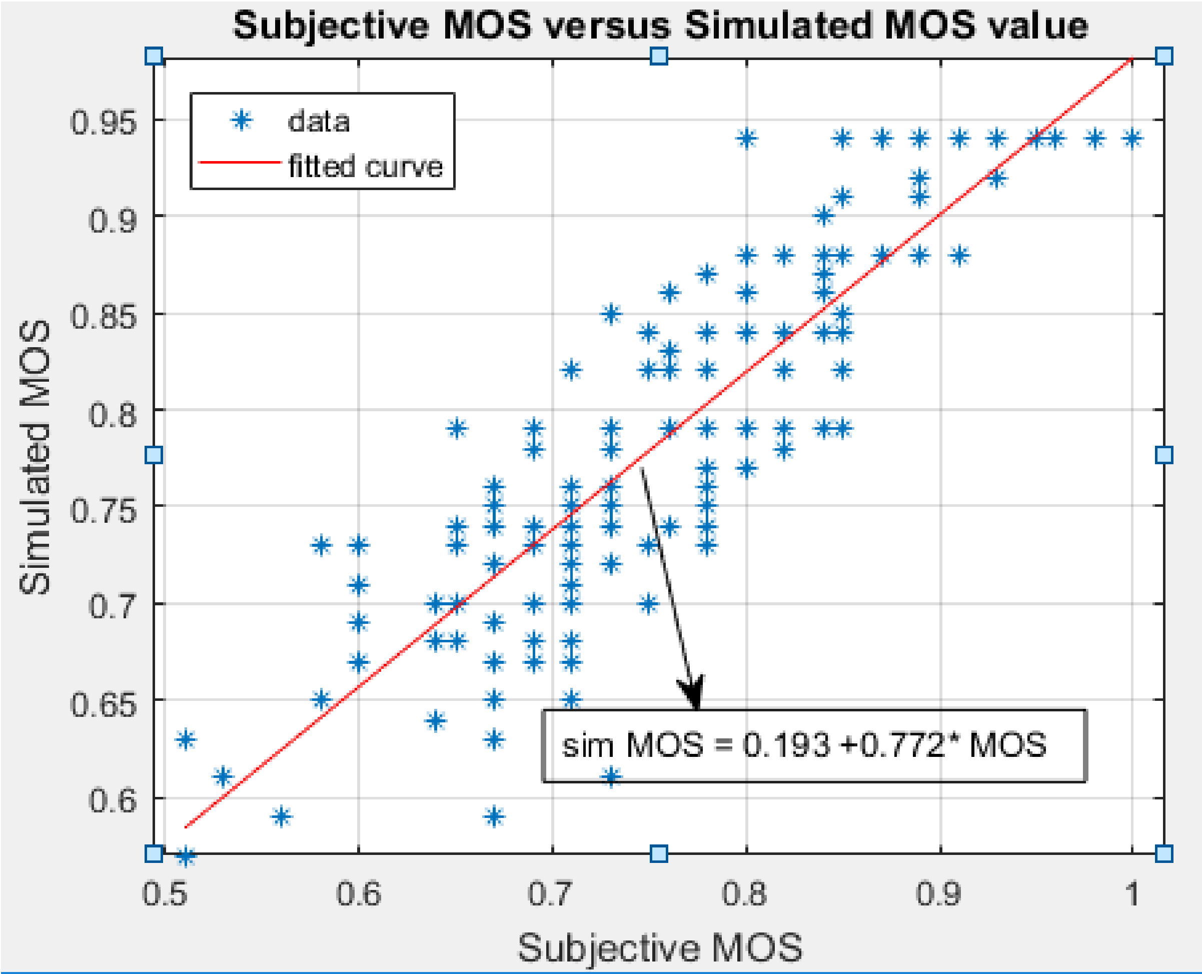


FIGURE 4.7: Curve fitting result of subjective and simulated MOS

also is a best linearity compared to the existing models performance.

