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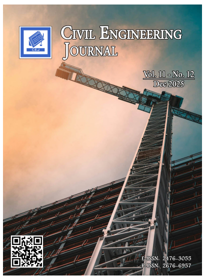

Measurement Invariance of Expectations Toward Sustainable Public Transport Service Quality Among Urban and Rural Older Adults

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Abstract

This study examines measurement invariance of expectations toward sustainable public transport service quality between urban and rural older adults in Thailand. Using second-order confirmatory factor analysis, data were collected from 1,189 elderly respondents across Thailand's four major regions through face-to-face interviews. The measurement framework incorporated eleven service quality dimensions: nine traditional attributes (Vehicle, Bus Stop, Accessibility, Convenience, Information, Staff, Safety and Security, Reliability, and Affordability) and two extended dimensions (Older's Facilities and Post-Pandemic Prevention). Results demonstrated successful measurement invariance, confirming that the eleven-factor structure operates equivalently across urban and rural contexts. Universal priorities emerged for Convenience, Staff quality, and Reliability, while rural elderly showed elevated importance for Safety and Security. The validation of Older's Facilities and Post-Pandemic Prevention as distinct dimensions establishes empirical support for incorporating age-inclusive design and health protection measures as permanent components of sustainable transport planning, justifying unified national standards while accommodating regional variations for Thailand's aging population.

Keywords: Elderly; Sustainable Public Transport; Service Quality Expectations; Multigroup Analysis; Post-COVID-19.

1. Introduction

The global demographic transition toward aging societies presents unprecedented challenges for public transportation systems, particularly in developing countries where rapid urbanization coincides with population aging. By 2050, the proportion of older adults (aged 60 and above) is projected to double globally, with the most dramatic increases occurring in Asia and other developing regions [1]. This demographic shift demands fundamental reconsiderations of how public transport services are designed, evaluated, and improved to ensure equitable mobility for all population segments.

1.1. Traditional Service Quality

The foundational framework for service quality assessment in public transport derives from the SERVQUAL model [2], which conceptualizes service quality as the gap between customer expectations and perceptions across five

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dimensions: reliability, assurance, tangibles, empathy, and responsiveness. While this model has been extensively adapted for transport contexts [3, 4], three critical limitations persist in the current literature.

First, existing service quality frameworks inadequately address the heterogeneous needs of aging populations. Previous studies have examined elderly transport requirements [5-7], yet these investigations typically treat older adults as a homogeneous group, overlooking significant variations in physical capabilities, technological literacy, and service expectations across different elderly cohorts. Recent research challenges traditional assumptions about loyalty formation in aging populations. Lieophairot et al. [8] demonstrated that service innovation—particularly interaction-oriented innovations and accessible delivery technologies—exerted the strongest overall effect on older adult loyalty in Thailand's rail sector, both directly and through its influence on service quality and passenger satisfaction. This finding suggests that innovation and perceived value may outweigh satisfaction as loyalty drivers, advancing SERVQUAL, Value–Attitude–Behavior, and Expectancy–Disconfirmation frameworks by showing that satisfaction is a necessary but insufficient condition for loyalty. Broome et al. [9] demonstrated that transport accessibility varies substantially among older adults based on functional limitations, while Hounsell et al. [10] identified five distinct profiles of older people based on fitness to travel, emphasizing varied information needs and mobility requirements.

Second, the geographic context—particularly the urban-rural divide—has received insufficient attention in elderly-focused transport research. While studies have documented service quality variations between urban and rural areas [11-13], comparative analyses examining how location shapes elderly passengers' service quality expectations remain scarce. The limited available evidence suggests substantial differences: Wong et al. [14] found that over 90% of elderly Hong Kong residents regularly used fixed-route transit. Cui et al. [15] further revealed that urban–rural bus service quality significantly influences rural residents' travel-mode choice, with reliability and convenience being the key determinants of satisfaction. The study also highlighted differences in satisfaction levels across demographic groups and confirmed that service quality positively affects bus usage among rural populations.

Beyond service quality differences, accessibility barriers compound these geographic disparities. Jahangir et al. [16] found that older adults and people with disabilities in Bangladesh face both physical barriers—including inadequate built environments such as roads, ramps, and footpaths—and social barriers such as low income, limited employment opportunities, and negative social attitudes, which collectively reduce accessibility to workplaces, healthcare, and social networks. These barriers are particularly acute in contexts with non-integrated public transport systems, where the lack of coordinated mass transit networks forces vulnerable populations to rely on informal paratransit modes like rickshaws and CNGs for last-mile connectivity. Such transport-induced social exclusion results not merely from dissatisfaction but from systemic barriers that limit access to essential services and social participation. These disparities indicate that universal service quality standards may be inappropriate, yet empirical frameworks for context-specific assessment are lacking.

Third, the COVID-19 pandemic has fundamentally transformed public transport service quality requirements, introducing health and safety dimensions that existing frameworks fail to adequately capture. Tirachini & Cats [17] and Dong et al. [18] began examining pandemic impacts on transport; however, the integration of pandemic prevention measures with traditional and age-specific quality attributes remains unexplored. Chuenyindee et al. [19] confirmed that COVID-19 protocols, tangibility, and assurance significantly affect service quality and customer satisfaction in public utility vehicles. Post-pandemic research shows that older passengers particularly value health safety measures [13, 19].

1.2. Methodological Limitations in Existing Research

The literature reveals significant methodological limitations that undermine the validity of cross-group comparisons. Most critically, measurement invariance—the statistical property ensuring that constructs are measured equivalently across groups—has been largely ignored in public transport research [20, 21]. Without establishing measurement invariance, observed differences between urban and rural elderly populations may reflect measurement artifacts rather than genuine variations in service quality expectations. Champahom et al. [22] recently addressed this gap in their study of elderly travelers' expectations of high-speed railway services, employing measurement invariance testing to ensure model equivalence across leisure and other-purpose traveler groups. Their rigorous application of configural, metric, and scalar invariance testing demonstrates the methodological standard necessary for valid cross-group comparisons in transport research.

The predominance of first-generation statistical methods such as regression analysis and ANOVA in existing studies further limits understanding of complex relationships among service quality dimensions. While Hadiuzzman et al. [23], Zhang et al. [24], and Fu & Juan [25] have begun employing structural equation modeling, second-order factor structures that could reveal hierarchical relationships among quality dimensions remain underexplored. This methodological gap prevents researchers from understanding whether certain service attributes function as higher-order constructs influencing multiple lower-order dimensions.

1.3. Emerging Evidence and Conceptual Integration

Thailand exemplifies the urgent need for evidence-based approaches to elderly-friendly public transport. With the elderly population reaching 19.5% in 2020 and projected to exceed 28% by 2040, Thailand faces one of the most rapid aging transitions globally [26]. The country's stark urban-rural disparities—with Bangkok's comprehensive mass transit system contrasting sharply with limited rural services—create natural variation for examining context-specific service quality expectations [27, 28].

The situation is further complicated by the inadequate and non-inclusive nature of existing transportation modes, which pose both infrastructural and attitudinal barriers that systematically exclude older adults and people with disabilities from equitable mobility. Studies reveal that transport personnel often exhibit insensitive behavior toward vulnerable groups, with only 4% receiving training on the needs of older adults and people with disabilities, while approximately 80% of passengers with disabilities report discourteous treatment from bus drivers and helpers [29, 30]. These behavioral barriers compound physical obstacles such as high bus floors, narrow doors, inadequate seating, and poor footpath conditions, creating multiple layers of exclusion.

Furthermore, Thailand's experience during the COVID-19 pandemic, including mandatory mask requirements, temperature screening, and capacity restrictions on public transport, provides crucial insights into integrating health safety measures with traditional service quality dimensions. Gkiotsalitis & Cats [31] emphasized that the pandemic necessitates a shift to evidence-based public transport planning to address reduced service capacity and passenger demand. This study's findings will inform evidence-based strategies for improving public transport services that meet diverse elderly needs while contributing to sustainable development and social inclusion goals [32].

Emerging evidence from Southeast Asia highlights the multidimensional nature of transport challenges facing older adults and people with disabilities. In Thailand's rail sector, interaction-oriented innovations and accessible delivery technologies have emerged as particularly influential for older passengers, underscoring the importance of human-centered innovation in aging societies [8]. However, the age-friendly city framework—while comprehensive in addressing outdoor spaces, housing, and social participation—has yet to be fully implemented in developing countries' transportation policies, leaving significant gaps in inclusive urban mobility infrastructure.

This reconceptualization of loyalty formation has profound implications for understanding transport-related social exclusion. Rather than viewing satisfaction as the primary pathway to sustained ridership, evidence suggests that systemic barriers—including non-integrated transport networks, inaccessible infrastructure, and discriminatory attitudes—fundamentally limit older adults' and people with disabilities' access to employment, healthcare, and social networks [16]. These barriers operate at multiple levels: physical (built environment), operational (service design), behavioral (staff and passenger attitudes), and institutional (policy frameworks), creating compound disadvantages that extend beyond service quality deficits.

1.4. Research Objectives and Contributions

This study addresses these critical gaps through three integrated objectives:

First, we develop and validate a comprehensive second-order confirmatory factor analysis (CFA) model that integrates traditional service quality attributes (Vehicle, Bus Stop, Accessibility, Convenience, Information, Staff, Safety and Security, Reliability, Affordability) with contemporary extended attributes (Older's Facilities and Post-Pandemic Prevention). This integration advances theoretical understanding by demonstrating how pandemic-related and age-specific dimensions relate to established quality constructs, responding to calls from researchers for more comprehensive models in post-COVID transport planning [17, 31].

Second, we empirically test measurement invariance between urban and rural older adults to ensure valid cross-group comparisons. By establishing configural, metric, and scalar invariance, this study provides methodological rigor absent from previous comparative research [12, 13], enabling confident identification of genuine differences in service quality expectations. As Champahom et al. [22] demonstrated in their high-speed rail study, such testing is essential for ensuring that observed differences reflect true variations rather than measurement artifacts. Following Vandenberg and Lance [20] argument, without such testing, group comparisons may be fundamentally flawed.

Third, we identify universal versus context-specific service quality priorities to inform both standardized quality benchmarks and tailored interventions. Through multi-group structural equation modeling, we determine which quality dimensions are equally important across contexts versus those requiring location-specific emphasis, addressing the gap identified by Berg & Ihlström [11] regarding the need for tailored rural transport solutions.

1.5. Theoretical, Methodological, and Practical Contributions

This research makes several critical contributions to the literature. Theoretically, it extends service quality frameworks to explicitly incorporate aging-related and pandemic-induced dimensions. While traditional SERVQUAL dimensions have been widely applied [3, 4], this study responds to recent calls for more comprehensive models that address both age-friendly design [6] and post-pandemic health safety requirements [13, 19]. By integrating these contemporary dimensions and demonstrating their hierarchical relationships with established constructs, the study provides a more holistic framework for understanding elderly passengers' service quality expectations in the post-COVID era. Furthermore, the findings contribute to reconceptualizing loyalty formation by examining whether innovation and value indeed outweigh satisfaction as loyalty drivers in bus transport contexts, extending insights from recent rail transport research [8].

Methodologically, this study demonstrates the importance of measurement invariance testing in transport research. Champahom et al. [22] recently highlighted this need in their high-speed rail study, but applications in conventional public bus transport remain limited. The research provides a template for rigorous cross-group comparisons by systematically testing configural, metric, and scalar invariance, ensuring that observed differences between urban and rural elderly populations reflect genuine variations rather than measurement artifacts [21]. This approach establishes best practices for future comparative studies in transport research, particularly in contexts where geographic, socioeconomic, and infrastructural disparities may confound service quality assessments.

