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Mehdizadeh, Milad; Kroesen, Maarten

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Does perceived accessibility affect travel behavior or vice versa? Alternative theories testing bidirectional effects and (in) consistency over time

Milad Mehdizadeh [a,*], Maarten Kroesen [b]

[a] *Norwegian University of Science and Technology (NTNU), Trondheim, Norway*
[b] *Delft University of Technology, Delft, The Netherlands*

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ABSTRACT

In theory, the unidirectional relationship between perception and behavior has been well established. In this line, the relationship between perceived accessibility and travel behavior has also gained traction in the transport domain. There is, however, less knowledge regarding the dynamic of bidirectional effects between these two variables and (in)consistency over time. Employing the Netherlands Mobility Panel data, we investigate the direction of the (causal) effect between perceived accessibility and travel behavior/travel preference. Using a two-wave cross-lagged panel model, we test how this theory works among urban travelers (n = 4,946). The findings show that the relationship between perceived accessibility and travel-related decisions varies depending on the transport mode and whether it is about travel behavior or preference. The effects might show bidirectionality, unidirectionality, or neither. Findings highlight that the perception-behavior theory is primarily consistent with revealed travel behavior as opposed to stated preferences. We find a bidirectional perception-(travel) behavior relationship. Unlike conventional wisdom and commonly used theoretical links, we find that travel mode use has a larger impact on perceived mode-specific accessibility than the reverse effect (the more expected link). Travel behavior also shows consistently lower levels of perception-behavior dissonance than preferences do. The study finds that perception consistently influences public transport use and preferences, unlike for cars and bicycles. Policy-wise, this implies that efforts aimed at correcting misperceptions about the accessibility of public transport could still have a positive impact on individuals' decisions to choose public transport.

1. Introduction

Investigating bidirectional effects and the consistency of the relationship between perceived mode-specific accessibility and travel behavior (mode use/choice) might give new insights into transport planning and policy implementation. The recognition of the interplay between these two variables provides valuable insights into how individuals make travel decisions and how accessibility perceptions influence such decisions and are affected by them. Having this understanding is essential for planners who strive to improve transport systems that are sustainable, efficient, and accessible.

As a seminal work, Handy et al. (2005) showed some effects between objective-built environmental factors and travel behavior

* Corresponding author at: Norwegian University of Science and Technology (NTNU), Bygg 12, 579, Dragvoll, Trondheim, Norway.
E-mail addresses: milad.mehdizadeh@ntnu.no, milad_mehdizadeh@ymail.com (M. Mehdizadeh).

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through a quasi-longitudinal design. However, the cited study and similar studies later have not addressed the extent to which bidirectional effects may exist between perceived mode-specific accessibility and mode-specific travel behavior/preferences employing a longitudinal study. Within the realm of geography, behavioral and cognitive approaches have recognized that decisions concerning spatial behavior stem from individuals' perceptions of their neighborhood (Pot et al., 2021; Kirk, 1963; Gold, 1980). Consequently, the accessibility concept is not solely shaped by the objective physical environment but is also shaped by how individuals subjectively perceive that environment. Different individuals can perceive the same geographic location in vastly divergent ways, owing to heterogeneous processes involving the collection, detection, filtration, and interpretation of information gleaned from their neighborhood (Golledge, 1978). This information regarding the physical environment can be acquired and detected either directly through firsthand interaction with the physical neighborhoods or indirectly through various representations of the environment, such as maps, media, descriptions provided by other individuals, and similar sources (Pot et al., 2021). In this line, the study of perceived accessibility, as one of the core determinants of travel behavior, has recently gained momentum in the research field (Pot et al., 2021; Lättman et al., 2016, 2018; Curl, 2018; Van Wee et al., 2019).

