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## Modelling Passenger Satisfaction in Light Rail Transit Using an Integrated TAN Bayes and PLS-SEM Approach

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### Highlights

- An integrated TAN Bayes and PLS-SEM framework is proposed for analysing LRT user satisfaction.
- Sustainability aspects and direct benefits emerge as the strongest drivers of user satisfaction.
- Socio-demographic variables significantly shape passengers' perceptions of metro service quality.

### Abstract

Light rail transit (LRT) is seen as an environmentally friendly public transport alternative compared to other motorised modes due to reduced air pollution, lower energy consumption, and greenhouse gas emissions. This study aims to investigate regular users' perception of LRT and whether socio-demographic variables influence its use. A questionnaire with attitudinal statements categorised into six main themes, namely service quality, network and infrastructure, accessibility, user benefits, sustainability aspects, and socio-demographics, was piloted and distributed using online channels across the Tyne and Wear Metro catchment area. Using a combination of Tree Augmented Naïve (TAN) Bayes and Partial Least Square Structural Equation Modelling (PLS-SEM) techniques, the interrelationships between statistically significant perception variables affecting regular users' metro use were identified. The analysis emphasises the influential role of accessibility, direct benefits, policy implementation, reliability and availability, sustainability, and security and safety in enhancing user satisfaction. Notable interrelationships were also found, including positive associations between comfort-customer care and reliability-availability, and between safety-security and accessibility. Valuable insights into factors affecting metro use provide transport planners and policymakers with scientific evidence to make informed decisions on improving the metro system's efficiency and effectiveness, enabling cost-effective investments to make LRT more attractive and increase patronage.

**Keywords:** Light Rail Transit Systems, Perception and attitudes, Partial Least Square-Structural Equation Modelling, Tyne and Wear Metro, Public Transport

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## 1. Introduction

Light rail transit (LRT) is considered an environmentally friendly public transport alternative due to its potential to reduce air pollution, energy consumption, and greenhouse gas emissions (Sarmiento, 2013). In recent decades, people's perceptions and attitudes towards public transport services have been investigated from many different perspectives (Arabikhan et al., 2016; Echaniz et al., 2018). The significance of service quality and its enhancement has drawn considerable attention across a range of research fields, with companies, operators, and governments increasingly recognising the need to provide high levels of service in order to enhance customer satisfaction and attract new users. The relationship between service quality and satisfaction has been thoroughly examined in a variety of sectors including marketing and tourism as well as online services (Ho & Lee, 2007; Shonk & Chelladurai, 2008). Within the field of public transport investigating service quality has become especially important for governments and operators who seek to challenge private car ownership by tackling problems such as mobility and traffic congestion along with air pollution (Beirão & Cabral, 2007; De Oña, 2015). Apart from service quality itself a wider collection of factors has been proven to impact an individual's choice to use public transport which includes land use patterns and network connectivity as well as socio demographic characteristics (Rasca & Saeed 2022). Numerous studies have investigated the factors influencing passenger satisfaction and preferences for light rail transit and they often highlight a specific group of service factors as the main drivers. Kamaruddin et al., (2012) discovered that light rail transit was the favoured method of travel because of its efficiency regarding time and speed as well as fare and accessibility alongside reliability and communication plus comfort and safety. In that work safety was seen as the primary expectation for passengers. Majumdar and colleagues (2020) pointed to fare and connectivity along with frequency as significant factors that impact the general quality of a metro service while noting that these areas needed better performance. Ibrahim et al., (2021) researched the impact of gender and age on how passengers see service quality for the Kuala Lumpur light rail transit and they found that the main drivers of satisfaction changed quite a bit between different gender and age groups. A comparison by Ismail and colleagues (2012) between the KTM commuter train services and light rail transit in Malaysia showed that passenger preferences and satisfaction were higher for light rail transit which stresses the importance of facilities and comfort as well as the quality of service. Ibrahim et al., (2022) also identified signage and amenities plus the way information is provided as the main factors that affect how satisfied users feel with light rail transit services in the Klang Valley of Malaysia. Overall these studies indicate a regular group of variables such as accessibility and reliability as well as availability and direct benefits plus security and safety alongside sustainability factors as being consistently influential across many situations. This provides the foundation for the variables chosen for this specific study. While these earlier works offer useful information they mostly treat service quality factors as independent ideas and very few have looked at the interrelationships between these factors or how socio demographic traits might change these relationships.

A variety of techniques have been used to investigate service quality within public transport including the Composite Index (De Oña et al., 2016) and Importance Performance Analysis (Weinstein, 2000) as well as Multinomial Logit models (Eboli & Mazzulla, 2008) and the VIKOR method (Kuo & Liang, 2011). Structural Equation Modelling has however become especially popular because of its capacity to manage several variables at the same time including latent variables and to analyse their structural relationships (Hapsari et al., 2017; Yilmaz & Ari, 2017). This approach is widely seen as one of the most successful ways to measure latent variables and to evaluate their interrelationships (Chiou and Chen 2012). Even with these benefits the use of this modelling in public transport research frequently misses the indirect effects that come from the interrelationships between various service dimensions. Research indicates that these dimensions can influence each other which creates indirect effects on total user satisfaction that standard methods might not always catch (Chou & Kim, 2009; Rahman et al., 2016). Combining Bayesian Network modelling with Structural Equation Modelling has been shown to work well in fixing this issue when looking at customer survey results (Duarte et al., 2011; Trentini et al., 2015). These results consistently show how vital the service quality perceptions of users are for solving urban mobility problems and for getting more people to use transit (Mandhani et al., 2021).

Despite these developments current Bayesian Network methods have not yet used Tree Augmented Naïve Bayes to look at how socio demographic variables influence perceptions of service quality in public transport. Researchers have called for the integration of Bayesian Network modelling with Partial Least Square Structural Equation Modelling (PLS-SEM) to address this gap (Wu, 2010). Moreover, whilst case study analyses in this field tend to focus on either light rail or metro systems in isolation, the Tyne and Wear Metro present a distinctive and particularly valuable case study context. Operating across the Tyne and Wear region in north-east England, it is one of 11 light rail transit systems in the British Isles and Ireland, and is notable for functioning as a light rail system whilst incorporating regular metro characteristics, including both underground and overground sections. This hybrid nature, combined with the diversity of its user base in terms of age, income, and employment, makes it a well-suited environment in which to investigate the relationships between service quality perceptions, user satisfaction, and socio-demographic characteristics. To the authors' knowledge, no previous study has applied a combined TAN Bayes and PLS-SEM framework to investigate user satisfaction in such a context, and this represents the primary contribution of the present work. The attitudinal statements used in the

questionnaire were derived from a prior thematic analysis of the academic literature on light rail transit ridership (Ayan et al., 2025), lending further validity to the variable selection and survey instrument employed.

This research consequently looks at the following research question: which service quality dimensions have the most significant impact on the satisfaction of regular users within the Tyne and Wear Metro, how do these dimensions connect with each other, and how far do socio demographic characteristics moderate these relationships? To tackle this question the following specific objectives have been established:

- To identify and analyse the main variables that affect user satisfaction such as accessibility and direct benefits as well as policy implementation and reliability with availability plus sustainability aspects and security with safety.
- To explore the interrelationships found between these variables by looking at factors like amenities and comfort with customer care and the general perceptions of the metro system.
- To investigate how socio demographic variables such as age and gender as well as education level and income plus impairment influence the perceptions users have regarding metro service quality.
- To use an integrated TAN Bayes and PLS-SEM analytical framework to reveal the interrelationships among variables and provide a detailed picture of their total impact on user satisfaction.
- To add to the current body of knowledge by showing the analytical worth of merging TAN Bayes and PLS-SEM when researching public transport user satisfaction.

The rest of this paper is organised in the following way. Section 2 includes the data collection methods and the analytical framework used. Section 3 sets out the results while Section 4 contains conclusions and considers the implications for policy and professional practice.

## 2. Materials and Methods

This part of the paper details the specific area of study and the procedures used for data collection along with the development of the survey instrument and the three-stage analytical framework utilised to explore the perceptions and satisfaction levels of regular passengers on the Tyne and Wear Metro.

### 2.1 Study Area and Data Collection

The Tyne and Wear Metro represents one of the eleven light rail transit systems that are currently in operation throughout the British Isles and Ireland, serving as a vital component of the regional transport infrastructure. Serving the metropolitan county of Tyne and Wear in north-east England, the network includes both underground and overground sections, connecting major urban centres including Newcastle upon Tyne, Sunderland, and Gateshead. The geographical layout of the network, illustrating the various stations distributed along the yellow and green lines, is presented in Figure 1. The system serves a diverse ridership in terms of age, employment, and income, making it a suitable context for examining the relationships between service quality perceptions and socio-demographic characteristics.