Practically, the findings offer evidence-based guidance for developing countries facing similar demographic and geographic challenges. As Cui et al. [15] noted, understanding urban–rural differences in elderly mobility is crucial for developing effective transport policies. The identification of both universal and context-specific service quality priorities enables transport planners and policymakers to develop nuanced interventions that balance standardization with local adaptation, supporting Thailand's commitment to achieving Sustainable Development Goal 11.2. Moreover, by examining both physical accessibility barriers and social exclusion mechanisms documented in recent research [16], the study provides insights into addressing the compound disadvantages faced by older adults in accessing public transport—from inadequate infrastructure and discourteous personnel to broader issues of poverty, employment, and social participation.

Finally, the remainder of this article is organized as follows: Section 2 reviews the literature on service quality in public transport, distinguishing between traditional and extended dimensions relevant to elderly passengers. Section 3 describes the research methodology, including questionnaire development, data collection procedures, and statistical approaches for confirmatory factor analysis and multi-group comparisons. Section 4 presents the empirical findings, encompassing descriptive statistics, measurement model validation, and measurement invariance testing across urban and rural groups. Section 5 discusses the theoretical and practical implications of the findings within a sustainability framework, examining both universal service quality priorities and context-specific adaptation strategies. Section 6 concludes with key contributions, policy recommendations for sustainable transport development, and directions for future research.

2. Literature Review

2.1. Traditional Service Quality

The conceptualization of service quality in public transport has evolved from broader service marketing theories, with the SERVQUAL model serving as a foundational framework. Zeithaml et al. [33] established three types of customer service expectations: desired, adequate, and predicted service, with a zone of tolerance between desired and adequate levels. Building on this foundation, Parasuraman et al. [34] developed the service quality framework, demonstrating that quality emerges from the gap between expectations and perceptions across five core dimensions: reliability, responsiveness, assurance, empathy, and tangibles. This framework has been extensively adapted for public transport contexts [3].

In the public transport domain, traditional service quality attributes have been consistently identified across numerous studies. De Oña & De Oña [4] emphasized that traditional attributes typically encompass punctuality, comfort, cleanliness, and safety, while Bakar et al. [35] confirmed through their systematic review of 41 Asian bus service studies that 13 key attributes including frequency, on-time performance, reliability, comfort, and safety are most critical. These core attributes form the foundation of service quality assessment, as confirmed by Ojo [36] who identified reliability, punctuality, affordability, and cleanliness as the most frequently cited factors across 85 reviewed articles. Additionally, Chaisomboon et al. [37] revealed through multiple analytical approaches that safety equipment and service reliability are paramount concerns across all demographic groups.

The traditional service quality framework encompasses nine fundamental attributes consistently validated across diverse contexts:

Vehicle: Vehicle characteristics directly impact passenger comfort and safety perceptions. Barabino et al. [3] identified cleanliness, air-conditioning, and spaciousness as critical attributes, while Deb & Ali Ahmed [38] found vehicle condition among the most poorly rated factors in developing countries. Shen et al. [39] demonstrated that modern features like low-floor designs serve as standard quality indicators, while Hadiuzzman et al. [23] established that vehicle safety features significantly affect behavioral intentions.

Bus stop: Bus stop characteristics constitute critical touchpoints influencing accessibility and waiting comfort. Sun et al. [40] found asymmetric effects of amenities like shelters and benches on satisfaction, with basic facilities significantly impacting dissatisfaction when absent. Sum et al. [41] identified bus stop facilities as the most significant factor in Phnom Penh's system, while Wong et al. [5] emphasized that stop conditions regarding cleanliness, lighting, and seating significantly influence overall satisfaction.

Accessibility: This encompasses both physical access and ease of system use. De Oña & De Oña [4] emphasized spatial coverage, walking distance, and frequency as fundamental determinants, while Das & Pandit [42] found significant differences in accessibility expectations between developed and developing nations. Güner [43] demonstrated that network connectivity critically influences perceptions, while Lin & Cui [44] emphasized context-specific requirements for aging populations.

Convenience: These attributes relate to ease and efficiency of service use. Esmailpour et al. [45] identified convenience as one of four principal components encompassing boarding ease and intermodal connections, while Li et al. [46] demonstrated that intelligent information services significantly enhance perceived quality. [47] found transfer convenience substantially influences journey satisfaction, while Wisutwattanasak et al. [13] revealed different convenience prioritization between urban and rural users.

Information: Information provision has emerged as crucial in the digital age, significantly influencing passenger confidence. Wu et al. [48] found timely, accurate information reduces uncertainty and enhances reliability perceptions, while Zhou et al. [49] demonstrated that information services before and during travel significantly influence transport choices. [10] noted elderly passengers prefer simple, clear displays over complex digital interfaces.

Staff: Staff behavior significantly influences service quality across all transport modes. Ratanavaraha and Jomnonkwao [50] found driver skills primary concerns for safety, while Sinha et al. [51] demonstrated that driver attitude significantly differentiates quality perceptions between systems. Joewono et al. [52] established staff courtesy as particularly important for vulnerable passengers, while Nguyen-Phuoc et al. [53] found personnel quality significantly influenced loyalty intentions.

Safety and Security: These represent fundamental prerequisites encompassing traffic safety and personal security. Mandhani et al. [54] identified these as high-priority aspects for elderly and disabled passengers, while Kacharo et al. [55] found 50.8% of women experienced violence using public transport. van Lierop & El-Geneidy [56] demonstrated that traffic safety significantly influences passenger confidence, while Kaewsopa & Fu [57] emphasized elderly vulnerability requiring comprehensive safety measures including surveillance.

Reliability: Service reliability encompasses punctuality, consistency, and predictability. Redman et al. [58] identified reliability as key for attracting car users, while Fu et al. [59] found reliability had the strongest effect on loyalty through perceived quality. Cui et al. [15] established reliability as the most critical factor for rural residents, while Wong et al. [5] demonstrated waiting time as a significant satisfaction factor for elderly users.

Affordability: This remains fundamental, particularly in developing countries and for vulnerable populations. Zhang et al. [24] demonstrated fare affordability significantly affected passenger satisfaction, while Sam et al. [60] found users often accept lower quality when fares are subsidized. Value for money, rather than absolute fares, often determines satisfaction, with passengers evaluating fares relative to service quality and alternatives [14].

2.2. Extended Service Quality

Extended service quality dimensions encompass age-specific requirements including specialized facilities and health protection measures particularly prominent post-pandemic [19, 61]. Recognition of older adults as distinct users with specific needs has led to two critical additional dimensions complementing traditional attributes: older adults' facilities and post-pandemic prevention measures, essential for inclusive systems serving aging populations [17, 54].

Older's facilities: Demographic shifts toward aging societies have prompted specialized facilities development. Wong et al. [5] demonstrated seat availability as most critical for elderly satisfaction, while priority seating has evolved beyond designated seats to include ergonomically designed spaces. Shrestha et al. [6] noted clear, high-contrast signage addresses age-related vision changes, while appropriate audio announcements accommodate hearing limitations. Yuan et al. [7] found support feature availability significantly influenced elderly safety feelings, while Broome et al. [9] found entry/exit ease prioritized above traditional attributes.

Post-pandemic prevention: COVID-19 has fundamentally transformed service quality requirements, introducing health measures as permanent attributes significantly influencing confidence. Tirachini & Cats [17] identified visible health protection as key confidence factors for older adults facing higher risks, while Gkiotsalitis & Cats [31] emphasized visible prevention measures directly impact perceived safety. Hsieh [62] demonstrated epidemic prevention needs incorporated into safety assessment, while Ding et al. [63] found pandemic prevention services significantly impact safety perception and satisfaction. Evidence from Taiwan shows lifting anti-epidemic measures may harm ridership recovery, as passengers prioritize safety over convenience [64]. Dong et al. [18] found elderly users particularly prioritize control measure visibility including hand washing facilities and sanitization protocols, while Li et al. [61] demonstrated comprehensive prevention measures significantly influence older adults' transport willingness.

Furthermore, this research has reviewed relevant literature on public transport service quality attributes among older adults, with particular attention to studies conducted during and after the pandemic (2019–Present). As shown in Table 1, the summary provides a comprehensive overview of these studies and indicates the presence or absence of each service quality attribute across various research contexts.

Table 1. Summary of previous studies on public transport service quality attributes among older adults (2019-Present)

Authors	Location	Method	Traditional service quality attributes									Extended service quality attributes	
			Vehicle	Bus Stop/Station	Accessibility	Convenience	Information	Staff	Safety & Security	Reliability	Affordability	Older's facilities	Post-pandemic prevention
This Study	**Thailand**	**Multigroup CFA**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lieophairot et al. [8]	Thailand/Rail Transport	SEM	✓	✓	✓	✓	-	✓	-	-	-	-	-
Jahangir et al. [16]	Bangladesh/Public transport	Scoping Reviews	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	-
Khurshid & Othayoth [65]	India	Probit model	✓	✓	✓	✓	-	-	✓	✓	✓	-	-
Mandhani et al. [54]	India	IPA, SEM	-	✓	✓	✓	✓	✓	✓	-	-	✓	-
Wisutwattanasak et al. [13]	Thailand	SEM	✓	✓	-	✓	✓	✓	✓	✓	-	-	-
Lan et al. [66]	China	IAA	✓	✓	-	✓	✓	✓	✓	✓	✓	-	-
Mariotti et al. [67]	Italy	Logistic regression	-	-	-	-	✓	-	✓	✓	✓	-	-
Tavares et al. [68]	Brazil	SEM	-	-	-	-	-	-	✓	✓	-	-	-
Chaisomboon et al. [37]	Thailand	IPA / Gap analysis	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-
Liu et al. [69]	USA	Probit model	-	✓	✓	-	-	-	-	-	-	-	-
Lättman et al. [70]	Europe	SEM	-	-	✓	-	-	-	-	-	-	-	-
Yuan et al. [7]	China	IPA, SEM	-	✓	✓	✓	✓	✓	✓	✓	✓	-	-
Cirella et al. [71]	Global	Systematic review	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-

Note: ✓ means attributes that were included in the studies, IPA: Importance-Performance Analysis, IAA: Impact-Asymmetry Analysis, SEM: Structural Equation Modeling

3. Methods

3.1. Questionnaire Development

The research instrument was developed through a systematic multi-stage process combining extensive literature review and expert validation procedures. The questionnaire comprised two primary sections: (1) demographic characteristics and (2) sustainable service quality expectations. The core measurement framework incorporated eleven traditional service quality attributes included Vehicle characteristics (4 items), Bus Stop facilities (4 items), Accessibility (3 items), Convenience (3 items), Information provision (3 items), Staff service (4 items), Safety and Security (3 items), Reliability (4 items), and Affordability (3 items). Extended dimensions specifically relevant to elderly populations encompassed Older's Facilities (3 items) addressing visual/audio aids, handrails, and accessibility features, and Post-Pandemic Prevention measures (3 items) evaluating screening protocols, hygiene controls, and safety measures.

