



# Necessary and sufficient conditions for attractive public Transport: Combined use of PLS-SEM and NCA

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## ABSTRACT

In order to effectively manage transportation systems, and improve the attractiveness of public transport, public authorities, policymakers and researchers need a better understanding of the conditions necessary for improving attractiveness and those that can be considered sufficient. The purpose of this study is to expand the analytical toolbox of transportation research and introduce an analytical approach to identifying and distinguishing between the conditions that are necessary and sufficient for a desired outcome. Specifically, we suggest a complementary approach to combining partial least square structural equation modelling (PLS-SEM) and necessary condition analysis (NCA) in order to examine which service quality attributes (functionality, information, security/safety, comfort, and cost) are sufficient, and what degree of satisfaction with these attributes is necessary for high overall travel satisfaction. The data consists of subjectively reported experiences from over 900 users of public transportation in four northern European countries. We find that, for high overall travel satisfaction, a minimum level of satisfaction with comfort (equal to 33.1%) is necessary. Furthermore, an increase in satisfaction with comfort, functionality/reliability and cost is sufficient to improve overall travel satisfaction. This means that comfort is both a necessary and a sufficient condition, whereas functionality/reliability and cost are sufficient but non-necessary conditions in this context. We conclude that using this complementary approach can guide public transport managers and researchers in identifying important bottlenecks and establishing priorities for improving service quality, essential knowledge when developing effective strategies for attractive public transport services.

## 1. Introduction

There is a need to transform today's transport systems in order to meet the goals of the United Nations 2030 Agenda for Sustainable Development<sup>1</sup>. Sustainable Development Goal number 13 on climate action focuses on efforts to reduce greenhouse gas emissions. This can be accomplished in a number of ways: One such way is to develop attractive alternatives to the car, e.g. public transport (Creutzig et al., 2018). However, in order for this to happen, a better understanding of what constitutes attractiveness is needed. Furthermore, in order to make effective managerial decisions, we need to understand the conditions necessary for improving attractiveness, and those that can be considered sufficient (De Oña and de Oña, 2015; Sukhov et al., 2021). This way, public authorities, policymakers and researchers will have more informed and precise tools for evaluating and managing transportation systems by outlining critical factors

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and significant terms, but also by refining the definitions of these significant terms. Doing so can further inform actors about what the key critical factors are, but also why they are critical.

In order to identify which service quality attributes are necessary, as well as which are sufficient for overall travel satisfaction, we apply an approach that combines the use of partial least squares structural equation modeling (PLS-SEM) with necessary condition analysis (NCA). In doing so, we follow the argument raised by Hair, Risher, Sarstedt and Ringle (2019), i.e. that “...social science scholars would be remiss if they did not apply all statistical methods at their disposal to explore and better understand the phenomena they are researching” (p.17). We want to draw attention to how combining the different methods improves the analysis of overall travel satisfaction, hence leading to a more informed understanding of how to enhance attractiveness. We provide specific insights into how to identify the necessary conditions, pinpointing the bottlenecks as regards improving overall travel satisfaction, and we discuss how this can contribute toward an effective strategy for improving overall travel satisfaction with public transport.

A common way of identifying critical factors during past research was outlining statistically significant determinants, and establishing their positive or negative correlations, providing researchers with a broad understanding of the key elements affecting certain outcomes. Recently, however, more attention has been paid to understanding critical factors in terms of their necessity and sufficiency (Dul, 2016; Sukhov et al., 2021). *Necessity* means that, in order for a specific outcome to be possible, certain necessary conditions need to be fulfilled, and that the outcome cannot occur without the required conditions (e.g., Dul, 2016; Goertz, 2003). In other words, the desired outcome of overall travel satisfaction – or a certain level of that outcome – is only possible if the necessary condition is in place or at a certain level (Richter et al., 2020). A necessary condition acts as a must-have condition, or a bottleneck, and is therefore critical when it comes to achieving the desired outcome. Bottlenecks are thus likely to be of interest when addressing the attractiveness of public transport since they present a clear starting point for effectively improving satisfaction. A necessary condition, however, may not be sufficient, in and of itself, to produce a desired outcome. *Sufficiency* means that the outcome can occur if certain key conditions are met (Schneider and Wagemann, 2012). During sufficiency analysis, the focus is often on identifying adequate grounds for the relationship between the determinants and the outcome, and on understanding the key factors contributing to the desired outcome (e.g. Mandel and Lehman, 1998; Aladwani, 2001). Understanding relationships in terms of sufficiency is helpful when trying to outline how service quality attributes are related, and how they contribute to overall travel satisfaction. This implies that, if a single service quality attribute is dissatisfactory, then the overall level of satisfaction with the service may be reduced, but still satisfactory, and that other service quality attributes may compensate for the dissatisfactory attribute. Generally, traditional quantitative methods, such as regression-based analysis, focus on outlining sufficient conditions and help to identify the critical factors of a particular outcome. However, despite being positively associated with the outcome, the condition may not constitute a critical bottleneck, and may not actually be necessary. Therefore, in order to advance our analysis of critical conditions, both the necessity and sufficiency of critical conditions need to be examined and understood.

By using a complementary approach (see Richter et al., 2020), it is possible to combine the necessity and sufficiency logics in order to obtain a broader understanding of empirical data, and in so doing to improve theorizing. A recent example is combining partial least squares structural equation modeling (PLS-SEM), on the basis of the sufficiency logic, with necessary condition analysis (NCA), on the basis of the necessity logic. As will be discussed in this paper, the value of such a complementary approach is yet to be explored in transport research, but it could contribute toward new insights, new theoretical models, and new practical implications. For instance, analyzing sufficient service quality attributes indicates which attributes will generally increase overall travel satisfaction. In contrast, analyzing necessary service quality attributes can generate new insights in terms of which specific service quality attributes are bottlenecks as regards medium or high levels of overall travel satisfaction.

In this study, we will use northern European data on the relationship between satisfaction with service quality attributes in public transport and overall travel satisfaction with the service. The data, subjectively reported by over 900 users of public transport, illustrates the benefits of applying complementary approaches in order to identify the necessary and sufficient attributes. This helps us to distinguish between conditions constituting bottlenecks and those having a significant influence on the outcome. Using PLS-SEM, individual indicator weights are estimated, including measurement errors, which are in turn used to calculate composite scores for defined latent variables (Hair et al. 2017). These scores are then used as input into NCA (Dul, 2016; Richter et al., 2020). By using PLS-SEM, we identify the (latent) service quality attributes (functionality, information, comfort, cost, and safety/security) producing the best possible outcome for overall travel satisfaction. Using NCA, we identify the (latent) service quality attributes, and their degree, that are critical when it comes to achieving high overall travel satisfaction.