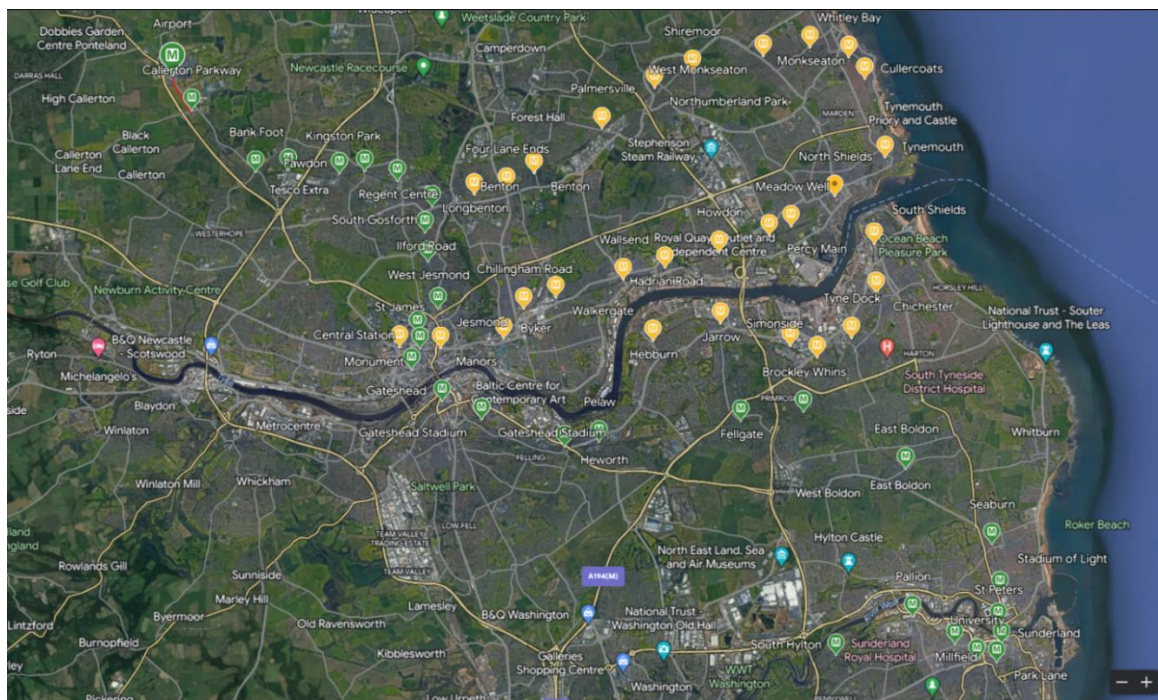


Figure 1. Map of the Tyne and Wear Metro system showing stations along the yellow and green lines.

Data were collected by means of an online questionnaire survey distributed across the Tyne and Wear Metro catchment area between 2nd March 2023 and 2nd April 2023. The questionnaire was piloted prior to full distribution and modified based on feedback received. Distribution was carried out via email to university staff and students, District Councils in the Tyne and Wear region, a panel connected to Nexus Passenger Transport Executive, and the market research company Prolific Ltd., which assists researchers in recruiting participants for online research. Approximately 900 responses were received in total. Following data cleaning and preparation, 344 responses from regular users, defined as those who used the metro at least once a week, were retained for analysis. A further 450 occasional users, defined as those using the metro two to three times a month or less, were excluded from the current analysis, with the aim of addressing this group in a separate forthcoming publication.

It is acknowledged that the online distribution method may have limited the representation of older age groups, who tend to engage less with online platforms. The sample is therefore more representative of working-age regular metro users, and findings should be interpreted with this in mind. Nevertheless, the achieved sample of 344 regular users provides a sufficient basis for the multivariate analytical techniques employed in this study.

## 2.2 Questionnaire Design

The questionnaire was developed on the basis of a prior thematic analysis of the academic literature on light rail transit ridership (Ayan et al., 2025), through which six main themes were identified: service quality, network and infrastructure, accessibility, user benefits such as time and cost, sustainability aspects, and user-focused factors such as socio-demographics. In total, 32 attitudinal statements were included in the survey, each rated on a seven-point Likert scale running from 1 (strongly disagree) to 7 (strongly agree). In addition to these attitudinal items, respondents were asked to provide information on their socio-demographic characteristics, including age, gender, education level, income, and impairment status, as well as details about their typical travel patterns and their intentions regarding future metro use.

## 2.3 Analytical Framework

The analytical framework employed in this study consists of three sequential stages, as illustrated in Figure 2: Principal Component Analysis (PCA), Tree Augmented Naïve (TAN) Bayes network learning, and Partial Least Square Structural Equation Modelling (PLS-SEM). These methods were applied in combination to provide both a data-driven understanding of the relationships among variables and a theoretically grounded assessment of their structural effects on user satisfaction.

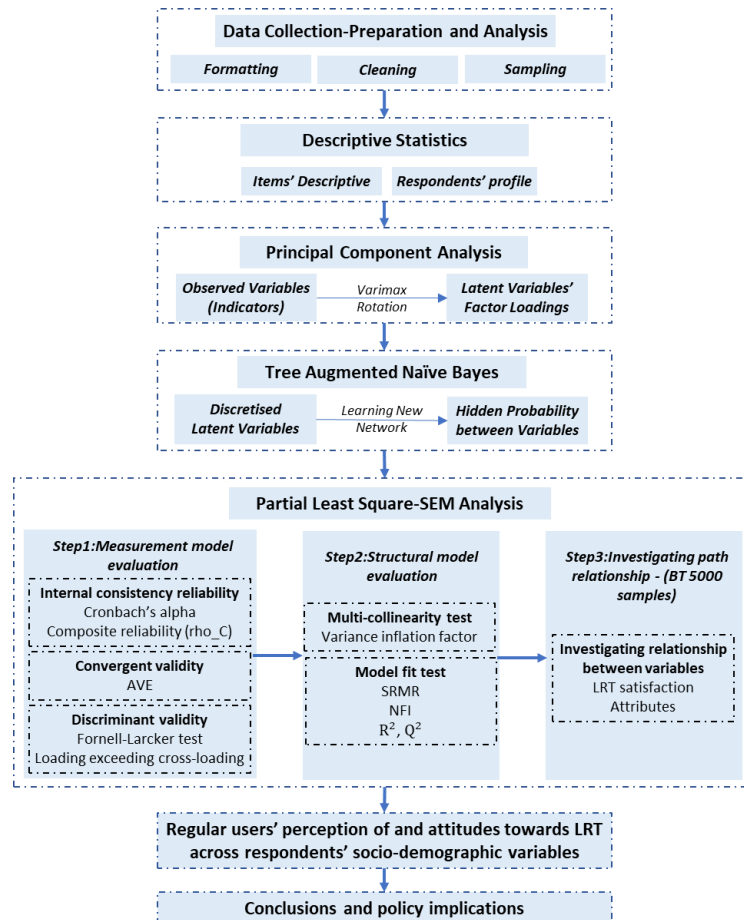


Figure 2. Methodological framework

### Principal Component Analysis

Because the research follows an exploratory path the first stage involved identifying the interrelationships found among the attitudinal statements to decide which items might form a latent variable. This objective was met by applying Principal Component Analysis with Varimax rotation within the IBM SPSS software environment. The primary goal of this technique is to condense the quantity of explanatory variables represented by  $n$  into a more compact set of principal components denoted by  $k$  which can successfully replace the initial variables while minimising any loss of information. Within this method the total number of principal components can match the number of variables in the data set so that  $k = n$  yet only those components showing eigenvalues above one are selected for subsequent investigation. Component loadings which are also referred to as factor loadings indicate the specific influence that every variable exerts upon a particular component. A greater loading value implies that the variable possesses a more robust impact on the associated component whereas a smaller value points to the absence of any significant influence. For the purposes of this investigation the relationships existing between the latent variables are analysed through the TAN Bayes method by building upon the findings generated during the initial analysis. The reliability of the various observed variables within each individual component was checked using Cronbach's alpha and ten distinct analyses were carried out to assess the factors one by one in a manner that aligns with earlier research conducted by Latif and Marimon in 2019.

### TAN Bayes Method

Tree Augmented Naïve (TAN) Bayes is a semi-naïve Bayesian learning method that relaxes the assumption of attribute independence in naïve Bayes by incorporating a tree structure, in which each attribute depends on the class variable and at most one additional attribute (Friedman et al., 1997). Classification is carried out using a maximum weighted spanning tree that optimises the likelihood of the training data (Zheng & Webb, 2010). Starting with a naïve Bayes structure, the TAN algorithm introduces connections between feature variables by considering all potential interconnections amongst them with respect to the class variable, whilst imposing the constraint that each feature variable may have only one additional parent beyond the class variable (BayesFusion, 2023). The TAN algorithm, introduced by Friedman et al. (1997), incorporates a tree structure that enables each attribute to depend on the class variable and, at most, one additional attribute. The conditional mutual information used to construct the tree is defined as follows (Friedman et al., 1997):

$$I_p(X; Y|Z) = \sum_{x,y,z} P(x,y,z) \log \frac{P(x,y|z)}{P(x|z)P(y|z)} \quad (1)$$

The algorithm is implemented through four sequential steps:

- For each pair of attributes where  $i \neq j$ , the conditional mutual information  $I_p(X_i; X_j|C)$  is computed.
- A complete undirected graph is constructed with attributes  $X_1, \dots, X_n$  as vertices, where the weight of each edge between  $X_i$  and  $X_j$  is set to the corresponding value of  $I_p(X_i; X_j|C)$ .
- A maximum weighted spanning tree is derived from this graph.
- The undirected tree is subsequently converted into a directed structure by selecting a root variable at random and orienting all edges away from it.

