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Assessing Service Quality of the Jaynagar–Janakpur–Bijalpura Railway Using an Integrated SEM-AHP Approach: A Passenger Perspective

by

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ABSTRACT

Rail transport has historically been limited in terms of network expansion and operational coverage in Nepal. The Jaynagar–Janakpur–Bijalpura Rail Service is the only operational passenger railway service in the country. Due to the limited development and small scale of the railway system, almost no studies have assessed railway service quality from the passengers' perspective in Nepal. Improving the service quality of Jaynagar–Janakpur–Bijalpura Rail Service is important to enhance the satisfaction of passengers.

Existing literature on railway service quality primarily focuses on developed countries, with limited attention given to the unique experiences and challenges of developing nations like Nepal. An integrated use of Partial Least Squares Structural Equation Modeling (PLS-SEM) and the Analytic Hierarchy Process (AHP) provide a broader understanding of railway service quality. PLS-SEM is used to examine the relationships between service quality dimensions and passenger satisfaction, while the Analytic Hierarchy Process (AHP) determines the relative importance of these dimensions through pairwise comparison based on Saaty's scale.

The PLS-SEM result indicates that the three latent variables, Operational Quality, Physical Quality, and Travel Convenience, positively affect passenger satisfaction among rail users. The AHP results further reveal that passengers assign the highest priority to Operational Quality, followed by Travel convenience and Physical Quality. At the sub-criteria level, on-time train service, ease in boarding and alighting, and safety in trains were identified as top-priority factors.

The findings suggest that improving railway services requires a balanced approach. This study provides a comprehensive, data-driven framework that can assist railway administrators in prioritizing service quality improvements and operational strategies to effectively enhance the passenger experience on this important cross-border rail link.

Keywords: Service Quality, Passenger Satisfaction, PLS-SEM, AHP, Railway Service.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

SEM	Structure Equation Modeling
SERVQUAL	Service Quality
RAILQUAL	Rail Quality
LIC	Low Income Country
OP	Operational Quality
PH	Physical Quality
TC	Travel Convenience
PLS	Partial Least Square
KMO	Kaiser-Meyer-Olkin
AVE	Average variance extracted
CR	Combined validity
SD	Standard Deviation.
M	Mean
GM	Geometric Mean
SRMR	Standardized root mean square residual
OVR	Overall Satisfaction
AHP	Analytical Hierarchy Process
MCDM	Multi-Criteria Decision Making
MCDA	Multi-Criteria Decision Analysis

CHAPTER 1: INTRODUCTION

1.1 Background

Rail transport across the world has evolved into one of the most efficient, sustainable, and user-oriented way of public transportation. Many countries have strengthened their passenger railway systems to reduce road congestion, improve safety, and enhance long-distance mobility. The railway transport industry is an important service sector that supports economic progress. In today's globalized world, the rapid movement of millions of people and huge freight is facilitated by railway transport. Rail transport in low-income countries (LICs) throughout Sub-Saharan Africa and South Asia are currently undergoing a renaissance as governments seek sustainable, cost-effective alternatives to road transport to meet the needs of growing populations. LICs have historically struggled to maintain these benefits due to dilapidated infrastructure, outdated manual signaling, and fragmented track gauges. The South Asian rail networks are passenger-dominated (80% of traffic) and achieve much higher traffic densities comparable to those in high-income European nations like Great Britain and Germany. However, they still face challenges with aged assets, single-track lines, and manual signaling (Blumenfeld et al., 2019). In contrast, Nepal's railway sector remains in its early stage of development, as the nation's transport system has historically been dominated by road-based mobility, limiting the growth and utilization of rail services. Nepal is still in the early stages compared to global rail systems. At present, only a small portion of railway operations is functional, and these services are still evolving in terms of reliability, frequency, and overall service quality.

The importance of quality in daily life has been increasing, and as a result, customers now expect a better service experience than before (Kumsa & Dilla, 2020). For measuring and assessing quality service for improvement, the only method is to know the extent of satisfaction deriving from service (Parasuraman, et al., 1985). There are some terms to measure Service quality such as customer perception, customer expectation, customer satisfaction, and customer attitude. Due to increased in access to information and tougher competition, the customer will expect a higher level of service. Quick and accurate comparisons are possible with new technology. Customer service should be a shared mindset of the whole organization, not just the job of one department (Sachdev & Verma, 2004). The escalating demand for efficient and reliable public transportation necessitates a thorough evaluation of railway services, particularly in developing regions where rail infrastructure plays a pivotal role in socio-economic development (Roy, et al., 2024).

Quality is an important indicator subject to performance measurement of the products or services and it is able to be considered as a primary indicator of performance. The analysis of passenger perceptions regarding rail services in Indian Railways has underscored the importance of factors such as availability of train, seating comfort, parking facilities, restroom facilities, and information offerings in shaping overall satisfaction (Huq & Muntaha, 2022) (Darling & R, 2023). Similarly, socio-economic factors, such as income, education, and occupation, significantly influence how passengers perceive railway infrastructure and service quality (Roy, et al., 2024). The experiences of India, Japan, and Southeast Asia show that, good intentions aside, rail system rewiring requires understanding travel behaviour and station-area conditions in highly dynamic societies far beyond the technical improvements offered by advanced signaling systems. Similar comparability of travelers is observed in Bangladesh, along with ongoing challenges in cleanliness of station, sanitation, punctuality, feeder-road access, waiting facilities, and inside comfort (Rahman et. al.).

Although the Jaynagar-Janakpur-Bijalpura corridor plays a significant role in regional mobility, passenger-centric studies remains scare, and a post-implementation service quality study has yet to be conducted. Originally constructed decades ago to serve industrial transport needs, the line gradually transitioned to passenger services, connecting local communities and supporting cross-border movement with India. It was shut down in 2014 for conversion to a broad-gauge railway line and reopened in 2022, funded by a grant from the Indian Government. Modern diesel-electric multiple units have also been introduced, significantly improving operational reliability and capacity. Given its unique status as Nepal’s only passenger rail service, assessing service quality on this route is essential, not only to improve travel experience but also to facilitate strategic planning for sustainable operations and regional development. Accordingly, this study intends to deliver a systematic evaluation of the service quality of the Jaynagar-Janakpur-Bijalpura passenger rail service, offering insights to guide improvements in operational performance and passenger satisfaction.

1.2 Problem Statement

Public transportation enhances mobility, improves access to employment and essential services. Quality of service and the satisfaction level of the passenger affect the success as well as the failure of the transportation industry. While these findings are well-documented for large urban systems globally, similar systematic assessments are often lacking in developing countries, where infrastructure constraints and limited-service options can significantly affect the passenger experience. In Nepal, several studies have focused on assessing service quality in road transportation. However, similar systematic evaluations for passenger rail services are largely absent, and the Jaynagar-Janakpur-Bijalpura railway, being the only operational passenger rail service, lacks a structured assessment of service quality. Passenger issues like overcrowding, delays, and low comfort remain understudied. To systematically analyze these issues, it employs structural equation modeling (SEM), a powerful tool that helps investigate the relation between variables that cannot be measured directly. Additionally, the study uses AHP to prioritize latent and observed variables/sub-criteria based on passenger response. This study fills this gap by assessing service quality from the user perspective, providing insights that can guide operational improvements and enhance overall passenger satisfaction.

1.3 Objectives

The primary objective of the study is to explore the underlying relationships between service quality and passenger satisfaction, and to develop an integrated framework for assessing and prioritizing the factors influencing passenger experience in the Jaynagar-Janakpur-Bijalpura rail service. The specific objectives are listed below:

1. To develop a service quality model using structural equation modelling and examine the influence of service quality dimensions on passenger satisfaction.
2. To establish a priority ranking of service quality attributes based on passenger preferences using Analytic Hierarchy Process(AHP).

1.4 Scope of Study

The models developed in this research can be utilized to appraise various aspects of the railway service performance. These models provide valuable support to operators, decision makers and transport planners, identifying areas requiring improvement. The exploration of the relationships between service quality dimensions and interactions influences overall user satisfaction, helping to understand key determinants of passenger perspectives. The prioritization of these factors can assist rail service providers in focusing their efforts on the most impactful aspects that significantly enhance user satisfaction. Based on findings, specific actionable strategies can be employed in each prioritized area. These strategies could confront tangible aspects like station maintenance, cleanliness, or intangible aspects like satisfaction and information service. The integrated application of Partial Least Squares Structural Equation Modeling (PLS-SEM), which explains relationships, and AHP, which prioritizes decision factors, strengthens the model's practical applicability. Furthermore, the model can be applied periodically as a monitoring tool, enabling continuous assessment and supports evidence based decision making by railway authorities and government agencies.

1.5 Limitations of the Study

The study report was prepared subject to the following limitations.

1. The study relies on present user perceptions and does not consider future potential changes in users' perceptions. The observed perceptions may not generalize to a wider population or the transportation passenger service industry as a whole.
2. The study is focused on passengers travelling only in the general coach of the rail service.

1.6 Organization of Report

This study is organized into the following chapters:

Chapter 1: Introduction

This section presents the background of the rail services and their global evolution including the South Asian region and Nepal. It provides insights into the problem statement, along with the objectives, scope, and limitations of the proposed study.

Chapter 2: Literature Review

This chapter reviews existing literature on service quality, customer satisfaction evaluation methods, Structural Equation Modeling(SEM), and the Analytic Hierarchy Process (AHP), focusing on rail transport and passenger services. It also includes the integrated SEM-AHP approach and the conceptual framework of the study.

Chapter 3: Methodology

This chapter outlines the research design, provides a brief description of the study area, and explains data collection methods. It also details the procedure of data validation and presents the data analysis using PLS-SEM and AHP.

Chapter 4: Results and Discussions

It deals with results obtained through the methodology outlined in Chapter 3. It discusses the findings derived from both PLS-SEM and AHP analysis.

Chapter 5: Conclusion and Recommendations

This section provides the conclusion of the study. It also provides a basis for future recommendations to improve the outcomes and better understanding of passenger satisfaction.

Reference

Appendix

CHAPTER 2: LITERATURE REVIEW

2.1 General

The assessment of service quality and passenger satisfaction holds paramount importance in rail transport, as it affects the efficiency of rail systems. Understanding the factors that influence passenger perceptions and satisfaction is critical for optimizing operations, improving service delivery, and encouraging sustainable use of rail transport. This literature review explores both theoretical frameworks and empirical studies that provide insights into service quality and passenger satisfaction in rail transport, highlighting their relevance for developing countries and for the context of Nepal.

2.2 Service Quality

A service is a deed provided by one party to another, involving an intangible act or performance that does not lead to ownership. In the context of this research, "service" specifically pertains to the functions, amenities, and operations offered by a railway system. Services are intangible products that encompass the entire passenger experience, including ticketing, boarding, travel comfort, safety, punctuality, communication, and passenger information. Scholars emphasize that services should be seen as processes and practices that are co-created by service providers and customers (De Ona, Eboli, & Mazzulla, 2014). Service quality can be explained as the extent of customer are satisfied or exceeded in the delivery of a service. It is a multidimensional construct that encompasses several key dimensions that play a vital role in passenger experiences within a public transit system. Many researchers have defined service quality from diverse perspectives. Several researchers have affirmed that the quality of service influences customer satisfaction. The characteristics of service are intangibility, heterogeneity, Perishability, inseparability, ownership, and Other people factor (Isibor & Agbadudu, 2020).

Service quality in transportation has been widely evaluated using various models. SERVQUAL is a widely recognized model for evaluating service quality, particularly in the context of public transportation (Parasuraman, Zeithaml, & Berr, 1988). It identifies five essential service quality dimension/criteria: Tangibility, Reliability, Responsiveness, Assurance, and Empathy. SERVQUAL focuses more on how passengers feel about a service, making it more people-centered. In contrast, many public transport systems tend to evaluate service quality using technical or measurable factors. To get a more complete picture, this study brings together attributes from SERVQUAL, public transport evaluations, and railway service studies to create a broader set of measurement items. The original SERVQUAL dimensions are adjusted, and three new aspects, convenience, comfort, and security, are added to develop the RAILQUAL model for assessing railway passenger services (Prasad & B, 2010). For instrument purification of RAILQUAL (Maruvada & Bellamkonda, 2017) an 18-item, six-dimensional RAILQUAL scale was formalized and tested, which includes Reservation and ticketing, platform facilities, services provided inside the train, punctuality, staff/employee behavior and support, and safety and security.

Beyond these other models, such as the SERVPERF model, focus only on performance-based evaluation, eliminating the need to measure expectations. Additionally, methods like Importance–Performance Analysis (IPA), the Kano model, have also been applied to assess service quality in various contexts.

2.3 Customer Satisfaction Evaluation Method

The concept of satisfaction has progressively evolved, resulting in the development of diverse measurement approaches. Researchers have proposed various evaluation methods based on their studies, including the analytical hierarchy process(AHP) and structural modeling techniques(SEM). This research employed both structural equation modeling and the analytical hierarchy process.

1. Analytic Hierarchy Process (AHP)

AHP divides the factors that influence research objectives into hierarchical levels and combines these influencing factors into a multi-indicator evaluation model for considering research objectives. The core of AHP is determining the weight of indicators. Determining weights must be based on personal experience and is too subjective (Vaidya & Kumar, 2006).

2. Structural Equation Method(SEM)

SEM is a statistical technique used to examine relationships between multiple factors, including those that cannot be directly measured (latent variables). It helps to show how these factors are connected by identifying both direct and indirect effects among them. SEM integrates principles of factor analysis and multiple regression, allowing for comprehensive model testing and validation. Due to its ability to handle measurement errors and assess causal relationships, SEM has been extensively applied in service quality and transportation research (Sarstedt, Ringle, & H, 2014).

2.4 Structure Equation Modelling (SEM)

The structural equation model consists of a measurement model and a structural model. The measurement model specifies the relation between latent constructs and their observed variables, while the model built between latent variables is a structural model (B & A, 2019) . The SEM method can be mostly used to analyze the relationships among variables and to quantitatively analyze the correlation coefficients between each variable. (De Ona, Eboli, & Mazzulla, 2014) applied structural modeling method to evaluate the service offered by Northern Italy, and found that the overall service characteristics of railway transportation directly affect service quality. SEM serves as a crucial tool for analyzing customer perceptions by developing models that capture complex relationships between variables.

2.4.1 Partial Least Squares Structural Equation Modeling (PLS-SEM) Theory

(PLS-SEM) Modeling plays a crucial role in estimating the parameters (Aparicio, 2011). The methodology known as (PLS-SEM) has obtained prominence in the area of study and analysis. This approach is widely utilized for constructing path models that involve latent variables and their interconnections. The primary objective of conducting PLS-SEM investigations is to unveil critical determinants of success and uncover the underlying sources of competitive edge in relation to pivotal constructs like passenger satisfaction or user behavior (Hair et. al., 2019). It is an outsmart tool for analyzing complex relationships among variables and is often used in studies that involve latent variables. It is also useful for researchers who are working with limited data or data that does not meet the assumptions of traditional statistical methods. Unlike covariance-based SEM (CB-SEM), which focuses on model fit and requires large samples and normally distributed data, PLS-SEM is distribution-free and performs well with small samples, non-normal data, and formative or reflective constructs (Sarstedt, Ringle, & H, 2014).

2.4.2 Measurement Theory

When assessing the effectiveness of the measurement, researchers frequently rely on various metrics like factor loadings, composite reliability, and average variance extracted. Factor loadings serve as a gauge for interaction among latent and observed variables, with stronger loadings indicating a more dependable measurement. Composite reliability, on the other hand, evaluates the internal coherence of the indicators associated with a latent variable, whereas average variance extracted quantifies the variance described by the latent variable relative to measurement inaccuracies. Researchers have also evaluated measurement model validity by examining the relationship between latent variables, making sure that they do not exhibit excessive levels of association. Excessive correlations between latent variables might suggest that they are capturing the identical hidden construct, potentially resulting in problems related to multicollinearity and exaggerated estimations of relationships within the structural model. Researchers have the option of either reflective or formative measurement models (Sarstedt et. al., 2021). Equation 2.1 below represents the formal relationship between a latent variable and its observed indicators.

$$\boldsymbol{X}=(\boldsymbol{lY}+\boldsymbol{e})$$

Where X denotes an observed variable, Y represents a latent construct, l is a coefficient that measures the strength of an interaction between variable X and Y, and e denotes error. In the realm of formative measurement models, it is imperative for researchers to differentiate between two distinct categories, namely causal and composite indicators. Constructs that are gauged using causal indicators exhibit an error term, indicating that these constructs have not been meticulously assessed by their corresponding indicators (Bollen & Bauldry, 2011). The measurement model involving causal indicators can be formally represented as Equation 2.2 given below.

$$\boldsymbol{Y}= \sum_{k=1}^{k} W_{\mathrm{k}} \mathrm{X}_{\mathrm{k}} +\boldsymbol{z}$$

In the equation, W_k denotes the contribution of X_k (K= 1, . . ., K), while z represents the error term associated with Y. A measurement model with composite indicators can be expressed in the form of Equation 2.3 given below.

$$\boldsymbol{Y}=\sum_{k=1}^{k} W_k X_k$$

Where Y is a linearly related variable X_k (k = 1,..., K), W_k is an indicator weight.

2.4.3 Model Estimation with PLS-SEM

The process of PLS-SEM involves the explicit calculation of case values, also known as construct scores, for estimating latent variables (Fornell & Bookstein, 1982). When using PLS-SEM, researchers typically follow a series of steps to test their hypotheses and analyze their data. These steps include model specification, assessment of the measurement model, evaluation of the structural model, and evaluation of the overall model fit.