To date, longitudinal research on travel behavior has also focused primarily on examining the (unidirectional) effects of habits, life events, and attitudes on behavior change over time (e.g., Schlich and Axhausen, 2003; Choi et al., 2014; Walker et al., 2015; Kroesen et al., 2017; Kalter et al., 2021; Haustein and Kroesen, 2022). In some studies, for example, travel behavior has been revealed to be a habitual behavior, whereas in others, attitudes have been found to affect changes in travel behavior. It has also been shown in a study that changes in travel behavior over time influence attitudes toward travel modes (Kroesen et al., 2017). Despite this, knowledge regarding a dynamic perception-(travel) behavior relationship is limited. The current study contributes to the literature by investigating bidirectional (causality) effects between mode-specific perceived accessibility and travel behavior/preferences so that interventions can be tailored to address specific aspects of the relationship. To put it another way, we aim to reveal how and to what extent mode-specific perceived accessibility (causes) affects travel behavior/preferences over time and the other way around.

We examine both travel behavior and travel preferences to determine the degree to which perceived accessibility influences travel decisions. In other words, we investigate whether perceived accessibility influences travel behavior or travel decisions at the level of preferences, as well as how the reverse (causal) effects operate in both cases. If it is evident that positive perceptions of accessibility are highly influential in driving travel mode choices, efforts can be directed towards improving these perceptions by implementing public awareness campaigns, disseminating information, and improving infrastructure to gradually correct misperceptions towards more accessible and eco-friendly transport modes. Accessibility perception may vary greatly from person to person based on their individual needs, preferences, and circumstances. What one person considers good accessibility might be perceived as bad accessibility by someone else in the same neighborhood (Pot et al., 2021). For example, someone may perceive 10 min of walking time to the closest public transit station as poor accessibility, while another may perceive it as reasonable accessibility. On the other hand, if travel behavior/preferences significantly affect accessibility perceptions, strategies could promote sustainable travel choices to improve accessibility perception towards sustainable modes and decrease car accessibility perception. Travel behaviors/preferences are often rooted in familiarity and comfort. Those who have grown accustomed to a particular transport mode, such as daily car commuters, may have a biased perception of accessibility towards other modes. They may underestimate the convenience and accessibility of alternatives like public transport or biking due to a lack of sufficient experience or exposure (Van Exel and Rietveld, 2009).

Furthermore, assessing the consistency of this relationship over time is critical to long-term planning and resource allocation. If the relationship between perceived accessibility and travel behavior remains stable, investments in improving perceived accessibility are likely to yield long-term benefits. Nevertheless, if these dynamics change over time because of evolving societal norms, technological advancements, or other factors, policymakers may need to adapt their strategies to fit the changing landscape of transport options. Overall, investigating bidirectional (causality) effects and the temporal consistency of these aspects is fundamental for informed decision-making, and effective policy implementation.

In the following section, we overview the application of the (accessibility) perception-behavior theory to previous research. Following this, the conceptual framework of the study will be described in Section 3. A description of the sample, measures, and modeling methodology is provided in Section 4. The results of the models are discussed in Section 5, followed by a discussion of the findings in Section 6. Lastly, Section 7 concludes the study.

2. The perception-behavior relationship

Theoretically, the unidirectional relationship (not necessarily causality) of perception-behavior has been a subject of investigation in various fields, such as psychology, sociology, and marketing. The perception-behavior relationship refers to the link between an individual's perception of a behavior/object, and their subsequent behavior or actions in response to that perception (Dijksterhuis and Bargh, 2001; Chartrand and Bargh, 1999). It has been found that positive perceptions towards a particular behavior can relate to conducting that particular behavior. In the transport domain, this unidirectional relationship, particularly between perceived accessibility and travel behavior, has also been reported in several empirical studies (e.g., Scheepers et al., 2016; Lättman et al., 2020; Blandin et al., 2023).

Generally, accessibility can be defined as the degree to which an individual is able to conveniently engage in a desired activity at a preferred location, using a preferred mode of transport, and at a preferred time (Bhat et al., 2000). Perceived accessibility, on the other hand, refers to individuals' subjective perception of their ability to access various opportunities distributed across different locations. While many accessibility studies have traditionally relied on spatial data derived from engineering-based transportation approaches, recent research has emphasized the significance of perceived accessibility (Curl et al., 2015; Curl, 2018; Lättman et al., 2016, 2018).