The remaining part of this paper is arranged into the following sections: Section 2 focuses on previous research on travel satisfaction. Specifically, we explain the difference between overall travel satisfaction and satisfaction with different service quality attributes. This section highlights a gap when it comes to general knowledge of the necessary and sufficient attributes used in public transport. Section 3 provides a general explanation of NCA since it is a new analytical method to transportation research. Section 4 presents our research method and procedures. Section 5 contains our data analyses of sufficient conditions using PLS-SEM, while Section 6 provides our analysis of necessary conditions using NCA. We end this paper by discussing three key contributions relating to (1) the theoretical relationship between satisfaction with different service quality attributes and overall travel satisfaction, (2) “should” and “must” service quality attributes as used in public transport, and (3) areas for further research.

## 2. Travel satisfaction: Necessary and sufficient attributes

### 2.1. Overall travel satisfaction

Overall travel satisfaction is a cognitive and/or affective response to travel. Overall travel satisfaction is sometimes referred to as

cumulative satisfaction (Suzuki et al., 2014), implying that it is made up of accumulated parts. This indicates that travel entails trips that vary in terms of mode, duration, company, comfort and other factors. Thus, travelers aggregate their cognitive and affective experiences when asked to report their overall travel satisfaction with their daily travel. The accumulated evaluation is influenced by previous experiences, as well as by pre-travel attitudes (Gärling et al., 2018).

In order to measure overall travel satisfaction, a single- or multi-item measure can be applied. A common single-item measure used in public transport reads: “In general, how satisfied are you with public transport?”. A single-item measure is beneficial under specific circumstances, especially in the case of long and complicated surveys (Bergkvist & Rossiter, 2007). Managers often prefer single-item measures for practical reasons, and when it comes to reducing costs related to data processing and collection. A theoretical argument for using a multi-item measure is the inclusion of both cognitive and affective dimensions in order to fully capture the travel experience. The multi-item Satisfaction with Travel Scale (STS), proposed and developed by Ettema et al. (2011), has become a standard for measuring travel satisfaction. The STS combines cognitive judgments regarding travel satisfaction with measures regarding the activation and valence dimensions of affect. Friman et al. (2013) empirically showed that, while the cognitive and affective dimensions are distinguishable in the STS, they are correlated in such a way as to form an overall construct of satisfaction with travel.

Originally, the STS consisted of nine items. Three items are averaged into a composite measure of a cognitive judgment of the quality of travel (referred to as Quality in Table 1). The following six items measure affect that varies between positive activation and negative deactivation (referred to as Enthusiasm and obtained by averaging items 4 through 6) and affect that varies between positive deactivation and negative activation (referred to as Stress and obtained by averaging items 7 through 9). The affective dimensions of Enthusiasm and Stress have high content validity in terms of representing the discrete emotional states (enthusiasm, boredom, relaxation, stress) frequently experienced during travel. Composite versions of these scales have been applied whereby one item was used for each dimension. In these items, each end-point was labelled with all three adjectives corresponding to the adjectives in the 9-item version (see, for example, Friman et al., 2017).

With slight refinements, in order to apply to different modes, languages, and age groups, the scale has been extensively applied to travel in general, for specific modes or combinations of these (see, for example, Singleton, 2019 for an overview). In line with the psychometrical testing of Friman et al. (2013), De Vos et al. (2015) and Singleton (2019) also conclude that the STS is best used as a single overall composite.

## 2.2. Satisfaction with service quality attributes

Satisfaction can also be broken down into satisfaction with performance or quality attributes (Anderson & Sullivan, 1993; Cronin & Taylor, 1992; Gotlieb, et al. 1994). This provides more detailed information on how separate quality attributes contribute to overall travel satisfaction. As shown in this section, however, there is limited knowledge of how service quality attributes are defined in terms of being either necessary or sufficient for overall travel satisfaction with public transport services.

In general, transport researchers have mainly focused on the sufficiency logic, by which service quality is sufficient when it comes to increasing overall travel satisfaction. The results can differ between the various segments (lifestyles, usage and personal characteristics) and contexts (urban or rural cities), but there are common service quality attributes which, on average, are considered important. Indeed, travelers may be less satisfied with their travel if the service is not reliable, frequent, comfortable, or safe, or lacks clear and simple information, or if the distance to their nearest stop is considered too far (see, for instance, Hensher et al., 2003; Tyrinopoulos and Aifadopoulou, 2008; Eboli and Mazzulla, 2007; Eriksson et al., 2008; Fellessen and Friman, 2008; Friman and Gärling, 2001; Van Lierop et al., 2018). However, the logic of necessary and sufficient conditions has only been sparsely adapted in public transport research (see, for example, De Oña and de Oña, 2015; Sukhov et al., 2021).

Although most travel research focuses on service quality attributes with the ability to alter overall travel satisfaction, the service quality attributes necessary for high overall satisfaction are equally important. Necessity concerns a constraint, a bottleneck, or a service quality attribute's critical level regarding overall travel satisfaction. The absence of a necessary service quality attribute cannot be compensated for by other service quality attributes: Thus, it is essential to focus on the conditions necessary for influencing the outcome. If the expected necessary level is not in place, dissatisfaction will be guaranteed. This implies that, if public transport does not

**Table 1**  
Adjectives and corresponding dimensions for the bipolar items used in the Satisfaction with Travel Scale.

Item number	Left end-point	Dimension	Right end-point
1	Worked very poorly	Quality	Worked very well
2	Held a low standard		Held a high standard
3	Worst imaginable		Best imaginable
4	Very bored	Enthusiasm	Very enthusiastic
5	Very tired		Very alert
6	Very fed-up		Very engaged
7	Very stressed	Stress	Very relaxed
8	Very worried		Very calm
9	Very hurried		Very confident

provide a certain level of, for example, safety (a necessary attribute according to Sukhov et al. 2021 in a study of a mid-sized Swedish city), then no high overall level of travel satisfaction will be present. Safety may not be the only service quality attribute necessary for overall travel satisfaction: Other service quality attributes, e.g. frequency or comfort, may also be necessary at a certain critical level. The various necessary service quality attributes may also differ depending on the context. By comparing satisfaction scores before and after an intervention aimed at increasing service quality, Sukhov et al. (2021) were able to show that the critical service quality attributes had changed, from just including safety as a necessary attribute for high overall travel satisfaction to also including three additional attributes post-intervention (functionality/reliability, courtesy/simplicity, and comfort). It is important to note that Sukhov et al. (2021) were only focusing on the differences between service quality attributes, while using a more basic form of necessity analysis. The present study is a further development of the necessity analysis of the service quality attributes used in public transport. In addition to Sukhov et al. (2021), who used calculated averages, we base our model on latent variables that will provide, according to Dul (2016) and Richter et al. (2020), greater precision during analysis.

In applying a complementary approach, we combine two different research techniques (PLS-SEM and NCA) with the aim of identifying the service quality attributes sufficient and necessary for overall travel satisfaction. Our analyses are guided by recent advances in information systems research (Richter et al., 2020). It is anticipated that this study will contribute toward a deeper understanding of the complementary approach to analyzing necessary and sufficient conditions in public transport, in a manner appropriate for future research.

