



**HAL**  
open science

## Modelling impacts of beliefs and attitudes on mode choices. Lessons from a survey of Luxembourg cross-border commuters

Philippe Gerber, Marius Thériault, Christophe Enaux, Samuel Carpentier-Postel

### ► To cite this version:

Philippe Gerber, Marius Thériault, Christophe Enaux, Samuel Carpentier-Postel. Modelling impacts of beliefs and attitudes on mode choices. Lessons from a survey of Luxembourg cross-border commuters. *Transportation Research Procedia*, 2018, 32, pp.513 - 523. 10.1016/j.trpro.2018.10.037 . halshs-01912734

**HAL Id: halshs-01912734**

**<https://shs.hal.science/halshs-01912734v1>**

Submitted on 5 Nov 2018

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

International Steering Committee for Transport Survey Conferences

# Modelling impacts of beliefs and attitudes on mode choices. Lessons from a survey of Luxembourg cross-border commuters

Philippe Gerber<sup>a\*</sup>, Marius Thériault<sup>b</sup>, Christophe Enaux<sup>c</sup>, Samuel Carpentier-Postel<sup>d</sup>

<sup>a</sup>LISER – Luxembourg Institute of Socio-Economic Research, 11 Porte des Sciences, L-4366 Esch/Alzette, Luxembourg

<sup>b</sup>Université Laval, ESAD/CRAD, Pavillon Félix-Antoine-Savard, 16<sup>e</sup> étage, Québec, G1V 0A6, Canada

<sup>c</sup>Université de Strasbourg, CNRS, UMR 7362 LIVE, 3 rue de l'Argonne, 67000 Strasbourg, France

<sup>d</sup>Aix Marseille Univ, Université Côte d'Azur, Avignon Université, CNRS, ESPACE, UMR 7300, Avignon, France

---

## Abstract

This article uses structural equation models (SEM) as a data-mining tool to unravel the endogenous relationships among attitudinal measurements, satisfaction and the perceived utility within the theory of planned behaviour. Based on a mobility survey among Luxembourg cross-border workers, this experiment yields a critical view about the specification of measurement indicators to be used for the survey of attitudes and beliefs and to test SEM as an exploration and data-mining tool. The findings show that: the impact of attitudes on mode choice is mediated by self-reported satisfaction with commuting. Furthermore, using SEM with semantic differentials is efficient to estimate attitudes about transport modes in complement of Likert scales used for beliefs.

© 2018 The Authors. Published by Elsevier Ltd.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>)

Peer-review under responsibility of the International Steering Committee for Transport Survey Conferences (ISCTSC).

*Keywords:* Mobility survey; Structural equation modelling; Attitudes and beliefs; Satisfaction; Data-mining; Semantic differentials

---

## 1. Introduction

Two decades ago, Gärling et al. (1998) argued for the reintroduction of attitude theories to predict transportation mode choice. Their initiative was further complemented by multiple articles dealing with the impact of attitudes and personality traits on transportation behaviour in both transportation and social-psychological literature (e.g. Johansson et al. 2006, Mann and Abraham 2012, Tudela et al. 2013). That same year, Bamberg and Schmidt (1998) present

---

\* Corresponding author. Tel.: +352-585855601; fax: +0-000-000-0000 .

E-mail address: [philippe.gerber@liser.lu](mailto:philippe.gerber@liser.lu)

results from a longitudinal survey to measure travel-mode changes and model the marginal impact of attitudes after the implementation of a new transportation policy. Their research was based on a slight extension of the theory of planned behaviour (TPB) developed by Ajzen (1991). Today the literature provides several empirical studies linking beliefs, attitudes and motivations to travel behaviour. Lanzini and Khan (2017) and Hoffman et al. (2017) present extensive literature reviews of these articles and attempt to synthesize findings using meta-analysis. Most of these studies report some significant relationships between attitudinal factors and travel mode choices.

A review of the literature reveals the intrinsic complexity of assessing the linkage between attitudes and behaviour: 1) multiplicity of socio-psychological theories; 2) discrepancy of results between implicit/indirect and explicit/direct measurement of preferences, attitudes and satisfaction (Bradley 2013); 3) need to better integrate qualitative assessments of attitudinal factors within quantitative travel mode choice models using methods compatible with interdisciplinary research (Bradley 2013); 4) mediation of attitudes towards behaviour through perceived necessities (Haustein and Hunecke 2007) and environmental constraints (Schwanen and Mokhtarian 2005); 5) mutual dependency between behaviour and attitudes over time (Kroersen et al. 2017).

This article shows an attempt to relate environmental beliefs and attitudes about the car and the train (as latent constructs) to the self-declared satisfaction with commuting and the perceived utility (PU) of transportation modes (latent) for commuting. Using a survey of Luxembourg's cross-border commuters, the objectives are: 1) to illustrate the use of structural equation models (SEM) as a data-mining tool to unravel the endogenous relationships among measurements, satisfaction and the perceived utility of public transit; 2) to test the usefulness of semantic differentials to complement Likert scales; 3) to use SEM to enhance confirmatory factor analysis (CFA) results with scarce measurements items. Shortcomings of this survey and suggestions to enhance the integration of beliefs and attitudes are discussed, leading to ways for improving measurement of psycho-social indicators needed to identify mediators that potentially condition commuting mode choices on top of the usual factors of socio-economic status, accessibility, parking availability/costs...

The paper is structured as follows. First, the case study of Luxembourg cross-border workers is presented with survey design and summary results. Second, we discuss the relationships between beliefs and attitudes based on the TPB to forecast the mode choice as an outcome. Third, data-mining steps gradually improve the overall TPB model fit with survey data. Finally, we discuss the findings in terms of survey design and model specification.