Despite the prevalence of objective measures derived from spatial data, it is important to recognize that perceived accessibility, which strongly influences travel behavior and activities, may not always align with these calculated indicators (Morris et al., 1979; Pot et al., 2021). This discrepancy suggests that traditional measures may not fully capture accessibility as experienced by individuals. Acknowledging the growing importance of perceived accessibility in research highlights the need for a more comprehensive understanding of how individuals perceive and interact with their built environment (Geurs and Van Wee, 2004).

Prior research has consistently reported a notable lack of alignment between perceived and objective measures of accessibility (McCormack et al., 2008; Ball et al., 2008). As discussed earlier, a possible explanation for this observed lack of correlation is the way in which individuals assimilate and retain information regarding their neighborhood, a process heavily influenced by attitudes, motivations, and preferences (Dewulf et al., 2012; Pot et al., 2021). For instance, when people misperceive the availability of public transportation stations in their immediate neighborhood, they tend to rely on their cars and thus decrease their likelihood of taking advantage of collective modes. Therefore, the mere physical presence of such facilities does not necessarily guarantee their use, underscoring the significance of considering perceived accessibility when testing the relationship between accessibility and travel behavior (Scheepers et al., 2016). For example, Lättman et al. (2018) showed that individuals who primarily use bicycles for their daily travel rate their perceived accessibility much higher than those who mainly rely on cars or public transport, contrary to what objective accessibility assumptions suggested.

In the cognitive-behavioral environment framework advanced by Pot et al. (2021), it is argued that perceived accessibility plays a central role in predicting travel behavior. When assessing the effectiveness of land use and transportation systems, computed measures based solely on spatial data serve merely as proxies for how accessibility is actually experienced (Pot et al., 2021). Pot et al. (2021) argue that accessibility-focused planning should take perceived accessibility into account. Van Exel and Rietveld (2009) also revealed a noteworthy phenomenon wherein the perceptions of travel time associated with public transport among habitual car commuters showed a significant bias, surpassing the objective temporal values by a substantial margin of 46 %. They concluded if these perceptual inaccuracies were corrected to align more closely with factual travel times, then a substantial proportion of the current cohort of car-dependent travelers, who do not think public transport is a viable alternative, would probably include it in their choice set and occasionally use it.

Empirical studies also showed the unidirectional relationship between perceived accessibility and travel behavior. Employing cross-sectional data from a Dutch sample, Scheepers et al. (2016) showed that there is a strong link between perceived accessibility and mobility choices, even after taking into consideration individual and environmental factors. They underscore the importance of considering perceived accessibility when promoting a transition from car use to cycling or walking. Using data collected from residents of Malmö, Sweden, Lättman et al. (2020) revealed that the perception of accessibility significantly diminishes among car users when their options for daily travel become restricted. In a survey conducted in Santiago, Chile, Blandin et al. (2023) examined how subjective perceptions of accessibility impact modal choice. Their results indicate that lower perceived accessibility to public transport is associated with a higher likelihood of choosing motorized modes of transport.

Perceptions of accessibility can also evolve over time as individuals interact with their environment, as reported by past studies (De Vos et al., 2018; De Vos, 2019, Van Wee et al., 2019; Pot et al., 2021). This evolving process can be conceptualized as a feedback loop, wherein behavior influences perceptions of accessibility. This bidirectionality is also conceptually recognized in the Pot et al. (2021) model. In the realm of studying the relationship between attitudes and behavior, some studies, such as those by Kroesen et al. (2017), have suggested that behavior may have a more pronounced impact on travel attitudes than the reverse. Hence, a notable research gap pertains to understanding the direction of the (causal) relationship between perceived accessibility and travel behavior.