### 3. Necessary condition analysis

NCA is a data analytic tool that has been developed to complement traditional analytic techniques such as multiple-regression and structural equation modelling (Dul 2016; Dul, Vis and Goertz, 2016; Richter et al., 2020). The value that NCA brings to data analysis is a more nuanced understanding of assessing necessary conditions that can vary in terms of both their kind and degree (Dul, 2016; Vis and Dul, 2018). In doing so, NCA helps us to identify specific bottlenecks, e.g. the level of satisfaction with a particular service quality attribute required for a particular level of overall travel satisfaction. In other words, in a situation where the studied predictors and outcomes take the form of a variable score, NCA is able to show which of the predictors is/are necessary and the degree to which that predictor will be necessary in order to achieve a particular degree of outcome.

NCA helps the researcher in two ways: First, it can determine ceiling lines and the corresponding bottleneck tables that help to visualize and interpret the relationships between the predictor and the outcome variables. Second, it calculates parameters such as the accuracy of the ceiling line and the effect sizes of the necessary conditions, and it performs significance testing in order to avoid calculation errors (Dul, 2016; Dul et al., 2020). NCA uses a Cartesian coordinate system to plot the values of the predictor (X-axis) and the values of the outcome (Y-axis) in each observed case. A ceiling line is then drawn between the zone containing observations and the zone not containing any observations (see Fig. 1). Although different techniques can be used for determining how the ceiling line is drawn (Dul, 2016), the most robust way is to use the ceiling envelopment with free disposal hull (CE-FDH), which results in a piecewise linear function along the upper left observations (i.e. a stepwise function). The size of the empty space in the upper left corner of this plot is what helps to determine the necessity of predictor X for outcome Y (Dul, 2016). A bottleneck table is a visualization of the ceiling line which summarizes the degree to which predictor X constrains outcome Y. Hence, a bottleneck analysis is a further specification of

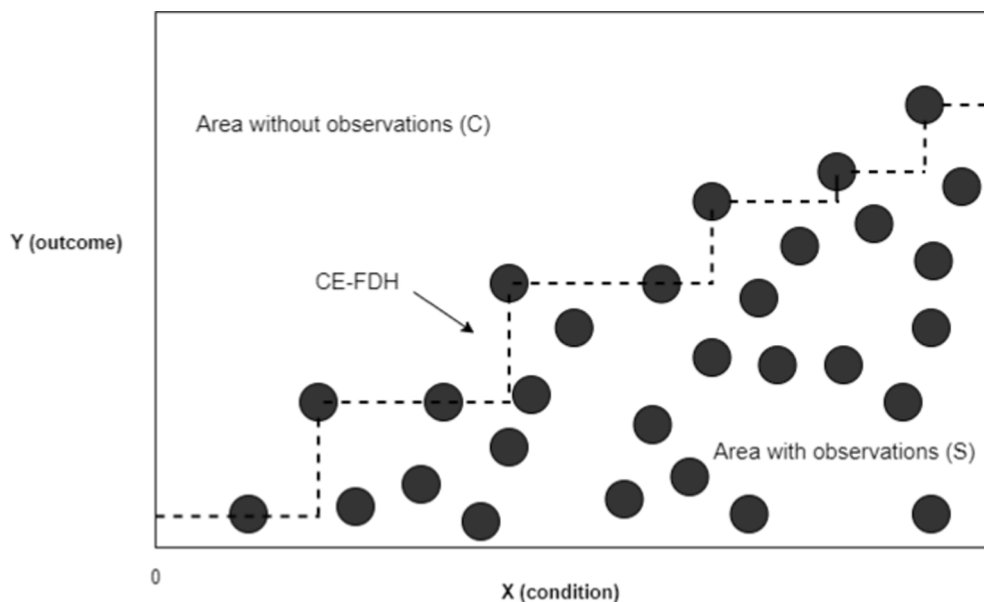


Fig. 1. Relationship regarding necessity of condition X for outcome Y using the ceiling envelopment with free disposal hull (CE-FDH).

which predictor levels will be necessary for different levels in the outcome. In order to understand the magnitude of the hypothesized necessary condition, NCA applies an effect size measure. This measure of effect size ( $d$ ) is represented by a ratio between the area containing observations (S) and the area not containing any observations (C) and can be expressed as follows:  $d = C/S$ . Furthermore, Dul (2016) introduces the following general thresholds between different effect sizes  $d$ , where  $0 < d < 0.1$  corresponds to a “small” effect size,  $0.1 \leq d \leq 0.3$  to a “medium”,  $0.3 \leq d \leq 0.5$  to a “large”, and  $0.5 \leq d \leq 1$  to a “very large” effect size. In addition to the effect size measures, NCA also provides means for statistical significance testing, namely testing the effect sizes against a null hypothesis to avoid Type 1 errors and false positives using a bootstrapping approach (Dul et al., 2020). Thus, in order to claim a condition is a necessity, the condition should meet three principal criteria: i) There needs to be theoretical justification, ii) the effect size  $d$  should be larger than zero, and iii) the condition should have a small  $p$  value (e.g.  $p < .05$ ) during significance testing (Dul et al., 2020).

Despite NCA’s numerous advantages, it also has some limitations. NCA is merely a data analysis tool for calculating ceiling lines, effect sizes and other relevant quantities: As such, it does not account for sampling errors, nor does it outline confidence intervals. Furthermore, NCA does not measure the trivialness of the necessary conditions, entailing that researchers should not blindly rely on NCA output, but should instead consider the relevance of their theoretical assumptions, the quality of their measurements, and their overall research design. Hence, according to Dul (2016), NCA is an addition to the researcher’s toolbox which complements other statistical methods of data analysis.

## 4. Method

### 4.1. Sample

Over the past 20 years, a number of cities in Europe have been collaborating in an annual public transport barometer. This barometer collects surveys of citizens’ travel experiences and usage. The data in the present study includes a survey, from 2020, of five cities in northern Europe (Stockholm,  $n = 228$ ; Helsinki,  $n = 154$ ; Oslo,  $n = 105$ ; Copenhagen,  $n = 176$ ; Bergen,  $n = 285$ ), collected between May and December. Nine hundred and forty-eight (948) respondents aged 16–90 (mean age 57.0 years), of whom 40% were women, 46% were working full time, 39% were retired, and about 11% were students or part-time employees, were asked to either complete a web survey or participate in a structured telephone interview. Slightly more respondents were collected in Bergen and slightly less in Oslo than in the other three cities. Data collection followed institutional guidelines and received Institutional Committee approval (C2017/938). All the participants received a small gift (a choice between a lottery or a cinema ticket, or donating the corresponding sum to charity).