## 2. The Luxembourg Survey

In 2010 and 2011, LISER and CNRS conducted a self-administered pencil-and-paper mobility survey (Enquête Mobilité des Frontaliers, Cross-Borders Mobility Survey, CBMS) among Luxembourg cross-border workers, based on a reference dataset of employees established in December 2009, using administrative records from National Social Security IGSS in Luxembourg (Inspection Générale de la Sécurité Sociale). Forty thousand workers were selected at random within a commuting area that assumes one return journey to work per day. Amongst them, 50% lives in the French region of Lorraine; 26% in Belgium (Wallonia); and 24% in Germany (Rheinland-Pfalz and Saarland). The sampling frame was controlled for socio-demographic factors (Gerber and Bienvenue 2005) and stratified in space (25 zones). The first survey phase (2010) attracted 7,235 respondents (18.1% response rate) to fill out a questionnaire dealing with the usual themes of a National Transport Survey (Schmitz et al. 2012). A second phase was undertaken in 2011 to enhance our understanding of the impact of beliefs, motivations and attitudes on mobility choices. It attracted 3,727 respondents among those of the first phase (52% response rate).

Table 1. Main (longest portion of the trip) commuting mode share (%) in 2007 and 2010. *Line up columns*

	Car		Train		Intercity Bus	
	2007	2010	2007	2010	2007	2010
Belgium	89.5	88.0	8.0	9.0	2.5	3.0
France	89.0	83.0	9.5	11.5	1.5	5.5
Germany	95.0	90.0	1.0	2.5	4.0	7.5
Total	91.0	86.0	7.0	9.0	2.0	5.0

Source surveys: LISER, STATEC 2007 Expenses of cross-border workers (5,724 respondents); LISER 2010 CBMS – phase 1

Table 1 displays the general change in mode shares from 2007 to 2010 in the study area. Main commuting mode is based on the mode used for the longest distance (as opposed to time) of the whole trip. Most trips using public transit involve either park-and-ride or kiss-and-ride (65%) in the home country, leaving a mere 27% to active modes

and 8% to city buses to access the departure station. Thanks to improvement of rail services and intercity bus, ridership rose from 2007 to 2010, leading to an estimated increase of train passengers (+3,200) and bus riders (+4,300). Nevertheless, using the car for commuting is still highly dominant (86%) among the cross-border workers. The recent change in mode shares increases relevance of modelling the influence of attitudes and beliefs on commuting choices. However, attitudes were surveyed only once, in 2011.

The questionnaire of the first phase was rather standard: employment status/control/agenda, description of commuting trips and other travel during the last working day, usual travel habits and household attributes, including transportation resources (car, bike, motorcycle) and monthly wages. Special emphasis was put on parking cost/availability at home and work places.

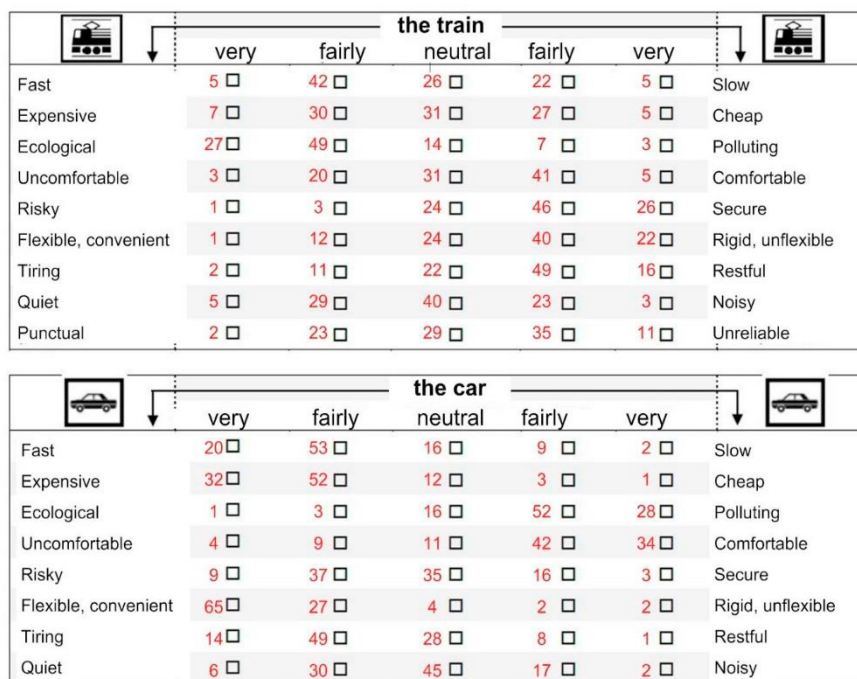
Table 2. Likert scales on beliefs about the environment (% of 3,700 respondents)

	Fully agree	Agree	Neutral	Disagree	Fully disagree
Increase of energy consumption is an overstated issue (EnerCons).	10.6	25.2	11.6	36.4	16.2
New technologies will solve the problem of fossil energies shortage (NewTechno).	8.3	43.3	26.6	19.2	2.6
When travelling, I try to reduce my GHG emissions (LowerEmis)	10.1	39.4	33.2	14.3	3.0
Safeguard my lifestyle is more important than environment and energy conservation (LifeStand).	3.2	16.4	28.4	44.4	7.6

Source: LISER 2011 CBMS – phase 2.

Several types of measurement instruments were involved in the second phase survey to allow for maximum flexibility in the assessment of beliefs about the environment (Table 2), perception of suitability, reliability and efficiency of transport modes (Figure 1), concerns about energy conservation, satisfaction with commuting and travel (4-level semantic differential scales, from very satisfied to very unsatisfied), pull factors to using public transit (e.g. more seats), etc. Qualitative responses were coded using semantic associations (keywords), dummies, Likert and semantic differential scales (Osgood et al. 1957).

Fig. 1. Opinion of respondents according to opposite qualities of the car and the train



Figures in red are the percentage of 3,400/3,600 respondents choosing each category

In this survey, one specific issue came from the fact that the questionnaires had to be bilingual (French and German) and was to handle slight differences of semantics from three cultures (French, German and Walloon

people). Moreover, as can be observed in Table 2 and Figure 1, many items of psychological scales are reverse worded to control for the acquiescence bias avoiding systematic compliance to subjective norms (or positive assessment of transportation modes) on each side of the scales.

These qualitative and attitudinal data were used to derive quantitative indicators to be used in the statistical analysis of mobility behaviour in a region (around Luxembourg) that is well serviced by public transit (efficient bus and train services, see Schiebel et al. 2015). We used ordinal assessment to measure satisfaction because it involves a simpler task than the valuation of numerical satisfaction levels (Donoso et al. 2013). It is noteworthy that self-reported satisfaction with commuting is globally higher among the PT users than the car drivers, which implies a positive appreciation of PT supply and/or some congestion on the motorway network at peak hours. Finally, use of PT modes and satisfaction of bus and train service are unequal among countries, meaning different levels of service that should be coordinated with the Luxembourg PT supply and/or sociocultural differences towards PT.