3. Research questions and conceptual model

Employing the Netherlands Mobility Panel data, we investigate the direction of the (causal) relationship between perceived

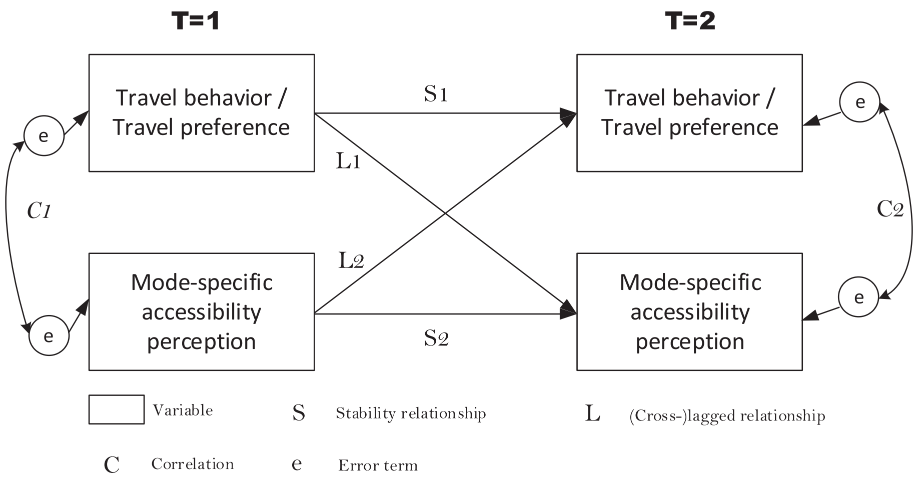

Fig. 1. The conceptual model of the study.

accessibility and travel behavior/preferences. As shown in Fig. 1, this analysis is conducted within the framework of a structural equation model, specifically employing a two-wave cross-lagged panel model (CLPM). Specifically, the current study aims to address the following research questions.

- Is there a bidirectional perceived accessibility-behavior/preference relationship? Do they affect each other over time? Is it a (in) consistent (causation) effect? What direction does have a larger effect?
- Do such effects vary across different transport modes?
- Do such effects exist at the level of perception-behavior or perception-preferences? And
- How dissonant/consonant are such relationships per mode? In line with Festinger's Theory of Cognitive Dissonance (Festinger, 1962), cognitive dissonance between one's behavior and perception engenders a state of psychological tension or arousal. Consequently, people are motivated to alleviate this dissonance. Therefore, we construct a variable, termed degree of dissonance, which is derived from individuals' mode use/preference and their perceived accessibility. We do not incorporate this measure into the CLPM, but we use it as a descriptive variable to monitor how the average degree of dissonance varies across different modes over time.

In the framework of the Cross-Lagged Panel Model (CLPM), we investigate (i) future travel behavior/preferences (T2) based on past ones (T1) and the mode-specific perceived accessibility at the initial time point, and (ii) future mode-specific perceived accessibility (T2) based on past ones (T1) and the travel behavior/preferences at the initial time point. This model incorporates parameters S1 and S2, representing stability coefficients, as well as L1 and L2, signifying the over-time (cross-)lagged influences between these variables. Furthermore, correlations C1 and C2 consider the initial overlap, accounting for potential prior causal influences in both directions or shared causes, alongside the association that persists after adjusting for stability (S1 and S2) and cross-lagged effects (L1 and L2). Ultimately, the significance and magnitude of parameters L1 and L2 help us determine whether the primary (causative) relationship goes from travel behavior/preference to mode-specific perceived accessibility, reverses direction, or operates in both directions concurrently (Finkel, 1995; Kroesen et al., 2017). Within the CLPM, the mode-specific perceived accessibility and behaviors/preferences are measured for car, bike, and public transit (described in the Method section). Furthermore, the model estimates the relationships (S1, S2, L1, and L2) while accounting for the effect of various exogenous background variables (i.e., age, gender, education, and job status), as detailed in Section 5. Consequently, the travel behavior/preference, and perceived mode-specific accessibility at both time points are treated as endogenous variables in the model.