TABLE 4.12: Antecedent Table for input and the output value

Rule No	SF 0.33	F. Sc	SD 0.262	F. Sc	PDR 0.212	F. Sc	SSR 0.197	F. Sc	MF Sc.
1	Poor	1	Poor	1	Poor	1	Poor	1	1
2	Poor	1	Poor	1	Poor	1	Medum	2	2
3	Poor	1	Poor	1	Poor	1	Good	3	2
4	Poor	1	Poor	1	Medum	2	Poor	1	2
5	Poor	1	Medum	2	Poor	1	Poor	1	2
6	Poor	1	Poor	1	Medum	2	Medum	2	2
7	Poor	1	Medum	2	Poor	1	Medum	2	2
8	Medum	2	Poor	1	Poor	1	Poor	1	2
9	Poor	1	Poor	1	Medum	2	Good	3	2
10	Poor	1	Poor	1	Good	3	Poor	1	2
11	Poor	1	Medum	2	Poor	1	Good	3	2
12	Medum	2	Poor	1	Poor	1	Medum	2	2
13	Poor	1	Medum	2	Medum	2	Poor	1	2
14	Poor	1	Poor	1	Good	3	Medum	2	2
15	Medum	2	Poor	1	Poor	1	Good	3	3
16	Poor	1	Good	3	Poor	1	Poor	1	2
17	Poor	1	Medum	2	Medum	2	Medum	2	3
18	Medum	2	Poor	1	Medum	2	Poor	1	2
19	Poor	1	Poor	1	Good	3	Good	3	3
20	Poor	1	Good	3	Poor	1	Medum	2	3
21	Medum	2	Medum	2	Poor	1	Poor	1	2
22	Poor	1	Medum	2	Medum	2	Good	3	3
23	Medum	2	Poor	1	Medum	2	Medum	2	3
24	Poor	1	Medum	2	Good	3	Poor	1	3
25	Medum	2	Medum	2	Poor	1	Medum	2	3
26	Poor	1	Good	3	Poor	1	Good	3	3
27	Good	3	Poor	1	Poor	1	Poor	1	2
28	Medum	2	Poor	1	Medum	2	Good	3	3
29	Poor	1	Good	3	Medum	2	Poor	1	3
30	Poor	1	Medum	2	Good	3	Medum	2	3
31	Medum	2	Poor	1	Good	3	Poor	1	3
32	Medum	2	Medum	2	Poor	1	Good	3	3
33	Good	3	Poor	1	Poor	1	Medum	2	3
34	Poor	1	Good	3	Medum	2	Medum	2	3
35	Medum	2	Medum	2	Medum	2	Poor	1	3
36	Poor	1	Medum	2	Good	3	Good	3	3
37	Medum	2	Poor	1	Good	3	Medum	2	3
38	Good	3	Poor	1	Poor	1	Good	3	3

39	Medum	2	Good	3	Poor	1	Poor	1	3
40	Medum	2	Medum	2	Medum	2	Medum	2	3
41	Poor	1	Good	3	Medum	2	Good	3	3
42	Good	3	Poor	1	Medum	2	Poor	1	3
43	Medum	2	Poor	1	Good	3	Good	3	4
44	Poor	1	Good	3	Good	3	Poor	1	3
45	Medum	2	Good	3	Poor	1	Medum	2	3
46	Good	3	Medum	2	Poor	1	Poor	1	3
47	Medum	2	Medum	2	Medum	2	Good	3	4
48	Good	3	Poor	1	Medum	2	Medum	2	3
49	Medum	2	Medum	2	Good	3	Poor	1	3
50	Poor	1	Good	3	Good	3	Medum	2	3
51	Medum	2	Good	3	Poor	1	Good	3	4
52	Good	3	Medum	2	Poor	1	Medum	2	3
53	Good	3	Poor	1	Medum	2	Good	3	4
54	Medum	2	Good	3	Medum	2	Poor	1	3
55	Good	3	Poor	1	Good	3	Poor	1	3
56	Poor	1	Good	3	Good	3	Good	3	4
57	Medum	2	Medum	2	Good	3	Medum	2	4
58	Good	3	Medum	2	Poor	1	Good	3	4
59	Good	3	Medum	2	Medum	2	Poor	1	3
60	Medum	2	Good	3	Medum	2	Medum	2	4
61	Medum	2	Medum	2	Good	3	Good	3	4
62	Good	3	Poor	1	Good	3	Medum	2	4
63	Good	3	Good	3	Poor	1	Poor	1	3
64	Medum	2	Good	3	Medum	2	Good	3	4
65	Good	3	Medum	2	Medum	2	Medum	2	4
66	Good	3	Poor	1	Good	3	Good	3	4
67	Medum	2	Good	3	Good	3	Poor	1	4
68	Good	3	Good	3	Poor	1	Medum	2	4
69	Good	3	Medum	2	Medum	2	Good	3	4
70	Medum	2	Good	3	Good	3	Medum	2	4
71	Good	3	Medum	2	Good	3	Poor	1	4
72	Good	3	Good	3	Poor	1	Good	3	4
73	Good	3	Good	3	Medum	2	Poor	1	4
74	Medum	2	Good	3	Good	3	Good	3	5
75	Good	3	Medum	2	Good	3	Medum	2	4
76	Good	3	Good	3	Medum	2	Medum	2	4
77	Good	3	Medum	2	Good	3	Good	3	5
78	Good	3	Good	3	Medum	2	Good	3	5
79	Good	3	Good	3	Good	3	Poor	1	4
80	Good	3	Good	3	Good	3	Medum	2	5
81	Good	3	Good	3	Good	3	Good	3	5