### 3. Beliefs, Attitudes and their Relationships with Mode Choice

#### 3.1. Conceptual framework

Azjen's TPB provides a rational actor theory to model the intention leading to choices (Figure 2). It includes a preference model to mediate the impact of beliefs using attitudes towards behaviour and a restriction model to mediate both subjective norms and control beliefs on perceived expectation of others and perceived control towards intention and the actual behaviour (e.g. mode choice). Bamberg and Schmidt (1998) extended the TPB with a utility model that can handle the usual economic view of travel cost and duration. As satisfaction is a long-term mediator of attitudes towards behaviour, we further extent this utility model to include self-declared satisfaction with travel to define a latent factor of the perceived utility that mediates the impact of preferences, restrictions and satisfaction towards behaviour and, in this case, commuting mode choice.

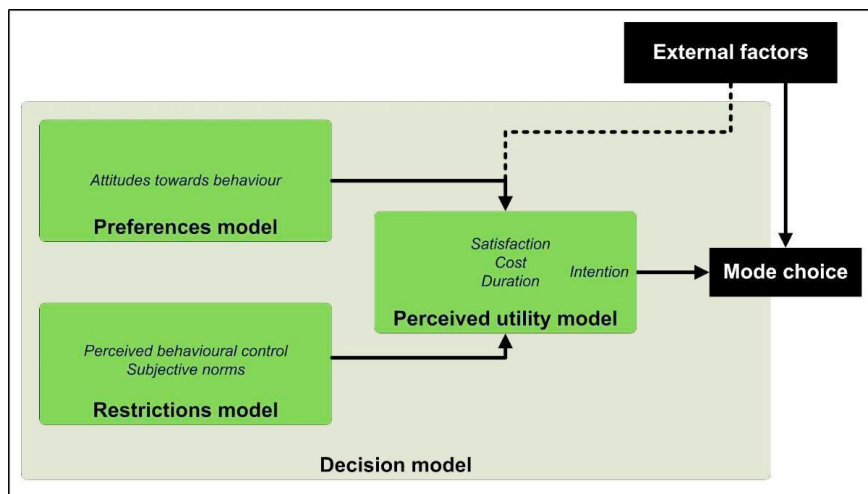


Fig. 2. Integration of the Azjen's TPB and utility to model mode choice.

We argue that satisfaction is needed when dealing with repeated "choices" like daily commuting because the impact of attitudes and controls evolve with experience and habits, eventually leading to routines that greatly condition the outcome (Gärling et al. 1998), while accumulation of unsatisfactory experience could lead to change of habits. Donoso et al. (2013) point out that perception and expectations are affected by past experiences while perception may also be influenced by beliefs, which include expectations. Looking at such mutual relationships, we believe that satisfaction is a central tenet that should be considered when modelling the utility of a routine habit/choice like daily commuting. Kroersen et al. (2017) state that in the long term, behaviour influences attitudes, meaning that we need to add some feedback to the TPB. That implies either leaning on longitudinal models or including feedback indicators like satisfaction with past experiences within cross-sectional models. Finally, external factors like personal/family needs (e.g. handicap) and other conditions (e.g. road closure, strike, parking availability...) could also influence both usual

(routine) and actual (of the day) mode choice. If permanent, these external factors condition the long-term utility model while they can also modify the daily mode choice directly if they change over time (e.g. congestion hours).

The decision model shown in Figure 2 includes: 1) a preference model; 2) a restriction model; 3) a utility model; 4) potentially, mediated impacts of external (or extrinsic) factors. Mokhtarian et al. (2015) make an explicit distinction between extrinsic (utilitarian and functional) and intrinsic (autotelic, hedonic and experiential) motivations of behaviour. Such a concept goes further than the usual “travel is a derived demand” paradigm and justifies inclusion of attitudinal and perceptual dimensions in the heart of the utility model.

However, there is a need to design latent constructs because the correlation between the mode choice (or the utility) and each attitudinal measurement is usually weak (if significant) and measurements are related and complementary. Thus, inclusion of attitudes should rely on the specification of latent constructs based on measurement items.

Moreover, as reported by Bradley (2013) there is no universal agreement about the definition of what is and what is not an “attitudinal measurement”. One point of view relies upon the “tendency to evaluate an object favourably or unfavourably” meaning that attitudes can include cognitive, affective, and behavioural dimensions but exclude subjective norms, expectations and intentions. Attitudes can change with experience, meaning that they are not entirely intrinsic to personality. Another point of view (Carrasco and Lucas 2015) excludes the emotional appeal of an object from attitudes and restrict their measurement to its importance and value, leading to independent specification of affective factors. That is the approach used by Tudela et al. (2013) to compare the effect of psychological factors on mode choice thanks to the theory of interpersonal behaviour in Concepcion (Chile) and Edmonton (Canada). For this research, we retain the first definition (including affective measurements) because it is more suitable in the context of the TPB as defined by Bamberg and Schmidt (1998).

### 3.2. Summarizing semantic differentials

Confirmatory factor analysis (CFA) was used to summarize semantic differential scales using indicative models and to define latent variables of attitudes related to appreciation of the car and the train. Factor scores of measurement models provide a continuous assessment of preconceived constructs based on the correlation of measurement indicators keeping their common signature (congruence) and cutting off disparities in specific error terms (Brown 2006). Only measurement sets meeting the alpha reliability criterium of 0.7 were retained to define three correlated factors (based on responses to questions from Figure 1): 1) the pro-car attitude (PCA); 2) the train comfort appreciation attitude (TCA); and, 3) a train environmental friendliness attitude (TEA). It is noteworthy that obvious qualities (like flexibility of the car) are not contained in the definition of latent variables because of their low congruence with other items. Figure 3 presents an improved view of these attitudinal factors using SEM to add two Likert scales on environmental beliefs (from Table 2) to define a pro-environment attitude (PEA) that influence the attitudes about transport modes. It uses self-reported satisfaction of commuters to further calibrate the definition (significant coefficients) of attitudinal factors. Unfortunately, items provided in Table 2 were poorly related, impeding the search for a stronger PEA factor. SEM uses a maximum likelihood approach to solve a given structure of relationships (provided by the scholar) to maximize the fit with the observed covariance matrix. This procedure estimates the support given by survey data to the given structure or construct. For this research, a quasi-maximum likelihood (QML) approach (Satorra and Bentler 1994) is used to handle the fact that measurements are not Gaussian.