### 4.2. Measures

The questionnaire included several subsections containing questions related to socio-demographic factors and travel, e.g. mode use, perceived accessibility, satisfaction with service quality attributes, travel satisfaction, and life satisfaction. Besides questions about socio-demographic factors (age, gender, and employment status), the focus of the present research was also on the modules covering the indicators of satisfaction with service quality attributes and on the overall level of satisfaction with everyday travel.

Building upon previous research (e.g., Redman et al., 2013; Sukhov et al., 2021), a number of items were included which reflected five different dimensions of satisfaction with service quality attributes (see Table 2): i.e. functionality (5 items), information (3 items), cost (2 items), safety/security (3 items), and comfort (5 items). These items were phrased as statements and measured on a scale ranging from (1) *I don’t agree at all* to (5) *I fully agree*.

Overall travel satisfaction was captured by the Satisfaction with Travel Scale, which measures three overarching dimensions using bipolar adjective scales: i.e. Quality, Enthusiasm, and Stress (see Section 2.1 and Table 1 for a full description of the scales). The three-item version was employed, and answered using 7-point bipolar scales.

### 4.3. Data analyses

With the aim of identifying the service quality attributes sufficient and necessary for overall travel satisfaction, we combined two different analytical techniques; i.e. PLS-SEM and NCA. Our analyses were informed both by guidelines presented in recent information systems research (Richter et al. 2020) and by best practices in how to analyze and report PLS-SEM data (Hair, Risher, Sarstedt and Ringle, 2019). In the choice between CB-SEM and PLS-SEM, we followed the recommendation that researchers intending to estimate a model of composites should use a composite-based method like PLS-SEM (Rigdon et al. 2017).

By presenting these two different analyses, we illustrate the benefits of applying complimentary approaches in order to identify sufficiency and necessity in the variables of interest. In PLS-SEM, individual indicator weights, including measurement errors, are estimated, and in turn used to calculate composite scores for the defined latent variables (Hair et al. 2017). These scores are then used as input into NCA (Richter et al., 2020). By using PLS-SEM, we identify the latent service quality attributes that produce the best possible outcome for overall travel satisfaction, whereas NCA identifies the attributes critical for a high overall level of travel satisfaction, as well as their degree.

## 5. Results PLS-SEM

Before valid results can be claimed from PLS-SEM, evaluations need to be done as regards indicators, latent composites,

**Table 2**  
Indicators and items of service quality attributes.

Service quality attribute	Indicator in model estimation	Item in questionnaire
Functionality	Transfer_easy	Transfers are easy
	Traveltime	Travel times on public transport are reasonable
	Waitingtime	Waiting times are short during transfers
	Close_to_house	Nearest stop is close to where I live
	Departures	I'm satisfied with the number of departures
Information	Info_problem	The information provided is good when traffic problems occur
	Info_stop_terminal	The information provided is good at stops and terminals
	Info_planning	It's easy to get the information I need when planning a trip
Security/safety	Secure_stations_stops	I feel secure at stations and bus stops
	Secure_onboard	I feel secure aboard buses and trains
	Notafraid_accidents	I'm not afraid of accidents when using public transport
Comfort	Comfortable	Traveling by public transport is comfortable
	Modern_vehicles	Buses and trains are modern
	Clean_vehicles	Buses and trains are clean
	Seat_available	I normally get a seat when I travel by public transport
	Nice_staff	The staff behave nicely and correctly
Cost	Value_for_money	Public transport gives value for money
	Price_reasonable	Public transport fares are reasonable

measurement models, and structural models (Hair et al., 2019). We performed data analysis using *SmartPLS v.3.3.3* (Ringle et al., 2015) and: 1) the PLS algorithm in order to estimate path coefficients and the predictive accuracy of composites; 2) the bootstrapping procedure in order to estimate the statistical significance of path estimates; 3) the blindfolding procedure in order to estimate the predictive relevance of composites; and 4) the finite mixture analyses in order to assess the potential heterogeneity of the data (i.e. analyses of possible subgroups within the sample).

### 5.1. Descriptive and measurement model evaluation

Before estimating the relationships between the composites, the reliability and validity were assessed. In Table 3, descriptive statistics are presented for each item within the latent composites in the form of means and standard deviations, alongside indicator loadings, internal consistency reliability (*pA*), convergent validity (*AVE*), and discriminant validity (*HTMT*), with proposed threshold

**Table 3**  
Indicator means and the loadings, reliability, and validity of the latent composites.

Composites and Indicators	N	Mean	SD	Loadings (>0.708)	<i>pA</i> (0.7–0.9)	<i>AVE</i> (>0.50)	<i>HTMT</i> (<0.85)
<b>Functionality</b>					0.852	0.611	0.543–0.744
Transfer_easy	882	3.77	1.03	0.779			
Traveltime	923	3.87	1.19	0.832			
Waitingtime	853	3.55	1.14	0.820			
Close_to_house	942	4.34	1.11	0.642			
Departures	904	3.56	1.30	0.818			
<b>Information</b>					0.791	0.704	0.359–0.744
Info_problem	819	3.05	1.19	0.845			
Info_stop_terminal	897	3.42	1.15	0.844			
Info_planning	914	3.94	1.07	0.828			
<b>Security/safety</b>					0.818	0.718	0.450–0.797
Secure_stations_stops	933	4.05	1.03	0.848			
Secure_onboard	934	4.14	0.98	0.912			
Notafraid_accidents	935	4.30	0.94	0.776			
<b>Comfort</b>					0.838	0.591	0.577–0.797
Comfortable	931	3.78	1.07	0.840			
Modern_vehicles	917	3.96	0.96	0.805			
Clean_vehicles	907	3.74	1.01	0.803			
Seat_available	911	4.00	0.99	0.755			
Nice_staff	877	4.11	0.93	0.621			
<b>Cost</b>					0.898	0.900	0.400–0.621
Value_for_money	927	3.30	1.29	0.955			
Price_reasonable	930	2.89	1.37	0.942			
<b>STS</b>					0.838	0.739	0.359–0.577
Quality	948	5.05	1.30	0.872			
Enthusiasm	948	4.61	1.31	0.829			
Stress	948	5.35	1.43	0.877			

Note: Items regarding the five quality composites were measured on five-point scales, while items regarding overall travel satisfaction (STS) were measured on seven-point scales.

values for each measure. As can be seen, internal consistency was established since all the internal consistency reliability ( $\rho_A$ ) measures were between 0.7 and 0.9. Convergent validity was also established since almost all the outer loadings of indicators were above 0.708, except for two indicators that were slightly below this threshold<sup>2</sup>. All the average variance extracted (AVE) measures were above 0.5. Furthermore, discriminant validity, as measured using the Heterotrait-Monotrait (HTMT) ratio, was also established since all the measures were below the threshold of 0.85. We therefore conclude that the measurement model is satisfactory.