TABLE 4.13: regression between Subjective and Simulated MOS

Model	R	R Square	Adj. R Square	RMSE
1	0.932	0.869	0.869	0.03175

TABLE 4.14: ANOVA Result for Subjective and the simulated MOS

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.436	1	1.436	1424.463	0
	Residual	0.216	214	0.001		
	Total	1.651	215			

TABLE 4.15: The Regression Coef. of the Subjective and Simulated MOS

Model		Unstandardized		Standardized	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.192	0.016		11.832	0
	Sim_MOS	0.772	0.02	0.932	37.742	0

TABLE 4.16: The correlation of subjective and Objective MOS

	Subjective MOS	Simulated MOS
Subjective MOS	1	0.932
Simulated MOS	0.932	1

5 Conclusions and Recommendations

5.1 Conclusions

The results obtained in this thesis can be grouped into two main conclusions:

- The correlation, regression, and ANOVA analysis result show the KQI parameters have a great influence on the video streaming QoE. The coefficient influence analysis shows the SF has the highest impact on video streaming which is 33% and SD plays higher role next to SF by 25%. This implies that the network performance on the capacity and delay parameters should be further investigated to improve the QoE. Because, the SF increase as the network capacity congested and SD increases as the packet delayed at different stage of transmission congestion.

- The proposed video streaming QoE model shows good accuracy, consistency and linearity. The RMSE value of 0.03175 is an accurate prediction result. The residual mean square error of 0.001 also shows the consistency of the model. The result of the Pearson correlation is 93.2%. It shows the linearity of the model. Therefore, the model has a better performance than the existing models and we have proposed it for Ethio Telecom to deploy it after designing the necessary frame work.

5.2 Recommendations

According to this thesis analysis result, this work has recommended the following future works:

- The spatio-temporal distribution of the user perception can be studied and the specific location and time resource allocation could be proposed for network designers and it will be very important for future network deployment.
- The impact of terminal device can be studied in technological specification as well as portability to identify their particular impact on the user perception.
- A frame work for deploying the proposed model could be done after the proposed model has got acceptance by the AAiT and Ethio Telecom. The frame work should include further management issues and the technical part which need a great team work.
- As SD is one of the influential parameter that affect the user perception, it should be further investigate to identify the node that make this delay. As SD represents the E2E network structure including the terminal devices, the core network, the access network and the user's usage experience, it should further have segmented and studied. The delay may be from a single node or multiple nodes across the E2E network structure.

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A Appendix A

A.1 Experimental Customer Survey

The experimental customer survey questionnaire detail information has been explained here. It has four parts. The first part explains an introduction about the questionnaire, The second part explains about user profile, the third part describes about the evaluation of the service quality and the last part discuss about the service delivery as shown below.

Introduction How to give Response for the Survey

During responding the survey, writing your name or phone number is not necessary. This survey needs only the profile of the customer as part of the research important factor on user perception. Based on that, we can improve the user perception.

The survey invites you to watch one of your favorite television program on the links posted below. To do this click the link below and click the play button on your browser. If there is an advisement pop up, click skip. Then make full screen to watch the streaming on full screen. After watching your favorite live streaming session, you are politely requested to give response for the survey. The watching and responding the survey should be repeated with different terminal device, different time of a day and different places of Addis Ababa sub-cities as much as possible. For example, a participant with a smartphone only can do the experiment four times at different time of the day (morning, afternoon, evening and night), a participant with a smartphone and laptop can do it 8 times and similarly a participant having a smartphone, tablet, computer and smart television can do the experiment 16 times. Even he can do at different sub-city and can have a maximum of 160 experiments. So that, you are politely requested to try it as much as possible.

The response expected to be the real situation at watching the video streaming session. Since the video streaming user perception required is for the Addis Ababa LTE network, you are politely requested to check your terminal device locked on LTE (4G) network during streaming.