A chi-squared test assesses the significance of the difference between the given structure and a saturated model (all potential links included). But a saturated model is not parsimonious and does not improve knowledge because it is potentially unstable (highly dependent on the data). Thus, a simpler best fit model is preferred. The strength of the adjustment of CFA and SEM is assessed using fit indices (Hooper et al. 2008). SEMs presented in this article report on three indices: 1) root mean squared errors of approximation (RMSEA) that should be below 0.06; 2) standardized root mean squared residual (SRMR) that should be below 0.05; and, 3) a comparative fit index (CFI) that is a relative assessment of goodness of fit where a value above 0.95 indicates a good fit (Hu and Bentler 1999).

As can be shown in Figure 3, the PEA is significantly ( $p < 0.001$ ) related to a positive evaluation of the train (TCA and TEA) and is negatively related to the PCA. Moreover, both TCA and PCA exert a significant positive influence of the self-reported satisfaction of commuters. However, correlations are relatively modest, meaning that this model does not “explain” a large part of the endogenous variance among measurements, leaving a large variance in error terms associated with each variable and factor receiving arrows in the path diagram. The main benefit of this model is to provide a preliminary estimate of four latent beliefs and attitudinal constructs (PEA, PCA, TCA and TEA) considering their mutual links, thanks to the capacity of SEM to properly handle endogeneity.

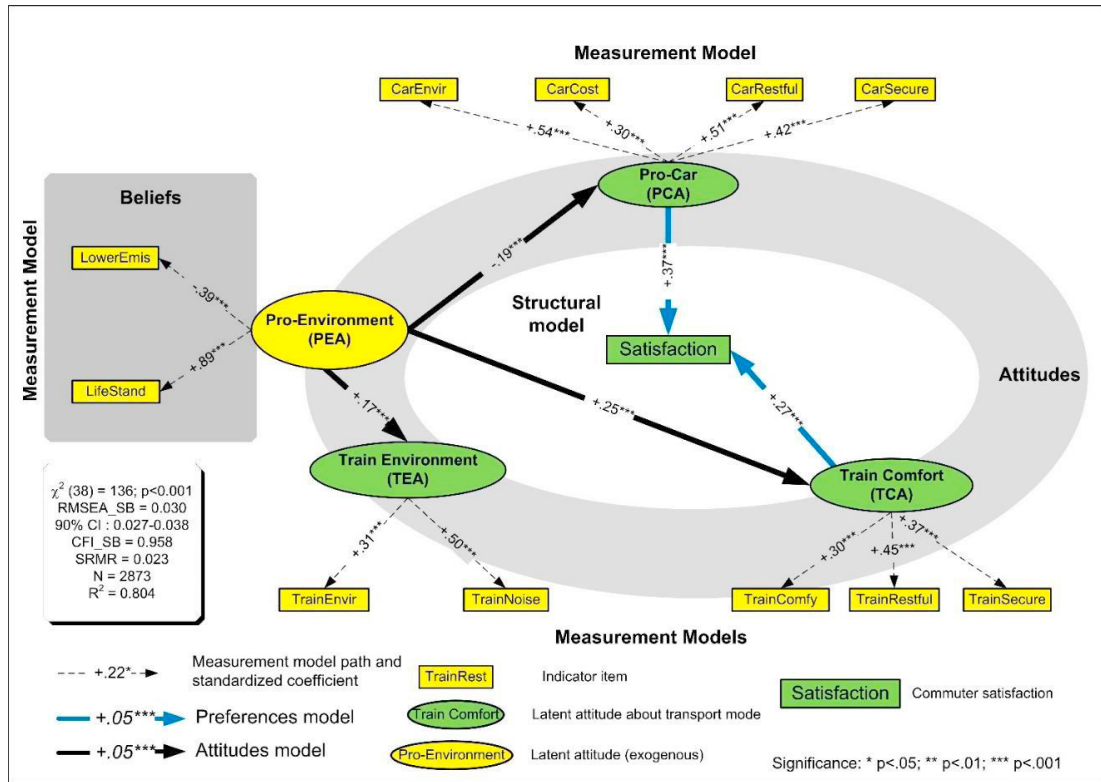


Fig. 3. SEM of attitudes about the environment, the car and the train

The previous step validates the existence of a relationship between attitudes and satisfaction but does not compare the given path structure with alternate views and does not bridge the link with intention or mode choice for commuting. Thus, we need a second-level construct to relate attitudes, satisfaction and mode choice (the utility model).

### 3.3. Linking attitudes and beliefs to travel mode choice

Decades ago, the concept of utility emerged in the transportation literature, considering the cost and duration of travel (and value of time) to compare modes. During recent decades, progress was made using multiple ways to integrate attitudes and socio-psychological context within various functional specifications of logistic regression and SEM. This integration could be made by adding new independent variables or using latent classes (assuming that attitudes are independent/complementary of the utility, see e.g. Ma et al. 2015) or by integrating the attitudes in the specification of the utility assuming their role in the shaping of utility. We argue that second option is better because the utility theory assumes that people have comprehensive knowledge of advantages/disadvantages of alternatives and use that information to optimize their choice considering their own needs. Attitudes about transport modes (e.g. Figure 3) are qualitative assessments of their suitability to support travel needs.

Table 3 presents a formative model approach using a generalized SEM (multinomial logit on mode choice) with QML. It estimates a latent construct of perceived utility (PU - considered as a combination of satisfaction with commuting, perceived cost difference of modes and duration of commuting) to bridge the gap between attitudinal/satisfaction factors and the mode choice. For this article, it is applied to the usual mode choice for commuting, making comparison of using PT versus the car; while mode choice (car, bus, train), the outcome, is used to calibrate the latent utility. In the specific case of Luxembourg, we need to set two controls (working in the centre i.e. Luxembourg City; and the home country) because local effects of difference in transport supply on mode choice should be accounted for. Finally, to stay in line with the objective to model the PU, duration of travel and travel costs

were estimated using self-reported categories rather than measured/simulated economic values. In fact, Table 3 provides the perceived utility model needed to operationalize the decision model of Figure 2.