## 5.2. Structural model evaluation

Using a satisfactory measurement model, the structural model (Fig. 2) was then evaluated using the PLS algorithm and pairwise deletion in order to handle any missing values.

No multicollinearity issues were observed, with the variance inflation factors (VIF) all being below 3. The predictive accuracy was measured using the coefficient of determination ( $R^2$ ) and the blindfolding-based redundancy measure  $Q^2$ , with both measures yielding satisfactory outcomes ( $R^2 = 0.26$ ;  $Q^2 = 0.18$ ). The model's out-of-sample predictive power was assessed using the PLSpredict procedure. In PLSpredict, the  $Q^2_{\text{predict}}$  statistic is tested against a naïve benchmark consisting of a linear regression model that is produced using the PLSpredict method (Hair et al. 2019). The results showed great predictive power since none of the indicators used during the PLS-SEM analysis had any root mean squared error (RMSE) values or any mean absolute error (MAE) values higher than the naïve LM benchmark.

To estimate the statistical significance of path coefficient ( $\beta$ ) estimates, the PLS algorithm with the bootstrapping procedure, using 4,999 samples, the pairwise deletion algorithm, the Bias-Corrected and Accelerated confidence interval estimation method, and two-tailed testing at the 0.05 level were all employed. As shown in Table 4, significant paths were observed for three of the five latent composites, namely comfort, functionality, and cost, while information and safety/security carried less weight.

Finally, the collected survey data was processed as one unit of data, while the surveys were collected in five different northern European cities varying as regards their urban form and the design of their infrastructure. Unobserved heterogeneity between subgroups (e.g. cities) may produce substantially different model estimates (Hair et al., 2019). Therefore, as a final step, and in order to account for potentially unobserved heterogeneity, Finite mixture segmentation analyses (FIMIX) were applied to the data. FIMIX captures heterogeneity by estimating the probabilities of the segment memberships of each observation while simultaneously estimating the path coefficients for all the segments. Solutions for between 2 and 5 segments were tested against seven different fit indices. As FIMIX may produce slightly varied estimates using its bootstrap procedure, recommendations were followed to test each solution over ten rounds (Hair et al., 2016). In Table 5, the results from one of the rounds is presented. For each fit measure, the optimal solution is the number of segments with the lowest value (see bold numbers in Table 5). As can be seen, no consistent findings were observed relating to the fit indices where the different indices suggest different segment solutions. Similar findings were observed for all ten rounds. These inconsistent findings suggest that there is no substantial level of heterogeneity in the data. Taking a closer look at the 5-segment solution shows that two of the segments are too small for segment-specific PLS-SEM analysis. As regards the 2-segment solution, the normed entropy statistic (EN) was below the threshold of 0.50, suggesting that the two segments are not well separated. Hence, based on the forty FIMIX analyses, we conclude that the initial model, with one homogeneous segment across the cities, is satisfactory.

In summary, PLS-SEM analyses show the importance of comfort, cost, and functionality for overall travel satisfaction. This suggests that improvements in comfort, cost and functionality will be sufficient when it comes to increasing overall travel satisfaction.

## 6. Results NCA

To further explore the relationship between satisfaction with service quality attributes and overall travel satisfaction, we supplemented PLS-SEM with Necessary Condition Analysis (NCA). According to the guidelines of Richter et al. (2020), we used the latent-variable scores of the service quality attributes and overall travel satisfaction, obtained using PLS-SEM, as a starting point when performing NCA. We imported these scores into the R software and followed the steps described in the quick start guide for running NCA (see Dul, 2021). In order to keep our analysis from inferring additional linear assumptions, between the predictor and the outcome variables, we used the recommended ceiling envelopment-free disposal hull (CE-FDH) line, which is a non-decreasing step function generated on the scatterplot between the predictor and the outcome variables (Dul, 2016; 2020; 2021). Using the CE-FDH ceiling line was also justified by having discrete data within a relatively small range and exhibiting a limited number of levels (Dul, 2021). This allowed us to separate the space containing observations from the space not containing any observations, and thus to identify how much each service quality attribute constrains overall travel satisfaction. This ceiling line also indicates the minimum level of a particular service quality attribute that is required in order to obtain a certain level of overall travel satisfaction (see Fig. 3). Furthermore, Fig. 3 displays a ceiling regression – free disposal hull (CR-FDH), which can be used when there are many levels within the data, and when it can be considered continuous. The figure also displays an OLS regression line that runs through the middle of the data as a reference point.

<sup>2</sup> These two indicators, however, were assessed as important for the composites from a theoretical stance and they were thus retained during further analyses. Further analyses, both with and without these two indicators, only had a negligible influence on the validity and reliability measures. Moreover, both indicators belonged to latent composites (comfort and functionality) with significant paths to STS, effects that did not change due to the inclusion or exclusion of these indicators.