- https://www.ethiovisit.com/videos/etv-entertainment–ethiopian-live-tv/2711/
- https://www.ethiovisit.com/videos/arts-tv/5769/
- https://www.ethiovisit.com/videos/ebs-tv/295/
- https://www.ethiovisit.com/videos/fana-tv–ethiopian-live-tv/5781/
- https://www.ethiovisit.com/videos/ethiopian-children-tv-ectv/5894/
- https://www.ethiovisit.com/videos/nasa-live-earth-from-space–nasa-live-stream/4776/
- https://www.ethiovisit.com/videos/bbc-news24-live-tv/288/

User Profile

Part two includes participants' profile regarding their gender, age, educational level, type of video they are watching, geographical location, time of the day they have watched the streaming, job status and their terminal device used for this experiment. This part includes eight questions (Q1 – Q8).

Q1) Select your gender from the given choice.It is requested to identify the participants' gender ratio in the survey.

Q2) Which age category are you from the given choice. It defines the age category of the participants.

Q3) Select your highest level of education in your carrier? It describes the participants' level of education.

Q4) What type of video streaming have you watched? It is used to identify the type of video streaming watched by the participants'.

Q5) Could you select the current geographical location when watching the video streaming? It is required to identify the geographical location for the participants during watching the video streaming.
Q6) What is your job status? It presents the job status of the survey participants.
Q7) Could you select the time of the day when you have been watching the video. It shows the time of the day in which the participants watched the video.
Q8) What type of terminal device you have used to watch this video. It displays the terminal device type used by the participants for this survey.
TABLE A.1 shows the participants gender, education background, the type of video streaming they have watched. A total of 216 participants responded the survey among which 69 are females and 147 are males. The result shows females like watching spiritual video, on line learning and film; whereas males like watching news and sport. The education background shows most of females are first degree and below; whereas males are second degree and below. TABLE A.2 shows the gender, job status, and type

TABLE A.1: User profile by type of stream and education

Education Level	Certificate	Degree	Masters	PHD	Grand Total
Female	23	34	8	4	69
Film	7	7	1		15
Music	3	6			9
News		4	2	1	7
learning	5	11		2	18
Sport	1				1
Spiritual	7	6	5	1	19
Male	5	79	51	12	147
Film		10	5	1	16
Music	1	9	6		16
News	1	23	12	9	45
learning	1	6	8	2	17
Sport	2	20	16		38
Spiritual		11	4		115
Grand Total	28	113	59	16	216

of terminal device used for video streaming. It shows that most of the participants are governmental employees and most of the terminal device used for watching the video streaming are smart phones and computers.

Evaluating Video Streaming scenario

TABLE A.2: User profile by terminal type and job status

Job Status	business	Gov.	Investor	Job Seeker	Private	Self	Grand Total
Female	17	26	2	5	6	4	69
Computer	2	6	1		1		14
Smart phone	9	14		1	3		29
Smart TV		2				3	5
Tablet	6	5		4	2	3	21
Male	10	101	5	3	8	2	147
Computer	2	30			3	2	44
Smart phone	3	55	2	3	4		69
Smart TV		8	3		2		13
Tablet	5	11					21
Grand Total	27	127	7	8	14	6	216

Part three collects the KQI parameters from participant's point of view such as SSR,SD, PDR, SF and STR. It includes questions Q9 – Q13.

Q9) According to your LTE video streaming experience you have watched now, how have you been satisfied with start success rate? It presents SSR satisfaction level for participants.

Q10) During your request to watch the streaming, how have you been satisfied with the delay to start the streaming after you have clicked the play button? It shows the SD satisfaction level of the survey participants.

Q11) In this video watching session, have you experienced any interruption of the streaming, how many time your streaming interrupts during watching? It collects the satisfaction level with respect to PDR has been presented.

Q12) During watching the streaming, there may be video artifacts such as video slow, stop, and blurred image which affect the video quality. With regard to such artifacts, how do you rate the quality of the video you watched? It collects the satisfaction level with respect to SF.