Content validity was rigorously assessed through expert evaluation involving five subject matter experts in public transportation who applied the Index of Item Objective Congruency (IOC) methodology to evaluate each measurement item. Only questions achieving an IOC score above 0.50 were retained in the final instrument, ensuring that all items demonstrated acceptable content relevance and alignment with the research objectives [72]. The instrument underwent pilot testing with 50 respondents to evaluate completion time and preliminary reliability estimates. All service quality items were measured using a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The 7-point scale was selected for its optimal balance between measurement precision and respondent usability, offering superior discrimination over 5-point scales while avoiding the cognitive burden of longer scales that may overwhelm elderly respondents with excessive options [73]. The final instrument demonstrated excellent internal consistency reliability across all constructs, with Cronbach's alpha coefficients ranging from 0.804 to 0.915, as presented in Table 2 alongside comprehensive statistical summaries for all measurement variables.

Table 2. Statistical summary: Mean, Standard deviation, Skewness, Kurtosis and Cronbach's alpha

Item	Measures	Urban (n= 631)				Rural (n = 558)			
		Mean	SD	SK	KU	Mean	SD	SK	KU
	Vehicle (Cronbach's α = 0.886)								
VEH1	Buses interiors have adequate lighting	6.36	0.84	-2.1	8.23	6.28	0.8	-0.7	-0.63
VEH2	Buses interiors are free from disturbing noise and vibration	6.32	0.86	-1.99	6.92	6.24	0.85	-1.03	0.98
VEH3	Buses have adequate seating space and comfort	6.42	0.84	-2.44	10.14	6.28	0.89	-1.15	1.06
VEH4	Overall, Bus is in good condition and feels safe	6.3	0.89	-1.82	5.94	6.24	0.89	-0.91	-0.01
	Bus Stop (Cronbach's α = 0.900)								
BST1	Bus stops are clean and usable	6.13	1.02	-1.12	1.01	6.13	0.93	-0.81	-0.23
BST2	Bus stops have weather protection	6.05	0.97	-0.88	0.71	6.05	0.93	-0.68	-0.37
BST3	Bus stops have adequate lighting	6.13	1	-1.05	1.07	6.09	0.95	-0.76	-0.11
BST4	Bus stops have adequate seating and waiting space	6.12	0.87	-1.09	2.24	6.07	0.91	-0.68	-0.26
	Accessibility (Cronbach's α = 0.866)								
ACC1	Appropriate distance from home to bus stop	6.09	0.96	-1.23	2.75	5.97	0.99	-0.68	-0.09
ACC2	Bus stop location is appropriate and accessible	6.12	0.98	-0.98	0.62	5.98	1	-0.66	-0.2
ACC3	Bus routes comprehensively cover various areas	5.94	1.07	-0.8	0.04	5.95	1.04	-0.66	-0.44
	Convenience (Cronbach's α = 0.894)								
CVN1	Convenient connections with other transport modes	6.12	0.88	-1.21	3.31	6.02	0.93	-0.57	-0.59
CVN2	Convenient boarding and alighting	6.21	0.87	-1.36	3.2	6.07	0.98	-0.68	-0.63
CVN3	Adequate and convenient luggage storage	6.17	0.93	-1.28	2.73	5.98	0.98	-0.58	-0.45
	Information (Cronbach's α = 0.850)								
IFM1	Adequate travel information at bus stops	6.35	0.74	-1.6	6.04	6.24	0.83	-0.91	0.26
IFM2	Adequate travel information on buses	6.34	0.8	-1.54	4.53	6.15	0.88	-0.81	0.28
IFM3	Advance notification of schedule changes	6.32	0.88	-1.67	4.68	6.16	0.9	-0.83	0.2
	Staff (Cronbach's α = 0.912)								
STF1	Driver/staff are ready for work (well-rested, sober)	6.32	0.88	-1.6	4.11	6.17	0.96	-0.89	-0.13
STF2	Driver/staff are dedicated and willing to serve	6.31	0.89	-1.85	5.75	6.16	0.97	-0.9	-0.13
STF3	Driver/staff provide polite and friendly service	6.32	0.88	-1.78	5.76	6.19	0.94	-0.92	-0.01
STF4	Driver/staff have good attitudes toward elderly	6.36	0.85	-1.92	6.88	6.15	0.97	-0.84	-0.33
	Safety and security (Cronbach's α = 0.914)								
SAF1	Safe bus stop usage (no obstacles, non-slip surfaces)	6.12	0.89	-1.12	2.75	5.98	0.94	-0.55	-0.59
SAF2	Personal and property safety during travel	6.22	0.85	-1.44	4.28	6.05	0.97	-0.72	-0.42
SAF3	Personal and property safety at bus stops	6.21	0.85	-1.29	3.12	6.03	0.96	-0.75	-0.08
	Reliability (Cronbach's α = 0.915)								
RLB1	Service follows schedule	5.99	0.95	-0.84	1.6	6.03	0.93	-0.56	-0.63
RLB2	Punctual arrivals and departures	6.1	0.94	-1.21	2.99	6.06	0.96	-0.64	-0.64
RLB3	Buses follow designated routes and stops	6	0.98	-0.76	0.46	6.03	0.95	-0.58	-0.73
RLB4	Appropriate waiting times	6.08	0.9	-1.27	3.68	6.04	0.94	-0.6	-0.66
	Affordability (Cronbach's α = 0.906)								
AFB1	Good value for money	6.24	0.85	-1.13	1.33	6.15	0.92	-0.84	-0.25
AFB2	Discounted rates for weekly/monthly/annual passes	6.17	0.89	-1.11	0.94	6.08	0.97	-0.75	-0.45
AFB3	Reasonable fare increases with better service	6.17	0.91	-1	0.38	6.08	1	-0.77	-0.49
	Older's facilities (Cronbach's α = 0.804)								
FCT1	Clear visual and audio information on buses								
FCT2	Handrails and stair rails on buses	6.23	0.84	-1.33	3.92	6.15	0.87	-0.89	1.04
FCT3	Ramps/lifts for wheelchair users on buses	6.22	0.95	-1.58	3.97	6.14	0.9	-0.89	0.61
	Post-Pandemic Prevention (Cronbach's α = 0.891)								
PPP1	Screening measures during outbreaks (registration, vaccination checks, temperature checks)	6.17	0.98	-1.29	2.12	6.1	0.93	-0.71	-0.45
PPP2	Prevention measures during outbreaks (distancing, masks, barriers)	6.21	0.93	-1.31	2.5	6.09	0.94	-0.93	0.78
PPP3	Control measures during outbreaks (hand washing, cleaning procedures)	6.23	1.07	-1.6	2.4	6.11	1	-0.97	0.41

Note: SD denote standard deviation, SK denote skewness, KU denotes kurtosis

3.2. Data Collection and Validation

Data collection was conducted between February and March 2024 using a comprehensive stratified sampling framework designed to capture representative perspectives from diverse geographical and socioeconomic contexts across Thailand. The sampling strategy targeted elderly participants aged 60 years and above who possessed previous experience using regional public transportation services, ensuring that respondents had practical knowledge of existing transport systems that could inform their expectations regarding sustainable service enhancements [60, 74]. The geographical stratification encompassed Thailand's four major regions - Northern, Southern, Central, and Northeastern - with provincial selection criteria prioritizing locations that maintained established public transportation infrastructure serving both urban and rural populations. This strategic selection enabled meaningful comparison of elderly expectations across varying levels of transportation service development and accessibility, reflecting the diversity of Thailand's transportation landscape from metropolitan areas with advanced transit systems to rural provinces with more limited service coverage.

Face-to-face interviews were administered by a team of trained research assistants specifically prepared to work with elderly populations and address potential challenges related to sustainable transportation terminology and conceptual understanding. Prior to questionnaire administration, research assistants provided carefully structured explanations of sustainable service quality attributes, including emerging bus technologies, accessibility features for older adults, and post-pandemic safety measures, ensuring that all participants possessed adequate conceptual understanding to provide informed responses. These explanatory sessions were designed to bridge potential knowledge gaps while avoiding leading or biasing participants' responses.

The data collection process strictly adhered to comprehensive ethical guidelines for research involving vulnerable populations, with the complete research protocol receiving formal ethical clearance from Suranaree University of Technology's Ethics Committee for Research Involving Human Subjects (COE No.3/2567). The interview protocol incorporated flexible pacing strategies to accommodate varying cognitive processing speeds and physical comfort needs, with each interview lasting approximately 20-30 minutes including consent procedures and conceptual explanations. The final validated sample comprised 1,189 respondents (631 urban, 558 rural) representing diverse socioeconomic backgrounds and transportation usage patterns across the four geographical regions, as detailed in Table 3, which provides comprehensive demographic characteristics including regional distribution alongside other key participant attributes.

Table 3. Demographic data

Characteristics	Category	Urban (n= 631)		Rural (n = 558)	
		Frequency	Percentage	Frequency	Percentage
Gender	Male	307	48.7%	266	47.7%
	Female	324	51.3%	292	52.3%
Status	Single	63	10.0%	36	6.5%
	Married	409	64.8%	385	69.0%
Age	60–69 years old	481	76.2%	429	76.9%
	70–79 years old	132	21.0%	115	20.6%
	≥ 80 years old	18	2.8%	14	2.5%
Education	Less than bachelor's degree	450	71.3%	489	87.6%
	Bachelor's degree	113	17.9%	45	8.1%
	Higher bachelor's degree	68	10.8%	24	4.3%
Occupation	Retired	137	21.7%	120	21.5%
	Government Employee	24	3.8%	17	3.0%
	Private Employee	51	8.1%	24	4.3%
	Business Owners	158	25.1%	102	18.3%
	Agriculturist	62	9.8%	178	31.9%
	General Laborer	188	29.8%	104	18.7%
	Other	11	1.7%	13	2.3%
Income	≤ 10,000 THB	323	51.2%	430	77.0%
	> 10,000 THB –20,000 THB	143	22.6%	67	12.0%
	> 20,000 THB –30,000 THB	107	17.0%	37	6.6%
	> 30,000 THB	58	9.2%	24	4.4%

Note (1): Sample size (N = 1,189); Note (2): 1 THB = 0.031 USD (November 20, 2025)

3.3. Statistical Methodology

3.3.1. Confirmatory Factor Analysis (CFA)

Confirmatory factor analysis was employed to evaluate the measurement model's validity and reliability for the eleven-factor structure of sustainable public transport service quality expectations. The CFA approach was selected over exploratory factor analysis due to the well-established theoretical foundation of service quality dimensions in public transport literature and the specific research objective of testing measurement invariance across geographical contexts [75]. The analysis was conducted using maximum likelihood estimation with robust standard errors to accommodate potential deviations from multivariate normality, as recommended by Finney & DiStefano [76] for survey data with Likert-scale responses.

The measurement model specification incorporated eleven first-order latent constructs representing traditional service quality attributes (Vehicle, Bus Stop, Accessibility, Convenience, Information, Staff, Safety and Security, Reliability, and Affordability) and extended dimensions specific to elderly populations (Older's Facilities and Post-Pandemic Prevention). Each latent construct was defined by three to four observed indicators, with factor loadings constrained to identify the model scale by fixing the first indicator loading to 1.0 for each construct. Error terms were assumed to be uncorrelated, consistent with the principle of local independence in factor analysis [77].

The CFA evaluation process encompassed three primary validation criteria: convergent validity, discriminant validity, and construct reliability. Convergent validity was assessed through examination of standardized factor loadings (target threshold ≥ 0.70), Average Variance Extracted ($AVE \geq 0.50$), and Composite Reliability ($CR \geq 0.70$), following guidelines established by Hair et al. [78]. Discriminant validity was evaluated using the Fornell-Larcker criterion, requiring that the square root of AVE for each construct exceed its correlations with other constructs [79]. Internal consistency reliability was assessed through Cronbach's alpha coefficients, with values ≥ 0.70 indicating acceptable reliability [80].