Figure 3 illustrates the Bayesian network representations of the models created by the Naïve Bayes and TAN algorithms, respectively. Chow and Liu (1968) presented an efficient approach for generating a maximum weighted spanning tree, with the goal of increasing the likelihood that the training data was generated by the tree. The mutual information between two attributes connected by an edge determines the weight assigned to that edge, and the TAN algorithm improves on this approach by using conditional mutual information as edge weights. In the present study, the factor scores obtained through PCA for each observed variable were discretised in the GeNIe programme, assuming a normal distribution, and a new network was subsequently generated using TAN Bayes, yielding the model shown in Figure 5a.

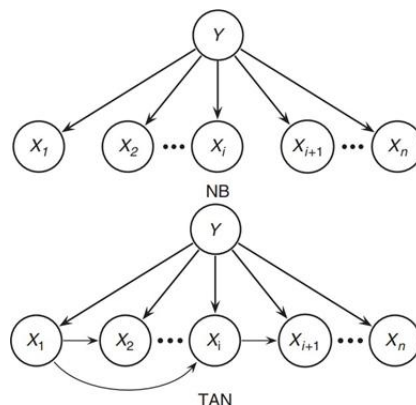


Figure 3. Bayesian network examples of the forms of the model created by NB and TAN, Source:(Zheng & Webb, 2010)

### PLS-SEM Method

Structural Equation Modelling (SEM) is a widely used statistical tool in the social sciences owing to its ability to model latent variables, account for measurement error, and assess complex theoretical structures. There are two principal variants: covariance-based SEM and variance-based SEM. The empirical variance-covariance matrix is used to estimate model parameters in covariance-based SEM, which is the preferred strategy when the hypothesised model includes one or more common components. Partial Least Square Structural Equation Modelling (PLS-SEM), on the other hand, is a variance-based approach that generates proxies through linear combinations of observable variables and uses these to estimate model parameters, making it the approach of choice when the hypothesised model comprises composites (Henseler et al., 2016). PLS path modelling is widely recognised as the most fully developed and general system amongst variance-based SEM methods (McDonald, 1996) and has been described as a silver bullet in this context (Hair et al., 2011). It allows sets of interrelationships among observed and unobserved variables to be assessed through a combination of PCA and least squares regression analysis (Tenenhaus et al., 2005).

PLS-SEM comprises two components: the measurement model, also referred to as the outer model, and the structural model, also referred to as the inner model. The relationship between each latent variable and its observed indicators is examined by the measurement model, whilst the direct and indirect relationships among the latent variables are examined by the structural model. The basic expressions for the measurement and structural models are given in Equations 2 and 3 respectively:

$$x_k = \pi_{k0} + \pi_k \xi + \varepsilon \quad (2)$$

$$\xi_j = \beta_{j0} + \sum_i \beta_{ji} \xi_i + v_j \quad (3)$$

In the present study, the TAN Bayes output model was transferred to SmartPLS for PLS-SEM analysis, yielding the model shown in Figure 5b. Model evaluation followed the criteria recommended by Henseler et al. (2016), encompassing internal consistency reliability, convergent validity, discriminant validity, and structural model fit.

### 3. Results

The results presented below draw on survey data collected from 344 regular Tyne and Wear Metro users and are organised to follow the sequence of the analytical framework, beginning with an overview of the respondent profile and descriptive statistics, before moving to the PCA outputs and then the measurement and structural model evaluations produced through the combined TAN Bayes and PLS-SEM approach.

#### 3.1 Descriptive Statistics

The socio-demographic profile of the respondents is presented in Figure 4. The age distribution reveals that the majority of participants fall within the 25 to 44 age range, with 28.1% in the 25 to 34 bracket and 27.5% in the 35 to 44 bracket, indicating a strong representation of working-age professionals. The survey achieved a reasonably balanced gender split, with 54.4% of respondents identifying as female and 44.8% as male. In terms of educational background, the largest proportions hold secondary school qualifications (46%) or vocational credentials (37.5%), whilst 8.1% had completed undergraduate or postgraduate studies. The sample captured a diverse range of occupations, with management and professional roles alongside higher education and research each accounting for the highest share at 26% apiece. Regarding income, most respondents fall within the £15,000 to £29,999 annual earnings bracket. It is also worth noting that the overwhelming majority of participants (89.8%) reported having no physical impairments. This breakdown provides useful context for interpreting the attitudinal findings, since perceptions of metro service can differ considerably depending on who is using it and how regularly.

The descriptive results reveal several noteworthy patterns in how regular users experience the metro. Station accessibility on foot is generally viewed positively, with many respondents agreeing that stops are conveniently located, though a notable share felt that the overall network coverage remains insufficient for their needs. Interchanges with other modes such as buses and trains are largely perceived as straightforward, which contributes to the metro's overall convenience. Facilities such as lifts, escalators, and platform seating received more mixed responses, pointing to areas where physical improvements could make a tangible difference to passenger comfort. Views on crowding were similarly divided, though a substantial proportion of users reported being satisfied with their ability to find a seat. Staff availability was rated only moderately, suggesting room for improvement in on-the-ground support. Both stations and trains were generally considered clean, and the metro's environmental credentials, particularly its contribution to reducing air pollution, were widely acknowledged and valued by respondents. Safety and security are regarded positively by the majority of users,

both within metro stations and on board metro vehicles. In terms of ticketing services, users generally find the information provided on the website and ticket vending machines understandable and accessible. Overall satisfaction with travelling by metro is relatively high, with 42% of respondents expressing contentment with how their travel needs are met, and a comparable proportion indicating they would recommend the metro to others.

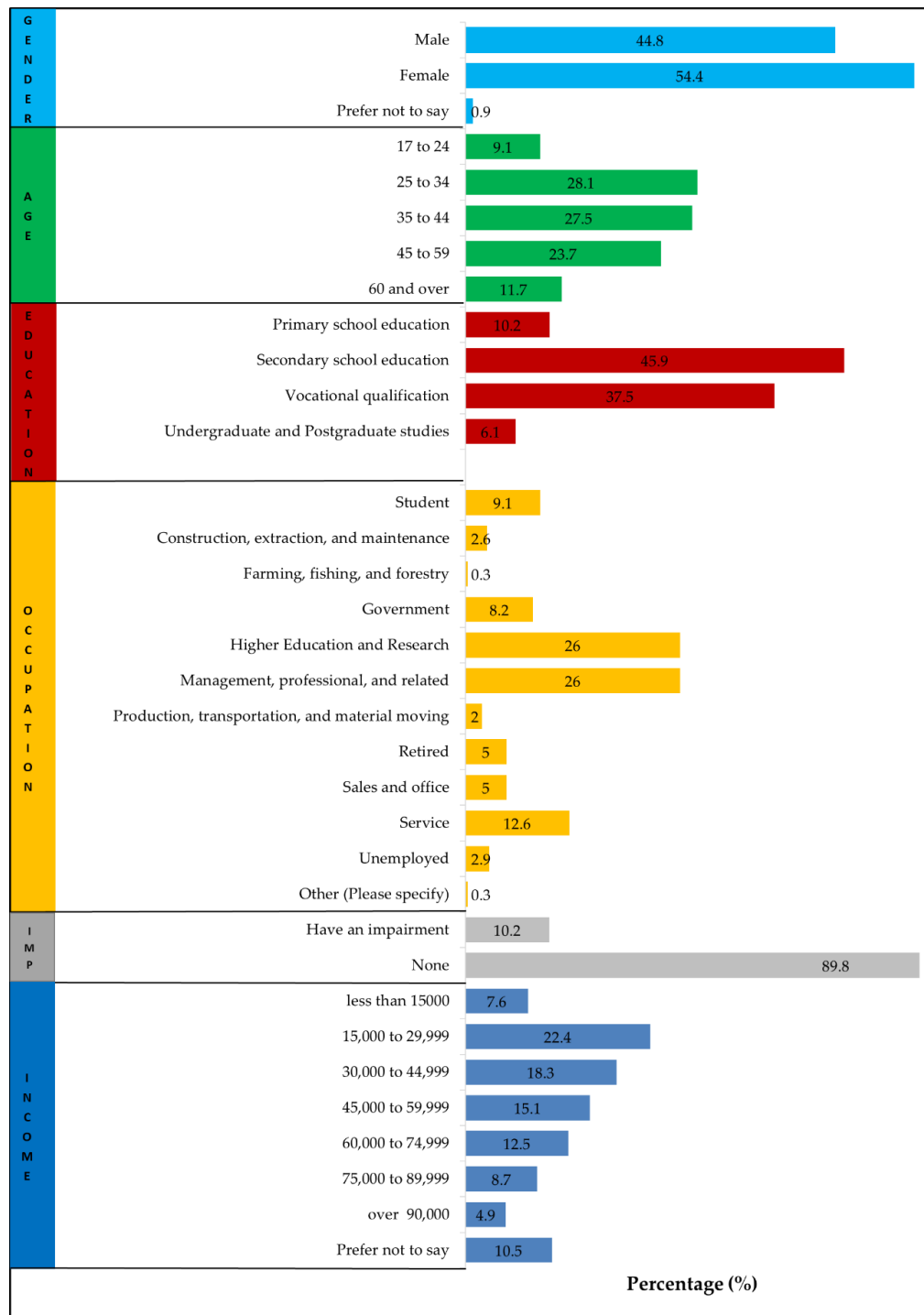


Figure 4. Socio-demographic profile of the survey participants (%)