Q13) According to your video watching experience, how do you perceive the overall LTE video streaming service? It presents the satisfaction level with respect to STR. The collected data is shown in TABLE A.3, TABLE A.4, TABLE A.5, TABLE A.6 and TABLE A.7 respectively. Each of them shows how the customer perceive the streaming quality and their educational background.
TABLE A.3 shows the SSR result and 34 female and 69 male participants are moderately satisfied and 22 female and 56 male participants are extremely satisfied. This results as the SSR is moderately satisfied with participants' average score.
Similarly, TABLE A.4 shows the SD average score is moderately satisfied level. Among

TABLE A.3: Subjective SSR response of streaming

SSR Satisfaction Level	certificate	Degree	Masters	PHD	Grand Total
Female	23	34	8	4	69
Extremely satisfied	8	13	2	1	22
Moderately satisfied	11	17	5	1	34
slightly satisfied	4	4	1	2	11
Male	5	79	51	12	147
Extremely satisfied	2	34	7	3	56
moderately satisfied	3	31	30	8	69
Neither satisfied or not		2			2
slightly satisfied		12	4	1	17
Grand Total	28	113	59	16	216

216 participants 34 females and 70 males are moderately satisfied and 17 females and 52 males are extremely satisfied.
In the same way, TABLE A.5 shows the PDR average score is extremely satisfied level. Among 216 participants 30 females and 56 males are moderately satisfied and 28 females and 72 males are extremely satisfied.
TABLE A.6 shows the SF average score is moderately satisfied level. Among 216 participants 34 females and 77 males are moderately satisfied and 8 females and 27 males are extremely satisfied.
TABLE A.7 shows the STR average score is moderately satisfied level. Among 216 participants 31 females and 77 males are moderately satisfied and 7 females and 30

TABLE A.4: Subjective SD response of streaming

SD Satisfaction Level	certificate	Degree	Masters	PHD	Grand Total
Female	23	34	8	4	69
Extremely satisfied	6	8	2	1	17
Moderately satisfied	10	19	4	1	34
Slightly satisfied	7	7	2	2	18
Male	5	79	51	12	147
Extremely satisfied	3	29	18	1	52
Moderately satisfied	1	35	27	7	70
Neither satisfied or Not		1			1
Slightly satisfied	1	12	8	4	25
Dissatisfied		2			2
Grand Total	28	113	59	16	216

TABLE A.5: Subjective PDR response of streaming

PDR Satisfaction Level	certificate	Degree	Master	PHD	Grand Total
Female	23	34	8	4	69
no interruption at all	7	16	4	1	28
one times per five minute	13	12	3	2	30
Five times per five minute	3	6		1	10
several times per five minute			1		1
Male	5	79	51	12	147
no interruption at all	4	43	22	3	72
one times per five minute	1	25	22	8	56
Five times per five minute		6	6	1	13
several times per five minute		4	1		5
Ten times per five minute		1			1

males are extremely satisfied.

Service Delivery

Part four of the questionnaire evaluate the service based on the participants' experience about the service delivery. This includes eight questions (Q14 – Q22). The figures followed starting from FIGURE A.1 to FIGURE A.8 shows the result of the service delivery survey.

TABLE A.6: Subjective SF response of streaming

SF Satisfaction Level	certificate	Degree	Master	PHD	Grand Total
Female	23	34	8	4	69
Extremely satisfied	2	4	1	1	8
moderately satisfied	9	18	4	1	34
slightly satisfied	11	12	3	1	27
Neither satisfied or Not	1			1	1
Male	5	79	51	12	147
Extremely satisfied	2	14	10	1	27
moderately satisfied	3	44	24	6	77
slightly satisfied		21	16	5	42
Neither satisfied or Not			1		1
Grand Total	28	113	59	16	216

TABLE A.7: Subjective STR response of streaming

STR Satisfaction Level	certificate	Degree	Masters	PHD	Grand Total
Female	23	34	8	4	69
Extremely satisfied	2	3	1	1	7
Moderately satisfied	8	18	4	1	31
Slightly satisfied	13	13	3	2	31
Male	5	79	51	12	147
Extremely satisfied	1	15	13	1	30
Moderately satisfied	3	44	25	5	77
Neither satisfied or Not		1			1
Slightly satisfied	1	19	13	6	39
Grand Total	28	113	59	16	216

Q14) Based on your usage experience, how have you been satisfied with the price of LTE video streaming in Ethio Telecom? It collects the price satisfaction level of participants. FIGURE A.1 shows 46% of participants are slightly satisfied with the price of the service and 37% are moderately satisfied.

Q15) As Ethio Telecom customer, how have you been satisfied with the call center support at 994 or 980 of Ethio Telecom? It presents the satisfaction level for call center. FIGURE A.2 shows 40% of the customers are slightly satisfied with the call center support and 26% are moderately satisfied.