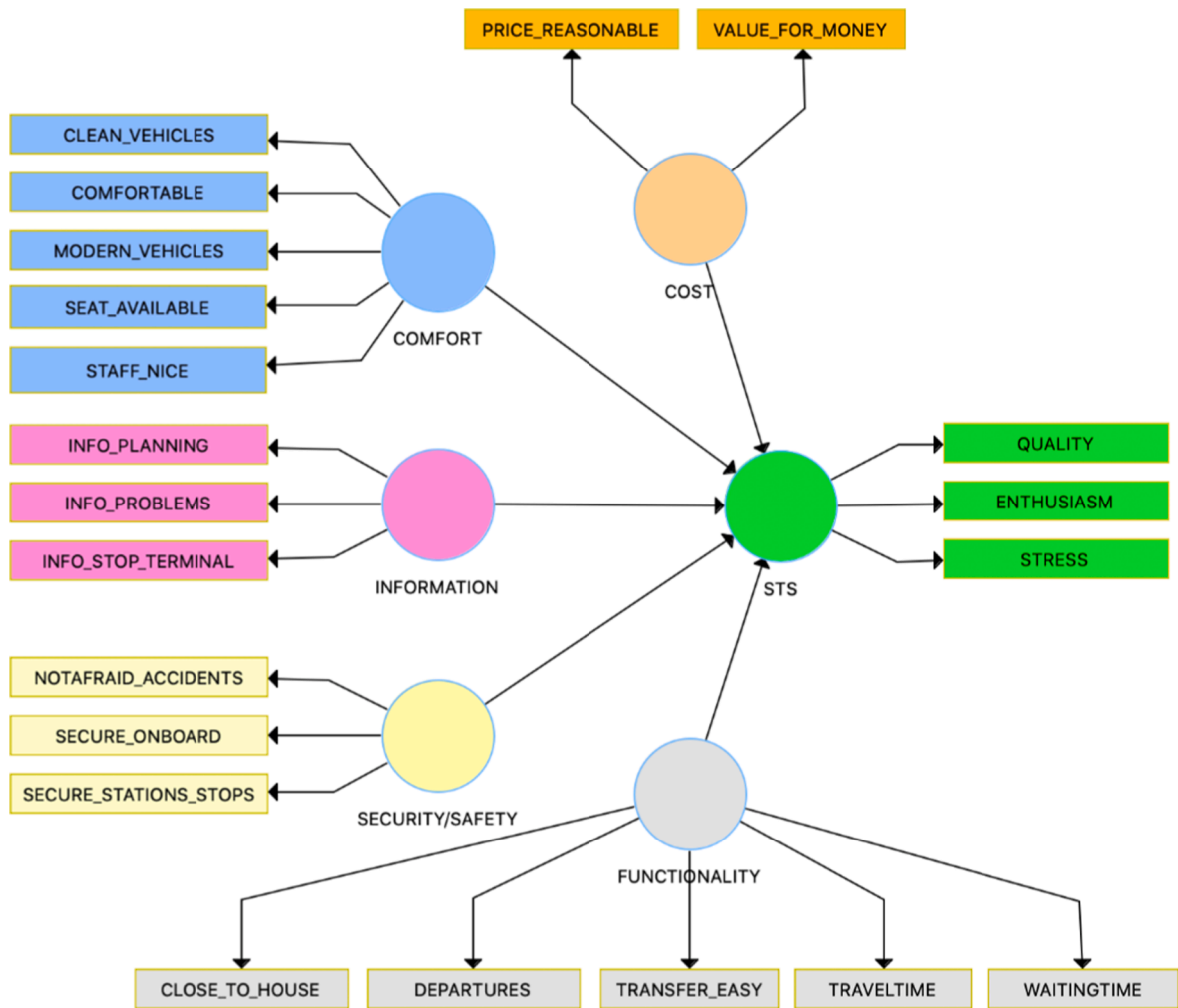


Fig. 2. Structural model of the service quality composites and overall travel satisfaction (STS).

Table 4

Results from the structural model.

Direct Effects	$\beta$	$t$	$p$	CI [2.5%-97.5%]	
COMFORT -> STS	0.319	6.046	<0.001	0.217	0.427
COST -> STS	0.104	2.799	0.005	0.031	0.174
FUNCTIONALITY -> STS	0.141	2.710	0.007	0.037	0.242
INFORMATION -> STS	-0.043	0.844	0.399	-0.140	0.060
SECURITY/SAFETY -> STS	0.073	1.550	0.121	-0.022	0.163

Table 5

Results from FIMIX analyses.

		Segment			
		5	4	3	2
Fit Indices	AIC	1642.514	1653.105	1657.099	1674.747
	AIC3	1676.514	1680.105	1677.099	1687.747
	AIC4	1710.514	1707.105	1697.099	1700.747
	BIC	1796.909	1775.713	1747.920	1733.780
	CAIC	1830.909	1802.713	1767.920	1746.780
	MDL5	2686.489	2482.144	2271.202	2073.913
	LnL	-787.257	-799.552	-808.550	-824.373

### 6.1. Effect size and significance testing

First, we investigated the effect sizes ( $d$ ) of the latent variable scores, testing their statistical significance using a recommended random sample size of 10,000 (Dul, 2016; 2021; Dul, van der Laan, & Kuik, 2020). According to Dul and colleagues (Dul, van der Laan, & Kuik, 2020), in order for a condition to be considered necessary, it needs to meet three criteria: i) theoretical justification, ii) effect size  $d > 0$ , and iii) a small  $p$  value ( $p < .05$ ). The NCA results (see Table 6) indicate that *comfort* is the only condition that fulfills these criteria. Specifically, satisfaction with *comfort* is necessary for overall travel satisfaction (STS), showing a borderline small to medium effect size ( $d = 0.091$ ) (Dul, 2016), which is statistically significant ( $p < .01$ ) (Dul, van der Laan, & Kuik, 2020).

### 6.2. Bottleneck analysis

Next, in order to provide further details, we performed a bottleneck analysis (see Table 7). For each desired outcome variable (STS) in the first column, Table 7 shows the minimum values required for the predictor variables (comfort, cost, functionality, information, and security/safety) in the following columns. According to Table 7, in order to reach a medium-to-high level of STS (30–90%), the necessary level of comfort needs to be at least 10.8%. Whereas, for a high level of STS (100%), satisfaction with the comfort level needs to be at least 33.1%. This means that, if a certain minimum level of comfort (33.1%) is not achieved, then the outcome of a high level of travel satisfaction will not occur.

According to Table 7, functionality and security/safety are also shown as conditions necessary for high overall travel satisfaction. However, since these attributes demonstrated a small effect size and had large  $p$  values during significance testing (functionality,  $p = .16$ ; safety/security,  $p = .526$ ), they did not meet the criteria for making them relevant necessary conditions (Dul, van der Laan, & Kuik, 2020), and could thus be considered as showing randomness, or being false positives. Hence, they were disregarded as relevant necessary conditions.

In summary, NCA shows both that comfort is the only significant necessary condition and that, in order to report a high overall level of travel satisfaction, respondents need to experience at least 33.1 % satisfaction with comfort.

## 7. Discussion

The objective of this study was to provide public authorities and policymakers with better tools for evaluating and managing public transportation systems with the aim of enhancing their attractiveness. This objective was addressed by presenting a combined approach that helps to distinguish between necessary and sufficient conditions (by combining PLS-SEM and NCA) in order to better understand the relationships between the predictor and the outcome variables and to enable the identification of critical bottlenecks. To this end, this study is able to present three key contributions, as discussed in this section.

First, a contribution outlined in the introduction is the theoretical relationship between satisfaction with different service quality attributes and the overall level of travel satisfaction on the basis of necessity and sufficiency. Considering the differences in reasoning between these types of critical conditions is a relatively new way of thinking in research on the attractiveness of public transport. More specifically, the necessity logic enables researchers to reveal the minimum requirements for achieving high travel satisfaction, while following the sufficiency logic helps to identify conditions with adequate grounds for increasing overall travel satisfaction. Although the sufficiency logic is a widespread perspective in transport research, PLS-SEM is as yet an emerging methodology. Furthermore, the application of NCA remains to be explored in transportation research. In this study, we show how PLS-SEM and NCA are complementary when the research objective is to explore the service quality attributes important for high travel satisfaction. This provides guidance to researchers wishing to apply these methods in order to develop further explanations of satisfaction with public transport,

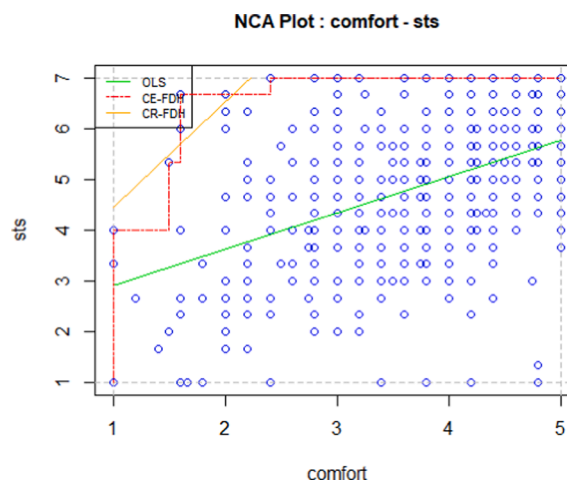


Fig. 3. Scatterplot of the predictor variable of comfort versus overall travel satisfaction (STS).