### 3.2 Principal Component Analysis

Exploratory Factor Analysis was conducted using PCA with Varimax rotation. The data were found suitable for analysis, as confirmed by a Kaiser-Meyer-Olkin measure of sampling adequacy of 0.901 and a statistically significant Bartlett's test of sphericity with  $p < 0.001$ . Due to their low loadings, two items were removed from the analysis. Consistent with previous studies (Latif & Marimon, 2019), ten separate PCAs were implemented to evaluate the factors individually. Cronbach's

alpha values exceeded the acceptable threshold of 0.6 in all cases (Van Griethuijsen et al., 2015), and item loadings exceeded the threshold value of 0.7, signifying their substantial contribution to their respective components. The resulting components and their constituent indicators are presented in Table 1. The ten latent variables identified were: Accessibility (AC), Amenities (AM), Comfort and Customer Care (CC), Direct Benefits (DB), Policy Implementation (PI), Reliability and Availability (RA), Sustainability Aspects (SA), Security and Safety (SS), Ticketing Service (TS), and User Satisfaction (US). The factor scores obtained through PCA for each observed variable were subsequently discretised in the GeNIe programme, and a new network was generated using TAN Bayes, leading to the creation of the model shown in Figure 5a. This was then transferred to SmartPLS for PLS-SEM analysis, as shown in Figure 5b.

**Table 1.** Results of the PCA of regular users' attitudes towards LRT

| Latent Variable              | Symbol | Indicator                                                                                                | Factor Loading | Cronbach's Alpha |
|------------------------------|--------|----------------------------------------------------------------------------------------------------------|----------------|------------------|
| Accessibility                | AC1    | Metro stations are reasonably and conveniently located for walking.                                      | 0.804          | 0.638            |
|                              | AC2    | The metro network coverage is sufficient.                                                                | 0.766          |                  |
|                              | AC3    | Transfers to other transport modes (e.g. bus/train) are easy.                                            | 0.722          |                  |
| Amenities                    | AM1    | The availability of lift/escalator is sufficient, and at suitable locations.                             | 0.802          | 0.656            |
|                              | AM2    | There are sufficient benches at the stations.                                                            | 0.767          |                  |
|                              | AM3    | The trains generally are not crowded, so I can get a seat.                                               | 0.741          |                  |
| Comfort and Customer Care    | CC1    | Staff is available when needed.                                                                          | 0.807          | 0.782            |
|                              | CC2    | The metro stations and its surrounding are clean.                                                        | 0.804          |                  |
|                              | CC3    | The metro trains are clean.                                                                              | 0.796          |                  |
|                              | CC4    | Staff is informative/helpful when I need guidance.                                                       | 0.700          |                  |
| Direct Benefits              | DB1    | Travel time on metro is reasonable.                                                                      | 0.814          | 0.645            |
|                              | DB2    | Waiting time on the platform is reasonable.                                                              | 0.790          |                  |
|                              | DB3    | Metro ticket fares are reasonable.                                                                       | 0.702          |                  |
| Policy Implementation        | PI1    | An increase in fuel prices encourages me to use the metro.                                               | 0.830          | 0.794            |
|                              | PI2    | An increase in parking charges and difficulties in finding parking places encourage me to use the metro. | 0.830          |                  |
| Reliability and Availability | RA1    | The frequency of metro service is sufficient, especially during rush hours.                              | 0.845          | 0.798            |
|                              | RA2    | Metro is mostly on time.                                                                                 | 0.837          |                  |
|                              | RA3    | Updated/accurate/reliable travel information in the metro and at station is available.                   | 0.786          |                  |
|                              | RA4    | Start/end timings of metro service is good.                                                              | 0.679          |                  |
| Sustainability Aspects       | SA1    | Metro reduces air pollution.                                                                             | 0.711          | 0.640            |
|                              | SA2    | The noise pollution from the metro is acceptable to people living close by.                              | 0.805          |                  |
|                              | SA3    | The metro is a convenient mode for social activities.                                                    | 0.771          |                  |
| Security and Safety          | SS1    | I feel safe/secure (theft/aggression) in metro stations.                                                 | 0.933          | 0.842            |
|                              | SS2    | I feel safe/secure (theft/aggression) on board.                                                          | 0.915          |                  |
|                              | SS3    | I feel safe on the way to/from the station/destination.                                                  | 0.756          |                  |
| Ticketing Service            | TS1    | Ticketing information provided on the website/machines is understandable.                                | 0.906          | 0.782            |
|                              | TS2    | Ticket vending machines are easy to access/use.                                                          | 0.906          |                  |
| User Satisfaction            | US1    | I am satisfied with traveling by metro.                                                                  | 0.884          | 0.826            |
|                              | US2    | Metro meets my travel needs.                                                                             | 0.829          |                  |
|                              | US3    | I would recommend others choose the metro for regular travel.                                            | 0.874          |                  |

### 3.3 Measurement Model Evaluation

Confirmatory factor analysis was performed on the observed and latent variables to refine and confirm the measurement model. The evaluation criteria recommended by Henseler et al. (2016) were applied, encompassing internal consistency reliability, convergent validity, and discriminant validity, as reported in Table 2.

For internal consistency, Cronbach's alpha values were calculated for each latent variable and found to be acceptable, ranging between 0.64 and 0.84. Composite reliability values (Dillon-Goldstein's rho\_C) and rho\_A values (Dijkstra-Henseler's) were estimated and found to be greater than 0.70, with the exception of a few questionable rho\_A values falling between 0.65 and 0.70, which are considered borderline acceptable (Henseler et al., 2016). These results indicate good internal consistency reliability across constructs.

For convergent validity, the outer loadings of the observed variables and the Average Variance Extracted (AVE) were examined. Almost all outer loadings were observed to be close to or greater than 0.7, and AVE values ranged between 0.58 and 0.83, all exceeding the threshold of 0.50, confirming sufficient convergent validity (Henseler et al., 2016).

Discriminant validity was assessed using the Fornell-Larcker criterion and cross-loading of all indicators. The square root of the AVE values for each latent variable exceeded the equivalent squared correlation with all other latent variables, indicating good discriminant validity. Cross-loading examination further confirmed that each observed variable had its maximum loading in its respective construct.