2.5 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a well-known multi-criteria decision-making technique introduced by Thomas L. Saaty for solving complex decision problems involving several evaluation factors. The method assists decision-makers in breaking down a complicated problem into smaller and more manageable levels, such as objectives, criteria, sub-criteria, and alternatives. By conducting pairwise comparisons among the criteria, AHP helps determine their relative priorities and overall importance. Due to its logical structure and ease of application, the method has been widely accepted in both academic research and practical decision-making processes (Vaidya & Kumar, 2006). Over the years, researchers have applied AHP in different fields, including transportation engineering, construction management, environmental studies, healthcare systems, logistics, and service quality analysis. Previous studies suggest that the method is particularly effective when decisions involve several conflicting criteria and require expert judgment. Since AHP can combine both numerical data and human perception within a single framework, it has become a useful tool for evaluating real-world problems where decision factors are interrelated and difficult to measure directly (Subramanian & Ramanathan, 2012).

Although AHP offers several advantages, researchers have also discussed certain limitations associated with the method. One of the major concerns is the possibility of inconsistency during pairwise comparisons because the results depend largely on human judgment and expert opinion. In some cases, subjective bias may influence the ranking process and affect the reliability of the outcomes. To minimize such issues, many studies recommend checking the consistency ratio carefully and integrating AHP with other methods capable of handling uncertainty and vagueness in decision-making (Zhou, Zhe-Hua, & Sun, 2020).

2.6 Integrated Structural Equation Modeling(SEM) and Analytic Hierarchy Process (AHP) approach

Recent literature also indicates an increasing trend toward combining AHP with other analytical methods. Several researchers have integrated AHP with fuzzy logic, TOPSIS, DEMATEL, and Structural Equation Modeling (SEM) to obtain more reliable and comprehensive results. These hybrid approaches are considered useful for reducing uncertainty in human judgments and improving the accuracy of decision-making outcomes, especially in complex transportation and service quality studies (Kriswardhana et. al., 2025). The integration of Structural Equation Modeling (SEM) and the Analytic Hierarchy Process (AHP) is used to analyze relationships between variables and prioritize their importance. SEM focuses on testing statistical relationships within a model, while AHP helps rank factors based on their relative importance using structured comparisons (Xhafaj et. al., 2022). In this approach, SEM is typically used first to identify and confirm which factors significantly influence an outcome. After that, AHP is applied to prioritize these significant factors based on expert or user judgment. This helps bridge the gap between statistical significance and practical importance. In some studies, AHP is used initially to reduce or refine variables before SEM analysis, while in others, SEM results such as path coefficients are used as inputs for AHP ranking. Variations like fuzzy AHP are also used to handle uncertainty in human judgments. Overall, combining SEM and AHP provides a more complete analysis by linking statistical relationships with decision-making priorities, making it useful for transportation and service quality studies (Ghafourian et. al., 2021).

2.7 Research Gap

Many international studies on railway service quality have examined variables such as service reliability, punctuality, comfort, safety, and staff behaviour, but this remains largely unexplored in the context of Nepal. No existing study has applied an integrated PLS-SEM and AHP framework for assessing the service quality of only passenger rail service, leaving a clear gap in rail service research.

2.8 Hypothesis Development

The formulation of hypotheses is a critical step in establishing a theoretical framework for the study. This study has formulated three hypotheses concerning the relationship between service quality measured by latent constructs and overall satisfaction of users in the Jaynagar-Janakpur-Bijalpura rail service.

(1) H1: Operational Quality has a positive influence on passenger satisfaction in rail service.

(2) H2: Physical Quality has a positive influence on passenger satisfaction in rail service.

(3) H3: Travel Convenience has a positive influence on passenger satisfaction in rail service.

2.9 Conceptual Framework

The conceptual framework visualizes interrelationships among key indicators in the study. This framework shows that latent dimensions directly influence passenger satisfaction.

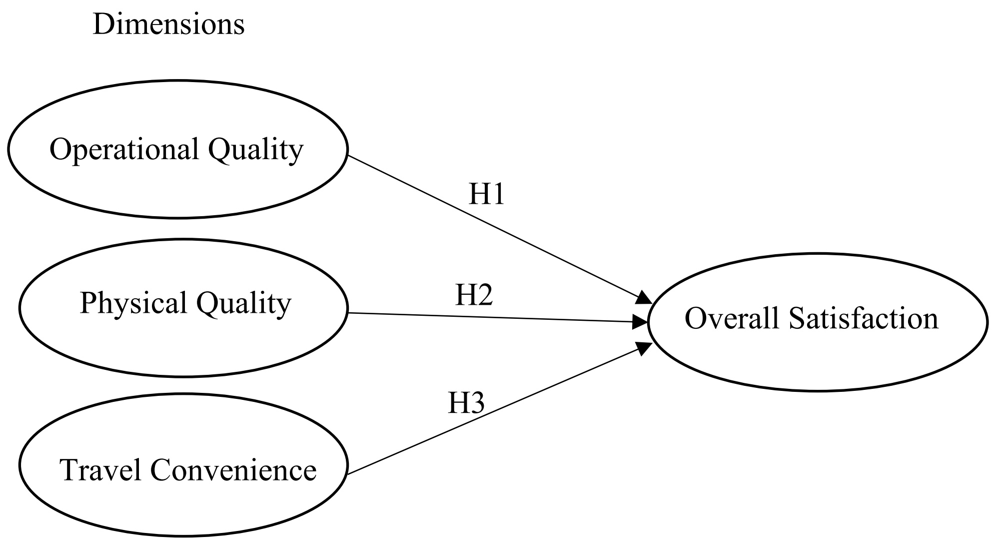

Figure 2. 1 Conceptual Framework

CHAPTER 3: METHODOLOGY

3.1 Research Design

The method of this research is focused on assessing the service quality of Jaynagar-Janakpur-Bijalpura rail service. Figure 3.1 below illustrates the proposed research design framework for this study.

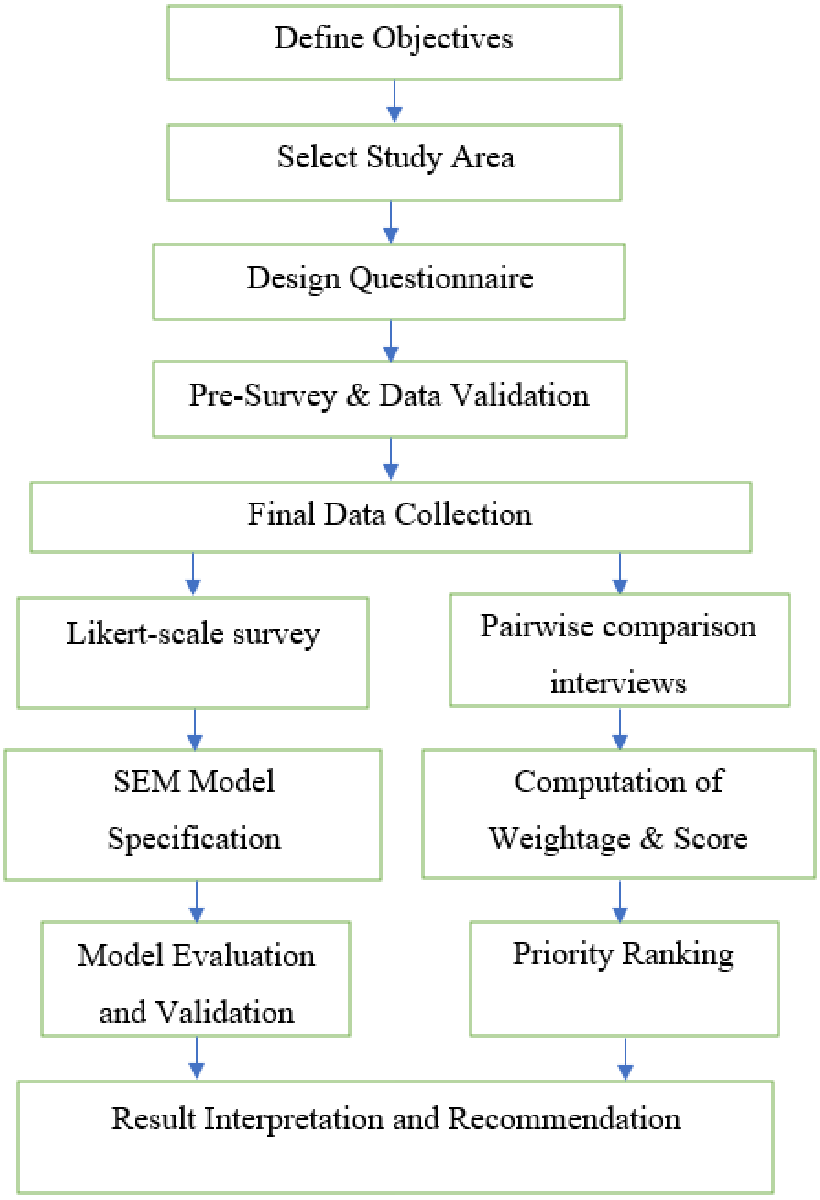

Figure 3. 1 Research Methodology

The proposed research is quantitative. It collects measurable data that can be analyzed and statistically tested. Figure 3.1 illustrates the systematic research methodology adopted for this study. A hybrid approach was employed, beginning with a comprehensive literature review to identify service indicators. Data was then collected from passengers for PLS-SEM analysis to test the structural relationships, and also from users for AHP analysis to establish priority weights. Finally, the results were synthesized to provide evidence-based recommendations for the Janakpur-Jaynagar railway service.

3.2 Study Area

The study focuses on the Jaynagar-Janakpur-Kurtha-Bijalpura railway line, an approximately 52 km long route, that is part of the cross-border railway line between India and Nepal. The railway starts from Jaynagar Railway Station in the Madhubani district of Bihar, India, and extends up to Bijalpura in the Mahottari District, Nepal. It crosses the India–Nepal border near Inarwa. Although customs checkpoints exist at both terminal stations, the border remains open for the movement of people, allowing relatively free cross-border travel. The Railway map is shown in Figure 3.2 below.

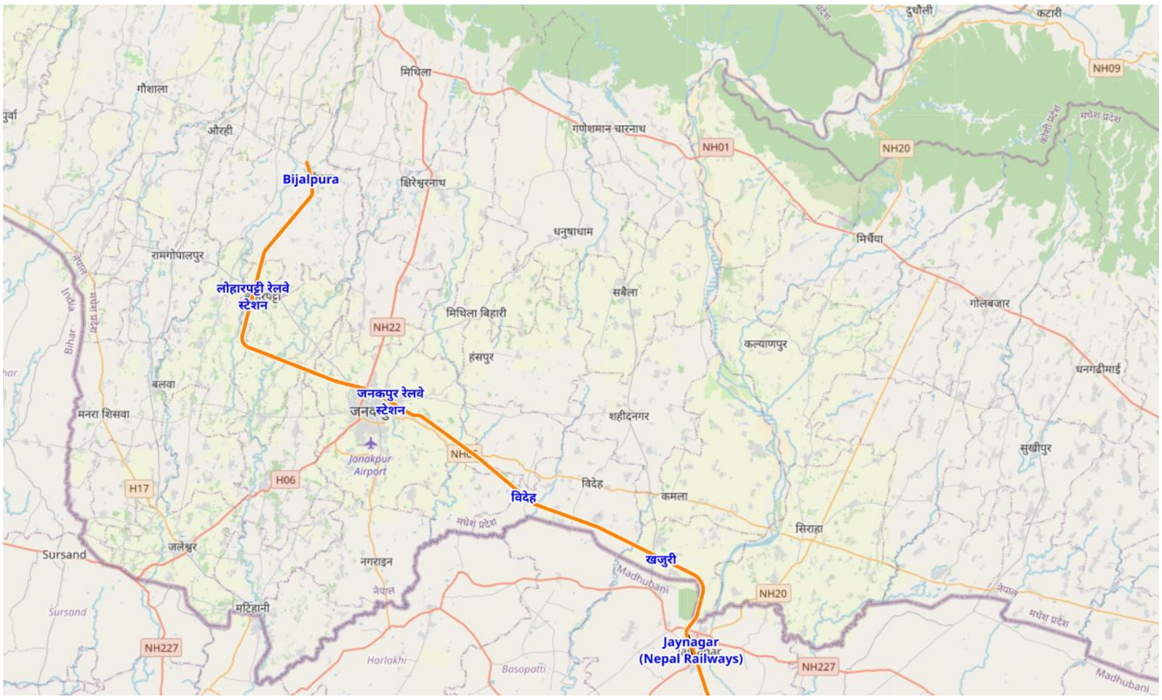

Figure 3. 2 Study Area: Jaynagar–Janakpur–Bijalpura Railway Line

(Source : OpenRailwayMap)

3.3 Sample Size

The number of samples for this study was calculated using the formula given by Cochran (1977) shown in Equation 3.1 for determining the sample size under simple random sampling.

$$n = \frac{z^2 pq}{e^2}$$

where n = Sample size for an infinite population

Z = Statistical parameter corresponding to confidence level (Z is 1.96 for 95% confidence interval)

e = Desired margin of error (adopted as 5%)

p = Hypothesized true proportion for population (adopted as 0.5 to account for the worst case) and q=1-p

Inserting these values in equation 3.1, $\frac{1.96^2 * 0.5 * 0.5}{0.05^2} = 384.16$

Therefore, the required sample size for estimating the proportion of rail passengers who are satisfied with the service within 5% of the true value at a 95% confidence level is 384. For the study, we have collected 400 data for the accuracy of our model.

3.4 Methodological Framework

Passenger satisfaction research typically adopts different methodological frameworks to identify and prioritize service quality dimensions. In several studies, importance is derived through statistical procedures such as SEM-based modeling or mean score analysis, where respondents' evaluations form the basis for estimating relative influence. Alternatively, the Analytic Hierarchy Process (AHP) applies a structured decision-making framework in which criteria are compared in pairs to generate priority weights (Saaty & katz, 1980). While SEM is primarily concerned with estimating relationships among latent constructs using observed data, AHP focuses on deriving ordinal priorities from comparative judgments.

From a methodological perspective, SEM relies on multivariate statistical estimation to explain causal relationships within a hypothesized model, whereas AHP transforms subjective judgments into quantitative weights through consistency-validated comparisons. In the present study, both approaches are employed in a complementary manner. AHP is used to establish the relative importance of service quality dimensions based on passenger preferences, while SEM evaluates their explanatory effect on overall satisfaction.

The combined interpretation of results allows a distinction between perceived importance and empirically estimated influence. This dual perspective provides a more nuanced understanding of railway service quality in the Jaynagar–Janakpur–Bijalpura passenger railway system, revealing that factors considered most important by passengers do not always correspond directly with those exerting the strongest statistical impact on satisfaction.

The data for the study were gathered manually using a structured paper-based questionnaire, which was prepared based on the research objectives.

3.4.1 Selection of Variables

The selection of variables presented in Table 3.1 and Table 3.2 was primarily based on a literature review of existing studies on railway service quality. Studies conducted in South Asian countries such as Bangladesh have considered variables including On-time performance of the trains, on-counter ticket purchase, ease of getting in and out of the train, waiting place condition, train schedule, ticket price, overall service quality, etc. (Huq & Muntaha, 2022) (Islam et. al., 2022). Research on Pakistan Railway has included variables such as over crowdness while purchasing ticket, satisfy with fare, availability of grab handles (Amin et. al., 2023). In the context of Indian railways, commonly used variables include punctuality of train services, safety during travel, information regarding train updates, comfortable seats, frequency of trains, ease of buying tickets, etc (Darling & R, 2023), (Maruvada & Bellamkonda, 2017), (Prasad & B, 2010). Studies from other South Asian contexts show that passengers are often dissatisfied due to issues including poor access roads, congestion at platforms, lack of proper sanitation, insufficient seating, and average-quality coaches (Rahman et. al.).

On the other hand, the Nepalese railway context is significantly different, as it is characterized by a single operational passenger railway system with limited service features and developing infrastructure. Therefore, instead of directly adopting all variables from previous studies, this study carefully selected only those variables that are relevant to the existing service conditions in Nepal. Core variables such as punctuality, safety, ticketing convenience, seating comfort, and accessibility were included in this study as they represent fundamental service quality dimensions applicable even in basic railway systems.. However, certain variables used in other studies, such as concession for disabled and elderly people, availability of carriers (Coolie and trolley), entertainment/newspaper option, ticket reservation system, etc., were excluded, as these services are either not available or not well developed in the Nepal railway context.

Table 3. 1 Classification and Description of Socio-Demographic and Travel Behavior Variables

S. N	Variables		Symbol	Description
1	Gender	Socio-Demographic Variables	GEN	Identity as male or female
2	Age		AGE	Length of time an individual has lived since birth
3	Qualification		QUA	Education Level of the passenger
4	Journey Purpose	Travel Behavior Variables	JOUR	Why the person is traveling
5	Waiting Time		WT	Time a passenger spends at the station before the train arrives
6	Usage Frequency		UF	How Often the person uses the train

Table 3. 2 Classification of Service Quality Variables

Latent Variables	Service Features	Symbol	References
Operational Quality	Provision of on-time train service	OP1	(Darling & R, 2023); (Hundal & Kumar, 2015); (Prasad & B, 2010); (Huq & Muntaha, 2022)
	Information on train schedule	OP2	(Darling & R, 2023); (Obsie et. al., 2020)
	Ticket Price	OP3	(Huq & Muntaha, 2022); (Obsie et. al., 2020); (Islam et. al., 2022)
	Frequency of train departure	OP4	(Darling & R, 2023); (Prasad & B, 2010)
	Ease to get ticket	OP5	(Darling & R, 2023); (Obsie et. al., 2020); (Kumsa & Dilla, 2020)
Physical Quality	Sense of Safety at Station	PH1	(Prasad & B, 2010); (De Ona, Eboli, & Mazzulla, 2014); (Kumsa & Dilla, 2020)
	Sense of Safety in the train	PH2	(Darling & R, 2023); (Kumsa & Dilla, 2020); (De Ona, Eboli, & Mazzulla, 2014)
	Seat comfort inside train	PH3	(Darling & R, 2023); (Kumsa & Dilla, 2020);
	Cleanliness of train coaches	PH4	(Darling & R, 2023); (Prasad & B, 2010); (Hundal & Kumar, 2015)
	Station seat and shelter	PH5	(Obsie et. al., 2020); (Kumsa & Dilla, 2020)
Travel Convenience	Crowdedness in station (during peak arrival time)	TC1	(Obsie et. al., 2020)
	Crowdedness in train	TC2	(Obsie et. al., 2020)
	Space for standing	TC3	(Kumsa & Dilla, 2020)
	Ease in Boarding & Alighting	TC4	(De Ona, Eboli, & Mazzulla, 2014); (Obsie et. al., 2020); (Huq & Muntaha, 2022)
Overall Satisfaction	Satisfied with the service	OVR1	(De Ona, Eboli, & Mazzulla, 2014)
	Recommend the service to others	OVR2	(Zeithaml, A., Berry, & Parasuraman, 1996)
	Reuse the service	OVR3	(Zeithaml, A., Berry, & Parasuraman, 1996)

3.4.2 SEM Questionnaire Design and Pilot Survey

In order to ensure clarity and validity of the questionnaire, a pilot study was conducted prior to the main survey with 30 passengers to identify any potential issues, such as unclear or confusing questions. Based on the feedback, the unclear, study area irrelevant questions were removed, and the final set of questions was selected. The questionnaire items for SEM are included in APPENDIX A. The questionnaire was divided into two sections.