Table 3. Generalized SEM of perceived utility of PT (unstandardized coefficients; N=2,819)

<b>Mode choice (Multivariate logit) (reference: Car)</b>		<b>Coefficients / significance</b>
<b>Bus</b>		
WorkCentre - control		2.184 ***
Country (ref. France) - control		
	Germany	0.550 **
	Belgium	-1.059 ***
<b>Perceived Utility (constrained)</b>		
Constant		1
		-5.341 ***
<b>Train</b>		
WorkCentre - control		2.071 ***
Country (ref. France) - control		
	Germany	-1.597 ***
	Belgium	-0.284
<b>Perceived Utility</b>		
Constant		1.145 ***
		-4.555 ***
<b>Perceived Utility (Linear regression)</b>		
Self-declared commute duration (ref. 46–60minutes)		
	0–15minutes	-0.259
	16–30minutes	-1.461 ***
	31–45minutes	-0.705 ***
	61–90minutes	1.332 ***
	More than 90 minutes	1.310 ***
Cost differential (ref. Train is cheaper than the car)		
	Car and train are cheap	-0.184
	Car is cheaper than train	-0.628
	Car and train are expensive	0.206
Commuter satisfaction (ref. unsatisfied)		
	Very unsatisfied	-0.992 ***
	Satisfied	1.419 ***
	Very satisfied	2.315 ***
<b>Train Comfort Attitude (TCA)</b>		
		0.524 **
<b>Pro-Car Attitude (PCA)</b>		
		-0.568 ***
<b>Train Environment Attitude (TEA)</b>		
		-0.387 **

Significance \* p<0.05; \*\* p<0.01; \*\*\* p<0.001; adjusted using QML specification

This model displays the significant contribution of attitudinal factors in the assessment of the latent perceived utility. The mode choice reference is the car. To estimate mode coefficients, the bus is constrained to 1 and the train coefficient assess the significance of the difference between using PT or the car. When the bus is constrained to 1, the coefficient for the train is 1.145, meaning that using the train is a little more likely than using the bus. If the train had been constrained to 1, the coefficient for the bus would be 0.873 \*\*\*. Both the controls for the work place and home country proved significant. Looking at the linear regression to assess the latent perceived utility, the cost differential did not yield significant result. The likelihood of using PT is lower for trips of less than 45 minutes and higher for longer commutes (one hour and up). In general, self-reported satisfaction with commuting is associated with a higher perceived utility of PT. Attitudinal factors have a significant impact on the PU of PT versus the car. A higher pro-car attitude (PCA) lowers the PU of PT (and the likelihood to use it). A positive assessment of the train comfort (TCA) raises the perceived utility of PT, while recognition of the environmental benefits of the train (positive TEA) does not benefit directly the PU of PT. The negative coefficient could be attributed to the dominance of car users in the analysis. Most car drivers believe that the train is environmentally friendly, but that belief is not sufficient to convince them to use PT for commuting. Values of the latent variable of “perceived utility” provides factor scores that can be standardized. This results in a bipolar predicted variable where positive values indicate that PT is preferred to the car.

#### 4. Data Mining the Mode Choice Determinants Using SEM

Thanks to the maximum likelihood (or to the QML) approach, SEM can handle a full matrix of relationships (variance-covariance) between variables and indicators to test a set of simultaneous equations that depict expected (user defined) paths of dependency. It handles endogeneity, estimate latent constructs and latent classes and can test



for the existence of mediator variables. It is flexible enough to integrate covariance among error terms and set parameters to fixed values to compare models based on likelihood ratio (LR) tests.