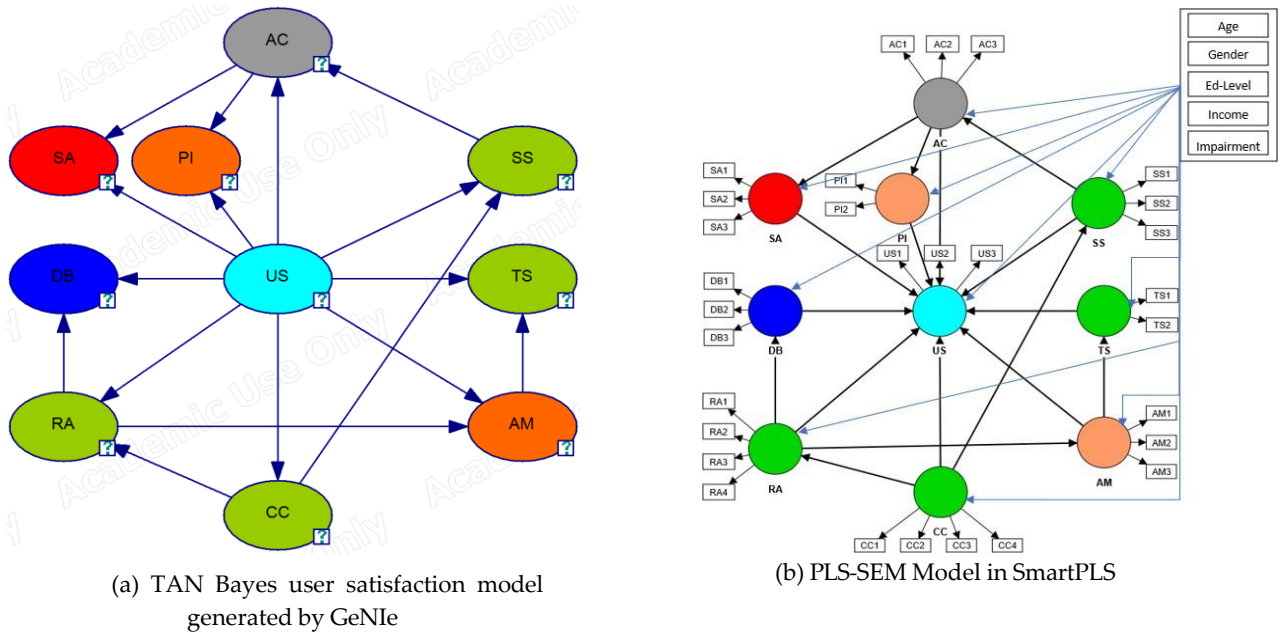


Figure 5. Regular metro users' satisfaction model

### 3.4 Structural Model Evaluation

Once the measurement model was confirmed as appropriate, the structural model was evaluated. The Variance Inflation Factor (VIF) was examined to ensure the absence of multicollinearity. The inner VIF values for all latent variables were below 3.9, well within the threshold of 5 (Henseler et al., 2016), indicating no multicollinearity concerns. The Standardised Root Mean Square Residual (SRMR) value for the structural model was found to be 0.066, below the 0.08 threshold, indicating a good model fit (Henseler et al., 2016). Furthermore, R-square values fell within the acceptable range of 0.50 to 0.99, signifying acceptable explanatory power and predictive relevance.

As a final step, bootstrapping with 5,000 sub-samples was performed to assess the significance and relevance of the path coefficients. The results of the path analysis are demonstrated in Table 3 and Figure 5b, on which the standardised path coefficients are shown for each structural link to facilitate interpretation.

The path analysis revealed several statistically significant relationships between the latent variables and the dependent variable, User Satisfaction. Accessibility ( $\beta = 0.098$ ,  $p = 0.023$ ), Direct Benefits ( $\beta = 0.244$ ,  $p < 0.001$ ), Policy Implementation ( $\beta = 0.078$ ,  $p = 0.032$ ), Reliability and Availability ( $\beta = 0.157$ ,  $p = 0.004$ ), Sustainability Aspects ( $\beta = 0.317$ ,  $p < 0.001$ ), Security and Safety ( $\beta = 0.174$ ,  $p < 0.001$ ), and Ticketing Service ( $\beta = 0.111$ ,  $p = 0.005$ ) all demonstrated positive and statistically significant influences on User Satisfaction. Conversely, Comfort and Customer Care ( $\beta = 0.030$ ,  $p = 0.583$ ) and Amenities

( $\beta = -0.050$ ,  $p = 0.225$ ) exhibited non-significant relationships with User Satisfaction. Among the entire group of variables, Sustainability Aspects and Direct Benefits were found to have the most significant impact, proving to be the primary factors that shape the general perceptions regular passengers have regarding the metro system.

**Table 2.** CFA for measurement model evaluation results

| Latent Variable              | Indicator | Factor Loading | Cronbach's alpha | CR    | rho_A | AVE   |
|------------------------------|-----------|----------------|------------------|-------|-------|-------|
| Accessibility                | AC1       | 0.816          | 0.644            | 0.808 | 0.652 | 0.584 |
|                              | AC2       | 0.735          |                  |       |       |       |
|                              | AC3       | 0.738          |                  |       |       |       |
| Amenities                    | AM1       | 0.791          | 0.657            | 0.813 | 0.664 | 0.592 |
|                              | AM2       | 0.730          |                  |       |       |       |
|                              | AM3       | 0.785          |                  |       |       |       |
| Comfort and Customer Care    | CC1       | 0.807          | 0.781            | 0.859 | 0.789 | 0.605 |
|                              | CC2       | 0.812          |                  |       |       |       |
|                              | CC3       | 0.796          |                  |       |       |       |
|                              | CC4       | 0.691          |                  |       |       |       |
| Direct Benefits              | DB1       | 0.801          | 0.656            | 0.813 | 0.670 | 0.593 |
|                              | DB2       | 0.815          |                  |       |       |       |
|                              | DB3       | 0.688          |                  |       |       |       |
| Policy Implementation        | PI1       | 0.926          | 0.795            | 0.906 | 0.812 | 0.829 |
|                              | PI2       | 0.894          |                  |       |       |       |
| Reliability and Availability | RA1       | 0.847          | 0.796            | 0.868 | 0.811 | 0.623 |
|                              | RA2       | 0.843          |                  |       |       |       |
|                              | RA3       | 0.785          |                  |       |       |       |
|                              | RA4       | 0.670          |                  |       |       |       |
| Sustainability Aspects       | SA1       | 0.652          | 0.640            | 0.801 | 0.695 | 0.576 |
|                              | SA2       | 0.763          |                  |       |       |       |
|                              | SA3       | 0.849          |                  |       |       |       |
| Security and Safety          | SS1       | 0.934          | 0.838            | 0.904 | 0.863 | 0.76  |
|                              | SS2       | 0.921          |                  |       |       |       |
|                              | SS3       | 0.747          |                  |       |       |       |
| Ticketing Service            | TS1       | 0.905          | 0.782            | 0.902 | 0.782 | 0.821 |
|                              | TS2       | 0.908          |                  |       |       |       |
| User Satisfaction            | US1       | 0.894          | 0.827            | 0.897 | 0.838 | 0.743 |
|                              | US2       | 0.817          |                  |       |       |       |
|                              | US3       | 0.874          |                  |       |       |       |

**CR:** Composite Reliability (Dillon-Goldstein's)

**rho\_A:** Dijkstra-Henseler's

**AVE:** Average Variance Extracted

Significant interrelationships were also identified between the various latent variables within the model. Strong positive relationships were discovered between Comfort with Customer Care and Reliability with Availability ( $\beta = 0.595$ ,  $p < 0.001$ ) as well as between Comfort with Customer Care and Security with Safety ( $\beta = 0.629$ ,  $p < 0.001$ ) which demonstrates that superior levels of comfort and customer care are linked with improved perceptions of reliability and security. The availability of safer and more secure facilities inside the metro system also seems to foster a greater sense of comfort and satisfaction regarding the total customer experience. Substantial positive relationships were also found between Reliability with Availability and Amenities ( $\beta = 0.603$ ,  $p < 0.001$ ) alongside Reliability with Availability and Direct Benefits ( $\beta = 0.711$ ,

$p < 0.001$ ) which suggests that a reliable and well-functioning metro service has a positive influence on how users perceive physical amenities as well as time and cost advantages. A robust positive relationship was also seen between Accessibility and Sustainability Aspects ( $\beta = 0.428$ ,  $p < 0.001$ ) which indicates that better accessibility is associated with a higher level of awareness and appreciation for the sustainability credentials of the metro. These important associations underline the interdependence of service quality dimensions and point towards the existence of indirect effects on User Satisfaction that go beyond the direct path relationships. This study adopts an exploratory approach, which acknowledges that not all variables identified could be accommodated within the model with statistically significant direct effects on User Satisfaction. The non-significant results for Amenities and Comfort and Customer Care may be associated with the fact that regular metro users, being familiar with the system, routes, and timetabling, may place comparatively less emphasis on these aspects, particularly given that journeys tend to be short.

**Table 3.** Path relationship in structural model

| Path relationship   | Path coefficient ( $\beta$ ) | S.D   | T-Value       | P-Value         |
|---------------------|------------------------------|-------|---------------|-----------------|
| AC $\rightarrow$ US | <b>0.098</b>                 | 0.043 | <b>2.273</b>  | <b>0.023</b>    |
| AM $\rightarrow$ US | -0.050                       | 0.042 | 1.213         | 0.225           |
| CC $\rightarrow$ US | 0.030                        | 0.054 | 0.549         | 0.583           |
| DB $\rightarrow$ US | <b>0.244</b>                 | 0.056 | <b>4.386</b>  | <b>&lt;.001</b> |
| PI $\rightarrow$ US | <b>0.078</b>                 | 0.036 | <b>2.143</b>  | <b>0.032</b>    |
| RA $\rightarrow$ US | <b>0.157</b>                 | 0.055 | <b>2.860</b>  | <b>0.004</b>    |
| SA $\rightarrow$ US | <b>0.317</b>                 | 0.040 | <b>7.999</b>  | <b>&lt;.001</b> |
| SS $\rightarrow$ US | <b>0.174</b>                 | 0.048 | <b>3.618</b>  | <b>&lt;.001</b> |
| TS $\rightarrow$ US | <b>0.111</b>                 | 0.039 | <b>2.830</b>  | <b>0.005</b>    |
| AC $\rightarrow$ PI | <b>0.226</b>                 | 0.058 | <b>3.862</b>  | <b>&lt;.001</b> |
| AC $\rightarrow$ SA | <b>0.428</b>                 | 0.052 | <b>8.229</b>  | <b>&lt;.001</b> |
| AM $\rightarrow$ TS | <b>0.347</b>                 | 0.048 | <b>7.225</b>  | <b>&lt;.001</b> |
| CC $\rightarrow$ RA | <b>0.595</b>                 | 0.040 | <b>14.991</b> | <b>&lt;.001</b> |
| CC $\rightarrow$ SS | <b>0.629</b>                 | 0.033 | <b>18.866</b> | <b>&lt;.001</b> |
| RA $\rightarrow$ AM | <b>0.603</b>                 | 0.035 | <b>17.437</b> | <b>&lt;.001</b> |
| RA $\rightarrow$ DB | <b>0.711</b>                 | 0.026 | <b>27.621</b> | <b>&lt;.001</b> |
| SS $\rightarrow$ AC | <b>0.365</b>                 | 0.055 | <b>6.630</b>  | <b>&lt;.001</b> |