4. Method

4.1. Sample

To test our developed CLPM illustrated in Fig. 1, the Netherlands Mobility Panel (MPN) longitudinal wave data was used (Mathijs de Haas- KiM Netherlands Institute for Transport Policy Analysis). The MPN examines travel behavior trends among a consistent group of individuals and households spanning an extended duration, dating back to 2013 (Hoogendoorn-Lanser et al., 2015). Its purpose is to ascertain how alterations in personal and household attributes, as well as other travel-related factors, align with shifts in travel behavior/preference over time. The MPN is conducted by a team of researchers affiliated with KiM Netherlands Institute for Transport Policy Analysis (Ministry of Infrastructure and Water Management).

As for this study, data from the 2017 and 2018 waves were taken into account. We selected these two waves because they encompass the variables of interest and are not affected by the COVID-19 era. To ensure reliable panel analysis, we chose to use only two consecutive waves instead of adding more, like three, to maintain a robust dataset reflecting travel behavior. This decision was made to prevent a decrease in the proportion of public transport and bicycle users within the sample. Additionally, selecting two closely spaced waves helps maintain an adequate sample size and minimizes the risk of sample attrition compared to choosing waves with a larger time gap.

The panel initially comprised around 10,600 individuals in 2017 and was drawn from a true probability sample of Dutch households. A year later, in 2018, the original participants were once again invited to partake in the same survey. After aligning data from both years and accounting for participation rates, missing values, and the relevance of survey items to the respondents' circumstances, including their travel behaviors and preferences, we ended up with 4,946 respondents for the CLPM analysis. As indicated in Table 1, for instance, 54.8 % of the participants were female, and 33.3 % held college or university degrees. Overall, the sample distributions align well with the respective population distributions, although some deviations can be observed. Specifically, young people (aged 12–17), men, and employed people are slightly underrepresented compared to the population.

4.2. Measures

Three following mode-specific items were used to measure perceived accessibility: (i) my neighborhood is easily accessible by car, (ii) my neighborhood is easily accessible by bicycle, and (iii) my neighborhood is easily accessible by public transport (PT). The level of agreement or disagreement with the items was evaluated on a five-point Likert scale ranging from (1) strongly disagree to (5) strongly agree.

As for travel behavior, the frequency of use of car, bicycle, and PT (including bus, tram, and metro) was measured on a six-point Likert scale ranging from (0) never, (1) 1 to 5 days per year, (2) 6 to 11 days per year, (3) 1 to 3 days per month, (4) 1 to 3 days per

Table 1
The respondents' characteristics participated in the two waves (2017–2018).

Variable	Category	Sample (%)	Population (%)[1]
Age	12–17	1.0	7.5
	18–24	6.8	10.2
	25–29	7	7.4
	30–39	18.7	14.6
	40–49	14.6	13.6
	50–59	17.5	16.2
	60–69	18.1	14.1
	70–79	13.1	10.8
	80 and older	3.1	5.6
Gender	Male	45.2	49.7
	Female	54.8	50.3
Education	College or university degree	33.3	34.7
	Other	66.7	65.3
Job-status	Employed	52.8	59.1
	Other	47.2	40.9

[1] Statistics Netherlands (2024).

week, and (5) 4 or more days per week. As the MPN data indicate a correlation between buses, trams, and subways, we opted to group them into a single category. Notably, the "car" category in the data does not encompass taxis. There were only three mode-specific perceived accessibility items available in the MPN dataset, therefore, the travel behavior for other modes of transportation, such as walking and e-scooters, was not considered in the analysis.

As for stated travel preferences, preferred modes of transport for 11 different trip purposes, including home-to-work commute, business, school/study, grocery shopping, shopping, hotel/restaurant, visiting other people, day trips, sports, informal care, and other leisure activities, were asked. A composite measure of preference was calculated for car, bicycle, and PT based on these data.[1] For example, we looked at how many times the car was reported as the preferred mode across 11 trip purposes. Accordingly, the initial scale ranged from 0 to 11 for each mode. To create a more consistent scale range with perceived accessibility, this original scale of composite preference, which ranged from 0 to 11, was transformed and mapped to a new range of 1 to 5.