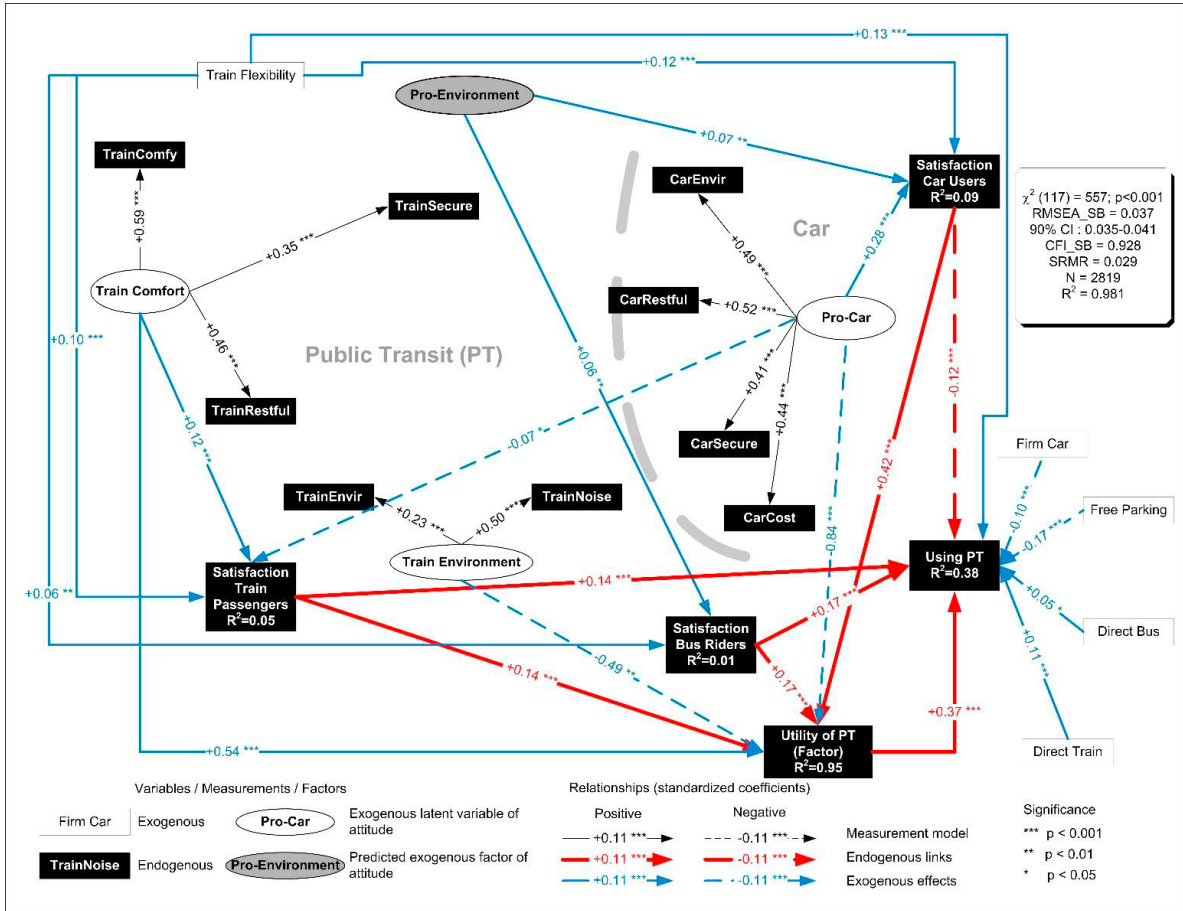


Fig. 4. Exploratory decision model based on the mode specific self-reported satisfaction

Let us further explore the survey data, without the constraints of the TPB framework, but with the aim of exploring the specification of a comprehensive model. The main problem in Table 3 specification is that the satisfaction with commuting is related to the actual mode choice and that one variable cannot handle the eventual divergence of consequences between car users and PT users (e.g. slight delay caused by road congestion versus missing the last train). Unfortunately, the survey did not ask for self-declared satisfaction about using competing modes. But satisfaction with commuting can be coded for each mode using negative values when unsatisfied (-2 very unsatisfied; -1 unsatisfied) and positive when satisfied (+1 satisfied; +2 very satisfied) and zero when the mode is not used. This allows for the specification of one satisfaction index for each mode. They are obviously independent since each respondent was using only one mode.

Figure 4 shows a SEM with such specification of satisfaction. This SEM analyse the endogenous core of relationships made of satisfaction (according to the mode), the PU of PT and the use of PT. While not perfect (CFI=0.928), the fit is sufficient to argue for a reasonable adjustment as an exploratory device. Endogenous relationships are shown in red.

According to this specification, satisfaction has a positive impact on the utility, but the strength of the influence is stronger for the car users (+0.42) than the PT users (bus: +0.17; trains: +0.14). However, satisfaction of car users is significantly detrimental to an eventual modal shift towards PT, while satisfaction of PT users consolidates their willingness to use PT. One can argue that the model is somewhat circular (made of endogenous relationships) because mode choice is used to split the satisfaction about mode choice, but SEM are made for handling such type of situation that can be argued on conceptual bases: satisfaction with commuting is both the result of previous commuting

experiences (that gradually reshape attitudes), and an incentive to eventually modify (or keep) future choices (intention). We are not searching for causal influence; our aim is limited to disentangle complex set of relationships.

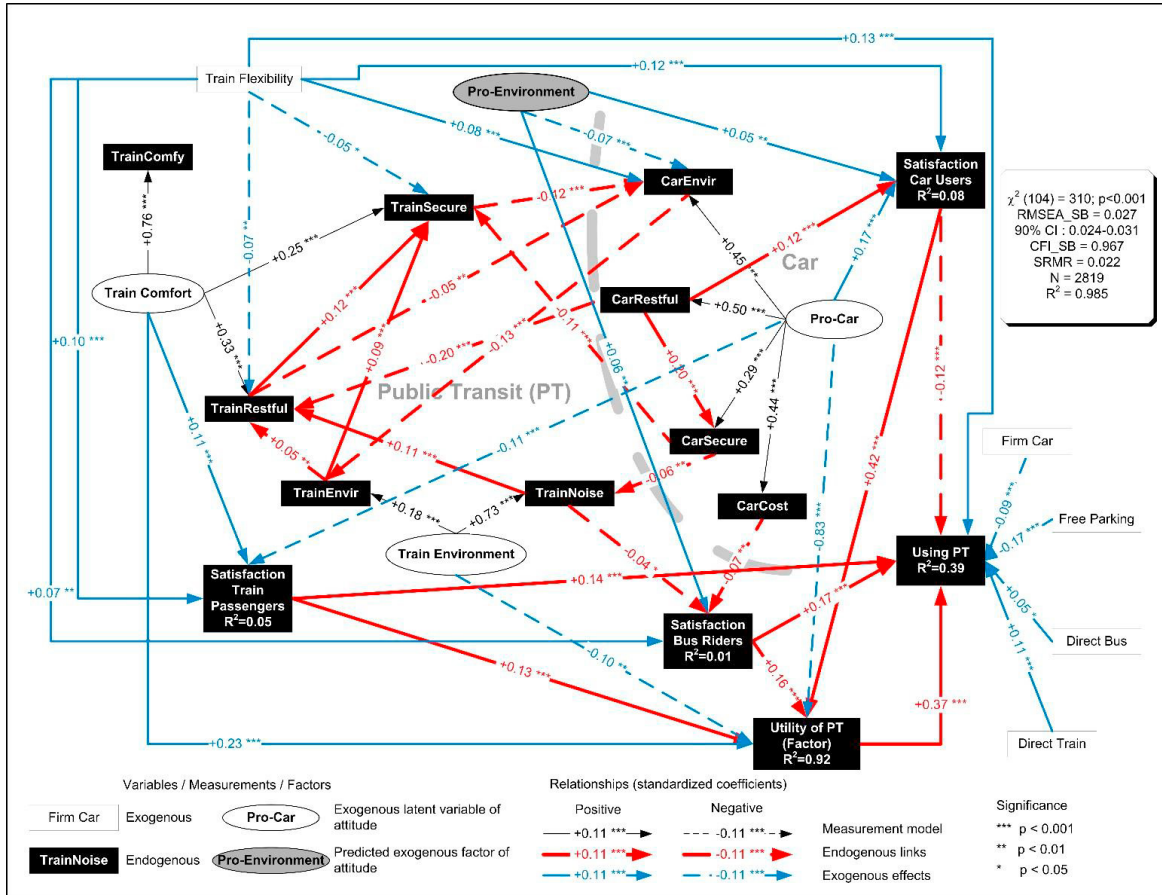


Fig. 5. Exploratory SEM of the endogenous core of attitude and satisfaction measurements

From another point of view, Figure 5 emphasizes the endogenous core of attitudes and satisfaction measurements showing perception/satisfaction of the train and the bus on the left side and those related to the car on the right side. Exogenous links are kept in the model, which includes latent variables of attitudes that are deemed personality traits (external to the actual transportation choice issue). Figure 5 (CFI=0.967; RMSEA=0.027) is well adjusted and useful to explore the significance of differences between the assessment of the car and the train (negative coefficients; e.g. car and train restfulness) and identify highly related measurements on top of those (congruent) integrated in Figure 3.