**Table 6**  
NCA effect sizes.

Service quality composite	Satisfaction with Travel Scale (STS)	
	CE-FDH	p-value
Comfort	0.091	0.009
Cost	0.000	1.000
Functionality	0.033	0.160
Information	0.000	1.000
Security/safety	0.030	0.526

**Table 7**  
Bottleneck table (percentages).

STS	Comfort	Cost	Functionality	Information	Security/safety
0	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	NN
30	10.8	NN	NN	NN	NN
40	10.8	NN	NN	NN	NN
50	10.8	NN	NN	NN	NN
60	10.8	NN	6.4	NN	NN
70	10.8	NN	6.4	NN	NN
80	10.8	NN	6.4	NN	NN
90	10.8	NN	10.1	NN	9.5
100	33.1	NN	10.1	NN	24.4

as well as for policymakers wishing to take measures that are more effective by focusing on important factors. Thus, one contribution lies in encouraging and guiding researchers as regards adopting a complementary approach, where PLS-SEM and NCA make a good combination when exploring travel satisfaction.

Our second contribution is about identifying “should” and “must” service quality attributes in public transport. By using PLS-SEM, we were able to identify “should” attributes that produce the best possible outcome. These are attributes that are of great importance for overall travel satisfaction. In line with previous research, our analysis shows that it is about satisfaction with comfort, cost, and functionality. By working with continuous quality improvements in relation to comfort (including noise, seating, modern and clean vehicles) and functionality (e.g., travel times, waiting times, numbers of departures, ease of transfer and proximity to nearest bus stop), managers will contribute toward increasing overall travel satisfaction. The cost of travel was also shown to be important for overall travel satisfaction, meaning that managers should provide services that give value for money and that costs should be reasonable in relation to what the user gets. However, such continuous quality improvements will have limited effects if critical factors are not addressed first. Departing from the necessity logic, we know that bottlenecks need to be resolved in order for travelers to report high levels of overall travel satisfaction. Bottlenecks are “must” attributes that need to be prioritized. By using the input from PLS-SEM, we were able to use NCA to identify critical “must” attributes needing attention.

We found that users of public transport need to be at least 33.1% satisfied with comfort, and that this is a necessary service quality attribute. This means that inadequate comfort prevents high overall travel satisfaction. This result differs from [Sukhov et al. \(2021\)](#), who identified a high level of satisfaction with safety as a necessary attribute of public transport. One explanation for the difference in results may be the complementary approach used, which allows the use of latent composites that account for the measurement errors inherent in the indicators. Another explanation may be contextual differences, whereby [Sukhov et al.](#) analyzed data collected in a mid-sized Swedish city, while this study focuses on five larger cities in Northern Europe. This is, however, a less likely explanation considering the finite mixture segmentation analyses conducted during this study, showing no differences between the five cities included. Differences in results justify more research aimed at determining whether or not comfort or safety, or both, are bottlenecks preventing a high level of satisfaction with public transport. We also noticed the non-significant effect of information. According to previous research, information is generally an important quality attribute, although sometimes heterogeneity between groups has been observed (as noted by, for example, [De Oña et al., 2015](#)). We show that travelers are generally fairly satisfied with the information provided. For overall satisfaction, however, other factors played a more central role. As our sample was collected from those using the service, information may not be as important to them as it is to infrequent users who are more reliant on information being provided (as indicated by [De Oña et al., 2015](#)).

Our results can be used to identify areas for further research. Based on what we found, we would argue that comfort would profit from more research since its definition and role are not very well understood in public transport. In their review, [Redman et al. \(2013\)](#) define perceived comfort, on the basis of previous research, as how comfortable the journey is regarding access to seats, noise levels, driver performance, and air conditioning. A review of interventions aimed at increasing comfort, included in the [Redman et al. \(2013\)](#) study, shows that managers tend to increase comfort by introducing new low-floor buses and covered bus shelters, and also by increasing standards regarding vehicle cleanliness, seat availability, and in-vehicle temperatures. We conclude that both managers and researchers focus on the instrumental aspects of comfort while leaving out the intrinsic value of comfortable travel (e.g., the value

associated with the essential nature of everyday travel). As a third contribution, we argue that, by providing additional perspectives on the meanings of everyday travel, e.g. physical or mental health, researchers can expand the definition of comfort used in public transport. For instance, [Ettema et al. \(2010\)](#), as well as others, argue that subjective wellbeing can provide an additional and valuable analytical framework for better understanding the complex relationships between the service quality provided and subjective travel satisfaction.

Given that our study was conducted in Northern Europe, its results may not necessarily be fully applicable to other parts of the world, e.g. the Global South, where micro mobility and informal public transportation co-exist with formal public transportation, and where formal public transportation is not always well developed. It is also important to acknowledge that data collection occurred during the pandemic (May-Dec 2020), when a general decline in public transportation use was observed. Indeed, we have all been highly affected by the pandemic in various ways, both in our private lives and in work settings. However, in line with previous research, we conclude that cost, functionality and comfort are generic service quality attributes of public transport. In our study, we only focused on users of the service. It is therefore impossible to know how, for example, frequent car users would experience a corresponding level of comfort. It is, however, likely that a high level of comfort will not initially be able to attract frequent car users onto public transport. But as, for example, [Pedersen et al \(2011\)](#) show, drivers can experience public transportation as satisfactory if there is success in getting them to try the service.