Q16) As a video streaming user, how have you been satisfied with the usefulness of

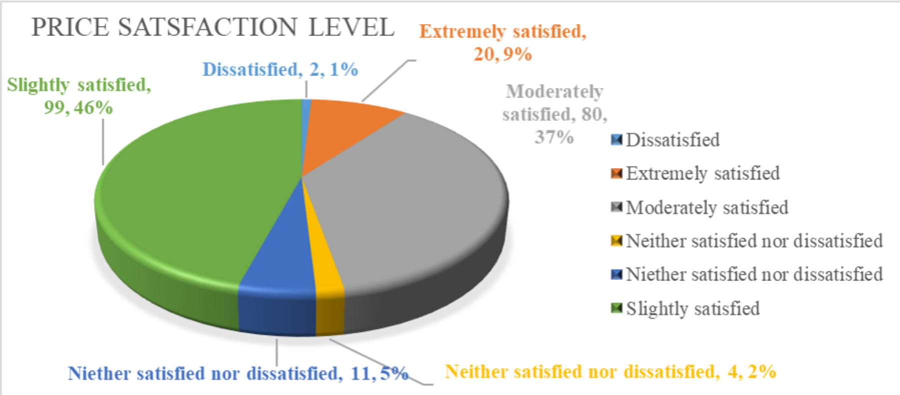

FIGURE A.1: price satisfaction of streaming

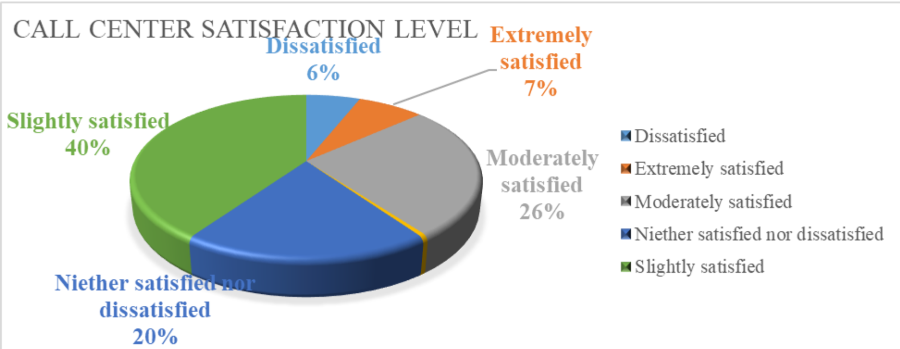

FIGURE A.2: Call center support satisfaction level of streaming

LTE video streaming? It shows the satisfaction level with respect to service usefulness. FIGURE A.3 shows about the usefulness of the LTE video streaming service in Addis Ababa. The result observed that 52% of the customers consider it as the most useful service and 35% as moderately useful. Based on this research, LTE video streaming should be expanded and delivered at best quality as users are highly interested to the service.

Q17) Ethio Telecom delivers the service at different data size and price to serve the customer according to his/her needs. For example, data package from 25 MB at Br.3 up to monthly unlimited with Br.4900, how have you been satisfied with the ability to customize the data service in this scenario? It presents the satisfaction level of the customization of ETHIO Telecom service. FIGURE A.4 shows the customization satisfaction level of the service. It means how much flexible to address the lower class

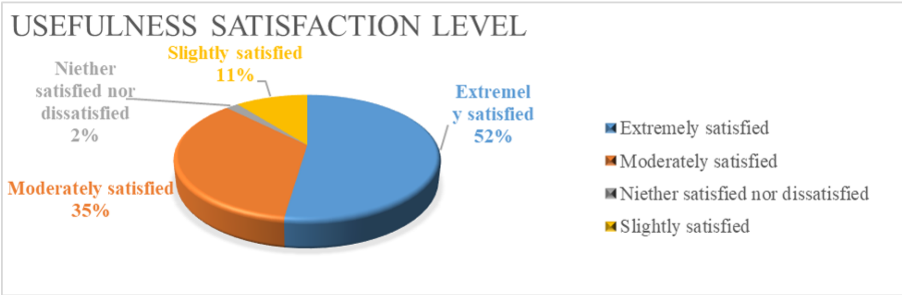

FIGURE A.3: Call center support satisfaction level of streaming

and to satisfy higher class of the customers as Ethio Telecom delivers the service at different data size and price to serve the customer according to his/her needs. For example, data package from 25 MB at Br.3 up to monthly unlimited with Br.4900. The result shows at 50% extremely satisfied level and 34% moderately satisfied level.