3.3.2. Multigroup Analysis

The multigroup confirmatory factor analysis framework was implemented to examine measurement invariance between urban and rural elderly populations, following the sequential testing procedure recommended by Vandenberg & Lance [20] and Putnick & Bornstein [21]. This analytical approach enables systematic evaluation of whether the measurement instrument operates equivalently across different groups, ensuring that observed differences in latent means reflect true group differences rather than measurement artifacts [81].

The measurement invariance testing sequence proceeded through increasingly restrictive nested models: (1) configural invariance establishing equivalent factor structure across groups with all parameters freely estimated, (2) metric invariance constraining factor loadings to equality across groups, and (3) scalar invariance examining equality of item intercepts in addition to factor loadings [82].

The analytical framework incorporated maximum likelihood estimation to accommodate the complex survey design. This estimation method assumes multivariate normality of observed variables and provides efficient parameter estimates when distributional assumptions are reasonably met. Distributional properties were examined through assessment of skewness and kurtosis statistics prior to model estimation [77].

3.4. Model Fit Criteria

Model fit evaluation employed a comprehensive battery of goodness-of-fit indices to assess both absolute and incremental fit, following contemporary best practices in structural equation modeling [83, 84]. The multi-index approach was adopted to provide convergent evidence for model adequacy, as no single fit index is sufficient for comprehensive model evaluation, particularly in complex multigroup contexts [85].

Absolute fit indices included the chi-square statistic (χ^2) and its associated probability value, recognizing that while statistical significance often occurs with large samples, the chi-square test provides important information about exact model fit. The chi-square to degrees of freedom ratio (χ^2/df) was evaluated using the criterion of ≤ 3.0 for acceptable fit and ≤ 2.0 for good fit, as recommended by Kline [77]. The Standardized Root Mean Square Residual (SRMR) was assessed using the criterion of ≤ 0.08 for acceptable fit and ≤ 0.05 for good fit [83]. The Root Mean Square Error of Approximation (RMSEA) was evaluated with 90% confidence intervals, applying criteria of ≤ 0.08 for acceptable fit, ≤ 0.06 for good fit, and ≤ 0.05 for excellent fit [86].

Incremental fit indices encompassed the Comparative Fit Index (CFI) and Tucker-Lewis Index [49], both assessed using the criterion of ≥ 0.95 for good fit and ≥ 0.90 for acceptable fit [83]. These indices compare the hypothesized model to a baseline independence model, providing information about the relative improvement in fit achieved by the proposed factor structure, while practical significance was evaluated through changes in CFI (ΔCFI), with values ≤ 0.01 indicating tenable invariance [87]. Additional consideration was given to changes in RMSEA (ΔRMSEA ≤ 0.015) and SRMR (ΔSRMR ≤ 0.010 for metric invariance and ≤ 0.030 for scalar invariance) as supplementary criteria for invariance evaluation [88]. The model fit evaluation process incorporated sensitivity analysis to examine the stability of findings across different estimation methods and missing data treatments. Given the elderly participant population and potential for response fatigue or comprehension difficulties, particular attention was paid to patterns of missing data and their potential impact on model fit and parameter estimates [89].

4. Results

This section presents the analytical results based on the systematic research procedure shown in Figure 1. The analysis commenced with comprehensive data preparation including data cleaning, validation, and normality assessment, followed by confirmatory factor analysis to evaluate each measurement model's convergent validity, internal consistency, and model fit. Subsequently, second-order confirmatory factor analysis was conducted for individual groups (urban and rural) to examine the hierarchical structure of service quality expectations. Finally, measurement invariance testing was performed through simultaneous modeling and factor loading constraints to assess measurement equivalence across groups. The analytical framework employed both SPSS 29.0 for descriptive statistics and Mplus 7.2 for confirmatory factor analysis, with maximum likelihood estimation ensuring robust parameter estimates and model evaluation.

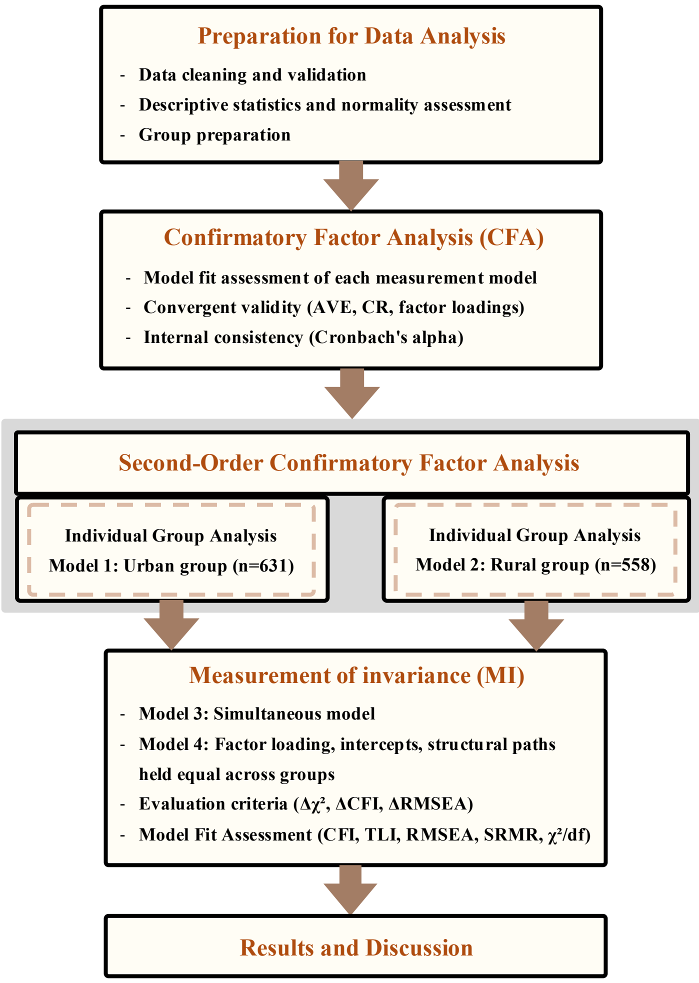

Figure 1. Research procedure

4.1. Descriptive Analysis

Table 3 presents the final validated sample comprising 1,189 elderly respondents, including 631 from urban areas (53.1%) and 558 from rural areas (46.9%). The table shows comprehensive demographic characteristics with balanced representation across key variables. Gender distribution was relatively even, with females comprising 51.3% of urban participants and 52.3% of rural participants. Age distribution showed concentration in the 60-69 years category, representing 76.2% of urban and 76.9% of rural respondents, while participants aged 70 years and above constituted approximately 24% of both groups. Educational attainment varied between urban and rural contexts, with 71.3% of urban participants and 87.6% of rural participants holding less than bachelor's degree qualifications. Occupational patterns differed notably, with urban areas showing higher proportions of business owners (25.1%) and general laborers (29.8%), while rural areas demonstrated greater representation of agriculturists (31.9%). Income distribution reflected geographical disparities, with 51.2% of urban participants and 77.0% of rural participants reporting monthly incomes ≤ 10,000 Thai Baht.

The comprehensive statistical summaries for all measurement items across urban and rural subsamples, including means, standard deviations, skewness, kurtosis, and reliability coefficients, are provided in Table 2. Mean scores across all service quality dimensions ranged from 5.941 to 6.422 for urban participants and 5.953 to 6.283 for rural participants, indicating generally positive expectations toward sustainable public transport services. Standard deviation values ranged from 0.742 to 1.068 for urban areas and 0.799 to 1.035 for rural areas, suggesting moderate variability in responses within acceptable ranges for subsequent analyses. Skewness values were predominantly negative across both groups, ranging from -0.279 to -2.435 for urban participants and -0.336 to -1.151 for rural participants, indicating slight negative skew but within acceptable limits for structural equation modeling (±2.0). Kurtosis values varied more substantially, with some items exceeding recommended thresholds, particularly in the urban subsample, necessitating careful attention during model estimation procedures. All constructs demonstrated excellent internal consistency reliability, with Cronbach's alpha coefficients ranging from 0.804 to 0.915 across both urban and rural groups, substantially exceeding the recommended threshold of 0.70 and providing strong evidence for measurement reliability.

4.2. Confirmatory Factor Analysis Results

4.2.1. Model Fit Assessment

The confirmatory factor analysis evaluated each measurement model's adequacy through comprehensive goodness-of-fit assessment across both geographical contexts. For the urban subsample (n=631), the measurement model demonstrated acceptable fit indices: χ^2 = 1227.299, df = 419, χ^2/df = 2.929, CFI = 0.959, TLI = 0.935, SRMR = 0.037, RMSEA = 0.055 (90% CI: 0.052-0.059). The rural subsample (n=558) exhibited superior fit statistics: χ^2 = 698.289, df = 437, χ^2/df = 1.598, CFI = 0.983, TLI = 0.974, SRMR = 0.026, RMSEA = 0.033 (90% CI: 0.028-0.037). Both models satisfied established criteria for good model fit, with CFI and TLI values exceeding 0.95 for rural areas and approaching this standard for urban areas. The χ^2/df ratios remained within acceptable ranges (<3.0 for rural, <5.0 for urban), while SRMR and RMSEA values demonstrated good absolute fit across both contexts. The superior fit statistics for rural participants (CFI = 0.983, RMSEA = 0.033) compared to urban participants (CFI = 0.959, RMSEA = 0.055) suggest more consistent response patterns and potentially greater conceptual clarity regarding sustainable public transport service expectations within this demographic. This may reflect that rural elderly, having experienced more limited and homogeneous transport services, possess more unified expectations about quality service, whereas urban elderly with exposure to diverse transport modes may exhibit more heterogeneous expectation patterns.

4.2.2. Convergent Validity Assessment

Examination of convergent validity through factor loadings, Average Variance Extracted (AVE), and Composite Reliability (CR) revealed mixed but generally acceptable results across the eleven service quality dimensions. As presented in Table 4, standardized factor loadings ranged from 0.581 to 0.890 for urban participants and 0.688 to 0.858 for rural participants, with most items exceeding the recommended threshold of 0.70. Average Variance Extracted values varied considerably across constructs and geographical contexts. For urban participants, AVE ranged from 0.338 (Information) to 0.792 (Convenience), with several constructs falling below the recommended threshold of 0.50, particularly Information (0.338) and Post-Pandemic Prevention (0.362). Rural participants demonstrated superior convergent validity, with AVE values ranging from 0.367 (Post-Pandemic Prevention) to 0.736 (Convenience), indicating more consistent measurement quality. Composite Reliability statistics exceeded the recommended threshold of 0.70 for all constructs across both groups, ranging from 0.806 to 0.940 for urban areas and 0.790 to 0.941 for rural areas, providing strong evidence for internal consistency reliability. The lower AVE values for Information (0.338) and Post-Pandemic Prevention (0.362) in urban areas suggest that while items are internally consistent (Cronbach's α = 0.850 and 0.891), they capture somewhat distinct facets rather than a single unified dimension. This is conceptually appropriate given that information provision encompasses diverse aspects (schedules, real-time updates, service changes) and pandemic prevention includes various measures (screening, distancing, hygiene). The construct validity is supported by high composite reliability despite moderate AVE values.