Combining different methods, as was the case in this study, does not give all the answers: However, the findings do provide valuable insights that can be used in future work on innovative comfort initiatives, both in research and in practice. Overall, it is concluded that public transport has the potential to become more attractive if it attains, at least, a moderate level of satisfaction regarding the comfort of the service, and if there are further improvements in satisfaction with comfort, functionality and cost.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### References

- Aladwani, A.M., 2001. Change management strategies for successful ERP implementation. *Business Process Management Journal* 7 (3), 266–275.
- Anderson, E.W., Sullivan, M.W., 1993. The antecedents and consequences of customer satisfaction for firms. *Marketing Science* 12 (2), 125–143.
- Bergkvist, L., Rossiter, J.R., 2007. The predictive validity of multiple-item versus single-item measures of the same constructs. *Journal of Marketing Research* 44 (2), 175–184.
- Creutzig, F., Roy, J., Lamb et al. 2018. Towards demand-side solutions for mitigating climate change. *Nature Climate Change*, 8(4), 260-263.
- Cronin Jr, J.J., Taylor, S.A., 1992. Measuring service quality: a reexamination and extension. *Journal of Marketing* 56 (3), 55–68.
- De Oña, J., de Oña, R., 2015. Quality of service in public transport based on customer satisfaction surveys: A review and assessment of methodological approaches. *Transportation Science* 49, 605–622.
- De Oña, J., de Oña, R., Eboli, L., Mazzulla, G., 2015. Heterogeneity in perceptions of service quality among groups of railway passengers. *International Journal of Sustainable Transportation* 9 (8), 612–626.
- De Vos, J., Schwanen, T., Van Acker, V., Witlox, F., 2015. How satisfying is the Scale for Travel Satisfaction? *Transportation Research Part F: Traffic Psychology and Behaviour* 29, 121–130.
- Dul, J., 2016. Necessary condition analysis (NCA) logic and methodology of “necessary but not sufficient” causality. *Organizational Research Methods* 19 (1), 10–52.
- Dul, J. 2020. Conducting Necessary Condition Analysis, *SAGE Publications*, ISBN: 9781526460141, <https://uk.sagepub.com/en-gb/eur/conducting-necessary-condition-analysis-for-business-and-management-students/book262898>.
- Dul, J., van der Laan, E., Kuik, R., 2020. A statistical significance test for Necessary Condition Analysis. *Organizational Research Methods* 23 (2), 385–395.
- Dul, J., 2021. Necessary Condition Analysis. R Package Version 3 (1).
- Eboli, L., Mazzulla, G., 2007. Service quality attributes affecting customer satisfaction for bus transit. *Journal of Public Transportation* 10 (3), 2.
- Eriksson, L., Friman, M., Gärling, T., 2008. Stated reasons for reducing work-commute by car. *Transportation Research Part F: Traffic Psychology and Behaviour* 11 (6), 427–433.
- Ettema, D., Gärling, T., Olsson, L.E., Friman, M., 2010. Out-of-Home Activities, Daily Travel, and Subjective Well-Being. *Transportation Research Part A* 44 (9), 723–732.
- Ettema, D., Gärling, T., Eriksson, L., Friman, M., Olsson, L.E., Fujii, S., 2011. Satisfaction With Travel and Subjective Well-Being (SWB): Development and Tests of a Measurement Tool. *Transportation Research Part F: Traffic Psychology and Behaviour* 14, 167–175.
- Fellesson, M., Friman, M., 2008. Perceived satisfaction with public transport services in nine European cities. *Journal of Transportation Research Forum* 47 (3), 93–103.
- Friman, M., Gärling, T., 2001. Frequency of negative critical incidents and satisfaction with public transport services. II. *Journal of Retailing and Consumer Services* 8 (2), 105–114.
- Friman, M., Fujii, S., Ettema, D., Gärling, T., Olsson, L.E., 2013. Psychometric analysis of the satisfaction with travel scale. *Transportation Research Part A* 48, 132–145.
- Friman, M., Olsson, L.E., Ståhl, M., Ettema, D., Gärling, T., 2017. Travel and residual emotional well-being. *Transportation Research Part F: Traffic Psychology and Behaviour* 49, 159–176.
- Goertz, G. 2003. The substantive importance of necessary condition hypotheses. In *Necessary conditions: Theory, methodology, and applications*, (pp. 65-94). Rowman & Littlefield Publishers, Inc.
- Gotlieb, J.B., Grewal, D., Brown, S.W., 1994. Consumer satisfaction and perceived quality: complementary or divergent constructs? *Journal of Applied Psychology* 79, 875.
- Gärling, T., Bamberg, S., & Friman, M. 2018. The role of attitude in choice of travel, satisfaction with travel, and change to sustainable travel. In *Handbook of Attitudes, Volume 2: Applications* (pp. 562-586). Routledge.

- Hair, J. F., Hult, G.T.M., Ringle, C.M. & Sarstedt, M. 2017. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, 2nd ed., Sage, Thousand Oaks, CA.
- Hair, J.F., Risher, J.J., Sarstedt, M., Ringle, C.M., 2019. When to use and how to report the results of PLS-SEM. *European Business Review*. 31 (1), 2–24.
- Hair, J.F., Sarstedt, M., Matthews, L.M., Ringle, C.M., 2016. Identifying and treating unobserved heterogeneity with FIMIX-PLS: part I—method. *European Business Review* 1, 63–76.
- Hensher, D.A., Stopher, P., Bullock, P., 2003. Service quality—developing a service quality index in the provision of commercial bus contracts. *Transportation Research Part A: Policy and Practice* 37 (6), 499–517.
- Mandel, D.R., Lehman, D.R., 1998. Integration of contingency information in judgments of cause, covariation, and probability. *Journal of Experimental Psychology: General* 127 (3), 269.
- Pedersen, T., Friman, M., Kristensson, P., 2011. Affective forecasting: Predicting and experiencing satisfaction with public transportation. *Journal of Applied Social Psychology* 41 (8), 1926–1946.
- Redman, L., Friman, M., Gärling, T., Hartig, T., 2013. Quality attributes of public transport that attract car users: A research review. *Transport Policy* 25, 119–127.
- Richter, N.F., Schubring, S., Hauff, S., Ringle, C.M., Sarstedt, M., 2020. When Predictors of Outcomes are Necessary: Guidelines for the Combined use of PLS-SEM and NCA. *Industrial Management & Data Systems* 120 (12), 2243–2267.
- Rigdon, E.E., Sarstedt, M., Ringle, C.M., 2017. On comparing results from CB-SEM and PLS-SEM: Five perspectives and five recommendations. *Marketing: ZFP—Journal of Research and Management* 39 (3), 4–16.
- Schneider, C. Q. & Wagemann, C. 2012. *Set-theoretic methods for the social sciences: A guide to qualitative comparative analysis*, Cambridge University Press.
- Singleton, P.A., 2019. Validating the Satisfaction with Travel Scale as a measure of hedonic subjective well-being for commuting in a US city. *Transportation Research Part F: Traffic Psychology and Behaviour* 60, 399–414.
- Sukhov, A., Lättman, K., Olsson, L.E., Friman, M., Fujii, S., 2021. Assessing travel satisfaction in public transport: A configurational approach. *Transportation Research Part D: Transport and Environment* 93, 102732.
- Suzuki, H., Fujii, S., Gärling, T., Ettema, D., Olsson, L.E., Friman, M., 2014. Rules for aggregated satisfaction with work commutes. *Transportation* 41 (3), 495–506.
- Tyrinopoulos, Y., dan G. Aifadopoulou., 2008, A complete methodology for the quality control of passenger services in the public transport business. *European Transport*, 38: 1-16.
- Van Lierop, D., Badami, M.G., El-Geneidy, A.M., 2018. What influences satisfaction and loyalty in public transport? A review of the literature. *Transport Reviews* 38 (1), 52–72.