Q18) Please choose the top first factor that are most influential in your decision to

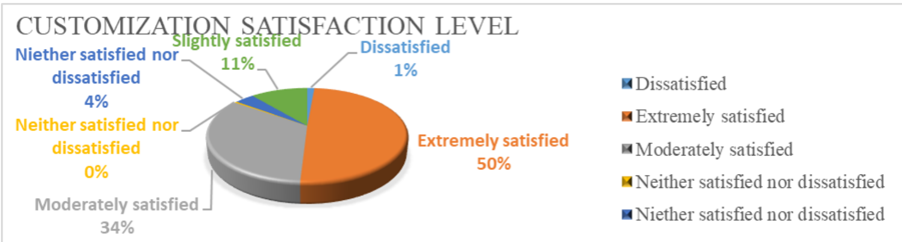

FIGURE A.4: Customization satisfaction level for streaming

purchase LTE video streaming service in Ethio Telecom? It shows the first factor the participants' consider during purchasing a service.FIGURE A.5 shows the first factor the customer considers during purchase of a service. According to this research work 58% of the customers prioritized the quality of the service and 31% considers the price of it.

Q19) Please choose the top second factor that are most influential in your decision to purchase LTE video streaming service in Ethio Telecom? It presents the second top factor for participants service selection criteria.The second factor to be considered is selected price at 37% and quality at 28% as shown in FIGURE A.6. This shows, the LTE customers in Addis Ababa prioritize quality than the price they paid. Therefore, Ethio Telecom expected to fulfill the quality of the streaming service at optimum cost.

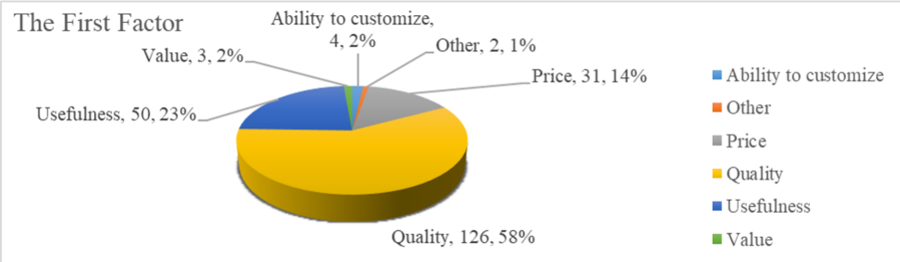

FIGURE A.5: The first factor proposed for streaming

Q20) Based on your experience with Ethio Telecom, how likely or unlikely are you to

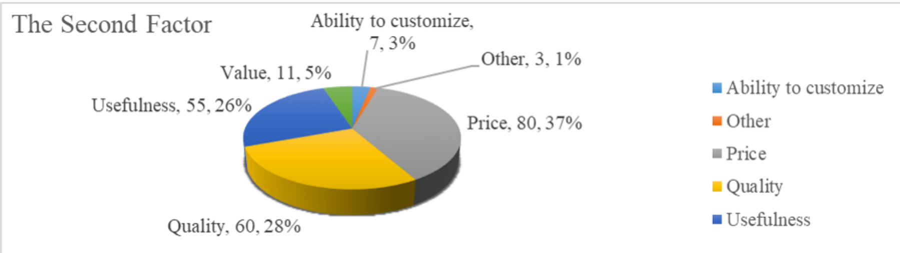

FIGURE A.6: The Second Factor proposed for streaming

continue as a customer in the future? It shows the participants interest to continue as a customer with Ethio Telecom. FIGURE A.7 shows how likely the costumer are interested to continue doing business. The result shows they are moderately likely above 53% and extremely likely above 21%.

Q21) If two or more telecom operators participate in Ethiopia telecom market and de-

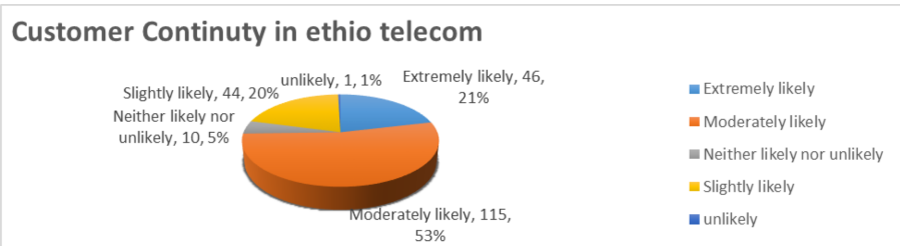

FIGURE A.7: Customer continuity level

liver a competitive telecom service, what will be your choice. It presents participants interest and reason to migrate to other operator. FIGURE A.8 shows the interest of the customers if two or more operators compute in telecom market of LTE video streaming service in Addis Ababa. The result shows 49% of the customers are interested to migrate into a new operator if the competitive operator delivers better quality and cheaper service; whereas 39% of customers will not migrate as far as their expectation is satisfied within Ethio Telecom.