1. The first section focused on collecting socio-demographic details and travel behavior variables of rail users.
2. The second section collected passenger opinions on various service quality variables, along with overall satisfaction variables, based on a 5-point Likert scale, with values ranging from 1 to 5.

3.5 SEM Data Analysis

3.5.1 Reliability

Reliability tests are conducted to ensure that research data and measuring instruments are accurate, consistent, and error-free. It measures the extent to which a set of items are interrelated, indicating whether they collectively represent the same underlying construct. In this study, Cronbach's alpha was applied to assess the internal consistency of the measurement items. A value of Cronbach's alpha exceeding 0.70 is regarded as an acceptable threshold for reliability in social science research.

3.5.2 Validity

In the context of the provided sources, validity was typically assessed through several rigorous statistical and qualitative frameworks. Researchers proceed through various stages to confirm the validity. These steps will include: Collecting data from reliable sources, specifically targeting respondents, which was our source of reliable data in this case study. In addition, the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity were performed to examine data adequacy and confirm the validity of the survey questions.

3.5.3 SEM Model Development

The model was developed in Smart-PLS. There are two types of models in SEM (Hair et. al., 2019).

- Measurement Model: It determines how the latent variables are represented by their observed indicators and is evaluated based on composite reliability as well as convergent and discriminant validity.
- Structural Equation Model: It determines the relationships between independent and dependent variables in the model and checks the multicollinearity issue.

3.6 Model Fitting

Model fit in SEM refers to the extent to which a specified PLS-SEM model adequately represents the observed data. In this study, approximate model fit was evaluated using SRMR, d_ULS, and d_G (geodesic and squared Euclidean discrepancy), along with the Normed Fit Index (NFI), to examine how well the proposed model corresponds with the collected data. An SRMR value less than 0.08 is good (Hu & Bentler, 1999). Furthermore, the structural model was assessed through path coefficients to test relationships among variables, R^2 to measure explanatory power, and f^2 to determine effect sizes.

3.7 Model Validation

Model validation is an important step to verify the proposed model correctly reflects the relationships among variables in the dataset. It helps establish the credibility and reliability of the model results. In this study, validation was carried out by examining convergent and discriminant validity. According to Hair et al. (2006), the average variance extracted (AVE) should be at least 0.5, while Byrne (2006) suggests that reliability values of 0.6 or higher are acceptable. The measurement model was further evaluated using composite reliability along with assessments of convergent and discriminant validity.

The composite validity, also known as convergent validity, evaluates how strongly different indicators (observed variables) of the same latent construct(unobserved variable) are related to one another. It ensures that the observed variables intended to measure a particular construct are actually capturing the same underlying concept. This is usually assessed by examining the factor loadings of the indicators on their respective latent variables through confirmatory factor analysis. High and statistically significant factor loadings indicate good composite reliability. When composite reliability is established, it means that the observed variables are effectively measuring the same underlying construct, providing evidence for the reliability and consistency of the measurement. Discriminant validity evaluates the extent to which different latent constructs in the model are distinct from each other. Low correlation indicates good discriminant validity. SMARTPLS 4 was used for the validation of the model.

3.8 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured decision-making method used to analyze complex problems by breaking them into a hierarchy and evaluating them systematically using mathematical principles and human judgment, widely applied in various fields, including transportation planning, infrastructure projects, and Multi-Criteria Decision Analysis (MCDA) (Saaty & katz, 1980). In this study, AHP was applied to prioritize latent and observed variables. The AHP model adopted for this study is shown in the figure below

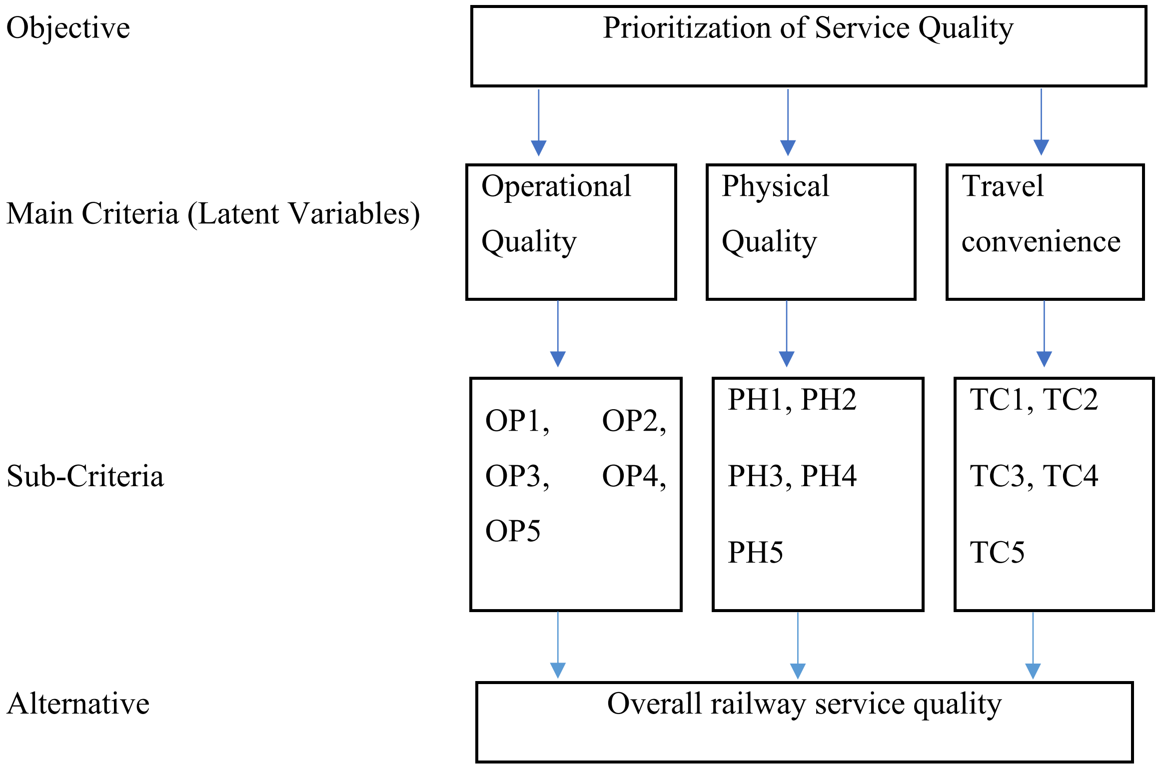

Figure 3. 3 AHP Model for the Study

3.8.1 Prioritization of Service Quality

The primary goal of AHP analysis is to prioritize service quality variables of railway transportation. This step focuses on identifying the relative importance of different criteria and sub-criteria that influence passenger perception of service quality. The prioritization is carried out to determine which factors contribute most significantly to overall service quality, forming the basis for further pairwise comparison and weight estimation.

3.8.2 Main Criteria (Latent Variables)

The main criteria of this study were same as of PLS-SEM analysis including operational quality, physical quality and travel convenience. The global weight of the main criteria are determined and based on these weights, the criteria are ranked according to their relative importance in influencing overall railway service quality.

3.8.3 Sub-Criteria (Observation Variables)

The sub-criteria of this study represent the observed variables used to used to evaluate the main service quality criteria. The operational quality criteria were provision of on-time train service, information on train schedule, ticket Price, frequency of train departure, ease to get ticket, physical quality included sense of safety at station, sense of safety in the train, seat comfort inside train, cleanliness of train coaches, station seat and shelter. Travel convenience included crowdedness in station (during peak arrival time), crowdedness in train, space for standing , ease in boarding & alighting.

3.8.4 Alternative

The alternative considered in this study represents the overall railway service quality of the Jaynagar–Janakpur–Bijalpura railway system, treated as a single evaluation unit rather than a set of competing alternatives.

3.8.5 Pairwise Comparison

For pairwise comparison, a pairwise comparison matrix was constructed. In this study, the matrix was developed for the main criteria: Operational Quality, Physical Quality, and

Travel Convenience. Similar matrices were then created for the sub-criteria within each main criterion. Saaty provides a standardized scale for pairwise comparisons, ranging from 1 to 9. As the values increase, the dominance of one criterion over another increases. This scale is shown in Table 3.3 below.

Table 3. 3 Satty's Scale

Score Value	Definition	Explanation
1	Equal Importance	Both criteria contribute equally
3	Moderate Importance	One criterion is moderately more important
5	Strong Importance	One criterion is strongly more important
7	Very Strong Importance	Dominance of one criterion proved in practice
9	Extreme Importance	The Highest order dominance of one element over another
2,4,6,8 can be used to express intermediate Values.		

3.8.6 Questionnaire Survey of Passengers

The pairwise comparison was conducted through a questionnaire survey with fifty passengers using the rail service. A sample of the questionnaire used for the survey is provided in APPENDIX B. The questionnaire includes questions designed to gather data for each cell value in the pairwise comparison matrix.

3.8.7 Analysis of Survey Data and Consistency Check

The responses collected from the various passengers need to be combined or normalized before performing the consistency check of the data. The normalized matrix values were obtained by calculating the mean of the corresponding cell values from all passengers. The mean can be either the geometric mean or the arithmetic mean. In this research, the geometric mean was used to compute the normalized matrix. After the normalized matrix was obtained, a consistency check was conducted using a statistical procedure to verify data reliability.

The statistical parameters for the consistency test can be used as given by Saaty. The Principal Eigenvalue (λ_{max}) refers to the highest eigenvalue derived from the pairwise comparison matrix. In an ideal situation, its value is equal to the number of criteria(n). The deviation from the ideal value makes the data more inconsistent.

The Consistency index (CI) is calculated as shown in Equation 3.2:

$$CI = (\lambda_{max} - n) / (n-1)$$

The Random Index (RI) refers to the average consistency index obtained from randomly generated matrices, and its value depends on the number of criteria. For different values of n, the RI is given in Table 3.4.

Table 3.4 Random Consistency Index

No of criteria	1	2	3	4	5	6	7	8	9	10
Random Index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The level of consistency is evaluated using the Consistency Ratio (CR), which is calculated by dividing the Consistency Index (CI) by the Random Index (RI), as shown in Equation 3.3 below. A CR value below 0.1 is generally considered acceptable, indicating that the judgments are consistent. If the CR exceeds 0.1, it suggests inconsistencies in the responses, and the comparisons may need to be reviewed or revised.

$$CR = CI/RI$$

The consistency check must be performed for each pairwise comparison matrix, including the main criteria and each sub-criterion. In this study, the consistency test was conducted for each individual's responses before the normalized matrix calculation. Out of the total 50 responses collected, 7 responses were considered to be inconsistent and removed from the analysis. In Multi-Criteria Decision Making (MCDM) approaches such as AHP, the statistical representation of participants is not a primary requirement, as the method generates deeper insights through structured pairwise comparisons rather than relying on conventional survey-based statistical inference (Saaty & katz, 1980). The focus is on consistency of judgments and logical synthesis rather than increasing sample size. The consistency test of some individual responses is provided in APPENDIX C.

3.8.8 Weights Calculation

After verifying the consistency of the data, the weights obtained from pairwise comparison matrices were considered final, provided that all matrices met the tabular data consistency requirements. The weights were calculated for the latent variable/main criteria, which are global variables, and for each observation variable/sub-criterion, which are local variables. The weights for the main criteria represent global weights, while the weights in the sub-criteria tables represent local weights. To compute the global weights for each variable/sub-criterion, the local weight is multiplied by the global weight of the corresponding criterion to which it belongs. The weight calculation and consistency check process are detailed in APPENDIX-C.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Measurement Model

The data was collected through a questionnaire survey. A total of 400 responses were collected, of which 8 were invalid due to incomplete information. After discarding the responses with incomplete information, 392 responses were taken for analysis purposes.

4.1.1 Sample Characteristics

The data shows the male passenger concentration of more than female. About 63.5% of users were male, and the rest were female. The majority of participants were between 36-50 years age group. A small percentage of passengers (6.40%) fell into more than 65 years age group. The educational background of the passengers is quite diverse. The highest group consists of those with elementary education (30.90%), followed by high school (27.30%), which is around the same. The percentage of illiterate people is 24.7%, whereas the percentage of undergraduates represents a small segment at 5.10%.
Understanding why people travel reveals the primary function of rail service. The majority of the passenger travels for family meetings and gatherings (38%), whereas business (29.3%) is also a major reason for travel. Shopping and other reasons for travel are much lower than these two. The waiting time reflects the efficiency of the service. The majority of people (43.10%) wait between 15 and 30 minutes. Very few passengers (8.70%) face wait times exceeding 45 minutes.

The usage frequency represents the loyalty of passengers. The most common frequency is once a month (43.40%), indicating many passengers travel for specific, non-daily purposes like family gatherings. A smaller but significant number of passengers (18.10%) use the service every day. Gender, Age group, Qualification, Journey purpose, Waiting time, and Usage frequency of rail service are given below in Figure 4.1.

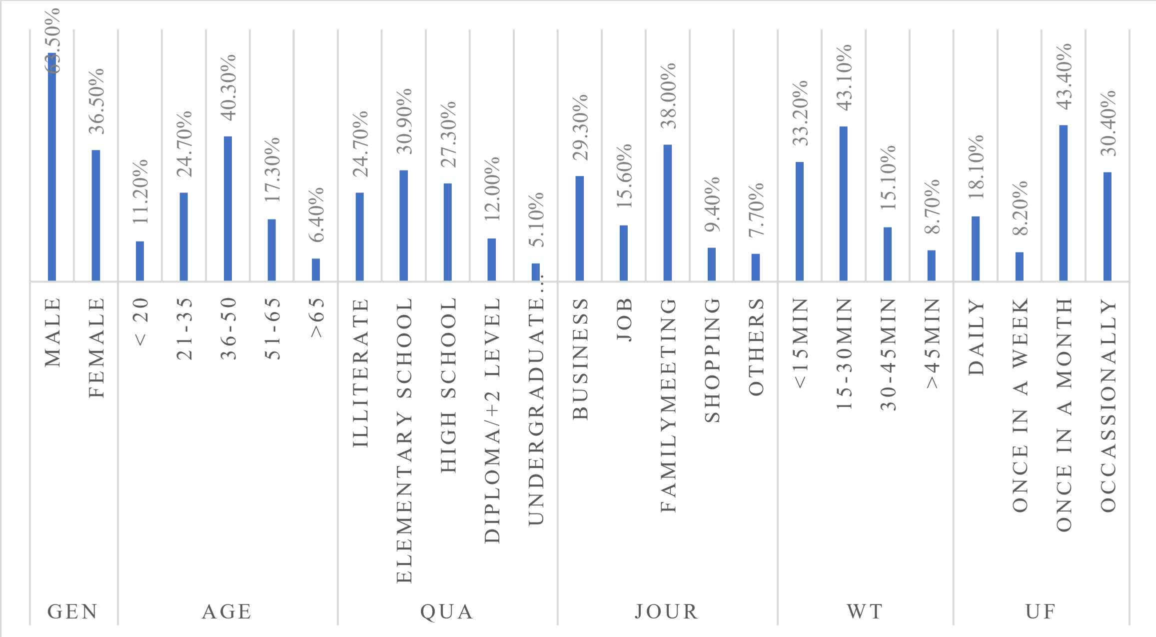

Figure 4. 1 Descriptive characteristics of the sample

4.1.2 Reliability test

For the SEM model, Cronbach's alpha test was done to verify the consistency of the data. The result is shown in Table 4.1 below.

Table 4. 1 Reliability test

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.897	0.918	17

The Cronbach's alpha value was 0.897, which revealed a high level of internal consistency among the items in the questionnaire. This suggests that the scale reliably measures the same underlying construct and demonstrates very good reliability. (Hair et. al., 2019).

The valid sample data collected from the survey questionnaire were integrated into SMART-PLS 4 to check the coefficients of the questionnaire.

According to the test results in Table 4.2, the reliability coefficient of Cronbach's alpha values is above 0.7, and the Average variance extracted (AVE) values are above 0.5; therefore, all values indicate higher reliability of the total scale for internal consistency. In general, this test confirmed that the data of the total scale has passed the internal consistency reliability test. Next, reliability tests will be conducted on each sub-scale, as shown below, using the factor loading coefficients.

Table 4. 2 Construct Validity

Constructs	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Operational Quality	0.742	0.869	0.837	0.557
Overall Passenger Satisfaction	0.706	0.724	0.836	0.630
Physical Quality	0.736	0.867	0.832	0.548
Travel Convenience	0.854	0.878	0.901	0.696

4.1.3 Discriminant validity analysis

Discriminant validity is a part of structural validity, which refers to the ability to distinguish and judge the values of different dimensions obtained by using different methods to measure different dimensions. When the square root of the AVE is higher than the absolute value of the correlation between factors, it can be considered to have differential validity. The results of differential validity analysis are shown in Table 4.3 below.