Table 4. Model fit indices for invariance test

Constructs and indicators	Urban (*N* = 631)			Rural (*N* = 558)		
	Standardized estimates (λ)	*t*-value	R^2	Standardized estimates (λ)	*t*-value	R^2
Vehicle	**(AVE = 0.702, CR = 0.904)**			**(AVE = 0.581, CR = 0.847)**		
VEH1	0.800	36.354**	0.640	0.729	25.540**	0.532
VEH2	0.821	39.604**	0.674	0.733	25.835**	0.537
VEH3	0.883	33.277**	0.780	0.798	24.747**	0.637
VEH4	0.844	43.468**	0.713	0.786	31.900**	0.618
Bus Stop	**(AVE = 0.679, CR = 0.894)**			**(AVE = 0.677, CR = 0.893)**		
BST1	0.809	47.166**	0.654	0.778	38.650**	0.605
BST2	0.838	48.834**	0.702	0.824	43.711**	0.678
BST3	0.861	56.817**	0.742	0.872	58.418**	0.761
BST4	0.787	43.055**	0.620	0.814	46.058**	0.663
Accessibility	**(AVE = 0.642, CR = 0.843)**			**(AVE = 0.665, CR = 0.856)**		
ACC1	0.811	40.699**	0.658	0.816	39.157**	0.666
ACC2	0.786	37.262**	0.618	0.807	37.622**	0.652
ACC3	0.806	40.889**	0.650	0.823	42.353**	0.677
Convenience	**(AVE = 0.701, CR = 0.875)**			**(AVE = 0.738, CR = 0.894)**		
CVN1	0.840	38.067**	0.705	0.858	36.336**	0.737
CVN2	0.887	53.238**	0.787	0.878	51.539**	0.770
CVN3	0.782	39.454**	0.612	0.841	45.781**	0.707
Information	**(AVE = 0.609, CR = 0.823)**			**(AVE = 0.616, CR = 0.827)**		
IFM1	0.777	31.008**	0.603	0.717	24.973**	0.515
IFM2	0.763	29.841**	0.582	0.777	29.337**	0.603
IFM3	0.800	34.718**	0.640	0.855	35.468**	0.730
Staff	**(AVE = 0.699, CR = 0.903)**			**(AVE = 0.714, CR = 0.909)**		
STF1	0.824	44.751**	0.679	0.824	42.809**	0.679
STF2	0.838	55.026**	0.703	0.852	53.818**	0.726
STF3	0.818	39.159**	0.669	0.856	42.112**	0.733
STF4	0.863	56.017**	0.744	0.847	47.799**	0.718
Safety and security	**(AVE = 0.826, CR = 0.934)**			**(AVE = 0.842, CR = 0.941)**		
SAF1	0.899	35.906**	0.808	0.943	39.776**	0.890
SAF2	0.919	77.047**	0.844	0.898	64.833**	0.807
SAF3	0.908	75.235**	0.824	0.912	68.254**	0.832
Reliability	**(AVE = 0.655, CR = 0.883)**			**(AVE = 0.682, CR = 0.896)**		
RLB1	0.795	36.297**	0.632	0.837	31.522**	0.701
RLB2	0.830	50.734**	0.690	0.813	39.591**	0.660
RLB3	0.717	28.157**	0.514	0.797	30.491**	0.635
RLB4	0.887	56.809**	0.786	0.855	43.292**	0.731
Affordability	**(AVE = 0.805, CR = 0.925)**			**(AVE = 0.740, CR = 0.895)**		
AFB1	0.922	91.307**	0.851	0.838	48.899**	0.702
AFB2	0.864	60.202**	0.747	0.882	49.522**	0.778
AFB3	0.904	81.283**	0.818	0.861	47.901**	0.741
Older's facilities	**(AVE = 0.581, CR = 0.806)**			**(AVE = 0.558, CR = 0.790)**		
FCT1	0.714	26.847**	0.510	0.684	23.128**	0.468
FCT2	0.781	26.836**	0.610	0.817	28.205**	0.667
FCT3	0.789	32.400**	0.623	0.734	22.421**	0.539
Post-pandemic prevention	**(AVE = 0.731, CR = 0.891)**			**(AVE = 0.698, CR = 0.874)**		
PPP1	0.829	40.233**	0.687	0.802	31.879**	0.644
PPP2	0.865	48.359**	0.749	0.843	38.412**	0.711
PPP3	0.870	47.722**	0.757	0.860	37.003**	0.739
Expected public transport service quality	**(AVE = 0.594, CR = 0.940)**			**(AVE = 0.570, CR = 0.935)**		
Vehicle	0.672	25.149**	0.452	0.688	22.340**	0.473
Bus stop	0.756	33.646**	0.571	0.767	32.840**	0.588
Accessibility	0.758	31.587**	0.574	0.765	30.798**	0.585
Convenience	0.890	42.592**	0.792	0.858	39.485**	0.736
Information	0.581	17.217**	0.338	0.619	17.613**	0.383
Staff	0.871	45.316**	0.759	0.850	39.209**	0.722
Safety and security	0.792	40.025**	0.627	0.811	38.902**	0.657
Reliability	0.871	43.140**	0.759	0.823	34.675**	0.677
Affordability	0.833	45.340**	0.693	0.779	31.694**	0.606
Older's facilities	0.777	26.693**	0.604	0.690	21.421**	0.476
Post-pandemic prevention	0.602	19.322**	0.362	0.606	17.777**	0.367

4.2.3. Internal Consistency Assessment

Internal consistency reliability demonstrated excellent performance across all service quality dimensions, with Cronbach's alpha coefficients substantially exceeding recommended standards. Reliability coefficients ranged from 0.804 (Older's Facilities) to 0.915 (Reliability) across both urban and rural contexts, providing strong evidence for the measurement instrument's internal consistency. Traditional service quality dimensions such as Safety and Security ($\alpha = 0.914$), Staff ($\alpha = 0.912$), and Reliability ($\alpha = 0.915$) demonstrated the highest reliability, while extended dimensions specific to elderly populations showed slightly lower but still excellent reliability coefficients. This pattern suggests that while the novel constructs (Older's Facilities and Post-Pandemic Prevention) are psychometrically sound, they represent well-defined conceptual domains that contribute meaningfully to the overall service quality framework.

4.2.4. Measurement Invariance Testing

The measurement invariance testing sequence examined whether the service quality measurement model operated equivalently across urban and rural elderly populations through systematic model comparison procedures. Table 5 presents comprehensive results for the invariance testing sequence. The configural invariance model (Model 3) established that the same eleven-factor structure was appropriate for both groups while allowing all parameters to be freely estimated across contexts. This simultaneous model demonstrated good fit: $\chi^2 = 1841.160$, df = 812, χ^2/df = 2.267, CFI = 0.971, TLI = 0.952, SRMR = 0.032, RMSEA = 0.046 (90% CI: 0.043-0.049), providing strong evidence that the theoretical structure of sustainable public transport service quality expectations was consistent across urban and rural elderly populations.

Table 5. Model fit indices for invariance test

Description	χ^2	*df*	χ^2/df	CFI	TLI	SRMR	RMSEA (90% CI)	$\Delta\chi 2$	Δdf	*p*
Individual groups										
Model 1: Urban	1227.299	419	2.929	0.959	0.935	0.037	0.055 (0.052-0.059)			
Model 2: Rural	698.289	437	1.598	0.983	0.974	0.026	0.033 (0.028-0.037)	152.76	89	< 0.001
Measurement of invariance										
Model 3: Simultaneous model	1841.160	812	2.267	0.971	0.952	0.032	0.046 (0.043-0.049)			
Model 4: Factor loading, intercepts, structural paths held equal across groups	1993.923	901	2.213	0.969	0.954	0.039	0.045 (0.043-0.048)			

The metric invariance model (Model 4) imposed equality constraints on factor loadings, intercepts, and structural paths across groups, testing whether measurement parameters operated equivalently between urban and rural contexts. This more restrictive model yielded slightly reduced but still acceptable fit: $\chi^2 = 1993.923$, df = 901, χ^2/df = 2.213, CFI = 0.969, TLI = 0.954, SRMR = 0.039, RMSEA = 0.045 (90% CI: 0.043-0.048). The chi-square difference test indicated significant change ($\Delta\chi^2 = 152.763$, Δdf = 89, $p < 0.001$), suggesting some parameter differences between groups. However, the change in practical fit indices was minimal (ΔCFI = 0.002), well below the 0.01 threshold, indicating that measurement invariance was tenable despite statistical significance. This result demonstrates that while some parameter differences exist, the practical significance is negligible, supporting use of the same measurement instrument across urban-rural contexts for valid comparisons.

4.3. Second-Order Confirmatory Factor Analysis

The second-order confirmatory factor analysis examined the hierarchical structure of service quality expectations through separate analysis of urban (Model 1) and rural (Model 2) elderly populations. For the urban subsample, the analysis demonstrated acceptable fit with second-order factor loadings ranging from 0.581 to 0.890, as illustrated in Figure 2. The strongest contributors to overall service quality expectations among urban elderly were Convenience ($\lambda = 0.890$), Staff ($\lambda = 0.871$), and Reliability ($\lambda = 0.871$), while Information ($\lambda = 0.581$) and Post-Pandemic Prevention ($\lambda = 0.602$) showed weaker associations with the overarching construct. The explained variance (R^2) values for second-order relationships varied considerably, with Convenience demonstrating the highest explained variance ($R^2 = 0.792$), followed by Staff and Reliability ($R^2 = 0.759$ each).