### 3.5 Socio-demographic Path Analysis

The path analysis examining the relationships between socio-demographic variables and the latent variables is presented in Table 4. Age had a statistically significant positive effect on Direct Benefits ( $\beta = 0.103$ ,  $p = 0.006$ ) and Sustainability Aspects ( $\beta = 0.107$ ,  $p = 0.029$ ), suggesting that older users perceive greater direct benefits and place greater value on the sustainability credentials of the metro. Conversely, age had a statistically significant negative relationship with Policy Implementation ( $\beta = -0.160$ ,  $p = 0.001$ ), implying that older users are less sensitive to changes in fuel and parking prices as incentives to use the metro, in contrast to younger users for whom such policies may exert a stronger influence on travel behaviour.

Gender was found to have a statistically significant negative effect on Amenities ( $\beta = -0.192$ ,  $p = 0.026$ ) and Security and Safety ( $\beta = -0.176$ ,  $p = 0.036$ ), indicating that female respondents hold comparatively more negative perceptions of amenities and safety and security than their male counterparts. Education level had no statistically significant effect on any of the latent variables. Income negatively affected Reliability and Availability ( $\beta = -0.104$ ,  $p = 0.017$ ), indicating that higher-income users tend to perceive the metro's reliability and availability less favourably, which may reflect higher expectations or greater access to alternative modes of transport. Physical impairment was found to have a statistically significant negative impact on Comfort and Customer Care ( $\beta = -0.414$ ,  $p = 0.036$ ) which shows that passengers with impairments experience much lower levels of comfort and customer service. These users often pointed to problems like overcrowding and a lack of help from staff as their main concerns. Apart from the specific relationships mentioned earlier the vast majority of socio demographic variables failed to show any statistically significant links with the latent variables. This finding might partly result from the nature of the current participant group which consists only of regular passengers. Adding data from occasional users in future research is anticipated to provide a better understanding of how socio demographic traits moderate these relationships. Differences between those who use the system regularly and those who use it only sometimes will be explored in a future paper.

**Table 4.** Path relationship for socio-demographic variables in structural model

| Path relationship | Path coefficient ( $\beta$ ) | S.D   | T-Value      | P-Value      |
|-------------------|------------------------------|-------|--------------|--------------|
| Age → AC          | -0.044                       | 0.052 | 0.845        | 0.398        |
| Age → AM          | -0.014                       | 0.047 | 0.292        | 0.770        |
| Age → CC          | -0.021                       | 0.055 | 0.393        | 0.694        |
| Age → DB          | <b>0.103</b>                 | 0.038 | <b>2.732</b> | <b>0.006</b> |
| Age → PI          | <b>-0.160</b>                | 0.047 | <b>3.380</b> | <b>0.001</b> |
| Age → RA          | -0.049                       | 0.044 | 1.112        | 0.266        |
| Age → SA          | <b>0.107</b>                 | 0.049 | <b>2.181</b> | <b>0.029</b> |
| Age → SS          | -0.037                       | 0.041 | 0.902        | 0.367        |
| Age → TS          | -0.080                       | 0.050 | 1.617        | 0.106        |
| Age → US          | 0.016                        | 0.033 | 0.494        | 0.621        |
| Gender → AC       | 0.084                        | 0.103 | 0.807        | 0.419        |
| Gender → AM       | <b>-0.192</b>                | 0.087 | <b>2.220</b> | <b>0.026</b> |
| Gender → CC       | -0.072                       | 0.108 | 0.668        | 0.504        |
| Gender → DB       | 0.062                        | 0.079 | 0.793        | 0.428        |
| Gender → PI       | -0.198                       | 0.105 | 1.880        | 0.060        |
| Gender → SA       | -0.092                       | 0.104 | 0.880        | 0.379        |
| Gender → SS       | <b>-0.176</b>                | 0.084 | <b>2.100</b> | <b>0.036</b> |
| Gender → TS       | 0.067                        | 0.107 | 0.626        | 0.531        |
| Gender → US       | -0.094                       | 0.064 | 1.469        | 0.142        |
| EdLevel → AC      | -0.073                       | 0.048 | 1.503        | 0.133        |
| EdLevel → AM      | 0.011                        | 0.040 | 0.274        | 0.784        |
| EdLevel → CC      | 0.070                        | 0.053 | 1.307        | 0.191        |
| EdLevel → DB      | 0.010                        | 0.040 | 0.236        | 0.814        |
| EdLevel → PI      | -0.006                       | 0.053 | 0.108        | 0.914        |
| EdLevel → RA      | 0.014                        | 0.042 | 0.327        | 0.744        |
| EdLevel → SA      | 0.012                        | 0.057 | 0.218        | 0.827        |
| EdLevel → SS      | 0.048                        | 0.044 | 1.078        | 0.281        |
| EdLevel → TS      | -0.072                       | 0.051 | 1.416        | 0.157        |
| EdLevel → US      | -0.001                       | 0.034 | 0.015        | 0.988        |
| Income → AC       | 0.042                        | 0.052 | 0.809        | 0.419        |
| Income → AM       | 0.001                        | 0.042 | 0.026        | 0.980        |
| Income → CC       | 0.021                        | 0.059 | 0.363        | 0.716        |
| Income → DB       | 0.016                        | 0.036 | 0.442        | 0.659        |
| Income → PI       | -0.045                       | 0.052 | 0.859        | 0.390        |
| Income → RA       | <b>-0.104</b>                | 0.044 | <b>2.382</b> | <b>0.017</b> |
| Income → SA       | 0.022                        | 0.048 | 0.454        | 0.650        |
| Income → SS       | 0.054                        | 0.042 | 1.308        | 0.191        |
| Income → TS       | 0.041                        | 0.051 | 0.803        | 0.422        |
| Income → US       | -0.013                       | 0.031 | 0.399        | 0.690        |
| Impairment → AC   | -0.205                       | 0.193 | 1.059        | 0.290        |
| Impairment → AM   | -0.038                       | 0.140 | 0.268        | 0.789        |
| Impairment → CC   | <b>-0.414</b>                | 0.198 | <b>2.098</b> | <b>0.036</b> |
| Impairment → DB   | -0.152                       | 0.136 | 1.120        | 0.263        |
| Impairment → PI   | -0.031                       | 0.184 | 0.167        | 0.867        |
| Impairment → RA   | 0.123                        | 0.133 | 0.922        | 0.356        |
| Impairment → SA   | 0.277                        | 0.203 | 1.360        | 0.174        |
| Impairment → SS   | -0.165                       | 0.134 | 1.228        | 0.219        |
| Impairment → TS   | -0.116                       | 0.165 | 0.703        | 0.482        |
| Impairment → US   | 0.003                        | 0.097 | 0.034        | 0.973        |

### 3.6 Importance-Performance Analysis

An Importance Performance Analysis was carried out to provide further context for the structural model results, where the path coefficients taken from the PLS SEM analysis served as a way to measure importance while the mean scores from the descriptive analysis represented performance. The resulting quadrant diagram is displayed in Figure 6, where Sustainability Aspects and Direct Benefits along with Accessibility and Security and Safety are located within the high importance and high-performance quadrant. It can be noted from this that not only do these dimensions significantly impact user satisfaction, but they also get favourable ratings from regular users, indicating that they need to be maintained at the current level. Ticketing Service comes under the high importance and low performance quadrant, implying that

while this dimension provides significant value, there is potential scope for improvement in this area. Reliability with Availability and Comfort with Customer Care come under the low importance and high-performance quadrant, implying that users have a positive perception about these aspects despite their lesser significance towards overall user satisfaction. Amenities and Policy Implementation come under the low importance and low performance quadrant, implying that these aspects need to be addressed last, even though their indirect impacts cannot be overlooked.