Table 4. 3 Fornell-Larcker Criterion

Criteria	Operational Quality	Overall Passenger Satisfaction	Physical Quality	Travel Convenience
Operational Quality	0.835			
Overall Passenger Satisfaction	0.699	0.794		
Physical Quality	0.805	0.713	0.827	
Travel Convenience	0.804	0.683	0.747	0.834

From the above result, we can understand that the Fornell-Larcker criterion in the table, the square root of AVE is higher for the indicator to which the factor belongs, compared with other indicators, which points to the construct having discriminant validity.

4.1.4 Data Suitability for Factor Analysis

In PLS-SEM, factor analysis is reflected through the assessment of the measurement model rather than being treated as a separate procedure. In this study, it is used to verify whether the observed indicators adequately represent the intended latent constructs. KMO and Bartlett's tests were carried out to check whether the data were appropriate for factor analysis. The KMO measure identifies the adequacy of sampling by indicating whether the variables share enough common variance for factor analysis to be meaningful. Bartlett's test of sphericity examines whether the correlation matrix significantly differs from an identity matrix, where variables are assumed to be uncorrelated.

The results showed a KMO value of 0.895, which indicates that the data are highly suitable for factor analysis. In addition, Bartlett's test produced a chi-square value of 2790.035 with 136 degrees of freedom and a significance level of 0.001. Since the p-value was less than 0.05, it confirms that the correlations among variables are statistically significant, further supporting the suitability of the dataset for factor analysis or SEM.

Table 4. 4 KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.895
Bartlett's Test of Sphericity	Approx. Chi-Square	2790.035
	df	136
	Sig.	0.001

4.1.5 Model Fit Criteria

From Table 4.5 below, we can understand that the SRMR value is less than 0.08 and the chi-square value is high, which indicates the model meets the basic requirements set for model fit. The coefficient of determination (R^2) represents how well the independent variables explain the variation in the dependent variable. Its value ranges from 0 to 1, where a higher value indicates better predictive capability of the model. According to commonly accepted guidelines, R^2 values of 0.75, 0.50, and 0.25 are considered substantial, moderate, and weak, respectively (Sarstedt et. al., 2021). In this study, the R^2 value for Overall Passenger Satisfaction was found to be 0.572, indicating that the model has a moderate level of predictive accuracy, as the selected service quality dimensions explain a considerable proportion of passenger satisfaction. The effect size (f^2) was also evaluated to understand the contribution of each predictor to the endogenous construct. The f^2 statistic measures the change in the R^2 value when a particular exogenous variable is removed from the model, thereby indicating the relative influence of that variable. Based on the guideline proposed by Cohen (1988), f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively. The results show that Operational Quality has a small effect on Overall Passenger Satisfaction (f^2 = 0.028). Similarly, Travel Convenience also demonstrates a small effect (f^2 = 0.044). Among the predictors, Physical Quality has the highest contribution with an f^2 value of 0.097, indicating a small to moderate effect on passenger satisfaction (Sarstedt et. al., 2021). In addition, the predictive relevance of the structural model was assessed using the Q^2 value. A Q^2 value greater than zero confirms that the model has predictive relevance for the endogenous construct. Generally, Q^2 values of 0.02, 0.15, and 0.35 indicate small, medium, and large predictive relevance, respectively (Hair et. al., 2019). The obtained Q^2 value of 0.561 is considerably higher than the recommended threshold, demonstrating strong predictive relevance of the model for Overall Passenger Satisfaction. This indicates that the structural model is capable of effectively predicting passenger satisfaction based on the selected service quality dimensions. The table containing these values is provided in APPENDIX E.

Table 4. 5 Model fit index

Criteria	Saturated model	Estimated model
SRMR	0.069	0.069
d_ULS	0.567	0.567
d_G	0.264	0.264
Chi-square	565.792	565.792
NFI	0.845	0.845

4.2 Structural Equation Model (SEM)

The construction of the structural equation model (SEM) was done using the theoretical concepts about the model obtained in the previous section. SMART- PLS 4, a statistical tool, was used to analyze the structural equation model based on the relationships between various variables, as shown in the figure. The model included four latent variables, including three external and one internal main variable. The external latent variables were: Operational Quality, Physical Quality, and Travel Convenience. On the other hand, the endogenous/internal latent variable was Overall passenger satisfaction.

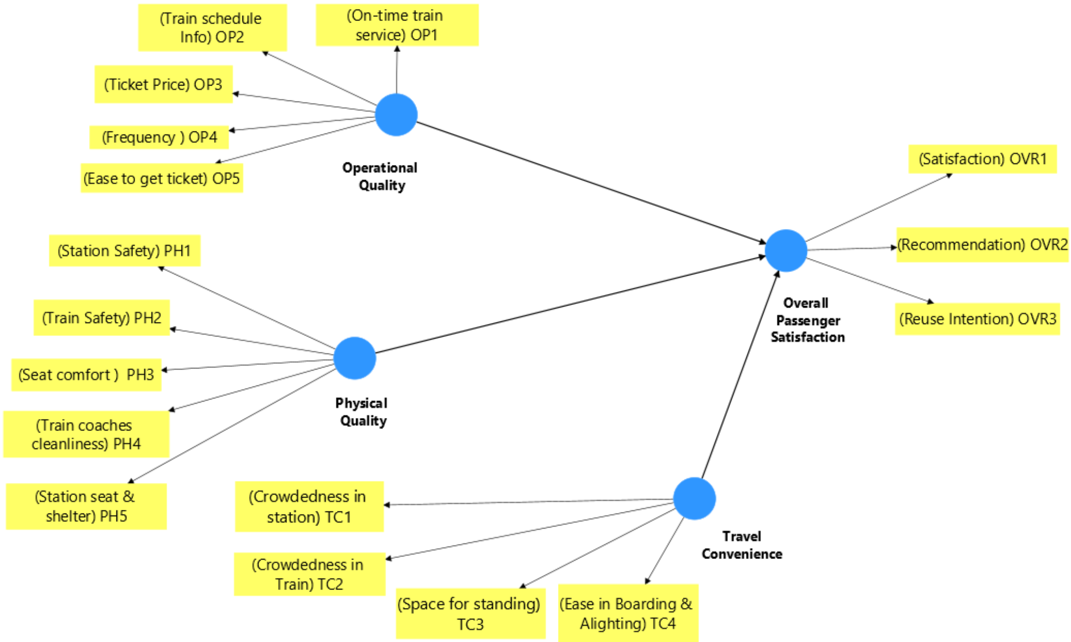

Figure 4. 2 Initial Model for Passenger Satisfaction

4.2.1 Model Preliminary Test

The path coefficients between each variable were analyzed using SMART- PLS software. The output of the analysis result with standardized path coefficients is analyzed, but in the case of observation variables, Ticket Price (OP3), and Station seat & Shelter(PH5) did not meet the minimum outer loading, so these two Items were deleted and evaluated for the second time. The low outer loadings of ticket price(0.043) and station seat & shelter(0.052) may be due to inconsistent or heterogeneous responses from participants, indicating that these indicators were not perceived uniformly in relation to their respective constructs.

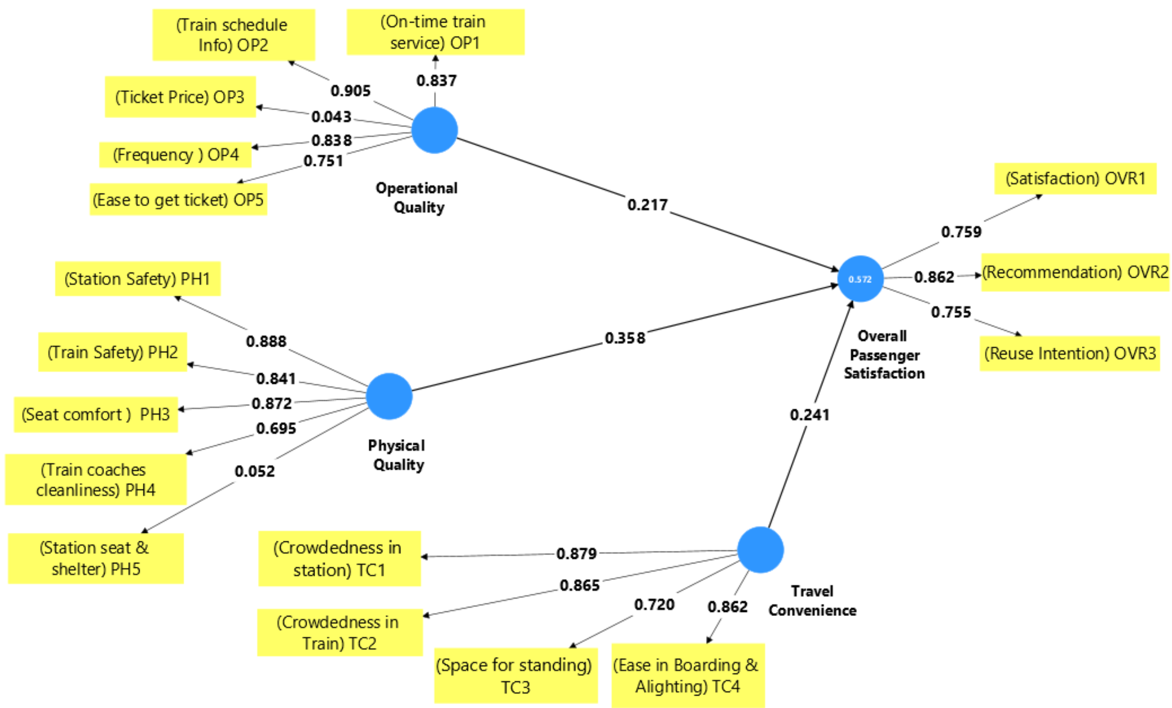

Figure 4. 3 Path Coefficient of Passenger Satisfaction Model

The path coefficients of main/latent indicators are presented in Table 4.6 below. The standardized coefficient values are between [-1, +1], which means it met the requirement. Therefore, further analysis of the path coefficients was performed to check whether the model met the significance requirements or not.

Table 4. 6 Path Relation

S.N	Path Relation	Path coefficients
1	Operational Quality -> Overall Passenger Satisfaction	0.217
2	Physical Quality -> Overall Passenger Satisfaction	0.358
3	Travel Convenience -> Overall Passenger Satisfaction	0.241

4.2.2 Model Correction and Retesting

Partial least squares (PLS) correlation analysis typically uses t-statistics and p-values to measure the significance level of correlation in a model. The T statistic indicates how strong the interplay among two variables is. A higher T value indicates a stronger relationship. The p-value denotes the probability of data is observed. A low p-value and high T-value ($P < 0.05$, and $T > 1.96$) indicate the relationship between the variables is statistically significant. Here, the significance between constructs in the model was evaluated through the corresponding value of T-statistics, and p-values are presented below in the table

Table 4. 7 Model Significance Level

S.N	Path Relation	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
1	OP1 <- Operational Quality	0.837	0.836	0.30	2.819	0.004
2	OP2 <- Operational Quality	0.905	0.905	0.15	6.0470	0.000
3	OP3 <- Operational Quality	0.043	0.047	0.075	0.574	0.566
4	OP4 <- Operational Quality	0.838	0.837	0.26	3.171	0.000
5	OP5 <- Operational Quality	0.751	0.750	0.35	2.138	0.032
6	OVR1 <- Overall Passenger Satisfaction	0.759	0.758	0.32	2.396	0.012
7	OVR2 <- Overall Passenger Satisfaction	0.862	0.862	0.13	6.811	0.000
8	OVR3 <- Overall Passenger Satisfaction	0.755	0.753	0.33	2.227	0.026
9	PH1 <- Physical Quality	0.888	0.887	0.12	7.459	0.000
10	PH2 <- Physical Quality	0.841	0.839	0.25	3.363	0.000
11	PH3 <- Physical Quality	0.872	0.871	0.19	4.536	0.000
12	PH4 <- Physical Quality	0.695	0.693	0.040	17.281	0.000
13	PH5 <- Physical Quality	0.052	0.055	0.074	0.696	0.486
14	TC1 <- Travel Convenience	0.879	0.879	0.13	6.636	0.000
15	TC2 <- Travel Convenience	0.865	0.864	0.19	4.631	0.000
16	TC3 <- Travel Convenience	0.720	0.718	0.036	19.817	0.000
17	TC4 <- Travel Convenience	0.862	0.861	0.20	4.204	0.000

A critical ratio T-Value with an absolute value less than 1.96 denotes that the P-value has not achieved a significance level of less than 0.05. According to the above table, the paths that had not achieved a significance level of 0.05 are (Ticket price) OP3 <- Operational Quality and (Station seat & shelter) PH5 <- Physical Quality. Therefore, according to the T-value, delete the insignificant paths in ascending order of the T absolute value, and recheck the model after each path deletion one by one until the path coefficient reaches the significance level, to refit the model. Finally, the model was rerun without these variables, and the final model is shown in Figure 4.4 below.

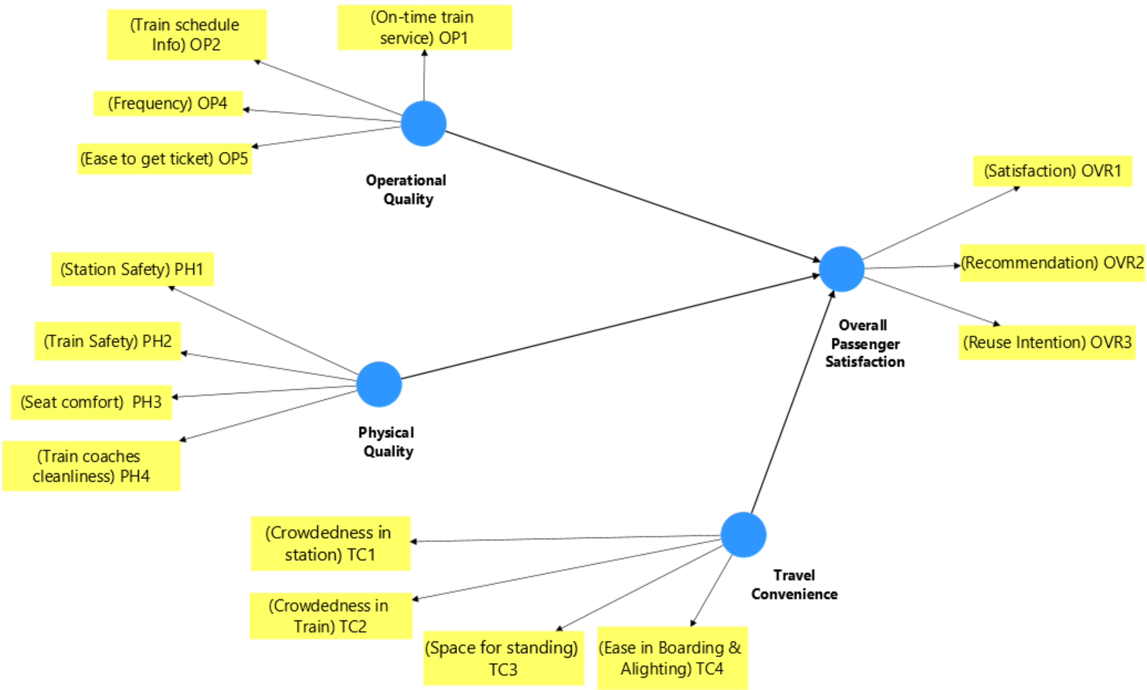

Figure 4. 4 Modified Final Model

Table 4.8 is the revised significance level for observation variables, which is within the required range. For latent/main variables, a critical ratio T-Value with an absolute value more than 1.96, and the P-value has reached the significance level of less than 0.05, as shown below.

Table 4. 8 Revised Model Significance Level

S.N	Path Relation	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
1	OP1 <- Operational Quality	0.837	0.836	0.30	2.819	0.004
2	OP2 <- Operational Quality	0.905	0.905	0.15	6.0470	0.000
4	OP4 <- Operational Quality	0.838	0.837	0.26	3.171	0.000
5	OP5 <- Operational Quality	0.751	0.750	0.35	2.138	0.032
6	OVR1 <- Overall Passenger Satisfaction	0.759	0.758	0.32	2.396	0.012
7	OVR2 <- Overall Passenger Satisfaction	0.862	0.862	0.13	6.811	0.000
8	OVR3 <- Overall Passenger Satisfaction	0.755	0.753	0.33	2.227	0.026
9	PH1 <- Physical Quality	0.888	0.887	0.12	7.459	0.000
10	PH2 <- Physical Quality	0.841	0.839	0.25	3.363	0.000
11	PH3 <- Physical Quality	0.872	0.871	0.19	4.536	0.000
12	PH4 <- Physical Quality	0.695	0.693	0.040	17.281	0.000
14	TC1 <- Travel Convenience	0.879	0.879	0.13	6.636	0.000
15	TC2 <- Travel Convenience	0.865	0.864	0.19	4.631	0.000
16	TC3 <- Travel Convenience	0.720	0.718	0.036	19.817	0.000
17	TC4 <- Travel Convenience	0.862	0.861	0.20	4.204	0.000

The structural model results indicate that Operational Quality, Physical Quality, and Travel Convenience have statistically significant positive relationships with passenger satisfaction in rail service. As presented in Figure 4.3 and Table 4.9, the standardized path coefficients and corresponding t-statistics confirm the significance of all hypothesized relationships.

Since all t-statistics exceed the recommended threshold ($t > 1.96$ at 5% significance level), hypothesis H1, H2, and H3 are supported. Overall, the findings suggest that improvements in these service quality dimensions are associated with increased passenger satisfaction.