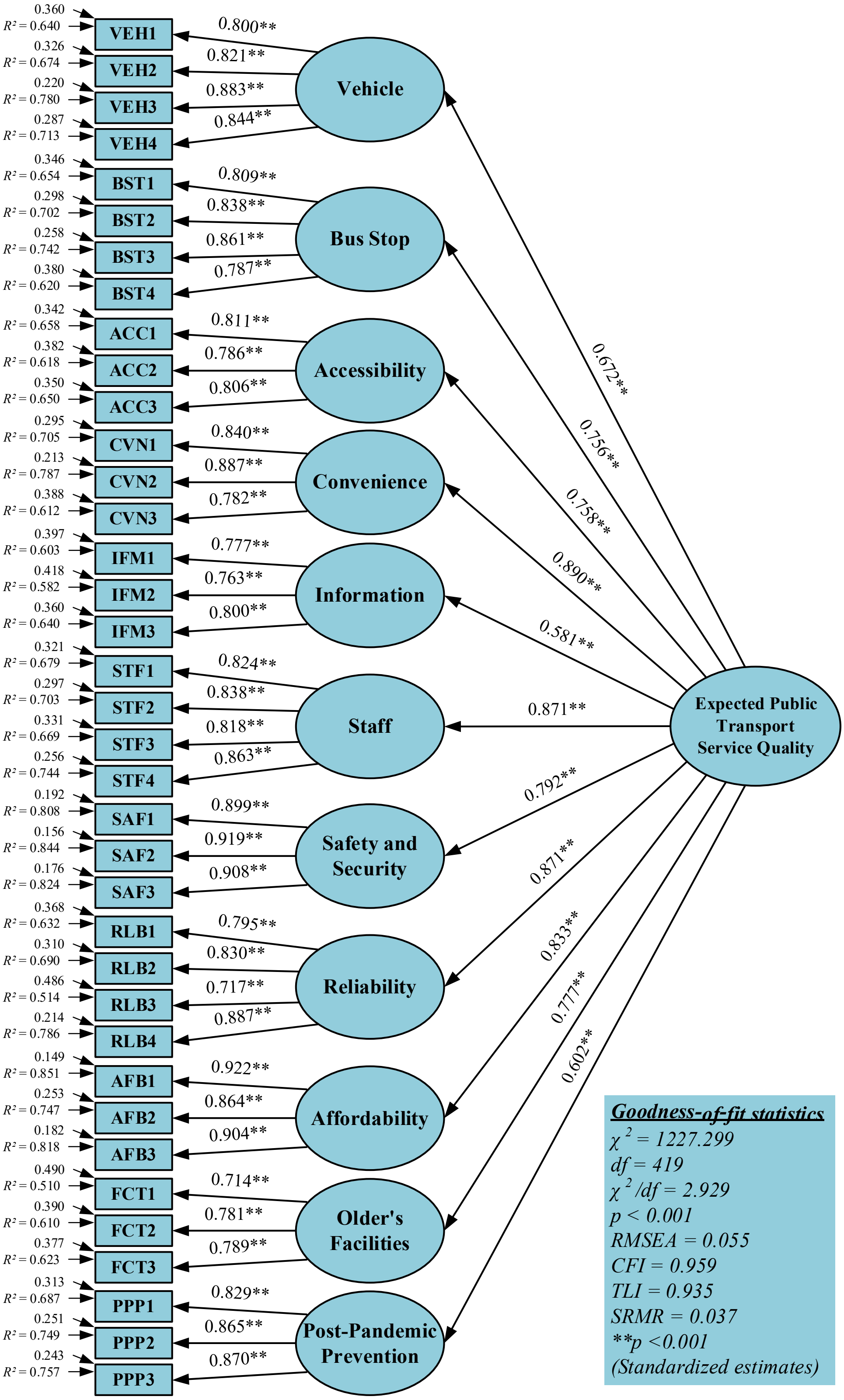

Figure 2. Second-order confirmatory factor analysis of the urban older adult group

The rural subsample exhibited superior model fit with second-order factor loadings ranging from 0.606 to 0.858, as presented in Figure 3. Key contributors to overall service quality expectations among rural elderly included Convenience (λ = 0.858), Staff (λ = 0.850), and Safety and Security (λ = 0.811), while Post-Pandemic Prevention (λ = 0.606) and Vehicle (λ = 0.688) demonstrated relatively weaker associations. The pattern of explained variance was more balanced across dimensions in rural contexts, with the highest values observed for Convenience (R^2 = 0.736), Staff (R^2 = 0.722), and Reliability (R^2 = 0.677). Both models achieved acceptable second-order factor fit, with the overall Expected Public Transport Service Quality construct demonstrating adequate explanatory power across all first-order dimensions.

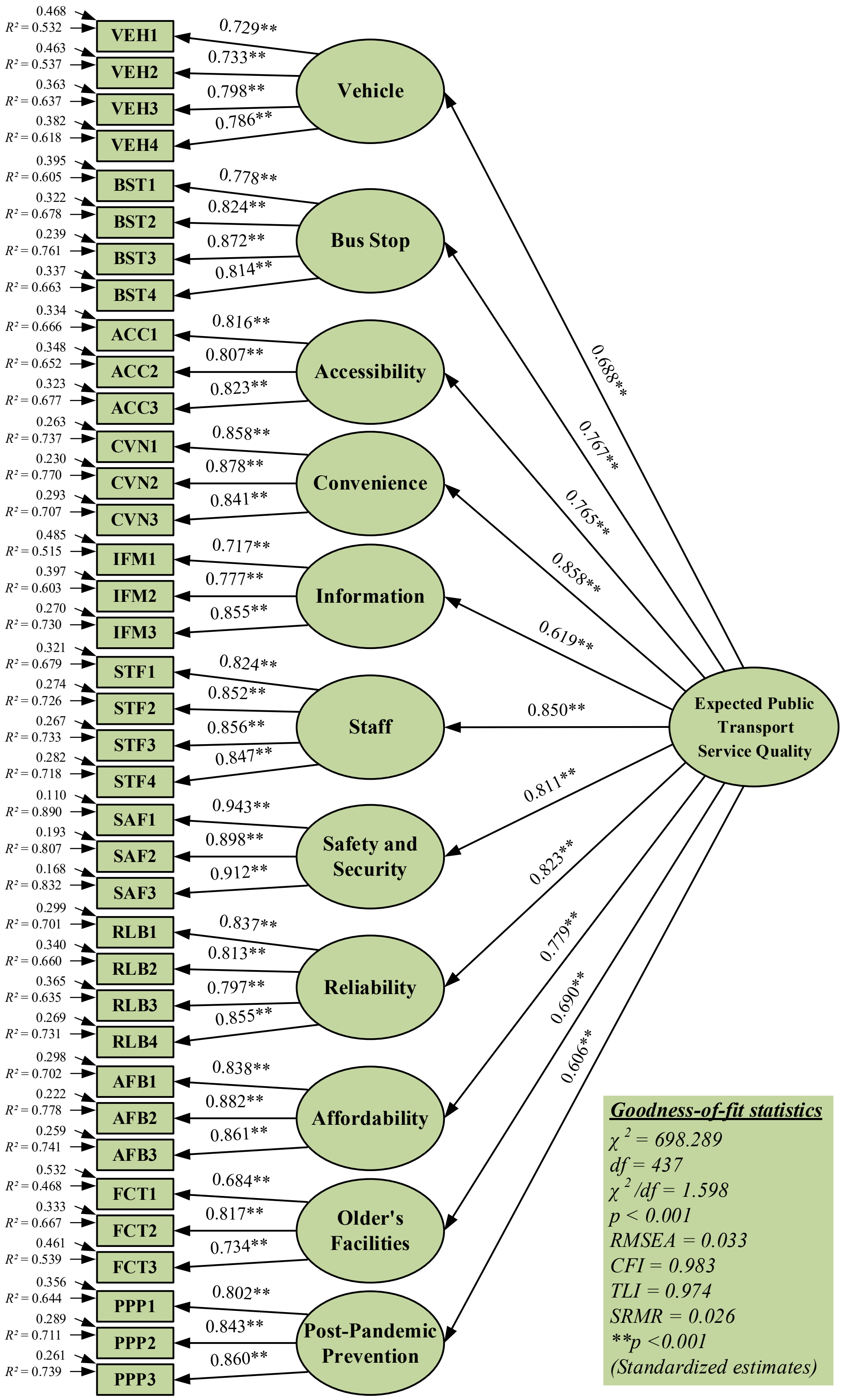

Figure 3. Second-order confirmatory factor analysis of the rural older adult group

Urban elderly prioritized Convenience ($\lambda = 0.890$, $R^2 = 0.792$), Staff ($\lambda = 0.871$, $R^2 = 0.759$), and Reliability ($\lambda = 0.871$, $R^2 = 0.759$), suggesting that urban elderly, accustomed to developed transport infrastructure, prioritize operational efficiency and service integration. Rural elderly showed similar patterns with Convenience ($\lambda = 0.858$), Staff ($\lambda = 0.850$), and Safety and Security ($\lambda = 0.811$). Notably, Safety and Security showed elevated importance in rural contexts ($\lambda = 0.811$ vs. $\lambda = 0.792$ urban), possibly reflecting concerns about infrastructure conditions, lighting, and personal security in less-developed facilities.

5. Discussion

5.1. Measurement Model Performance and Cross-Context Validation

The successful establishment of measurement invariance across urban and rural contexts provides critical theoretical and methodological contributions that advance understanding of service quality expectations among elderly populations, directly addressing concerns about result interpretation and comparison with previous literature.

Universal cognitive framework despite contextual differences: The configural invariance results demonstrate that the same eleven-factor structure operates consistently across geographical contexts, indicating that elderly passengers maintain equivalent cognitive frameworks for evaluating sustainable transport service quality regardless of their current service environment [32, 90]. This finding directly contradicts implicit assumptions in previous literature. Ponrahono et al. [12] and Das & Pandit [42] implicitly assumed that urban-rural service quality differences necessitate fundamentally different conceptual models, yet the measurement invariance results confirm elderly passengers across contexts share the same dimensional structure for quality evaluation. This has profound policy implications: unified national standards are justified because elderly passengers understand quality through the same framework, though implementation must accommodate regional priority variations.

Expectation coherence through constraint: The superior model fit in rural contexts compared to urban areas represents a striking finding that contradicts common assumptions embedded in transport literature. Previous studies implicitly assumed urban populations, with greater education and transport exposure, would demonstrate more consistent understanding [12]. The results reveal that sophistication and consistency are distinct properties—rural elderly demonstrate equal conceptual sophistication in understanding quality dimensions but exhibit greater consensus in their evaluations. Limited current service options create "expectation coherence through constraint": having experienced fewer transport alternatives, rural elderly possess more unified, crystallized expectations about what constitutes quality service. Conversely, urban elderly exposed to diverse modes including mass transit, buses, taxis, and ride-sharing exhibit more heterogeneous expectation patterns reflecting genuine diversity shaped by varied experiences rather than conceptual confusion. This interpretation challenges previous research that may have incorrectly interpreted urban-rural fit differences as evidence of rural respondents' limited understanding rather than recognizing urban diversity and rural coherence as equally valid patterns. The practical implication: limited current services may facilitate clearer future expectations rather than constraining conceptual understanding, providing opportunities to build upon existing clarity in rural service development.

Practical equivalence despite statistical differences: The metric invariance model demonstrated that while the chi-square difference test indicated statistical significance when constraining factor loadings across groups, the practical fit change was minimal, well below recommended thresholds for rejecting invariance [87, 88]. This pattern demonstrates that observed parameter differences, though statistically detectable with large samples, lack practical significance for measurement comparisons. The finding validates using identical measurement instruments across urban-rural contexts while acknowledging that relative priorities may vary—a nuanced conclusion impossible without rigorous invariance testing that previous comparative studies lacked [13, 15]. This methodological advancement extends Champahom et al. [22] recent demonstration of invariance testing importance in high-speed rail contexts to conventional bus transport and geographic comparisons, broadening the empirical foundation for valid cross-group comparisons in transport research.

5.2. Hierarchical Structure

The second-order factor analysis reveals both universal priorities and context-specific adaptations, providing nuanced understanding through systematic comparison with previous research.

Universal priorities: Convenience, Staff, and Reliability. Three dimensions emerged as primary drivers across both urban and rural elderly populations: Convenience, Staff quality, and Reliability. The remarkable consistency of these priorities across contexts indicates that sustainable public transport must integrate operational excellence with environmental responsibility, challenging false dichotomies suggesting sustainability requires sacrificing service quality [4, 24].

This finding extends and refines previous research in important ways. Cui et al. [15] identified reliability and convenience as key determinants for rural Chinese residents, confirming service quality positively affects bus usage. The hierarchical model extends their work by demonstrating these dimensions function as primary drivers within a broader eleven-factor structure, explaining their disproportionate influence on overall quality perceptions. The high factor loadings and explained variance reveal that improvements in these dimensions yield greater overall quality enhancement than equivalent investments in lower-priority attributes. Lieophairot et al. [8] demonstrated that service innovation drives elderly loyalty in Thailand's rail sector, with human-centered innovations showing strongest effects. The finding that Staff quality ranks as a universal primary driver across bus transport contexts supports their emphasis on human-centered service delivery, suggesting this principle transcends transport modes. The practical implication: elderly passengers do not view environmental sustainability as conflicting with service quality; rather, they expect future systems to deliver reliable, convenient service through environmentally responsible means. This integration requirement should guide sustainable transport development: electric buses must maintain scheduling reliability, renewable energy systems must support seamless multimodal integration, and sustainability initiatives must not compromise the human-centered service delivery that elderly passengers prioritize universally.