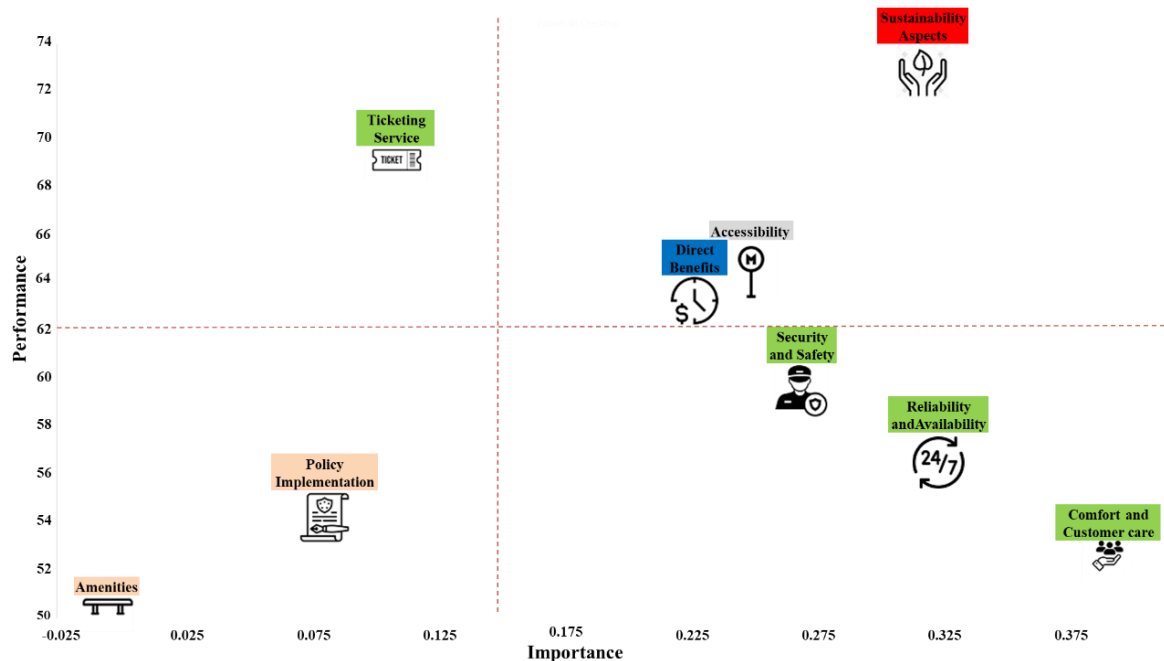


Figure 6. Importance-Performance analysis of attributes

#### 4. Conclusions

This study set out to examine how service quality dimensions, socio-demographic characteristics, and user satisfaction interact within the context of the Tyne and Wear Metro, drawing on an integrated TAN Bayes and PLS-SEM analytical framework. The results speak to each of the objectives outlined at the outset and offer a number of findings that are relevant to both the academic literature and to those working in transport planning and operations.

The path analysis makes clear that Sustainability Aspects and Direct Benefits are the strongest drivers of regular users' satisfaction with the metro, ahead of Security and Safety, Reliability and Availability, Ticketing Service, Accessibility, and Policy Implementation. This pattern sits well with what the wider public transport literature has consistently reported, namely that reliability, accessibility, and tangible user benefits tend to sit at the heart of passenger satisfaction (Kamaruddin et al., 2012; Mandhani et al., 2021). Comfort and Customer Care and Amenities did not produce statistically significant direct effects on User Satisfaction in this study, which is perhaps less surprising than it might initially appear. Regular users who know the system well and travel on it frequently may simply not weigh these factors as heavily, especially on the relatively short journeys that characterise metro use. The structural model also brought to light a set of meaningful interrelationships among the latent variables that deserve attention. Comfort and Customer Care was found to be positively associated with both Reliability and Availability and Security and Safety, which suggests that making the metro environment safer and more secure is likely to have wider knock-on effects on how passengers experience the service overall. In a similar vein, Reliability and Availability showed strong links with both Amenities and Direct Benefits, reinforcing the idea that a dependable, well-run service tends to colour how users perceive almost everything else about it. The positive association between Accessibility and Sustainability Aspects adds another layer to this picture, pointing to the interconnected nature of these dimensions and their combined potential to influence overall satisfaction. Taken as a whole, these interrelationships point to indirect effects on satisfaction that go well beyond what direct path relationships alone can reveal, and this is precisely where the combined TAN Bayes and PLS-SEM approach demonstrates its value over more conventional single-method analyses. Turning to socio-demographic influences, the findings show that age, gender, income, and impairment status each leave a mark on how specific service dimensions are perceived, whereas education level had no statistically significant bearing on any variable. Older respondents reported stronger satisfaction with the direct benefits and sustainability credentials of the metro, while younger users showed greater sensitivity to policy levers

such as fuel price increases and parking charges as motivators for public transport use. Female respondents held notably more negative views of amenities and security and safety, which points to a clear need for targeted improvements in these areas if the metro is to better serve its female passengers. Those travelling with impairments rated comfort and customer care considerably lower than their counterparts, raising concerns about crowding and the adequacy of staff support that warrant serious attention. Higher-income users were less satisfied with reliability and availability, which may reflect either higher baseline expectations or the fact that they have more viable alternatives at their disposal. Collectively, these findings make a strong case against uniform, one-size-fits-all approaches to service improvement, and suggest that operators and planners would do well to develop interventions that are more carefully calibrated to the needs of distinct user groups.

On a practical level, the results point fairly clearly towards where investment would have the greatest impact: sustainability-related upgrades, improvements in fare and travel time competitiveness, and stronger provisions around security and safety. Policies that raise the cost of driving, such as fuel duty increases or parking charges, are likely to be particularly effective in drawing younger passengers towards public transport. For users with impairments, the priority should be on accessibility enhancements and better-trained, more available staff. Achieving meaningful progress in these areas will, however, require coordinated effort across policymakers, metro operators, and other relevant stakeholders, with an awareness that improvements in one service dimension can reverberate through others.

There are a number of limitations worth acknowledging. The findings are grounded in data from the Tyne and Wear Metro and a sample of regular users, and they should not be extended uncritically to other systems or user populations. Conducting the survey online may have under-represented older age groups, and this is worth keeping in mind when reading the socio-demographic results. The study was also conducted within a defined timeframe, and developments that occurred after data collection, whether policy shifts, service changes, or broader contextual factors, fall outside what the data can speak to. The decision to focus on regular users in this paper means that occasional users are not represented here, and the relatively narrow socio-demographic variation within a regular-user sample may partly account for the limited number of significant associations observed between demographic variables and service quality perceptions. Data from occasional users will be analysed in a separate forthcoming paper, and comparing the two groups is expected to shed further light on how socio-demographic characteristics moderate metro service quality perceptions more broadly. Future work might also test whether the TAN Bayes and PLS-SEM framework travels well to other light rail and metro contexts, and whether broadening the scope to include non-regular users and a wider set of contextual variables can deepen our understanding of what drives passenger satisfaction in urban transit settings.

#### **Ethical Standards Statement**

The authors declare that they have complied with all ethical standards.

#### **Author Contributions Statement (CRediT)**

Author 1: Resources, Investigation, Methodology, Study design, Data Analysis, Writing – original draft, Visualisation

Author 2: Methodology, Project administration, Writing - review and editing

Author 3: Conceptualisation, Project administration, Writing - review and editing

#### **Conflict of Interest Statement**

The authors declare that they have no conflict of interest regarding the content of this article.

#### **Data Availability**

Data will be provided upon request.

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#### **5. References**

- Arabikhan, F., Postorino, M. N., Dupont-Kieffer, A., & Gegov, A. (2016). Gender-based analysis of zones of tolerance for transit service quality considering intelligent transportation systems. *Transportation Research Record*, 2541(1), 73–80. <https://doi.org/10.3141/2541-09>
- Ayan, H., Bell, M., & Dissanayake, D. (2025). Investigating the factors that influence the ridership of light rail transit systems using thematic analysis of academic literature. *Future Transportation*, 5, 22. <https://doi.org/10.3390/futuretransp5010022>
- BayesFusion. (2023). *Tree augmented naive Bayes*. Retrieved June 13, 2023, from [https://support.bayesfusion.com/docs/GeNIe/structurelearning\\_tan.html](https://support.bayesfusion.com/docs/GeNIe/structurelearning_tan.html)
- Beirão, G., & Cabral, J. S. (2007). Understanding attitudes towards public transport and private car: A qualitative study. *Transport Policy*, 14(6), 478–489. <https://doi.org/10.1016/j.tranpol.2007.04.009>