### 5. Discussion and Conclusion

This article shows: 1) an operational integration of perception variables (self-reported satisfaction with commuting and the PU of PT) assuming they mediate the impact of attitudes on mode choice; 2) an exploration of the potential of SEM to unravel the dependency paths (marginal relationship) among survey measurements, latent constructs, self-reported assessments and mode choice, and; 3) a combination of semantic differentials and Likert scales to model attitudes and beliefs. This procedure led us to identify methodological issues related to the information that should be supplied by transport and mobility surveys to support this type of modelling and better the understanding of the linkage between attitudes and behaviour at the borders of various national or sociocultural contexts.

Firstly, the Luxembourg survey used several types of measurement instruments: asking for word associations (Abric 2003) with a theme, Likert scales related to sentences to build beliefs indicators, semantic differentials to

characterize features of transportation modes, self-declared satisfaction levels, dummies to identify change factors. On the one hand, this diversity provided a rich set of socio-psychological measurements that can be compatible with several analysis methods. On the other hand, while the semantic differentials were suitable for unravelling the latent attitudes about transportation modes, we were somewhat restricted in this analysis by an insufficient number of Likert-based sentences to build strong factors of beliefs (Figure 3); we had only two scales on general environmental concerns and two on energy issues (Table 2). Fortunately, thanks to the SEM approach, it was possible to refine the estimate of the pro-environment attitude using relationships with pro-car and pro-train attitudes to mediate its impact on satisfaction with commuting. For future surveys, we recommend providing at least 5 or 6 sentences for each theme factor that is expected to be relevant. Finally, we were unable to relate the dummies of incentives to use PT (e.g. more seats, lower price) into the SEM, even considering them as external factors. In fact, dummies do not allow for the definition of related motivations and none of the measurement was significantly related to anything else. In future surveys, we suggest replacing dummies with 4- or 5-level assessments of the importance/efficiency of each incentive (e.g. adding more seats— has no effect, has a slight effect, increases attraction, is highly attractive—for using PT). This improvement should not raise respondent burden significantly.

Secondly, measurement scales retained in this study had 4 to 5 levels. That was sufficient to estimate latent factors of attitude on continuous scales that are close to the normal distribution thanks to the use of SEM to complement CFA. For example, a one factor CFA with 3 measurement items on a 5-point scale leads to a potential set of 125 discrete values on the continuous scale. Conversely, a set of 3 or 4 related factors (latent variables) like the SEM in Figure 3 yields a continuum of values on each latent variable because the redundancy between instruments of factors defines correlations between factors, which propagate minor adjustments all over the model. Is this an improvement or an artifact of precision? That is an open research question, but one should admit that the assumption of independence among socio-psychological factors is unlikely, thus the interest to allow for correlation.

Thirdly, the process of mode choice occurs over time and involves complex dependencies and feedback on attitudes based on previous experience. In this research, we used the self-reported satisfaction to approximate these effects in a cross-sectional model. However, it is obvious that a longitudinal approach would be better to improve our understanding of these adjustments over time and that panel survey of attitudes would be required to handle time dependency between previous attitudes, previous mode choices, change in mode and changes in attitudes (besides, a panel survey would imply an increase of cost which should be considered). Again, the SEM approach provides resources to model such change using growth and/or survival approaches to search for thresholds related to mode changes, including potential autoregressive mediation or interaction terms to model the process of experience accumulation. We believe that such a sophisticated device (panel survey with longitudinal SEM) would be useful for improving mode choice modelling for planned trips and is likely essential to better understand “routine choices” like commuting where habits impede immediate change. Delays should be handled using survival models.

Thanks to its flexibility, the SEM approach provides an efficient data mining approach for the exploration of intricate relationships between attitudinal measurements and other factors leading to mode choice. While, the final specification should rely on a suitable theory, nothing forbids its use for the exploration of endogenous relationships between constructs to generate hypotheses and deepen our understanding of the intertwined linkages among sets of Likert and differential measurement scales.

To conclude, we successfully transform qualitative indicators from the Luxembourg cross-border commuters survey into a statistical analysis to assess the significance of their impact on commuting mode choice. Using mostly semantic differentials, CFA and SEM proved efficient to estimate latent variables to disentangle intertwined relationships between beliefs, perceptions and attitudes related to mediators (satisfaction and perceived self-utility) towards the choice of PT in commuting. Our approach is based on the theory of planned behavior but rely on complementary semantic differential indicators of transport mode assessment to complement the usual Likert scales. Finally, this article shows that the SEM approach could be used as a data-mining tool to gain an in-depth knowledge of relationships among survey measurements and improve cross-sectional model specification, but without claiming identification of causal links that would need a longitudinal approach and can be hidden by mere correlations.

## Acknowledgments

This paper is registered as part of the Prof. Marius Thériault visiting professor scheme held at LISER in 2015 and is linked to the CONNECTING research project (Consequential Life Cycle Assessment of multimodal mobility

policies - the case of Luxembourg, FNR CORE C14/SR/8330766). The used database relies on the work of the CABaC 2010–2013 research project (Construction and Analysis of a Knowledge Base on mobility habits and attitudes towards energy of cross-border workers in Luxembourg, FNR INTER/CNRS/09/01). The survey was funded by the Ministry of Higher Education of Luxembourg. The realization of this paper was supported by the “Accès à la Cité” team funded by Fonds de Recherche Québécois Société et Culture (Québec, Canada).