Table 4. 9 Hypothesis Test

S.N	Path Relation	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Conclusion
1	Operational Quality -> Overall Passenger Satisfaction	0.215	0.218	0.066	3.284	0.001	Supported
2	Physical Quality -> Overall Passenger Satisfaction	0.353	0.352	0.065	5.419	0.000	Supported
3	Travel Convenience -> Overall Passenger Satisfaction	0.246	0.245	0.061	4.039	0.000	Supported

4.3 Analysis Results and Interpretation

As per research results, the model is an overall logical structure, composed of 4 latent variables and important interrelationships, of which 3 are external latent variables, which include Operational Quality, Physical Quality, and Travel Convenience. The internal latent variable is Overall Passenger Satisfaction. All three service quality dimensions positively influence passenger satisfaction, but their strengths differ. Physical Quality has the strongest impact (0.358), showing that safety, comfort, and cleanliness play the biggest role in shaping satisfaction. Travel Convenience (0.241) also contributes meaningfully, meaning ease of access, space for standing, and less crowdedness matter to passengers. Operational Quality has a positive but comparatively smaller effect (0.217), indicating that punctuality, staff service, and operational efficiency still matter, but less than physical and convenience aspects in this case.

4.3.1 Analysis Result

SEM examines how the dimensions statistically influence passenger satisfaction. As per the above PLS-SEM analysis, three paths directly affect passenger satisfaction, which are

1) Operational Quality → Overall Passenger Satisfaction
2) Physical Quality → Overall Passenger Satisfaction
3) Travel Convenience → Overall Passenger Satisfaction

These paths represent the structural relationships between the latent constructs and indicate that all three service quality dimensions are directly associated with passenger satisfaction.

4.4 Weight

The AHP method was used to identify the relative importance of service quality dimensions based on passenger preferences. The weights of service quality criteria/variables were determined using the Analytic Hierarchy Process (AHP), as described in Chapter 3. Before the computation of weights, a consistency check was essential for the global criteria and their corresponding sub-criteria. The pairwise comparison matrices of some respondents were obtained from a questionnaire survey of passengers and are provided in APPENDIX-C. The pairwise comparison matrix was normalized by taking the geometric mean of each cell value, as shown in Tables 4.10 to 4.13 below.

Table 4. 10 Pairwise Comparison for Global Criteria

Global Pairwise	Operational Quality	Physical Quality	Travel Convenience
Operational Quality	1	1.245	1.790
Physical Quality	0.803	1	0.589
Travel Convenience	0.559	1.696	1

Table 4. 11 Pairwise Comparison for Operational Quality

Operational Quality	Provision of on-time train service	Information on train schedule	Ticket Price	Frequency of train departure	Ease to get ticket
Provision of on-time train service	1.000	2.621	3.287	3.342	2.201
Information on train schedule	0.381	1.000	2.460	2.905	2.875
Ticket Price	0.304	0.407	1.000	1.664	1.317
Frequency of train departure	0.299	0.344	0.601	1.000	1.690
Ease to get ticket	0.454	0.348	0.759	0.592	1.000

Table 4. 12 Pairwise Comparison for Physical Quality

Physical Quality	Sense of Safety at Station	Sense of Safety in the train	Seat comfort inside train	Cleanliness of train coaches	Station seat and shelter
Sense of Safety at Station	1	1.813	2.727	2.544	4.375
Sense of Safety in the train	0.552	1.000	3.135	2.997	4.658
Seat comfort inside train	0.367	0.319	1.000	1.650	3.481
Cleanliness of train coaches	0.393	0.334	0.606	1.000	3.472
Station seat and shelter	0.229	0.215	0.287	0.288	1

Table 4. 13 Pairwise Comparison for Travel Convenience

Travel Convenience	No Crowdedness in station (during peak arrival time)	No Crowdedness in train	Space for standing	Ease in Boarding & Alighting
No Crowdedness in station (during peak arrival time)	1.000	0.958	0.592	0.557
No Crowdedness in train	1.043	1.000	1.666	0.851
Space for standing	1.689	0.600	1.000	0.350
Ease in Boarding & Alighting	1.796	1.176	2.857	1.000

The consistency check for each table is shown in APPENDIX C. It was observed that the tables for Global criteria, Operational Quality, Physical Quality, and Travel Convenience were consistent, as the Consistency Ratio (CR) is less than 0.1. Therefore, we proceed to determine the weights for the criteria and sub-criteria. Table 4.14 shows that the Physical Quality was the least preferred, whereas Operational Quality was highly preferred among the passengers.

Table 4. 14 Weights for Global Criteria

Criteria	Weight
Operational Quality	0.423
Physical Quality	0.256
Travel Convenience	0.321

The local weights in Table 4.15 were used to calculate the relative importance of each variable/criterion. Within the Operational Quality criterion, Provision of on-time train service was considered the most important, as it can directly influence reliability perception, reduce waiting time, and overall trust in rail service. Information on train schedule is also an important factor, while ease to get ticket is the least preferred. In the Physical Quality criterion, Sense of Safety in the train was the most preferred factor by the passengers. Sense of Safety at Station and Cleanliness of train coaches also play a major role, according to the passengers. In the Travel Convenience criterion, ease in boarding & alighting were the most preferred, followed by not preferring crowdedness in the train. Space for standing was preferred as it enhances passengers' comfort during peak hours, while no crowdedness in station (during peak arrival time) was least preferred by the passengers'.

Table 4. 15 Weights for Local Criteria

Latent Variables	Global Weight	Service Features	Local Weight	Global Weight
Operational Quality	0.423	Provision of on-time train service	0.368	0.156
		Information on train schedule	0.216	0.091
		Ticket Price	0.130	0.055
		Frequency of train departure	0.164	0.069
		Ease to get ticket	0.121	0.051
Physical Quality	0.256	Sense of Safety at Station	0.257	0.066
		Sense of Safety in the train	0.296	0.076
		Seat comfort inside train	0.161	0.041
		Cleanliness of train coaches	0.202	0.052
		Station seat and shelter	0.084	0.022
Travel Convenience	0.321	No Crowdedness in station (during peak arrival time)	0.189	0.061
		No Crowdedness in train	0.248	0.079
		Space for standing	0.201	0.065
		Ease in Boarding & Alighting	0.362	0.116

4.5 Discussion of AHP and PLS-SEM Outcomes

Operational Quality was ranked first in the AHP analysis with the highest weight of 0.423, indicating that passengers considered operational aspects such as on-time train service, train schedule, ease to get ticket, frequency to be the most important components of railway service quality. However, in the SEM analysis, Operational Quality ranked third with a path coefficient of 0.217, suggesting that although passengers highly value operational performance, its direct contribution toward improving satisfaction is comparatively lower.

Travel Convenience maintained the second position in both analyses, with an AHP weight of 0.321 and an SEM path coefficient of 0.241. The relatively similar ranking and moderate values indicate consistency between passenger perception and its actual influence on satisfaction. This suggests that travel convenience plays a stable and balanced role in shaping passenger satisfaction.

Physical Quality showed the most contrasting result between the two methods. In the AHP analysis, it ranked third with the lowest weight of 0.256, meaning passengers gave comparatively less priority to physical facilities and infrastructure. However, SEM analysis ranked it first with the highest path coefficient of 0.358, indicating that physical aspects such as cleanliness, seating comfort, station safety have the strongest positive effect on overall passenger satisfaction.

This finding suggests that passengers may not initially recognize the importance of physical quality, but improvements in these aspects significantly enhance their travel experience and satisfaction. Similar differences between what passengers consider important and what actually influences their satisfaction have also been reported in previous service quality studies using hybrid methods on various fields. The notable differences between the two methods indicate that each approach captures respondent opinions differently, with varying levels of accuracy and representation (Zhu et. al., 2011). Furthermore, structural equation modeling studies in transport contexts show that the strongest statistical drivers of satisfaction are sometimes different from what users initially perceive as most important, since SEM focuses on actual relationships between service factors and satisfaction outcomes (Hadiuzzaman et. al., 2022). Overall, these findings suggest that passenger perception of importance and statistical influence do not always align, which supports using combined approaches like AHP and SEM for a more complete understanding of service quality.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Passengers demand high-quality service that offers reliability, comfort, safety, and convenience, so it is essential to focus on enhancing passenger satisfaction within Jaynagar–Janakpur–Bijalpura Rail Service. This study evaluated passenger satisfaction of the Rail Service using a combination of PLS-SEM (Partial Least Squares Structural Equation Modelling) and AHP (Analytical Hierarchy Process). The PLS-SEM method was adopted to examine the causal relationships between latent variables. In parallel, AHP was used to identify the relative importance (weightage) of service attributes based on passenger judgments. While SEM captures the influence on satisfaction, AHP reflects the perceived importance of service attributes.

The main conclusions derived from the analysis are given below

- PLS-SEM was used to determine the overall present passenger satisfaction scores for latent variables. The result of PLS-SEM points out that among the three latent variables, Operational Quality, Physical Quality, and Travel Convenience positively influence the service quality of rail service. All these latent variables are important aspects of rail service. Twelve specific service aspects (observed variables) contribute to three broader categories (latent variables), thereby increasing passengers' overall satisfaction.
- The AHP analysis showed that passengers assigned the highest importance to Operational Quality (global criteria 0.423), followed by Travel Convenience (0.321) and Physical Quality (0.256). This indicates that passengers value the railway's reliability and efficiency.
- At the sub-criteria level, on-time train service, ease in boarding and alighting, and safety in trains were identified as the most important factors. These results suggest that passengers strongly prioritize time reliability, smooth access, and safety when evaluating railway services. Interestingly, factors such as seat comfort and station facilities received comparatively lower importance, indicating that passengers are more concerned with functional performance than physical comfort when explicitly asked to prioritize.

AHP results reflect what passengers think is important, while SEM results reflect what actually drives their satisfaction. The findings suggest that improving railway services requires a balanced approach. While operational efficiency, such as punctuality and scheduling, remains critical, equal attention should be given to physical conditions inside trains and stations. This finding provides empirical evidence for the railway sector to understand passenger needs, identify areas of improvement, increase passenger perceived value, narrowing the gap between passenger expectations and actual service, passenger satisfaction.

5.2 Recommendation

The findings of this study indicate that several practical and research-oriented recommendations can be suggested to improve railway service quality and passenger satisfaction. The present PLS-SEM and AHP analysis considered only three criteria/variables: Operational Quality, Physical Quality, and Travel Convenience. This is based on the current satisfaction level; similar methods can be used in the future with other dynamic factors, such as accessibility, customer service, and staff behaviour, which can be included for a better understanding of rail service quality. Longitudinal studies may also be useful to capture how passenger perceptions change over time with service improvements. Finally, future research may explore combining AHP and SEM with other methods, such as Fuzzy Analytic Hierarchy Process(FAHP), logit model could further enhance the results and provide a better understanding of passengers' satisfaction.

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APPENDIX A : SEM SURVEY FORM

A. General Information सामान्य जानकारी

1. Gender लिङ्ग

a) Male पुरुष ☐ b) Female महिला ☐

2. Age group(yrs) उमेर समुह(वर्ष)

a) < 20 २० वर्षभन्दा कम ☐
b) 21-35 २१–३५ ☐
c) 36-50 ३६-५० ☐
d) 51-65 ५१-६५ ☐
e) > 65 ६५ वर्षभन्दा माथि ☐

3. Qualification शैक्षिक योग्यता

a) Illiterate निरक्षर ☐
b) Elementary School प्राथमिक तह ☐
c) High School माध्यमिक तह ☐
d) Diploma/+2 Level डिप्लोमा / +२ तह ☐
e) Undergraduate Level and above स्नातक तह वा सोभन्दा माथि ☐

4. What is the main purpose of your journey today? तपाईंको आजको यात्रा गर्न मुख्य उद्देश्य के हो?

a. Business व्यापार ☐
b. Job जागिर ☐
c. Family Meeting पारिवारिक भेटघाट ☐
d. Shopping किनमेल ☐
e. Other अन्य ☐

5. How long do you usually wait for the rail at the platform? **तपाईं प्रायः प्लेटफर्ममा रेलको लागि कति समय पर्खनुहुन्छ**?

a. Less than 15min ☐
१५ मिनेट भन्दा कम

b. 15-30 min ☐
१५-३० मिनेट

c. 30-45 min ☐
३०-४५ मिनेट

d. more than 45 min ☐
४५ मिनेट भन्दा धैरै

6. How Often you use the Rail Service? **तपाईं कति पटक रेल सेवा प्रयोग गर्नुहुन्छ**?

a) Daily **दैनिक** ☐

b) At least once in a week **हप्तामा कम्तीमा एक पटक** ☐

c) Once in a month **महिनामा एक पटक** ☐

d) Occasionally **कहिलेकाहीँ** ☐

B. Please Kindly evaluate the given Jaynagar-Janakpur-Bijalpura Railway Service Features by using Five-point Likert Scale. **कृपया तल दिइएका जयनगर–जनकपुर–बिजलपुरा रेल सेवा सुविधाहरूलाई पाँच बुँदे** Likert Scale **प्रयोग गरी मूल्याङ्कन गर्नुहोस्।**

Strongly Disagree =1	Disagree=2	Neutral=3	Agree=4	Strongly Agree=5
पूर्ण रुपमा असहमत = १	**असहमत = २**	**तटस्थ = ३**	**सहमत = ४**	**पूर्ण रुपमा सहमत = ५**

S. N	Service Features	(1)	(2)	(3)	(4)	(5)
1.	Trains arrive on time **रेल समयमा आइपुग्छ ।**	☐	☐	☐	☐	☐
2.	Information about train schedule is easily available. **रेल सेवाको तालिका सम्बन्धि जानकारी सजिलै उपलब्ध हुन्छ।**	☐	☐	☐	☐	☐
3.	The ticket price is reasonable for passengers. **यात्रुहरूका लागि टिकटको मूल्य उचित छ।**	☐	☐	☐	☐	☐
4.	The frequency of train service is adequate for my travel needs **मेरो यात्रा आवश्यकताका लागि रेलको आवतजावत प्रयाप्त छ।**	☐	☐	☐	☐	☐
5.	It is easy to get a train ticket **रेल टिकट प्राप्त गर्न सजिलो छ।**	☐	☐	☐	☐	☐

6.	I feel safe while waiting or moving around at stations. **म स्टेशनमा पर्खिंदा वा हिँड्दा सुरक्षित महसुस गर्छु।**	☐	☐	☐	☐	☐
7.	I feel safe inside the train during travel. **म रेल यात्राको क्रममा रेलभित्र सुरक्षित महसुस गर्छु।**	☐	☐	☐	☐	☐
8.	Seats inside the train are comfortable **रेलका सिटहरू आरामदायक छन्।**	☐	☐	☐	☐	☐
9.	Train coaches are clean **रेलका डब्बाहरु सफा छन्।**	☐	☐	☐	☐	☐
10.	Waiting areas at stations are comfortable **स्टेशनका प्रतीक्षालयहरू आरामदायक छन्।**	☐	☐	☐	☐	☐
11.	Railway stations are not crowded during arrival of train **रेलको आगमनको समयमा स्टेशनमा यात्रुको भीड हुँदैन ।**	☐	☐	☐	☐	☐
12.	The train is not crowded **रेलभित्र यात्रुको भीड धेरै छैन ।**	☐	☐	☐	☐	☐
13.	There is enough space for passengers to stand inside train. **रेलभित्र यात्रुहरू उभिनको लागि पर्याप्त स्थान छ।**	☐	☐	☐	☐	☐
14.	Boarding and alighting the train is orderly without congestion **अत्यधिक यात्रु भीडबिना रेल चढ्ने र झर्ने प्रक्रिया व्यवस्थित र सजिलो छ।**	☐	☐	☐	☐	☐
15.	Overall, I am satisfied with the service. **समग्रमा यो रेल सेवासँग म सन्तुष्ट छु।**	☐	☐	☐	☐	☐
16.	I will recommend this service to other people. **म यो रेल सेवा अरुलाई प्रयोग गर्न सिफारिस गर्छु।**	☐	☐	☐	☐	☐
17.	I will reuse this service. **समग्रमा यो रेल सेवाको गुणस्तर राम्रो छ।**	☐	☐	☐	☐	☐

APPENDIX B: AHP SURVEY FORM

Table 1 : Pairwise Comparison table for Main Criteria

Pairwise Comparison	More Important Criterion	Value (1–9)
Operational Quality vs Physical Quality		
Operational Quality vs Travel Convenience		
Physical Quality vs Travel Convenience		

Table 2: Pairwise Comparison table for Sub-Criteria of Operational Quality

Pairwise Comparison	More Important Criterion	Value (1–9)
Provision of on-time train service vs Information on train schedule		
Provision of on-time train service vs Ticket Price		
Provision of on-time train service vs Frequency of train departure		
Provision of on-time train service vs Ease to get ticket		
Information on train schedule vs Ticket Price		
Information on train schedule vs Frequency of train departure		
Information on train schedule vs Ease to get ticket		
Ticket Price vs Frequency of train departure		
Ticket Price vs Ease to get ticket		
Frequency of train departure vs Ease to get ticket		

Table 3 : Pairwise Comparison table for Sub-Criteria of Physical Quality

Pairwise Comparison	More Important Criterion	Value (1–9)
Sense of Safety at Station vs Sense of Safety in train		
Sense of Safety at Station vs Seat comfort inside train		
Sense of Safety at Station vs Cleanliness of train coaches		
Sense of Safety at Station vs Station seat and shelter		
Sense of Safety in train vs Seat comfort		
Sense of Safety in train vs Cleanliness		
Sense of Safety in train vs Station seat and shelter		
Seat comfort vs Cleanliness		
Seat comfort vs Station seat and shelter		
Cleanliness vs Station seat and shelter		

Table 4: Pairwise Comparison table for Sub-Criteria of Travel convinence

Pairwise Comparison	More Important Criterion	Value (1–9)
Crowdedness in station vs Crowdedness in train		
Crowdedness in station vs Space for standing		
Crowdedness in station vs Ease in Boarding & Alighting		
Crowdedness in train vs Space for standing		
Crowdedness in train vs Ease in Boarding & Alighting		
Space for standing vs Ease in Boarding & Alighting		

APPENDIX C : WEIGHT CALCULATIONS AND CONSISTENCY CHECK FOR AHP

Global Pairwise

1. Collect pairwise comparison data and construct individual comparison matrices for each respondent.
2. Combine each matrix using the geometric mean method and develop a single aggregated pairwise comparison matrix from all responses.