- Chiou, Y.-C., & Chen, Y.-H. (2012). Service quality effects on air passenger intentions: A service chain perspective. *Transportmetrica*, 8(6), 406–426. <https://doi.org/10.1080/18128602.2010.548837>
- Chou, J.-S., & Kim, C. (2009). A structural equation analysis of the QSL relationship with passenger riding experience on high speed rail: An empirical study of Taiwan and Korea. *Expert Systems with Applications*, 36(3), 6945–6955. <https://doi.org/10.1016/j.eswa.2008.08.056>
- Chow, C., & Liu, C. (1968). Approximating discrete probability distributions with dependence trees. *IEEE Transactions on Information Theory*, 14(3), 462–467. <https://doi.org/10.1109/TIT.1968.1054142>
- De Oña, J., & De Oña, R. (2015). Quality of service in public transport based on customer satisfaction surveys: A review and assessment of methodological approaches. *Transportation Science*, 49(3), 605–622. <https://doi.org/10.1287/trsc.2014.0544>
- De Oña, J., De Oña, R., Diez-Mesa, F., Eboli, L., & Mazzulla, G. (2016). A composite index for evaluating transit service quality across different user profiles. *Journal of Public Transportation*, 19(2), 128–153. <https://doi.org/10.5038/2375-0901.19.2.8>
- Duarte, C. W., Klimentidis, Y. C., Harris, J. J., Cardel, M., & Fernández, J. R. (2011). A hybrid Bayesian Network/Structural Equation Modeling (BN/SEM) approach for detecting physiological networks for obesity-related genetic variants. In *2011 IEEE International Conference on Bioinformatics and Biomedicine Workshops* (pp. 696–702). IEEE. <https://doi.org/10.1109/BIBMW.2011.6112455>
- Eboli, L., & Mazzulla, G. (2008). A stated preference experiment for measuring service quality in public transport. *Transportation Planning and Technology*, 31(5), 509–523. <https://doi.org/10.1080/03081060802364471>
- Echaniz, E., dell'Olio, L., & Ibeas, Á. (2018). Modelling perceived quality for urban public transport systems using weighted variables and random parameters. *Transport Policy*, 67, 31–39. <https://doi.org/10.1016/j.tranpol.2017.05.006>
- Friedman, N., Geiger, D., & Goldszmidt, M. (1997). Bayesian network classifiers. *Machine Learning*, 29, 131–163. <https://doi.org/10.1023/A:1007465528199>
- Hair, J. F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a silver bullet. *Journal of Marketing Theory and Practice*, 19(2), 139–152. <https://doi.org/10.2753/MTP1069-6679190202>
- Hapsari, R., Clemes, M. D., & Dean, D. (2017). The impact of service quality, customer engagement and selected marketing constructs on airline passenger loyalty. *International Journal of Quality and Service Sciences*, 9(1), 21–40. <https://doi.org/10.1108/IJOSS-07-2016-0048>
- Henseler, J., Hubona, G., & Ray, P. A. (2016). Using PLS path modeling in new technology research: Updated guidelines. *Industrial Management & Data Systems*, 116(1), 2–20. <https://doi.org/10.1108/IMDS-09-2015-0382>
- Ho, C.-I., & Lee, Y.-L. (2007). The development of an e-travel service quality scale. *Tourism Management*, 28(6), 1434–1449. <https://doi.org/10.1016/j.tourman.2006.12.002>
- Ibrahim, A. N. H., Borhan, M. N., Md. Yusoff, N. I., Ismail, A., Mat Yazid, M. R., Mhd Yunin, N. A., & Yukawa, S. (2021). Gender and age do matter: Exploring the effect of passengers' gender and age on the perception of light rail transit service quality in Kuala Lumpur, Malaysia. *Sustainability*, 13(2), 990. <https://doi.org/10.3390/su13020990>
- Ibrahim, A. N. H., Borhan, M. N., Osman, M. H., Mat Yazid, M. R., & Md. Rohani, M. (2022). The influence of service quality on user's perceived satisfaction with light rail transit service in Klang Valley, Malaysia. *Mathematics*, 10(13), 2213. <https://doi.org/10.3390/math10132213>
- Ismail, R., Hafezi, M. H., Mohd Nor, R., & Ambak, K. (2012). Passengers preference and satisfaction of public transport in Malaysia. *Australian Journal of Basic and Applied Sciences*, 6(8), 410–416. [https://www.researchgate.net/publication/263932765\\_Passengers\\_Preference\\_and\\_Satisfaction\\_of\\_Public\\_Transport\\_in\\_Malaysia](https://www.researchgate.net/publication/263932765_Passengers_Preference_and_Satisfaction_of_Public_Transport_in_Malaysia)
- Kamaruddin, R., Osman, I., & Che Pei, C. A. C. (2012). Public transport services in Klang Valley: Customer expectations and its relationship using SEM. *Procedia - Social and Behavioral Sciences*, 36, 431–438. <https://doi.org/10.1016/j.sbspro.2012.03.047>
- Kuo, M.-S., & Liang, G.-S. (2011). Combining VIKOR with GRA techniques to evaluate service quality of airports under fuzzy environment. *Expert Systems with Applications*, 38(3), 1304–1312. <https://doi.org/10.1016/j.eswa.2010.07.003>
- Latif, K. F., & Marimon, F. (2019). Development and validation of servant leadership scale in Spanish higher education. *Leadership & Organization Development Journal*, 40(4), 499–519. <https://doi.org/10.1108/LODJ-01-2019-0004>
- Majumdar, B. B., Dissanayake, D., Rajput, A. S., Saw, Y. Q., & Sahu, P. K. (2020). Prioritizing metro service quality attributes to enhance commuter experience: TOPSIS ranking and importance satisfaction analysis methods. *Transportation Research Record*, 2674(6), 124–139. <https://doi.org/10.1177/0361198120919711>
- Mandhani, J., Nayak, J. K., & Parida, M. (2021). Establishing service quality interrelations for metro rail transit: Does gender really matter? *Transportation Research Part D: Transport and Environment*, 97, 102888. <https://doi.org/10.1016/j.trd.2021.102888>
- McDonald, R. P. (1996). Path analysis with composite variables. *Multivariate Behavioral Research*, 31(2), 239–270. [https://doi.org/10.1207/s15327906mbr3102\\_5](https://doi.org/10.1207/s15327906mbr3102_5)
- Rahman, F., Das, T., Hadiuzzaman, M., & Hossain, S. (2016). Perceived service quality of paratransit in developing countries: A structural equation approach. *Transportation Research Part A: Policy and Practice*, 93, 23–38. <https://doi.org/10.1016/j.tra.2016.08.002>
- Rasca, S., & Saeed, N. (2022). Exploring the factors influencing the use of public transport by commuters living in networks of small cities and towns. *Travel Behaviour and Society*, 28, 249–263. <https://doi.org/10.1016/j.tbs.2022.03.007>
- Sarmiento, H. M. A. (2013). *Environmental sustainability of light rail transit in urban areas* (Doctoral thesis). The University of North Carolina at Charlotte, Charlotte, NC, USA. <http://hdl.handle.net/20.500.13093/etd:1652>
- Shonk, D. J., & Chelladurai, P. (2008). Service quality, satisfaction, and intent to return in event sport tourism. *Journal of Sport Management*, 22(5), 587–602. <https://doi.org/10.1123/jsm.22.5.587>
- Tenenhaus, M., Vinzi, V. E., Chatelin, Y.-M., & Lauro, C. (2005). PLS path modeling. *Computational Statistics & Data Analysis*, 48(1), 159–205. <https://doi.org/10.1016/j.csda.2004.03.005>
- Trentini, F., Malgaroli, M., Camerini, A. L., Di Serio, C., & Schulz, P. (2015). Multivariate determinants of self-management in health care: Assessing Health Empowerment Model by comparison between structural equation and graphical models approaches. *Epidemiology, Biostatistics and Public Health*, 12(1). <https://doi.org/10.2427/11126>
- Van Griethuysen, R. A., van Eijck, M. W., Haste, H., Den Brok, P. J., Skinner, N. C., Mansour, N., Savran Gencer, A., & BouJaoude, S. (2015). Global patterns in students' views of science and interest in science. *Research in Science Education*, 45, 581–603. <https://doi.org/10.1007/s11165-014-9438-6>
- Weinstein, A. (2000). Customer satisfaction among transit riders: How customers rank the relative importance of various service attributes. *Transportation Research Record*, 1735(1), 123–132. <https://doi.org/10.3141/1735-15>

- Wu, W. W. (2010). Linking Bayesian networks and PLS path modeling for causal analysis. *Expert Systems with Applications*, 37(1), 134–139. <https://doi.org/10.1016/j.eswa.2009.05.021>
- Yilmaz, V., & Ari, E. (2017). The effects of service quality, image, and customer satisfaction on customer complaints and loyalty in high-speed rail service in Turkey: A proposal of the structural equation model. *Transportmetrica A: Transport Science*, 13(1), 67–90. <https://doi.org/10.1080/23249935.2016.1209255>
- Zheng, F., & Webb, G. I. (2010). Tree augmented naive Bayes. In C. Sammut & G. I. Webb (Eds.), *Encyclopedia of machine learning*. Springer. [https://doi.org/10.1007/978-0-387-30164-8\\_850](https://doi.org/10.1007/978-0-387-30164-8_850)