Context-specific adaptation: Elevated rural safety concerns. Despite universal dimensional importance, relative priorities show meaningful variations revealing context-specific needs. Safety and Security demonstrated elevated importance in rural contexts compared to urban areas. While the absolute difference appears modest, the consistent pattern across all three Safety and Security indicators and its higher ranking in rural contexts suggest genuine priority elevation. This likely reflects concerns about infrastructure conditions, lighting quality at isolated bus stops, personal security in less-populated waiting areas, and emergency response capabilities in areas with limited police or medical services [54, 56].

This finding validates and extends previous research. Cui et al. [15] observed that urban-rural service quality significantly influences travel choices but did not examine safety-security specifically. The results demonstrate that perceived vulnerability varies systematically by geographic context, with infrastructure limitations in rural areas creating elevated security concerns. Jahangir et al. [16] documented multi-level accessibility barriers in Bangladesh, finding only 4% of transport personnel trained on elderly/disabled needs and 80% of disabled passengers reporting discourteous treatment. The quantitative validation that Staff quality ranks as a universal primary driver confirms their qualitative emphasis on behavioral barriers as critical accessibility constraints. While they documented current barriers, the expectation framework reveals future priorities for overcoming them through integrated solutions: physical infrastructure (Accessibility), operational design (Convenience, Reliability), and critically, staff competency addressing diverse needs respectfully. The practical implication: sustainable transport solutions must address infrastructure vulnerabilities while incorporating renewable energy sources and environmentally responsible security technologies. Rural implementations should emphasize well-lit bus stops with emergency call systems, visible security measures such as CCTV surveillance powered by solar panels, and comprehensive driver training on security awareness and passenger assistance.

5.3. Extended Dimensions

The validation of two extended dimensions—Older's Facilities and Post-Pandemic Prevention—provides important insights for inclusive and resilient transport planning, while systematic comparison with previous research reveals their nuanced roles.

Older's Facilities: Complementary rather than primary. The moderate factor loadings validate age-specific facilities as a distinct dimension while revealing they function as complementary rather than primary drivers of overall quality expectations. This finding provides critical nuance absent from previous elderly transport research.

Yuan et al. [7] found support features and driver services "critical" for elderly bus passenger satisfaction in Harbin, China, while Wong et al. [5] identified seat availability as "most critical" for elderly satisfaction in Hong Kong. These studies employed flat factor structures examining attributes individually without hierarchical context. The second-order structure reveals that Older's Facilities, while important, ranks below universal operational attributes such as Convenience and Reliability as well as human factors like Staff quality in both urban and rural contexts. This hierarchical positioning demonstrates that age-friendly features enhance but do not define quality perceptions—elderly passengers prioritize operational excellence and respectful service delivery over specialized accommodations.

These finding challenges deficit-based models treating elderly passengers primarily through their limitations. Broome et al. [9] found entry/exit ease prioritized above traditional attributes in Australian age-friendly bus evaluations, potentially reflecting their focus exclusively on elderly-specific features without broader quality context. The comprehensive framework reveals that elderly passengers conceptualize themselves as regular transit users who value the same primary attributes as general populations including convenience, reliability, and staff quality while appreciating but not prioritizing age-specific accommodations. The practical implication: age-friendly features should be integrated seamlessly into standard infrastructure rather than creating separate "elderly services" that may reinforce stigmatization and undermine dignity. Universal design approaches supporting independence for all users—low-floor vehicles, clear information, adequate lighting—serve elderly needs while benefiting diverse passengers including parents with strollers, travelers with luggage, and temporarily injured persons [6].

The lower loading in rural contexts compared to urban areas warrants interpretation. This may reflect lower baseline expectations shaped by current rural service limitations—having experienced minimal elderly-specific facilities, rural elderly may not yet conceptualize them as core quality components. Alternatively, rural elderly may prioritize basic service provision including safety, staff presence, and schedule adherence over specialized features, particularly if current services remain inadequate on fundamental dimensions.

Post-Pandemic Prevention: Temporal evolution from dominance to integration. The Post-Pandemic Prevention dimension showed the lowest second-order loadings across both contexts, revealing important temporal evolution in pandemic-related expectations through systematic comparison with previous pandemic-era research.

Dong et al. [18] analyzed Chinese post-COVID transit satisfaction using 2020-2021 data during acute pandemic phases, finding infection concern as a critical component of safety perception significantly impacting satisfaction. Hsieh [62] examined Taiwan's post-COVID transit hierarchy using 2021-2022 transition-phase data, demonstrating epidemic prevention needs incorporated into satisfaction assessment. Tirachini & Cats [17] emphasized visible health protection as key confidence factors for older adults facing higher COVID-19 risks during the global pandemic's early months. These studies consistently emphasized pandemic prevention's dominance or high criticality during acute crisis periods.

The 2024 data collection during Thailand's endemic COVID-19 transition reveals striking temporal evolution. Post-Pandemic Prevention exhibits the lowest factor loadings across all eleven dimensions, contradicting acute-phase dominance findings. This suggests a three-phase evolution model:

- Acute Crisis Phase (2020-2021): Pandemic prevention dominates, potentially overriding traditional quality concerns as survival and safety become paramount (Dong et al.'s findings period).
- Transition Phase (2022-2023): Prevention integrates with traditional attributes as societies adapt to "new normal" conditions while maintaining heightened vigilance (Hsieh's findings period).
- Endemic Phase (2024+): Prevention becomes permanent but moderated component—universally expected but no longer dominant, as societies learn to manage ongoing viral presence while resuming normal activities (current findings period).

The remarkably consistent loadings across urban-rural contexts indicate that health protection has become a permanent quality component transcending geographic boundaries, confirming Tirachini & Cats [17] and Li et al. [61] regarding permanence while providing crucial nuance about relative importance. Unlike early pandemic recommendations from Tirachini & Cats [17] emphasizing health measures above all else, the endemic-phase findings suggest transport systems should integrate rather than prioritize health protection—elderly passengers expect basic hygiene provisions and adequate ventilation but prioritize operational excellence and human service quality that endure across crises.

This temporal evolution challenges static service quality models, demonstrating that crisis-induced dimensions transform from dominant to complementary as societies adapt psychologically and operationally to new realities. The methodological implication: researchers must consider temporal context when interpreting service quality priorities, as dimensions showing dominance during crises may normalize over time. The practical implication: transport investments should maintain adequate pandemic prevention including hand sanitizer availability, enhanced cleaning protocols, and improved ventilation systems while emphasizing primary drivers that remain stable across extraordinary circumstances such as convenience, reliability, and staff quality. Over-investing in pandemic prevention during endemic phases risks misallocating resources away from attributes elderly passengers prioritize for long-term mobility and independence.

5.4. Methodological Contributions and Comparative Advancement

This study makes three significant methodological contributions distinguishing it from previous elderly transport research, directly addressing concerns about methodological clarity and comparison completeness.

Rigorous measurement invariance testing enabling valid comparisons. While Champahom et al. [22] recently demonstrated measurement invariance testing in high-speed rail contexts across trip purposes (leisure vs. other-purpose travelers), applications to conventional bus transport and urban-rural geographic comparisons remained limited. The systematic testing of configural and metric invariance establishes that observed priority differences between urban and rural elderly reflect true variations rather than measurement artifacts—a critical distinction that descriptive comparative studies by Chaisomboon et al. [37] and Sum et al. [41] could not determine.

Without invariance testing, researchers cannot distinguish whether group differences stem from (1) genuine priority variations, (2) different interpretations of measurement items, or (3) different response styles across groups. For example, if rural respondents systematically use midpoints of Likert scales while urban respondents use extremes, observed mean differences reflect response style rather than true priority differences. The configural invariance confirms both groups conceptualize quality through the same eleven dimensions, while metric invariance demonstrates factor loadings operate equivalently, enabling confident interpretation that elevated rural Safety and Security importance reflects genuine priority rather than measurement artifact.

This methodological rigor provides confidence that recommendations for context-specific interventions—such as emphasizing security infrastructure in rural areas—are based on genuine differences rather than confounded by measurement non-equivalence. Previous descriptive comparisons could only observe that rural and urban elderly rated attributes differently but could not confirm whether differences reflected true priorities or measurement problems.

Hierarchical factor structure revealing relative importance. Most previous elderly transport studies employed flat factor structures or single-order models examining how individual attributes relate to satisfaction or behavioral intentions [5, 7, 15]. This prevents understanding how specific attributes relate to overall quality conceptualization and which dimensions function as primary versus complementary drivers.

The second-order confirmatory factor analysis reveals that eleven first-order dimensions load onto a higher-order Expected Public Transport Service Quality construct with adequate explanatory power, demonstrating that elderly passengers evaluate service quality through both specific attribute assessments and holistic service conceptualization. The hierarchical structure provides several insights unavailable from flat models:

First, it reveals relative importance—dimensions with higher second-order loadings such as Convenience, Staff, and Reliability contribute more strongly to overall quality perceptions than dimensions with lower loadings such as Information and Post-Pandemic Prevention. Second, it enables cost-benefit prioritization—improvements in primary drivers yield greater overall quality enhancement than equivalent investments in complementary dimensions. Third, it contextualizes individual findings—when Wong et al. [5] identified seat availability as "most critical," they lacked hierarchical context showing how elderly facilities relate to other quality dimensions. The model positions Older's Facilities as important but complementary to universal operational attributes.

Integration of traditional and contemporary dimensions within unified framework. While traditional SERVQUAL applications in transport focus on reliability, responsiveness, assurance, empathy, and tangibles [3, 4], the framework extends these foundations by validating two contemporary dimensions—Older's Facilities and Post-Pandemic Prevention—within a unified eleven-factor structure. This integration responds to recent calls from Gkiotsalitis & Cats [31] and Tirachini & Cats [17] for comprehensive post-pandemic transport models while addressing Shrestha et al. [6] emphasis on age-friendly design requirements.

The successful integration demonstrates that contemporary concerns complement rather than replace traditional quality dimensions, providing a more complete framework for understanding elderly transport expectations in the post-COVID era. Previous pandemic research often examined health measures in isolation [18, 62], preventing understanding of how pandemic prevention relates to established quality dimensions. The integrated model reveals pandemic prevention functions as the least influential dimension despite its novelty and recency, suggesting elderly passengers maintain stable priority structures emphasizing operational excellence even during extraordinary circumstances.

6. Conclusions and Implications

6.1. Summary of Key Findings

This research establishes the first validated measurement framework for sustainable public transport service quality expectations among elderly populations across urban-rural contexts in developing countries, providing significant empirical evidence for advancing sustainable transport development in aging societies.

Measurement invariance validation: The successful establishment of configural and metric invariance across urban and rural elderly populations confirms that the eleven-factor framework operates equivalently across geographical contexts, validating that elderly passengers maintain consistent cognitive frameworks for evaluating future sustainable transport services. The minimal practical fit change when constraining parameters across groups demonstrates measurement equivalence despite statistical detection of minor differences, enabling valid cross-context comparisons.