## References

- Abric, J.-C., 2003. *Méthodologie de recueil des représentations sociales (Survey Methodology of Social Representations)*. In: Abric, J.-C. (Ed.) *Pratiques sociales et représentations*. Fourth Edition, Presses Universitaires de France, pp. 59-82. [in French]
- Ajzen, I., 1991. The theory of planned behaviour. *Organizational Behavior and Human Decision Processes* 50, 179–211.
- Bamberg, S., Schmidt, P., 1998. Changing travel-mode choice as rational choice: results from a longitudinal intervention study. *Rationality and Society* 10(2), 223–252.
- Beck, M., Rose, J., 2014. *The Best of Times and the Worst of Times: A New Measure of Attitudes Towards Public Transport Experiences*. Presented at the 10th International Conference on Transport Survey Methods, November 2014, Leura, Australia.
- Bradley M., 2013. Workshop synthesis: Measuring the influence of attitudes and perceptions. In J. Zmud, M. Lee-Gosselin, M. Munizaga, J.A. Carrasco. *Transport Survey Methods. Best Practice for Decision Making*, Emerald, Bingley, U.K., pp. 643–646.
- Brown, T.A., 2006. *Confirmatory Factor Analysis for Applied Research*. New York: Guilford Press.
- Carrasco J.A., Lucas K., 2015., Workshop synthesis: Measuring attitudes; quantitative and qualitative methods. *Transportation Research Procedia, Transport Survey Methods* 11, 165–171.
- De Vos, J., Mokhtarian P.L., Schwanen, T., Van Acker, V., Witlox, F., 2015. Travel mode choice and travel satisfaction: bridging the gap between decision utility and experienced utility. *Transportation*, DOI 10.1007/s11116-015-9619-9.
- Donoso P., Munizaga M., Rivera J., 2013. Measuring user satisfaction in transport services: Methodology and applications. In J. Zmud, M. Lee-Gosselin, M. Munizaga, J.A. Carrasco. *Transport Survey Methods. Best Practice for Decision Making*, Emerald, Bingley, U.K., pp. 603–623.
- Gärling, T., Gillholm, R., Gärling, A., 1998. Reinroducing attitude theory in travel behaviour research. The validity of an interactive interview procedure to predict car use. *Transportation* 25, 129–146.
- Gerber, P., Bienvenue, J.-Y., 2005. Échantillonnage spatial et difficultés de production de données d’enquête à l’échelle intra-urbaine : l’exemple de la Ville de Luxembourg (Spatial sampling and survey data gathering issues at the suburban scale: The case of Luxembourg City). In: T. Ramadier and A.C. Bronner (Eds.) *Techniques d’enquête. Actualité scientifique de la méthode et des outils* (pp. 19-23). Strasbourg : CNRS et CEMAGREF [CD-ROM]. ISBN 2-9526014-0-2. [in French]
- Haustein, S., Hunecke, M., 2007. Reduced use of environmentally friendly modes of transportation caused by perceived mobility necessities: An extension of the theory of planned behaviour. *Journal of Applied Social Psychology*, 37(8), 1856–1883.
- Hoffmann, C., Abraham, C., White, M.P., Ball, S., Skippon, S.M., 2017. What cognitive mechanisms predict travel mode choice? A systematic review with meta-analysis. *Transport Reviews*. DOI: 10.1080/01441647.2017.1285819.
- Hooper, D., Coughlan, J., & Mullen, M., 2008. Structural equation modelling: Guidelines for determining model fit. *Electronic Journal of Business Research Methods* 6(1), 53–60.
- Hu, L.T., Bentler, P.M., 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modelling* 6 (1), 1–55.
- Johansson, M. V., Heldt, T., & Johansson, P., 2006. The effects of attitudes and personality traits on mode choice. *Transportation Research Part A* 40 (6), 507–525.
- Kroers, M., Handy, S., Chorus, C., 2017. Do attitudes cause behavior or vice versa? An alternative conceptualization of the attitude-behavior relationship in travel behavior modeling. *Transportation Research Part A* 101, 190–202.
- Lanzini, P., Khan S.A., 2017. Shedding light on the psychological and behavioral determinants of travel mode choice: A meta-analysis. *Transportation Research Part F* 48, 13–27.
- Ma, T., Gerber, P., Carpentier, S., Klein, S., 2015. Mode choice with latent preference heterogeneity: a case study for employees of the EU institutions in Luxembourg. *Transportmetrica A: Transport Science*, 1 23. <https://doi.org/10.1080/23249935.2015.1007175>
- Mann, E., Abraham, C., 2012. Identifying beliefs and cognitions underpinning commuters’ travel mode choices. *Journal of Applied Social Psychology* 42 (11), 2730–2757.
- Mokhtarian, P.L., Salomon, I., Singer, M.E., 2015. What moves us? An interdisciplinary exploration of reasons for traveling. *Transport Reviews*, 35 (3), 250–274.
- Osgood, C.E., Suci, G., Tannenbaum, P., 1957. *The Measurement of Meaning*. Chicago: University of Illinois Press.
- Satorra, A., Bentler, P.M., 1994. Corrections to test statistics and standard errors in covariance structure analysis. In: A. von Eye and C. C. Clogg (Eds.) *Latent Variables Analysis: Applications for Developmental Research*, (pp. 399–419). Thousand Oaks, CA: Sage.
- Schiebel, J., Omrani, H. Gerber, P., 2015. Border effects on the travel mode choice of resident and cross-border workers in Luxembourg, *European Journal of Transport and Infrastructure Research* 15 (4), 570–596.
- Schmitz, F., Drevon, G., Gerber, P. (eds.), 2012. *La mobilité des frontaliers du Luxembourg : Dynamiques et perspectives (The Mobility of Luxembourg Cross-border Workers: Dynamics and Perspectives)*. Les Cahiers du CEPS/INSTEAD, LISER, Luxembourg. [in French]
- Schwanen, T., Mokhtarian, P.L., 2005. What affects commute mode choice: Neighborhood physical structure or preference toward neighborhoods? *Journal of Transport Geography* 13:83–99.
- Tudela A., Nurul Habib K.M., Osman Idris A., 2013. Semantic approach to capture psychological factors affecting mode choice: Comparative results from Canada and Chile. In J. Zmud, M. Lee-Gosselin, M. Munizaga, J.A. Carrasco. *Transport Survey Methods. Best Practice for Decision Making*, Emerald, Bingley, U.K., pp. 625–642.