Q22) Please share any additional comments or feedback regarding LTE video stream-

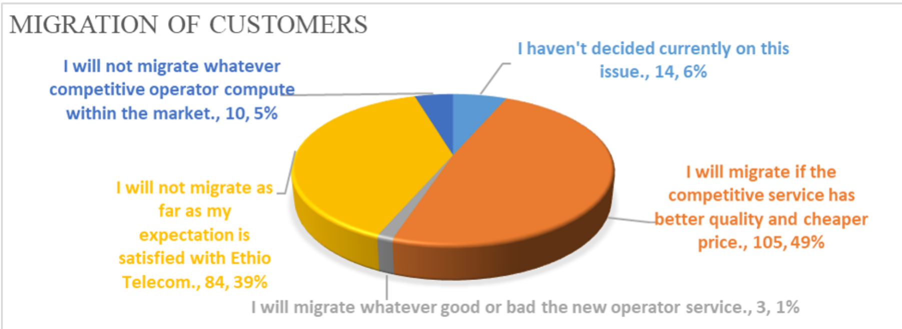

FIGURE A.8: Migration interest of streaming Customers

ing service in Ethio Telecom in the space provided below.

There have been 145 responses among 216 participants for this question. Most of them discuss about coverage, capacity and price issue. Some of the participant's explanation are pasted here as a sample.

- No VOLTE, coverage, capacity, price issues should be considered.
- For LTE video streaming, in addition to the above mentioned, the type of mobile equipment has great role.
- The data rate supported or provided by LTE and 3G technology is almost the same. The data rate provided by ET is not the same with advertised data rate.
- Ethio -Telecom service make it free from various massages (make us bored tones every minute,), costly services, always internet interruptions, thief, Quality should be improved, not expanded to remote areas. (it is centralized not reached to local community)

- Network coverage is not fully addressed even in Addis Ababa and it should be continuing to the whole country or in major towns of Ethiopia. And LTE is only works for Data so that LTE voice should be added.
- The current LTE service has better quality whereas I have doubt whether it stay sustainable as the number of customer rapidly increased.
- Ethiotelecom LTE service uses CSFB scenario to use voice service it is better if the network supports VoTE service in addition.
- Quality and speed if this service are very good but price needs further consideration.
- There is no LTE coverage around Kality Gelan condominium and some other far end AA city areas, so it's better to consider this as well for better customer satisfaction.
- LTE video streaming is very important to have new information and knowledge in all aspects and expecting this service with excellent quality and low price through market competition.

A.2 Fuzzy Inference System (FIS)

Fuzzy logic can make development and implementation much simpler. It needs no complicated mathematical models, only a practical understanding of the overall system behavior. Fuzzy logic mechanisms can result to higher accuracy and smoother control as well. It differs from conventional logic in that it is multivalued. Fuzzy deals with degrees of truth and degrees of membership. Membership functions characterize the fuzziness in a fuzzy set; whether the elements in the set are discrete or continuous, in a graphical form for eventual use in the mathematical formalisms of fuzzy set theory [24].

There are two types of inference systems differ somewhat in the way outputs are determined. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani. Mamdani-type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification [22].

Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant. Sugeno FIS is similar to the Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant [22].

The FIS Structure

The FIS structure is the MATLAB object that contains all the FIS information. All the information for a given fuzzy inference system is contained in the FIS structure, including variable names, membership function definitions, and so on. This structure can itself be supposed of as a ladder of structures (or flow charts), as shown in the FIGURE A.9 which is adopted in [22].

In recent years, the number and variety of applications of fuzzy logic have increased

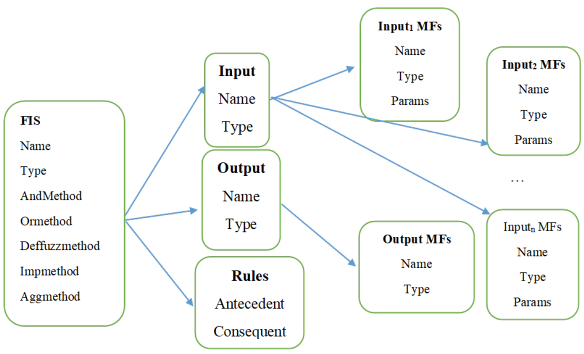

FIGURE A.9: FIS structure or flow chart

significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. The modelling has been done using MATLAB fuzzy logic Toolbox based on the analyzed dataset weighted coefficients.