Global Pairwise	Operational Quality	Physical Quality	Travel Convenience
Operational Quality	1	1.245	1.790
Physical Quality	0.803	1	0.589
Travel Convenience	0.559	1.696	1

3. Each element of the pairwise comparison matrix is normalized by dividing it by the sum of its respective column.

Global Pairwise	Operational Quality	Physical Quality	Travel Convenience	Average weight
Operational Quality	0.414	0.316	0.508	0.413
Physical Quality	0.333	0.254	0.183	0.256
Travel Convenience	0.253	0.430	0.310	0.331
Sum	1	1	1	1

4. Calculate the principal eigen value (λ_{max}) of the comparison matrix and evaluate the consistency of judgments using Consistency Index (CI) and Consistency Ratio (CR)

Global Pairwise	Operational Quality	Physical Quality	Travel Convenienc e	Weighted sum value	Average weight	λ	λ_{max}	CI	RI	CR
Operational Quality	0.413	0.319	0.542	1.274	0.413	3.088				
Physical Quality	0.331	0.256	0.195	0.783	0.256	3.054	3.088	0.044	0.58	0.076
Travel Convenience	0.252	0.435	0.331	1.018	0.331	3.075				

After dividing each element by its respective column sum, the resulting values represent the normalized weights. The average of each row is then computed to obtain the priority weight (weightage) of each criterion. For example, for the Operational Quality criterion, the weighted sum value is calculated as:

Weighted sum value= (0.413+0.319+0.542)=1.274

The average weight is:

Average weight = Average of (0.414,0.316,0.508) = 0.413

Next, the eigen value (λ) for each criterion is determined using the following expression:

λ = (Weighted sum value) / (Priority weight)

For Operational Quality:

λ=(1.274)/0.413= 3.088

Similarly, eigen values for other criteria are computed, and the maximum value among them is considered as λ_{max}.

The Consistency Index (CI) is then calculated using the formula given below.

CI = (λmax − n) / (n − 1)

Here, the value of n is 3.

CI = (3.088-3)/(3-1) = 0.044

The Random Index (RI) value for n = 3 is taken from the standard table, where RI = 0.58.

Finally, the Consistency Ratio (CR) is calculated as

CR= CI/RI = 0.044/0.58 = 0.076 < 0.1, Hence the data is consistent and no further calculation is required.

In Similar way , Weightage of each sub criterion is computed.

Local Pairwise

The calculations for the local criteria are given below

Observation Variable: Operational Quality

Operational Quality	Provision of on-time train service	Information on train schedule	Ticket Price	Frequency of train departure	Ease to get ticket
Provision of on-time train service	1.000	2.621	3.287	3.342	2.201
Information on train schedule	0.381	1.000	2.460	2.905	2.875
Ticket Price	0.304	0.407	1.000	1.664	1.317
Frequency of train departure	0.299	0.344	0.601	1.000	1.690
Ease to get ticket	0.454	0.348	0.759	0.592	1.000
Sum	2.439	4.720	8.107	9.503	9.083

Operational Quality	Provision of on-time train service	Information on train schedule	Ticket Price	Frequency of train departure	Ease to get ticket	Average weight
Provision of on-time train service	0.410	0.555	0.405	0.352	0.242	0.393
Information on train schedule	0.156	0.212	0.303	0.306	0.316	0.259
Ticket Price	0.125	0.086	0.123	0.175	0.145	0.131
Frequency of train departure	0.123	0.073	0.074	0.105	0.186	0.112
Ease to get ticket	0.186	0.074	0.094	0.062	0.110	0.105
Sum	1	1	1	1	1	1

Operational Quality	Provision of on-time train service	Information on train schedule	Ticket Price	Frequency of train departure	Ease to get ticket	Weighted sum value	Average weight	λ	λ_{max}	CI	RI	CR
Provision of on-time train service	0.393	0.678	0.430	0.375	0.232	2.108	0.393	5.364				
Information on train schedule	0.150	0.259	0.322	0.326	0.302	1.359	0.259	5.251				
Ticket Price	0.120	0.105	0.131	0.187	0.139	0.681	0.131	5.202	5.364	0.091	1.12	0.0813
Frequency of train departure	0.118	0.089	0.079	0.112	0.178	0.575	0.112	5.127				
Ease to get ticket	0.179	0.090	0.099	0.066	0.105	0.539	0.105	5.128				

Observation Variable: Physical Quality

Physical Quality	Sense of Safety at Station	Sense of Safety in the train	Seat comfort inside train	Cleanliness of train coaches	Station seat and shelter
Sense of Safety at Station	1	1.813	2.727	2.544	4.375
Sense of Safety in the train	0.552	1	3.135	2.997	4.658
Seat comfort inside train	0.367	0.319	1	1.650	3.481
Cleanliness of train coaches	0.393	0.334	0.606	1	3.472
Station seat and shelter	0.229	0.215	0.287	0.288	1
Sum	2.540	3.680	7.755	8.479	16.985

Physical Quality	Sense of Safety at Station	Sense of Safety in the train	Seat comfort inside train	Cleanliness of train coaches	Station seat and shelter	Average weight
Sense of Safety at Station	0.394	0.493	0.352	0.300	0.258	0.359
Sense of Safety in the train	0.217	0.272	0.404	0.353	0.274	0.304
Seat comfort inside train	0.144	0.087	0.129	0.195	0.205	0.152
Cleanliness of train coaches	0.155	0.091	0.078	0.118	0.204	0.129
Station seat and shelter	0.090	0.058	0.037	0.034	0.059	0.056
Sum	1	1	1	1	1	1

Physical Quality	Sense of Safety at Station	Sense of Safety in the train	Seat comfort inside train	Cleanliness of train coaches	Station seat and shelter	Weighted sum value	Average weight	λ	λ_{max}	CI	RI	CR
Sense of Safety at Station	0.359	0.551	0.414	0.329	0.243	1.897	0.359	5.282				
Sense of Safety in the train	0.198	0.304	0.476	0.387	0.259	1.625	0.304	5.342				
Seat comfort inside train	0.132	0.097	0.152	0.213	0.194	0.787	0.152	5.184	5.342	0.085	1.120	0.076
Cleanliness of train coaches	0.141	0.101	0.092	0.129	0.193	0.657	0.129	5.086				
Station seat and shelter	0.082	0.065	0.044	0.037	0.056	0.284	0.056	5.102				

Observation Variable: Travel Convenience

Travel Convenience	Crowdedness in station (during peak arrival time)	Crowdedness in train	Space for standing	Congestion in Boarding & Alighting
Crowdedness in station (during peak arrival time)	1.000	1.014	0.586	0.581
Crowdedness in train	0.986	1.000	1.409	0.853
Space for standing	1.706	0.710	1.000	0.372
Congestion in Boarding & Alighting	1.722	1.173	2.690	1.000
Sum	5.414	3.897	5.685	2.805

Travel Convenience	Crowdedness in station (during peak arrival time)	Crowdedness in train	Space for standing	Congestion in Boarding & Alighting	Average weight
Crowdedness in station (during peak arrival time)	0.185	0.260	0.103	0.207	0.189
Crowdedness in train	0.182	0.257	0.248	0.304	0.248
Space for standing	0.315	0.182	0.176	0.133	0.201
Congestion in Boarding & Alighting	0.318	0.301	0.473	0.356	0.362
Sum	1	1	1	1	1

Travel Convenience	Crowdedness in station (during peak arrival time)	Crowdedness in train	Space for standing	Congestion in Boarding & Alighting	Weighted sum value	Average weight	λ	λ_{max}	CI	RI	CR
Crowdedness in station (during peak arrival time)	0.189	0.251	0.118	0.210	0.768	0.189	4.070				
Crowdedness in train	0.186	0.248	0.284	0.309	1.026	0.248	4.145				
Space for standing	0.322	0.176	0.201	0.135	0.834	0.201	4.140	4.196	0.065	0.900	0.072
Congestion in Boarding & Alighting	0.325	0.290	0.542	0.362	1.519	0.362	4.196				

Consistency test of individual response

Main criteria	Operational Issues (OP)	Physical Issues (PH)	Travel Convenience (TC)	Average	λ_{max}	C.I	R.I	C.R
OP	0.181	0.157	0.333	0.224	3.109	0.054	0.58	0.0942
PH	0.727	0.631	0.5	0.619				
TC	0.090	0.210	0.166	0.156				
Sum	1	1	1	1				

Travel convinence

	TC1	TC2	TC3	TC4	Weight	λ_{max}	C.I	R.I	C.R
TC1	0.132	0.068	0.222	0.173	0.149	4.182	0.061	0.90	0.067
TC2	0.401	0.206	0.222	0.173	0.250				
TC3	0.066	0.103	0.111	0.131	0.103				
TC4	0.401	0.623	0.444	0.524	0.498				
Sum	1	1	1	1	1				

Physical Quality

	PH1	PH2	PH3	PH4	PH5	Weight	λ_{max}	C.I	R.I	C.R
PH1	0.141	0.105	0.319	0.255	0.231	0.210	5.370	0.093	1.12	0.083
PH2	0.706	0.526	0.319	0.511	0.385	0.489				
PH3	0.035	0.132	0.080	0.042	0.154	0.089				
PH4	0.071	0.132	0.242	0.128	0.154	0.145				
Sum	1	1	1	1	1	1				

Operational Quality

	OP1	OP2	OP3	OP4	OP5	Weight	λ_{max}	C.I	R.I	C.R
OP1	0.513	0.676	0.308	0.444	0.435	0.475	5.278	0.070	1.12	0.062
OP2	0.128	0.169	0.308	0.333	0.261	0.240				
OP3	0.128	0.042	0.077	0.056	0.043	0.069				
OP4	0.128	0.056	0.154	0.111	0.174	0.125				
OP5	0.103	0.056	0.154	0.056	0.087	0.091				
Sum	1	1	1	1	1	1				

APPENDIX D : SEM RESPONSE SAMPLE

S.N.	(On-time train service) OP1	(Train schedule Info) OP2	(Ticket Price) OP3	(Frequency) OP4	(Ease to get ticket) OP5	(Station Safety) PH1	(Train Safety) PH2	(Seat comfort) PH3	(Train coaches cleanliness) PH4	(Station seat & shelter) PH5	(Crowdedness in station) TC1	(Crowdedness in Train) TC2	(Space for standing) TC3	(Ease in Boarding & Alighting) TC4	(Satisfaction) OVR1	(Recommendation) OVR2	(Reuse Intention) OVR3
1.	3	3	2	2	3	3	3	3	3	2	2	2	2	2	2	3	3
2.	5	3	4	4	2	3	3	4	3	3	2	2	1	2	3	4	4
3.	4	4	4	4	4	2	2	4	2	5	1	1	1	3	2	3	2
4.	3	3	2	3	3	3	3	3	3	1	2	2	2	2	3	3	4
5.	4	4	3	4	4	3	4	4	4	4	1	2	3	3	2	3	4
6.	1	4	2	4	4	4	2	4	2	4	3	1	1	3	4	3	4
7.	2	2	2	2	2	2	2	3	3	1	1	1	2	1	2	3	3
8.	4	3	2	4	4	4	3	4	3	2	3	2	1	2	3	4	3
9.	3	3	4	3	3	3	3	3	3	3	2	2	2	2	4	2	3
10.	2	2	2	2	2	2	2	2	2	3	1	1	1	1	2	3	4
11.	4	3	4	4	4	4	2	4	2	1	3	3	1	3	2	3	3
12.	3	3	1	3	3	3	3	3	3	2	2	2	2	2	3	3	4
13.	2	2	2	2	2	2	3	3	3	1	2	1	2	1	2	3	3
14.	2	2	2	2	2	2	2	2	2	1	2	1	1	1	2	2	4
15.	3	2	2	2	2	2	3	3	3	3	1	2	2	1	3	2	2
16.	3	3	1	2	2	3	3	3	3	1	2	2	2	2	3	3	4
17.	3	3	5	3	3	2	3	3	3	1	2	2	2	2	2	2	3
18.	4	4	2	2	4	4	4	4	3	1	3	1	3	3	4	3	4

19.	3	3	3	3	3	3	3	3	3	4	2	2	2	2	3	3	3
20.	3	3	3	3	2	3	3	3	3	1	1	1	2	2	4	3	3
21.	3	3	5	3	3	3	2	3	3	2	2	2	1	2	3	4	4
22.	2	2	4	2	2	2	3	2	2	1	1	1	1	1	2	2	3
23.	3	3	1	3	3	3	4	3	4	1	2	2	2	2	3	3	4
24.	3	3	5	4	3	4	4	4	3	2	2	1	2	2	3	4	3
25.	3	3	4	3	3	3	3	3	3	3	2	2	2	2	3	2	3
26.	2	2	2	2	2	2	2	2	2	1	1	1	1	1	2	2	2
27.	4	4	1	4	2	4	4	4	4	1	3	1	1	3	4	3	3
28.	5	5	4	3	2	3	4	4	2	2	4	4	4	4	3	4	4
29.	2	2	2	2	2	2	2	2	2	4	1	1	1	1	2	2	2
30.	3	3	1	3	3	3	3	3	3	2	2	2	2	2	3	3	3
31.	3	3	3	3	3	3	3	3	2	4	1	2	2	2	3	3	3
32.	4	4	2	4	4	3	2	4	2	3	3	3	1	3	4	3	4
33.	3	2	4	3	2	2	3	3	3	2	1	2	2	2	2	2	3
34.	3	3	1	3	3	3	3	3	3	4	2	1	2	2	3	3	3
35.	4	4	4	4	3	4	2	4	3	2	2	3	2	3	4	4	4
36.	4	2	4	2	4	4	4	3	4	2	1	2	3	3	2	3	4
37.	4	4	2	4	4	3	4	4	2	1	2	1	1	2	4	4	5
38.	3	3	1	3	3	2	2	3	3	2	2	2	1	2	2	2	3
39.	3	2	3	3	2	3	3	3	3	2	2	2	2	1	3	2	4
40.	3	3	3	3	2	2	3	3	2	1	1	2	1	2	2	3	3
41.	3	3	3	2	3	3	3	3	3	2	2	2	2	2	3	3	4
42.	3	3	4	3	3	3	2	3	3	1	1	1	2	2	3	4	3
43.	2	2	2	2	3	3	3	3	3	1	1	2	1	1	3	3	5
44.	4	4	2	4	2	4	4	4	2	5	2	1	2	3	2	3	2
45.	2	2	1	2	2	2	2	2	2	1	1	1	1	1	2	2	3
46.	2	2	1	2	2	2	2	2	2	3	1	1	1	1	2	2	2
47.	3	3	3	3	3	3	3	3	1	1	2	2	2	2	3	3	3
48.	3	3	2	2	3	4	3	3	3	3	2	2	1	2	3	3	4

49.	3	3	3	3	3	3	3	3	4	1	2	2	2	2	3	4	3
50.	2	2	2	2	2	2	2	2	3	4	1	2	2	1	3	3	2
51.	2	2	4	2	2	2	2	2	2	1	1	1	1	1	3	2	2
52.	3	3	3	3	3	2	1	1	3	1	3	2	2	2	3	4	4
53.	2	2	2	2	2	2	2	2	2	5	1	1	1	1	2	2	3
54.	3	3	3	3	2	3	3	3	3	3	2	2	2	2	2	3	4
55.	4	3	4	3	3	3	3	3	2	2	1	1	1	1	4	3	3
56.	3	3	1	3	3	3	3	3	3	2	2	2	2	2	3	3	2
57.	3	3	2	4	4	3	2	3	4	1	2	2	1	2	4	3	4
58.	3	3	4	3	3	3	3	4	3	2	1	2	2	2	3	4	4
59.	3	3	1	3	2	3	3	3	3	1	2	1	2	2	3	2	3
60.	4	4	3	4	4	4	4	4	2	2	1	1	1	1	4	3	4
61.	3	3	3	3	3	3	3	3	3	4	2	2	2	2	3	4	2
62.	4	4	4	2	4	4	4	4	2	5	1	1	3	2	4	4	4
63.	3	3	3	3	3	3	3	3	2	1	2	2	2	2	3	3	4
64.	4	3	4	4	4	3	4	4	4	1	3	3	1	2	4	4	4
65.	3	3	5	3	3	3	3	3	3	4	2	2	1	2	3	3	3
66.	3	3	1	3	2	3	3	3	3	3	1	2	2	1	2	2	2
67.	4	4	4	4	4	2	2	4	4	2	3	3	3	3	3	4	3
68.	2	2	3	2	2	2	2	2	3	3	1	1	1	1	2	2	2
69.	2	2	2	2	2	3	3	3	3	3	1	1	1	1	2	3	3
70.	3	3	4	3	3	4	3	4	3	1	3	2	2	2	3	4	4
71.	3	3	3	3	3	3	3	2	3	4	2	2	2	2	3	3	3
72.	3	3	2	3	3	2	1	3	3	3	2	2	2	2	3	3	4
73.	3	3	3	3	3	3	3	3	1	1	2	2	1	2	3	2	2
74.	2	2	2	2	2	2	2	2	3	4	1	1	1	1	2	1	2
75.	3	3	4	3	3	3	3	3	3	2	3	2	2	2	4	3	3
76.	3	3	4	3	3	3	3	3	4	1	2	2	1	2	3	3	3
77.	3	3	2	3	3	3	3	3	3	2	2	2	2	2	3	3	3
78.	3	3	1	4	2	4	2	3	4	1	3	3	2	2	3	3	4