Universal and context-specific priorities: Three dimensions emerged as universal priorities: Convenience, Staff quality, and Reliability. These findings indicate that sustainable transport must prioritize operational excellence alongside environmental responsibility. Context-specific findings reveal elevated Safety and Security importance in rural areas, providing guidance for targeted investment strategies.

Extended dimensions validation: The validation of Older's Facilities and Post-Pandemic Prevention as distinct dimensions establishes empirical support for incorporating age-inclusive design and health protection measures as permanent components of sustainable transport planning, extending traditional SERVQUAL frameworks.

Theoretical advancement: These findings advance service quality theory by demonstrating that elderly populations possess sophisticated, multidimensional expectations for future sustainable transport requiring both specific attribute evaluation and holistic service conceptualization. The superior model fit in rural contexts challenges assumptions about urban sophistication, revealing that expectation coherence through constraint creates clearer quality frameworks in limited-service environments.

6.2. Current State and Policy Implications

6.2.1. Current Elderly-Friendly Transport Provision in Thailand

Understanding current conditions provides essential context for recommendations. Most Thai public buses lack adequate climate control, featuring hard plastic seats with limited cushioning and inadequate spacing for mobility aids. Vehicle floors remain high, limiting accessibility despite modernization efforts. Bus stop facilities vary dramatically: urban stops increasingly feature covered shelters with limited seating, while rural stops frequently consist of simple poles with no weather protection, seating, or lighting. While Thailand's 2007 Promotion of Quality of Life for Persons with Disabilities Act mandates accessible transport, implementation remains incomplete. Priority seating exists but enforcement is inconsistent. Audio-visual announcement systems remain rare outside Bangkok. Staff training addressing elderly needs is limited and inconsistent.

Post-pandemic, Thailand implemented temporary measures partially persisting today. Enhanced cleaning protocols continue at major operators with reduced frequency. Mask requirements were lifted except during outbreaks. Ventilation improvements saw limited implementation beyond opening windows. Hand sanitizer stations remain primarily at premium services rather than systematically. Critical gaps persist: no systematic integration of elderly-specific facilities with pandemic prevention measures, minimal rural attention, digital information systems lacking accessibility features, and sustainability initiatives not explicitly considering elderly needs.

6.2.2. Context-Specific Sustainable Implementation

Building upon this current state, measurement invariance findings justify developing unified national standards for sustainable elderly-friendly public transport integrating environmental sustainability with social accessibility. National policies should mandate:

Integrated Sustainable Systems: Electric bus networks with renewable energy integration, emphasizing Convenience and Reliability priorities identified across both contexts [24, 59]. Given universal prioritization of these dimensions in both contexts, national investments should focus on: (1) seamless multimodal integration enabling convenient transfers between electric buses, rail systems, and other modes; (2) real-time information systems powered by renewable energy providing reliable schedule adherence monitoring; (3) predictable service delivery through optimized routing and frequency planning that maintains consistency across time and conditions.

Age-Inclusive Sustainable Design: Universal design principles incorporating energy-efficient accessibility features, smart information systems powered by renewable sources, and sustainable materials in elderly-specific infrastructure [6, 14]. Given the validation of Older's Facilities as a distinct dimension, implementations should include: (1) ergonomically designed priority seating with adequate handrails positioned appropriately for diverse elderly heights and grip strengths; (2) clear, high-contrast visual signage and simple audio announcements addressing age-related sensory changes; (3) low-floor electric vehicles with wide doors and level boarding platforms minimizing mobility barriers; (4) renewable energy-powered lighting systems ensuring adequate illumination at stops and on vehicles.

Staff Development for Sustainability: Training programs combining elderly passenger service skills with sustainability awareness and green technology operation [50, 53]. Given Staff quality's universal high priority in both contexts, programs should develop: (1) empathy and communication skills for supporting elderly passengers with diverse capabilities; (2) technical competencies for operating electric vehicles and sustainable infrastructure systems; (3) emergency response protocols addressing elderly vulnerabilities during service disruptions; (4) cultural awareness promoting dignity and independence rather than paternalistic assistance approaches.

6.2.3. Context-Specific Sustainable Implementation

Regional implementation strategies should reflect differential priority patterns revealed through measurement model analysis:

Urban Sustainable Transport: Prioritize electric bus rapid transit systems, integrated renewable energy infrastructure, smart mobility platforms, and multimodal sustainable transport hubs that reduce environmental impact while enhancing operational convenience and reliability [46, 91]. Urban strategies should emphasize: (1) seamless integration between existing mass transit systems including BTS and MRT with electric bus networks; (2) smart payment systems with elderly-accessible interfaces enabling barrier-free multimodal trips; (3) real-time passenger information displays at major hubs showing integrated timetables across all modes; (4) priority boarding lanes and dedicated waiting areas for elderly passengers at high-volume stations.

Rural Sustainable Transport: Develop demand-responsive electric vehicle services, community-based sustainable transport cooperatives, locally-sourced renewable energy charging infrastructure, and hybrid conventional-sustainable service models that maintain human-centered service delivery while progressing toward environmental goals [22, 44]. Given elevated Safety and Security priority in rural contexts, implementations should emphasize: (1) well-lit bus stops with emergency call systems and CCTV surveillance addressing isolation concerns; (2) community-operated demand-responsive services maintaining personal connections with elderly users; (3) driver training emphasizing assistance and security awareness for vulnerable passengers; (4) infrastructure improvements addressing non-slip surfaces, obstacle removal, and weatherization before introducing electric vehicle technology.

6.3. Sustainable Transport Innovation Directions

The research identifies specific innovation priorities building upon the validated measurement model:

Technology Integration: Age-friendly smart systems powered by renewable energy that enhance convenience while reducing environmental impact [48, 49]. Innovations should focus on: (1) simplified mobile applications with large text, voice commands, and step-by-step guidance for trip planning; (2) contactless payment systems with multiple redundant methods including cards, mobile, and cash ensuring no elderly passengers are excluded by digitalization; (3) real-time vehicle tracking displays showing estimated arrival times in accessible formats; (4) solar-powered information kiosks at bus stops providing route information, emergency assistance, and weather protection.

Health-Environment Integration: Sustainable health protection technologies including energy-efficient air filtration, renewable-powered antimicrobial systems, and environmentally responsible cleaning protocols [31, 63]. Given Post-Pandemic Prevention's validated but moderate importance, implementations should integrate rather than dominate: (1) high-efficiency particulate air (HEPA) filtration systems powered by vehicle regenerative braking or solar panels; (2) antimicrobial surface materials on high-touch areas including handrails and seats using sustainable copper alloys or UV-C disinfection; (3) visible but unobtrusive hand sanitizer stations at vehicle entrances; (4) ventilation systems with energy recovery ensuring fresh air circulation without excessive energy consumption.

Community-Centered Sustainability: Sustainable transport solutions maintaining high-quality staff interaction while incorporating environmental responsibility and local community involvement [51, 52]. Given Staff quality's universal priority in both contexts, innovations should preserve human elements: (1) driver retention programs recognizing that experienced staff familiar with elderly passengers' needs provide superior service; (2) community advisory committees including elderly representatives in sustainable transport planning decisions; (3) volunteer ambassador programs where trained elderly passengers assist peers during technology transitions; (4) flexible service models allowing driver discretion to provide personalized assistance within operational parameters

7. Limitations and Future Research Directions

7.1. Study Limitations

Several limitations should be considered when interpreting findings. First, the cross-sectional design captures expectations at a single time point (February-March 2024) during Thailand's endemic COVID-19 transition, preventing examination of how expectations evolve as sustainable transport systems are implemented or as pandemic conditions change. Second, the study focuses exclusively on bus transport in Thailand, limiting generalizability to other transport modes including rail or paratransit, or cultural contexts with different aging patterns, transport development stages, or sustainability priorities. Third, while measurement invariance establishes equivalence across urban-rural contexts, the study does not examine other potentially important sources of heterogeneity such as income levels, functional limitations, or digital literacy that may moderate service quality expectations. Fourth, the expectation-based approach, while valuable for proactive planning, does not examine how expectations translate into satisfaction, loyalty, or actual ridership behaviors, limiting understanding of which expectation dimensions most strongly influence behavioral outcomes.

7.2. Future Research Priorities

Future research should extend this measurement framework through several critical directions:

Longitudinal expectation-satisfaction trajectories: Track how elderly passengers' expectations evolve as sustainable transport innovations are implemented, examining whether initial expectations are confirmed, positively disconfirmed (exceeded), or negatively disconfirmed (unmet). This research would assess measurement model stability over time and identify whether high expectations create satisfaction barriers or motivate continued service improvements. Particular attention should examine whether Post-Pandemic Prevention expectations decrease, stabilize, or increase as time passes from acute pandemic phases, and whether measurement invariance holds longitudinally as service conditions change.

Technology acceptance integration: Investigate elderly passengers' acceptance and adaptation to emerging technologies such as autonomous vehicles, smart payment systems, mobile applications, and real-time information platforms across urban-rural contexts. This research would reveal how technological advancement integrates with established service quality dimensions, whether technology creates new quality dimensions or enhances existing ones, and how age-related technology anxiety moderates relationships between service quality expectations and behavioral intentions.

Cross-cultural validation: Expand the framework to diverse international contexts with varying aging patterns (rapid vs. gradual), transport development stages (developing vs. developed), cultural values (collectivist vs. individualist), and sustainability priorities (environmental vs. social focus). Cross-cultural validation would strengthen theoretical foundations by identifying universal dimensions transcending cultural boundaries versus culturally-specific expectations requiring localized frameworks. Particular value would come from comparing rapidly-aging Asian societies including Thailand, China, and Japan with aging Western societies such as Europe and North America where infrastructure development trajectories differ substantially.

Service quality-ridership nexus: Examine relationships between service quality expectations, satisfaction, and environmental sustainability outcomes, providing comprehensive understanding of the sustainability-satisfaction connection. Research should investigate whether higher service quality perceptions correlate with increased ridership and subsequent environmental benefits including reduced private vehicle use and lower emissions, whether sustainability features themselves influence ridership independent of traditional quality dimensions, and whether trade-offs exist between environmental sustainability goals and service quality perceptions among elderly passengers.

Heterogeneity exploration: Investigate how functional limitations, income levels, digital literacy, social support networks, and transport dependency moderate service quality expectations. Research employing latent profile analysis or finite mixture modeling could identify distinct elderly passenger segments with different expectation profiles, enabling more precisely targeted interventions than broad urban-rural categorizations. Understanding within-group heterogeneity would help avoid treating elderly passengers as homogeneous categories and develop inclusive services serving diverse aging populations.

These research directions will provide crucial evidence for policymakers regarding the practical value of investing in comprehensive sustainable transport systems that effectively serve aging populations while achieving environmental sustainability goals. The validated eleven-factor measurement framework established in this study provides a robust foundation for these future investigations, enabling cumulative knowledge development about sustainable transport service quality for aging societies globally.

8. Declarations

8.1. Author Contributions

Conceptualization, A.C., P.W., and S.J.; methodology, A.C. and D.C.; software, V.R. and S.J.; validation, P.W. and T.C.; formal analysis, A.C. and D.C.; investigation, S.J.; resources, V.R. and T.C.; data curation, P.W. and F.W.; writing—original draft preparation, A.C.; writing—review and editing, P.W. and S.J.; visualization, T.C.; supervision, V.R. and S.J.; project administration, S.J. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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8.5. Conflicts of Interest

The authors declare no conflict of interest.

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