The descriptive analysis of these items is described in Table 2. For both revealed travel behavior and travel preferences, car was the most used mode and preferred mode of transport in both waves, while PT was the least used/favored option. Among the three transport modes, the perceived accessibility of bicycles was rated the highest, while PT perceived accessibility was assessed as the lowest.

We also constructed a third variable, termed degree of dissonance, which was derived from individuals' mode use/preference and their perceived accessibility. Our CLPM did not include this measure, but we used it as a descriptive variable to analyze how the average degree of dissonance varies over time across different modes. The perceived accessibility scale was established using a 5-point ordinal rating scale, while mode use behavior was represented as a scale from 0 to 5. To make these two variables comparable, we mapped the original scale of mode use behavior to the new range (1 to 5). For each mode considered, we computed the degree of dissonance as the absolute difference between these two 5-point scales, yielding a 'dissonance' variable that ranges from 0 to 4. To illustrate, if someone's car use was rated "5″ and their perceived accessibility was "5," the degree of dissonance would be "0". The same calculation was made between perceived accessibility and travel preference, yielding a 'dissonance' variable ranging from 0 to 4. Observing Table 2, it is evident that the degree of dissonance is most pronounced when considering the dissonance between mode-specific perceived accessibility and travel preferences.

4.3. Model

A two-wave cross-lagged panel model (CLPM) is used to explore how variables measured at two different time points, referred to as "waves," interact and influence each other. This was useful for investigating the (causal) connections between perceived mode-specific accessibility and travel behavior/preference over time. This model allows assessing how changes in one variable at the first wave relate to changes in another variable at the second wave, while also considering potential reciprocal effects between the two (Finkel, 1995). In essence, it helps uncover temporal dynamics and provides insights into whether and how changes in one domain impact changes in another. The model includes stability coefficients to measure the consistency of each variable over time, correlation coefficients to account for any initial overlap between the variables, and cross-lagged coefficients to evaluate the strength and direction of (causal)

[1] Respondents were asked about their preferred travel mode for various destinations irrespective of the actual frequencies of undertaking the respective trips (respondents answered the questions for all destinations). Hence, we believe a summed scale adequately captures the variance in people's travel preferences.

Table 2
The mean and standard deviation of tested variables in the CLPM.

Variables		(n = 4,946)	
		Wave 1	Wave 2
Perceived accessibility (1–5)	Car	4.39 (0.85)	4.47 (0.78)
	Bike	4.57 (0.70)	4.60 (0.67)
	PT	3.62 (1.2)	3.65 (1.22)
Travel behavior/mode use (0–5)	Car	4.03 (1.26)	3.98 (1.32)
	Bike	3.02 (1.98)	2.88 (2.03)
	PT	1.35 (1.52)	1.29 (1.50)
Travel preference (1–5)	Car	2.16 (0.99)	2.11 (0.99)
	Bike	1.57 (0.81)	1.50 (0.78)
	PT	1.05 (0.21)	1.05 (0.22)
Degree of dissonance between travel behavior and perceived accessibility (0–4)	Car	0.85 (0.95)	0.85 (0.96)
	Bike	1.54 (1.21)	1.58 (1.26)
	PT	2.58 (1.24)	2.65 (1.22)
Degree of dissonance between travel preference and perceived accessibility (0–4)	Car	2.31 (1.09)	2.43 (1.07)
	Bike	2.17 (1.22)	2.26 (1.23)
	PT	3.52 (0.73)	3.55 (0.71)

* Mean (standard deviation).