79.	1	3	5	3	3	3	3	3	3	2	2	2	1	2	4	2	3
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81.	3	3	4	3	3	3	3	4	3	4	1	1	1	1	4	3	4
82.	3	3	3	2	2	2	1	3	3	1	2	2	2	2	3	3	3
83.	3	3	3	3	3	3	3	3	3	2	2	1	2	2	2	3	3
84.	3	3	3	2	3	3	3	3	3	2	1	2	1	2	3	3	3
85.	3	3	5	3	3	3	3	3	3	2	2	1	2	2	2	3	3
86.	3	3	2	3	3	4	3	3	3	2	2	2	2	1	3	3	4
87.	3	3	4	3	3	3	3	3	3	1	2	2	2	2	3	2	2
88.	3	3	2	2	3	2	3	3	3	5	2	2	2	2	2	3	4
89.	3	2	2	3	3	3	2	3	3	1	2	2	1	1	3	3	3
90.	2	3	3	3	3	3	3	3	3	2	2	2	2	2	3	4	4
91.	3	4	2	4	4	3	4	2	2	2	2	3	2	2	4	4	4
92.	4	4	4	2	4	4	4	4	4	3	1	1	1	3	3	2	3
93.	4	4	4	4	2	4	3	4	2	3	3	3	3	3	3	4	5
94.	4	4	3	4	4	4	4	4	4	4	1	1	2	2	4	3	3
95.	4	4	2	4	4	2	3	3	4	1	3	3	3	3	4	3	4
96.	3	3	4	3	3	2	3	3	3	3	2	2	2	2	3	3	4
97.	3	3	1	3	3	3	3	3	3	3	2	1	2	2	3	3	3
98.	4	4	2	4	4	4	2	4	4	2	3	1	2	1	2	3	3
99.	3	3	2	3	3	3	3	3	3	2	2	2	2	2	3	4	4
100.	4	4	5	4	2	4	4	4	4	4	3	1	1	3	4	4	5
101.	1	3	4	3	3	3	3	3	3	3	2	2	2	2	3	3	3
102.	4	4	3	4	4	4	2	4	2	2	1	1	2	2	3	3	4
103.	2	2	1	2	2	2	2	2	2	3	1	1	1	1	2	2	2
104.	4	4	3	4	2	4	4	4	4	4	3	1	3	3	4	3	4
105.	2	2	2	2	2	2	3	3	3	1	1	2	1	1	2	3	2
106.	3	3	2	2	3	3	3	3	3	1	2	2	2	2	3	1	3
107.	3	3	2	3	3	3	3	3	3	1	2	2	2	2	3	3	4
108.	2	2	3	2	2	2	2	2	3	3	1	2	1	1	3	3	4

109.	3	3	1	3	3	3	3	3	3	2	2	2	2	2	3	4	4
110.	4	3	2	3	3	3	4	4	4	2	2	2	1	2	2	3	3
111.	4	4	4	4	4	4	4	4	1	2	3	3	3	3	1	4	4
112.	2	2	1	2	2	2	2	2	2	1	1	1	1	1	2	1	4
113.	5	5	1	3	2	4	3	3	2	4	3	2	2	2	3	4	4
114.	2	2	2	2	2	3	1	2	1	1	1	1	1	1	2	2	3
115.	2	2	2	2	2	2	2	2	2	5	1	1	1	1	2	2	4
116.	3	3	3	3	3	3	3	3	3	1	2	2	2	2	3	3	2
117.	4	4	4	4	4	3	2	4	1	2	3	3	2	2	4	3	4
118.	3	2	4	2	2	3	3	3	2	2	2	1	1	1	3	2	3
119.	3	3	4	3	2	3	3	3	3	2	2	2	2	2	3	3	2
120.	3	3	2	3	3	3	3	3	2	4	2	2	2	2	3	4	3
121.	3	4	1	4	4	4	4	4	4	2	1	1	2	3	4	5	4
122.	2	2	4	2	2	2	2	2	2	1	1	1	1	1	3	2	4
123.	3	3	4	3	3	3	3	3	3	5	2	2	2	2	3	3	3
124.	1	1	2	1	1	2	2	1	1	4	1	1	1	1	1	1	4
125.	2	4	2	4	4	4	4	4	4	3	3	2	1	3	4	4	4
126.	4	4	1	4	2	4	3	4	4	5	1	1	2	3	2	4	3
127.	4	4	3	4	4	3	4	4	4	5	3	3	2	3	4	4	4
128.	2	2	2	2	3	3	3	3	3	2	2	2	2	2	3	2	3
129.	3	3	3	3	3	2	2	3	3	4	2	1	2	2	2	3	3
130.	3	3	1	3	3	3	3	3	2	3	2	2	2	2	3	3	4
131.	3	3	4	3	3	3	1	3	3	1	2	2	2	2	3	3	4
132.	2	2	1	2	2	3	2	2	2	1	2	1	1	1	2	2	3
133.	3	3	1	3	3	3	3	3	3	3	2	1	2	2	3	3	4
134.	4	4	4	4	4	4	2	3	4	1	3	1	1	3	1	3	4
135.	3	3	3	3	3	2	3	3	3	2	2	2	2	2	3	2	3
136.	2	2	4	2	2	2	2	3	2	3	1	1	1	1	2	3	2
137.	5	3	4	5	5	5	5	5	4	4	2	2	1	4	4	4	4
138.	3	3	1	3	3	3	3	3	3	1	2	2	2	2	4	3	3

APPENDIX E : SEM MODEL RESULT

Collinearity Statistics Outer Model

Variable	OP1	OP2	OP4	OP5	OVR1	OVR2	OVR3	PH1	PH2	PH3	PH4	TC1	TC2	TC3	TC4
VIF	2.287	2.899	2.005	1.551	1.311	1.566	1.387	2.486	2.040	2.300	1.420	2.381	2.295	1.564	2.122

Collinearity Statistics Inner Model

	VIF
Operational Quality -> Overall Passenger Satisfaction	3.862
Physical Quality -> Overall Passenger Satisfaction	3.090
Travel Convenience -> Overall Passenger Satisfaction	3.074

f-square test result

	f-square
Operational Quality -> Overall Passenger Satisfaction	0.028
Physical Quality -> Overall Passenger Satisfaction	0.097
Travel Convenience -> Overall Passenger Satisfaction	0.044

PLSPredict LV Summary

	Q^2 Predict	RMSE	MAE
OVR	0.561	0.667	0.524

Outer Weights

	Operational Quality	Overall Passenger Satisfaction	Physical Quality	Travel Convenience
OP1	0.273			
OP2	0.354			
OP4	0.299			
OP5	0.267			
OVR1		0.404		
OVR2		0.484		
OVR3		0.365		
PH1			0.344	
PH2			0.293	
PH3			0.330	
PH4			0.231	
TC1				0.343
TC2				0.306
TC3				0.210
TC4				0.327

त्रिभुवन विश्वविद्यालय
TRIBHUVAN UNIVERSITY
इन्जिनियरिङ्ग अध्ययन संस्थान
INSTITUTE OF ENGINEERING
पुल्चोक क्याम्पस
PULCHOWK CAMPUS

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पुल्चोक, ललितपुर ।
Pulchowk, Lalitpur

त्रिभुवन विश्वविद्यालय इन्जिनियरिङ अध्ययन संस्थान पुल्चोक क्याम्पस

Date: May 9, 2026

To Whom It May Concern:

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Assessing Service Quality of the Jaynagar–Janakpur–Bijalpura Rail Service: A Passenger Perspective

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Abstract
Rail transport has existed historically but limited in terms of network expansion and operational coverage in Nepal. The Jaynagar–Janakpur–Bijalpura Rail Service is the only operational passenger railway service in the country. Due to the limited development and small scale of the railway system almost no studies have assessed railway service quality from passenger perspective in Nepal. Improving service quality of Jaynagar–Janakpur–Bijalpura Rail Service is important to enhance the satisfaction of passengers. Existing research on rail systems primarily focuses on developed countries, neglecting the unique experiences and challenges of developing nations like Nepal. Structural Equation Modeling (PLS-SEM) was employed to analyze a more comprehensive understanding of the complex relationships among service quality dimensions and passenger satisfaction. This study investigation showed that among the three latent variables 'Operational Quality', 'Physical Quality' and 'Travel Convenience' positively influence service quality of rail service, with Physical quality emerging as the most significant, followed by Travel convenience. The findings offer a comprehensive, data-driven tool for railway administrators to prioritize service quality improvements and operational strategies that most effectively improve the passenger experience on this critical cross-border rail link.

Keywords
Service Quality, Passenger Satisfaction, PLS-SEM, Railway Service

1. Introduction

1.1 Background

Service quality can be measured in terms of customer perception, customer expectation, customer satisfaction, and customer attitude[1]. In the context of increasing access to information and tougher competition, the customer will be more demanding for service. Technology will enable them to make comparisons quickly and accurately. High quality customer service will have to mean more than a customer service department and customer care will have to be a state of mind and be accepted by all levels of management and staff. [2]. The escalating demand for efficient and reliable public transportation necessitates a thorough evaluation of railway services, particularly in developing regions where rail infrastructure plays a pivotal role in socio-economic development[3]. Rail transport across the world has evolved into one of the most efficient, sustainable, and user-oriented modes of public transportation. Many countries have strengthened their passenger railway systems to reduce road congestion, improve safety, and enhance long-distance mobility.

In contrast, Nepal's railway sector remains in its early stage of development, as the nation's transport system has historically been dominated by road-based mobility, limiting the growth and utilization of rail services. Apart from being a vital part of the public transport around the world, railways also help support economic growth, manage road congestion, and combat climate change.To measure and evaluate the quality of service for improvement, the only way is to find out the level of satisfaction the passengers derive from the services[4]. The analysis of passenger perceptions regarding rail services in other regions, such as the Bangladesh Railway Line and Indian Railways, has underscored the importance of factors such as availability of train, seating comfort, parking facilities, restroom facilities, and information offerings in shaping overall satisfaction[5][6]. Similarly, socio-economic factors, such as income, education, and occupation, significantly influence how passengers perceive railway infrastructure and service quality[3]. Given its unique status as Nepal's only passenger rail service, assessing service quality on this route is essential, not only to enhance the travel experience but also to support strategic planning for sustainable operations and regional development. This study, therefore, aims to provide a systematic evaluation of the service quality of the Jaynagar-Janakpur-Bijalpura passenger rail service, offering insights that can guide improvements in operational performance and passenger satisfaction.

1.2 Problem Statement

The Jaynagar-Bijalpura railway lacks a structured evaluation of service quality and key passenger issues such as overcrowding, delays, and low comfort remain understudied. This study addresses this gap by evaluating service quality from the users' perspective to guide improvements.

1.3 Research Objectives

The main objective of the study is to explore the underlying relationships between service quality and passenger satisfaction, and to develop a structured framework to assess the impact of service quality on passenger experience in the Jaynagar-Janakpur-Bijalpura rail service. The specific objectives are listed below:

1. To develop a service quality model using structural equation modeling.
2. Investigate how the dimensions of service quality influence overall passenger satisfaction.
3. To assess the service quality of Jaynagar-Janakpur-Bijalpura rail service and the status of Operational Quality, Physical Quality and Travel Convinence variables.

1.4 Limitations

This study focuses on present user perceptions and may not consider potential future changes in users' perceptions.

2. Literature Review

2.1 Service Quality

Service quality can be explained as the extent to which customers are satisfied or exceeded in the delivery of a service[4][1]. It is a multidimensional construct that encompasses several key dimensions that play a vital role in passenger experiences within a public transit system. Many researchers have defined Service Quality from diverse perspectives. Several researchers have affirmed that the quality of service influences customer satisfaction. The characteristics of service are intangibility, heterogeneity, Perishability, inseparability, Ownership and Other people factor[7].

2.2 Service Quality Measurement Models

The SERVQUAL Model is a widely recognized model for evaluating service quality, particularly in the context of public transportation. This model identifies five essential dimensions of service quality that are Tangibility, Reliability, Responsiveness, Assurance and Empathy[1]. In order to measure the quality of service thoroughly, the attributes used in SERVQUAL, the public transport industry, and the railway service sector should be grouped to form a pool of items for measurement. The attributes in the SERVQUAL model are modified and added three new dimensions, namely, convenience, comfort, and security and created RAILQUAL for the measurement of Railway passenger Services[8]. For instrument purification of RAILQUAL researchers, a formalized and tested six-dimensional RAILQUAL scale. These scales are Reservation and ticketing, Platform services, In-train service, Punctuality, Employee service, Safety and security[9].
Beyond these other model such as SERVPERF model focuses only on performance-based evaluation, eliminating the need to measure expectations. Additionally, methods like Importance–Performance Analysis (IPA), the Kano model, have also been applied to assess service quality in various contexts.

2.3 Structure Equation Modeling (SEM)

The structural equation model consists of both measurement and a structural model. The model built between latent and observed variable belongs to the measurement model, while model built between latent variables is a structural model[10].SEM method can mostly use to analyze the relationships among variables, and to quantitatively analyze the correlation coefficients between each variable. SEM serves as a crucial tool for analyzing customer perceptions by developing models that capture complex relationships between variables.

2.3.1 Partial Least Square Structural Equation Modeling (PLS-SEM) Theory

(PLS-SEM) modeling plays a crucial role in estimating the parameters[11]. The methodology known as (PLS-SEM) has gained significant traction in the area of study and analysis. This approach is widely utilized for constructing path models that involve latent variables and their interconnections. The primary objective of conducting PLS-SEM investigations is to unveil critical determinants of success and uncover the underlying sources of competitive edge in relation to pivotal constructs like passenger satisfaction or user behavior[12]. It is out smart tool for analyzing complex relationships among variables and is often used in studies that involve latent variables. It is also useful for researchers who are working with limited data or data that does not meet the assumptions of traditional statistical methods. Unlike covariance-based SEM (CB-SEM), which emphasizes model fit and requires large samples and normally distributed data, PLS-SEM is distribution-free and performs well with small samples, non-normal data, and formative or reflective constructs[13].

2.3.2 Measurement Theory

The effectiveness of a measurement is assessed by the use of indicators such as factor loadings, composite reliability, and average variance extracted. Factor loadings indicate the strength of the relationship between observed indicators and their underlying latent variables, with higher loadings reflecting more reliable measurements[11]. Composite reliability assesses the consistency among the indicators of a latent construct, while average variance extracted measures the proportion of variance in the indicators that is explained by the latent variable rather than by measurement error[13]. Additionally, the validity of a measurement model can be examined by analyzing the relationships among latent variables to ensure that they are not excessively correlated. High correlations may indicate that different constructs are capturing the same underlying concept, which can lead to multi collinearity issues and overestimated effects in the structural model. Researchers may choose between reflective or formative approaches depending on the nature of their constructs[14] [15].

2.3.3 Model Estimation with PLS-SEM

The process of PLS-SEM involves the explicit calculation of case values, also known as construct scores for estimating latent variables[16]. When using PLS-SEM, researchers typically follow a series of steps to test their hypotheses and analyze their data. These steps include model specification, both measurement, and structural model assessment, and evaluation of the overall model fit.

2.4 Research Gap

Many studies on railway service quality are well-established internationally but remains largely unexplored in Nepal leaving a clear gap that this study addresses using PLS-SEM to analyze passengers rail service quality.

2.5 Hypothesis Development

Depending on the review of the literature, this study has formulated three hypotheses concerning the relationship between service quality, measured by latent constructs, and the overall satisfaction of users in the Jaynagar-Janakpur-Bijalpura rail service.

1. H1: Operational Quality has a significant positive impact on passenger satisfaction in the rail service.
2. H2: Physical Quality has a significant positive impact on passenger satisfaction in the rail service.
3. H3: Travel Convenience has a significant positive impact on passenger satisfaction in the rail service.

2.6 Conceptual Framework

The conceptual framework visualizes the interrelationships between the key variables in the study. This framework shows that latent dimensions directly influence passenger satisfaction.

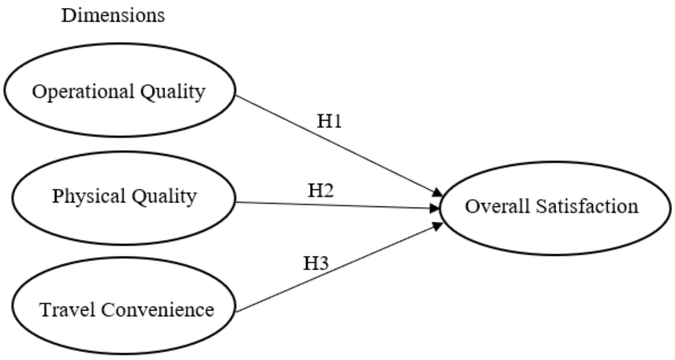

Figure 1: Conceptual Frame Work

3. Methodology

3.1 Study Area

The study focuses on the Jaynagar-Janakpur-Kurtha-Bijalpura railway line, an approximately 52 km long route, that is part of the cross-border railway line between India and Nepal. The railway begins at Jaynagar railway station in the Madhubani district of Bihar, India. The railway links Bijalpura, Mahottari, with Jaynagar, crossing the India-Nepal border near Inarwa. There are customs checkpoints at both of these stations, but the border is maintained as an open border for people. The Railway map is shown in the figure below

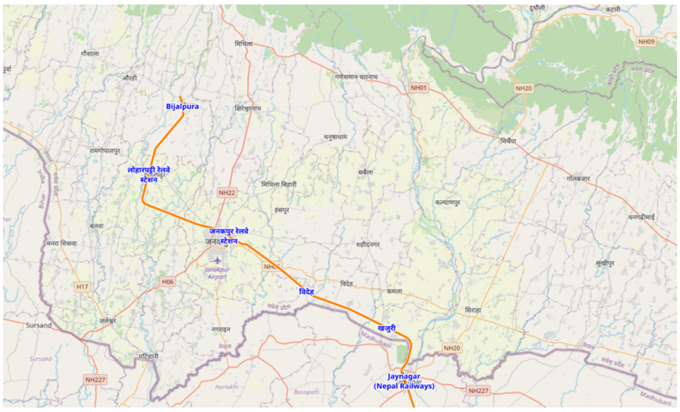

Figure 2: Study Area: Jaynagar–Janakpur–Bijalpura Railway Line Source: OpenRailwayMap

3.2 Sample Size

The sample size for this study will be determined by using formula given by Cochran (1977) for determining the sample size under simple random sampling.

$$n = \frac{Z^2 pq}{e^2} \tag{1}$$

where,
n = Sample size for infinite population
Z = Statistical parameter corresponding to confidence level (Z is 1.96 for 95% confidence interval)
e = Desired margin of error (adopted as 5%)
p = Hypothesized true proportion for population (adopted as 0.5 to account for the worst case) and q=1-p
Substituting the values in Equation 1:

$$n = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.05)^2} = 384.16 \tag{2}$$

Therefore, the sample size required to estimate the proportion of rail passengers who are satisfied with the service within 5% of the true value at a 95% confidence level is 384. For the study we have collected 400 data for the accuracy of our model.

3.3 Data Collection

A pilot survey was conducted before the main questionnaire survey on 30 passengers to identify any issues, such as ambiguous or confusing questions. The data for the research was collected manually using a paper-based questionnaire, designed in accordance with the research objectives. The questionnaire was divided into two sections.

1. The first section gathered socio-demographic information and travel behavior variables of the rail service.
2. The second section collected passenger opinions on various service quality variables, along with overall satisfaction variables, using a Likert scale ranging from 1 to 5.

3.3.1 Selection of Variables

The variables were selected from questionnaire survey carried out manually after pilot survey of passenger.

The socio-demographic information are gender, age group, qualifications, and travel behavior variables are journey purpose, waiting time, and usage frequency of the rail service. The service quality variables are mentioned in the table below:

Table 1: Classification of Service Quality Variables

SN	Service Features	Symbol	References
Operational Quality			
1	Provision of on-time train service	OP1	[6] [17][18]
2	Information on train schedule	OP2	[6] [19]
3	Ticket Price	OP3	[5] [19]
4	Frequency of train departure	OP4	[6] [18]
5	Ease to get ticket	OP5	[6] [19] [20]
Physical Quality			
6	Sense of Safety at Station	PH1	[18] [21] [20]
7	Sense of Safety in the train	PH2	[6] [22] [20]
8	Seat comfort inside train	PH3	[6] [17] [22]
9	Cleanliness of train coaches	PH4	[6] [18]
10	Station seat and shelter	PH5	[19] [20]
Travel Convenience			
11	Crowdedness in station (during peak arrival time)	TC1	[19]
12	Crowdedness in train	TC2	[19]
13	Space for standing	TC3	[20]
14	Ease in Boarding & Alighting	TC4	[5][21] [19]
Overall Satisfaction			
15	Satisfied with the service	OVR1	[21]
16	Recommend the service to others	OVR2	
17	Reuse the service	OVR3	

3.4 Data Analysis

3.4.1 Reliability

Reliability tests were performed to assess the quality of the data and to evaluate the consistency of the measurement item. It evaluates how closely related a set of items are as a group, aiming to determine if they measure the same underlying construct or concept. This study employs Cronbach's alpha to evaluate the internal consistency of measurement items. Cronbach alpha, greater than 0.707 is considered a sufficient indicator of reliability[12].

3.4.2 Validity

Validity indicates how accurately the data measure what it is intended to measure. Researchers follow various stages to confirm validity. The KMO (Kaiser-Meyer-Olkin) and Bartlett's tests were performed to ensure the validity of the survey questions.

3.4.3 Model Development

The model was developed in Smart-PLS 4. There are two types of models in SEM[12].

- Measurement Model: It determines the relationship between the latent variables and indicators; analyzes according to composite reliability, convergent validity, and discriminant validity.
- Structural Equation Model: It determines the relationship between the dependent and independent factors/variables.

3.4.4 Model Fitting

Model fitness in SEM refers to the evaluation of how well a specified PLS-SEM model fits the observed data. Various measures, including Chi-square, Standardized Root Mean Square Residual (SRMR), d_ULS and d_G (Geodesic & Squared Euclidean Discrepancy), and Normed Fit Index (NFI) were used to assess how well the proposed model aligns with the collected data. SRMR value less than 0.08 is good[23]. The structural model was fitted using path coefficients, R^2 for explanatory power, f^2 for effect size.

3.4.5 Model Validation

Researchers recommended that the average variance extracted (AVE) should be 0.5 or higher[12][24]. The validation of the measurement model was done by composite reliability, convergent validity and discriminant validity. The composite validity is also known as convergent validity, which assesses the extent to which different indicators (observed variables) of the same latent construct (unobserved variable) are related to each other. It confirms that the indicators chosen to measure a latent construct are indeed related and converge onto that construct. It was typically assessed by examining the factor loadings of the observed variables on their latent construct in a confirmatory factor analysis. High, statistically significant factor loadings indicate good composite reliability. When composite reliability is established, it indicates that the observed variables effectively measure the same underlying construct, providing evidence of reliability and consistency in measurement. Discriminant validity evaluates the extent to which different latent constructs in the model are distinct from each other. Low correlation indicates good discriminant validity. SMART-PLS 4 was used for the validation of the model.

4. Results and Discussions

4.1 Measurement Model

The data was collected through a questionnaire survey of 400 passengers. After discarding the questionnaires with incomplete information, 392 responses were taken for analysis purposes.

4.1.1 Descriptive Analysis

Table 2: Descriptive characteristics of sample

Category	Sub-Category	Percentage (%)
Gender (GEN)	Male	63.50
	Female	36.50
Age (AGE)	< 20	11.20
	21–35	24.70
	36–50	40.30
	51–65	17.30
	> 65	6.40
Qualification (QUA)	Illiterate	24.70
	Elementary	30.90
	High School	27.30
	Diploma / +2 Level	12.00
	Undergraduate	5.10
Purpose of Journey (JOUR)	Business	29.30
	Job	15.60
	Family Meeting	38.00
	Shopping	9.40
	Others	7.70
Wait Time (WT)	< 15 Min	33.20
	15–30 Min	43.10
	30–45 Min	15.10
	> 45 Min	8.70
Usage Frequency (UF)	Daily	18.10
	Once a Week	8.20
	Once a Month	43.40
	Occasionally	30.40

The data show that the concentration of male passengers is higher than female passengers. About 63.5% of users were male, while rest were female. The majority of respondents were between 36-50 years age group. A small percentage of passengers (6.40%) fell into more than 65 years age group. The educational background of passenger is quite diverse. The highest group consists of those with elementary education (30.90%) followed by high school (27.30%), which is around the same. The percentage of people who, are illiterate is 24.7%, whereas undergraduates represent a small segment at 5.10%.
Understanding why people travel reveals the primary function of rail service. The majority of the passengers travel for family meetings and gatherings (38%), whereas business (29.3%) is also a major reason for travel. Shopping and other reasons of travel are much lower than these two. The waiting time reflects efficiency of the service. The majority of people (43.10%) wait between 15-30 minutes. Very few passengers (8.70%) face wait time exceeding 45 minutes.
The usage frequency represents loyalty of passengers. The most common frequency is once in a month (43.40%) indicating many passengers travels for specific, non-daily purpose like family gatherings. A smaller but significant number of passengers (18.10%) use the service every day.

4.1.2 Reliability Test

For SEM model, Cronbach's alpha test was done to check the consistency of the data. The result is shown in table 2.

Table 3: Reliability Test

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.897	0.918	17

The Cronbach's alpha value was determined to be 0.897, indicating that the items in the questionnaire or scale were internally consistent and likely measure the same underlying construct. The valid sample data obtained from the survey questionnaire are integrated into SMART-PLS 4 to check the coefficients of the questionnaire.

4.1.3 Validity Test

The KMO value, which assesses the adequacy of the data for factor analysis, was 0.895, indicating that the data was well-suited for factor analysis. The test results showed a chi-square value of 2790.35 with 136 degrees of freedom (df) and a significance level of 0.001. A significant result ($p<0.05$) in Bartlett's test suggested that the correlation matrix among the variables was statistically significant, further supporting the suitability of the data for factor analysis or SEM.

Table 4: KMO and Bartlett's Test

Measure	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.895
Approx. Chi-Square	2790.035
df	136
Sig.	0.001

4.1.4 Construct Validity

Table 5: Reliability and Validity of Constructs

Constructs	Cronbach's alpha	Composite reliability (ρ_a)	Composite reliability (ρ_c)	AVE
Operational Quality	0.742	0.869	0.837	0.697
Overall Passenger Satisfaction	0.706	0.724	0.836	0.630
Physical Quality	0.736	0.867	0.832	0.683
Travel Convenience	0.854	0.878	0.901	0.696

According to the test results in the above table, the reliability coefficients of Cronbach's alpha and composite reliability values were above 0.7, and the Average variance extracted (AVE) values were above 0.5; therefore, all values indicate higher reliability of the total scale for internal consistency.

4.1.5 Discriminant validity analysis

Discriminant validity refers to the extent to which a construct was truly different from other constructs in the model.

Table 6: Fornell Larcker Criterions

Criteria	Operational Quality	Overall Passenger Satisfaction	Physical Quality	Travel Convenience
Operational Quality	**0.835**			
Overall Passenger Satisfaction	0.699	**0.794**		
Physical Quality	0.805	0.713	**0.827**	
Travel Convenience	0.804	0.683	0.747	**0.834**

The Fornell Larcker Criterion was used, which was satisfied when the square root of Average Variance Extracted(AVE) for each construct(shown in bold) were greater than its correlations with all other constructs in the model.

4.2 SEM Model

When the measurement model assessment is satisfactory, the next step in evaluating PLS-SEM results is assessing the structural model[12]. The construction of the structural equation model (SEM) was done using the theoretical concepts about the model obtained in the previous section. SMART- PLS 4 created a structural equation model based on the relationships between various variables, as shown in Figure 4 below. The model included four latent variables, including three external and one internal latent variable. The external latent variables were: Operational Quality, Physical Quality, and Travel Convenience. On the other hand, the endogenous latent variable was Overall passenger satisfaction. The collinearity among the predictor constructs should be assessed to ensure it does not bias the regression estimates. This procedure uses latent variable scores of the predictor constructs in a partial regression to compute the Variance Inflation Factor (VIF) values. VIF values exceeding 5 indicate potential collinearity issues among the predictor constructs[24]. The results show that Operational Quality (VIF = 3.862), Physical Quality (VIF = 3.090), and Travel Convenience (VIF = 3.074) all have VIF values below the recommended threshold of 5. This indicates that there is no serious multicollinearity issue among the predictor constructs, and the structural model estimates are not biased due to collinearity.

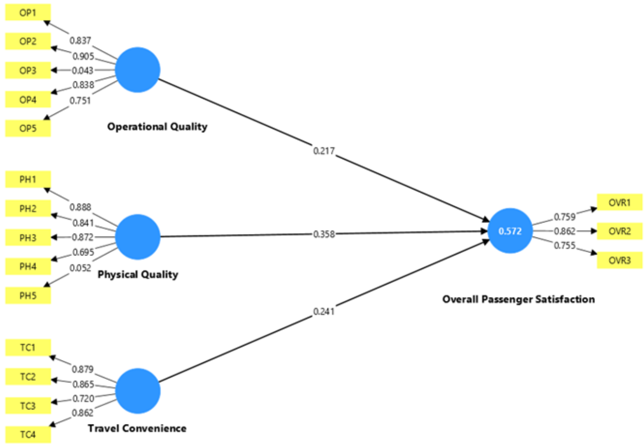

Figure 3: Path Coefficient of Passenger Satisfaction Model

As per the above Structural Equation Model analysis, all the path coefficients were determined, and the results were presented in the table below. From Table 6 below, we can see that the values of standardized coefficients are between [-1, +1], which means that the values meet the requirement. Therefore, further analysis of the path coefficients was performed to check whether the model met the significance requirements.

Table 7: Path Coefficients and Significance Results

S.N	Path Relation	Path Coefficients	T Statistics (|O/STDEV|)	P values
1	Operational Quality → Overall Passenger Satisfaction	0.217	3.284	0.001
2	Physical Quality → Overall Passenger Satisfaction	0.358	5.419	0.001
3	Travel Convenience → Overall Passenger Satisfaction	0.241	4.039	0.001

Partial least squares (PLS) correlation analysis typically uses t-statistics and p-values to measure the significance level of correlation in a model. The T statistic indicates how strong the interplay among two variables is. With a higher T value indicating a stronger relationship. The p-value, on the other hand, indicates the probability of the observed data. A low p-value and high T-value ($P< 0.05$, and $T>1.96$) indicates the relationship between the variables is statistically significant. In this study significances between constructs in the model was evaluated through the corresponding value of T Statistics and p-value is presented below in table.

Table 8: Measurement Model Results

S.N	Path Relation	T Statistics	P values
1	OP1 ← Operational Quality	2.819	0.004
2	OP2 ← Operational Quality	6.047	0.001
3	OP3 ← Operational Quality	**0.574**	**0.566**
4	OP4 ← Operational Quality	3.171	0.001
5	OP5 ← Operational Quality	2.138	0.032
6	OVR1 ← Overall Passenger Satisfaction	2.396	0.012
7	OVR2 ← Overall Passenger Satisfaction	6.811	0.001
8	OVR3 ← Overall Passenger Satisfaction	2.227	0.026
9	PH1 ← Physical Quality	7.459	0.001
10	PH2 ← Physical Quality	3.363	0.001
11	PH3 ← Physical Quality	4.536	0.001
12	PH4 ← Physical Quality	17.281	0.001
13	PH5 ← Physical Quality	**0.696**	**0.486**
14	TC1 ← Travel Convenience	6.636	0.001
15	TC2 ← Travel Convenience	4.631	0.001
16	TC3 ← Travel Convenience	19.817	0.001
17	TC4 ← Travel Convenience	4.204	0.001

According to the above table, the paths that have not reached the significance level of 0.05 are OP3 (Ticket Price), and PH5(Station seat and shelter). The variation in perception, heterogeneous passenger may reduce the consistency of responses.These insignificant paths, OP3 and PH5 were deleted, and the model was evaluated for the second time.

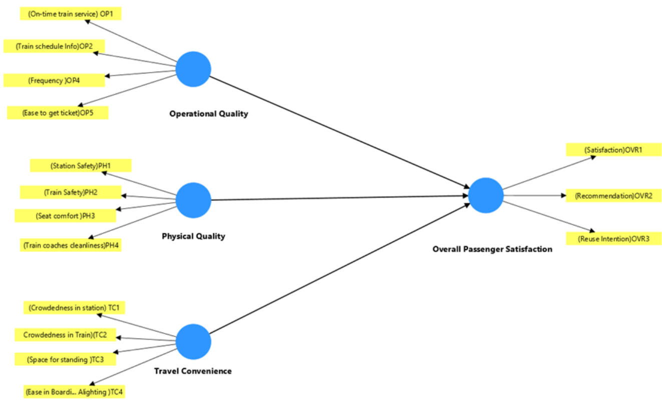

Figure 4: Modified Final Model

4.2.1 Model Fit Criteria

The SRMR value was less than 0.08 and the chi-square value was high which indicate the model meets basic requirements set for model fit.

Table 9: Model Fit Index

Criteria	Saturated Model	Estimated Model
SRMR	0.069	0.069
d_{ULS}	0.567	0.567
d_{G}	0.264	0.264
Chi-square	565.792	565.792
NFI	0.845	0.845

The R^2 ranges from 0 to 1, with higher levels indicating more predictive accuracy. As a rough rule of thumb, the R^2 values of 0.75,0.50, and 0.25 can be considered substantial, moderate, and weak[24]. The R^2 value was 0.572, which indicates moderate predictive accuracy. The f^2 effect size in SEM measures how much an individual predictor contributes to the R^2 of an endogenous variable by showing the change in R^2 when that predictor is removed from the model. It is used to assess the relative importance of predictors and is often similar in interpretation to path coefficients. As a guideline (Cohen, 1988), f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively. It is mainly reported when needed, especially if it helps explain differences in predictor importance or mediation effects [24]. The results indicate that Operational Quality has a small effect (f^2 = 0.028), Physical Quality has a small to moderate effect (f^2 = 0.097), and Travel Convenience also shows a small effect (f^2 = 0.044) on Overall Passenger Satisfaction. The Q^2 value was determined to confirm the model's predictive relevance for the endogenous latent variable[12]. As a relative measure of predictive relevance, Q^2 values of 0.02, 0.15, and 0.35 indicate that an exogenous construct has a small, medium, or large predictive relevance, respectively, for a certain endogenous construct[24]. The obtained Q^2 value of 0.561 was greater than zero, indicating that the model has strong predictive relevance for Overall Passenger Satisfaction. This suggests that the structural model has good capability in accurately predicting the endogenous construct.

4.3 Analysis Results and Interpretation

As per research results, the model is an overall logical structure, composed of 4 latent variables and important interrelationships, of which 3 are external latent variables, which include Operational Quality, Physical Quality, and Travel Convenience. The internal latent variable is Overall Passenger Satisfaction.

4.3.1 Hypothesis Test Result

The structural model results indicate that Operational Quality, Physical Quality, and Travel Convenience have statistically significant positive relationships with passenger satisfaction in rail service. As presented in Figure 4 and Table 8, the standardized path coefficients and corresponding t-statistics confirm the significance of all hypothesized relationships. Since all t-statistics exceed the recommended threshold ($t >$ 1.96 at 5% significance level), hypothesis H1, H2, and H3 are supported. Overall, the findings suggest that improvements in these service quality dimensions are associated with increased passenger satisfaction.

As per the above analysis, there are three path that directly affects passenger satisfaction, which are

1. Operational Quality → Overall Passenger Satisfaction
2. Physical Quality → Overall Passenger Satisfaction
3. Travel Convenience → Overall Passenger Satisfaction

5. Conclusion

In conclusion, as passengers increasingly demand high-quality service that offers reliability, comfort, safety, and convenience, it is essential to focus on enhancing passenger satisfaction within Jaynagar–Janakpur–Bijalpura Rail Service. PLS-SEM was used to determine the overall present passenger satisfaction scores for latent variables. The result of PLS-SEM points out that among the three latent variables, Operational Quality, Physical Quality, and Travel Convenience positively influence the service quality of rail service. All these latent variables are important aspects of rail service. Twelve specific service aspects (observed variables) contribute to three broader categories (latent variables), increasing the overall satisfaction of passengers. Based on the findings of this study, several practical and research-oriented recommendations can be made to improve railway service quality and passenger satisfaction.

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