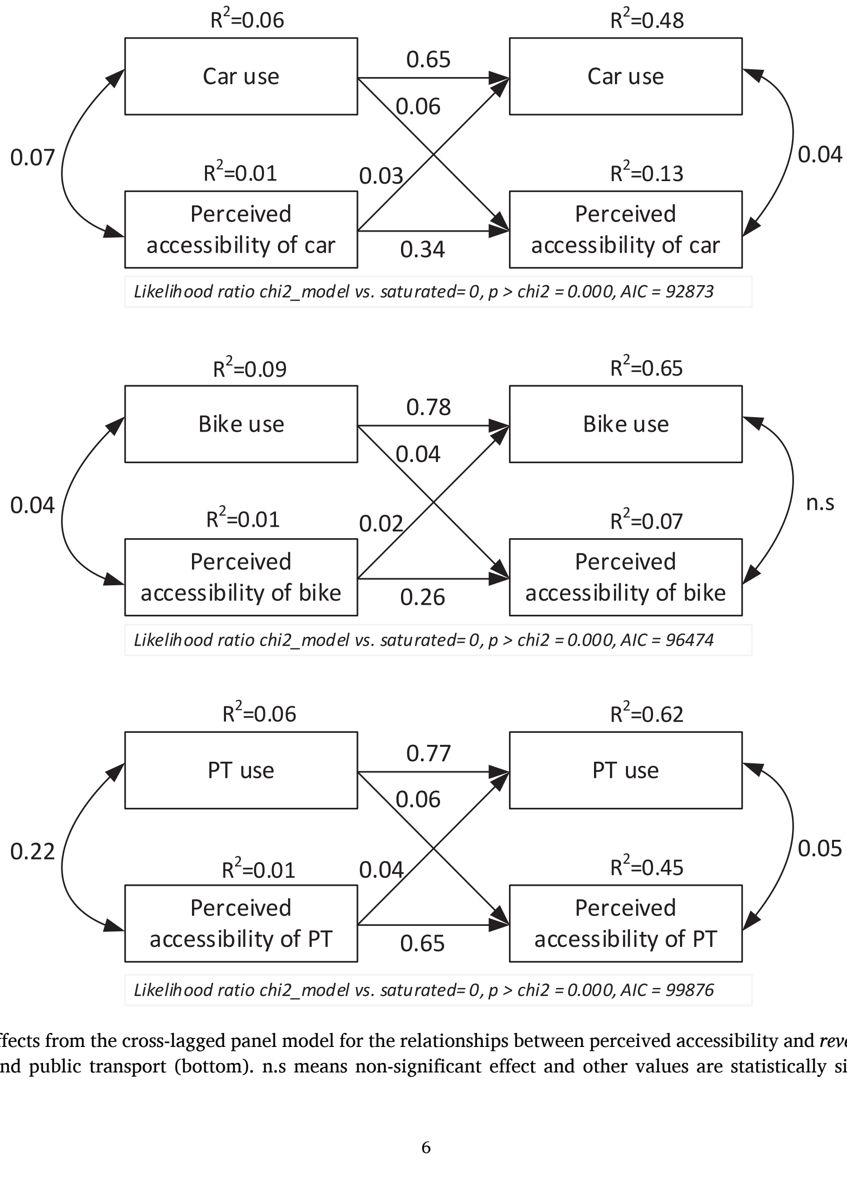

Fig. 2. Standardized effects from the cross-lagged panel model for the relationships between perceived accessibility and *revealed travel behavior*. Car (top), bike (middle), and public transport (bottom). n.s means non-significant effect and other values are statistically significant at 95% confidence intervals.

relationships. Four exogenous background variables were included in the CLPMs to account for the possible influence of confounding variables on perceived accessibility and travel behavior/preference. The factors included gender, age, level of education, and job status. To preserve the parsimonious nature of the models, changes in the background variables are not taken into account (as they are relatively minor).

To assess the quality of model fit, a range of fit statistics was employed, including the Likelihood Ratio Test (comparing the model against saturated and baseline models), equation-level goodness of fit, R-squared, and Akaike's Information Criterion (AIC). These metrics provided a comprehensive evaluation of how well the model captures the data and its overall goodness of fit. The CLPMs were estimated using StataMP version 18.

5. Results

Based on the CLPM, the standardized effects for the relationships between perceived accessibility and revealed travel behavior and for the relationships between perceived accessibility and stated travel preferences are presented in Fig. 2 and Fig. 3, respectively. There were three mode-specific models developed for each case (i.e., travel behavior and travel preference), resulting in six separate models. According to the likelihood ratio test, equation-level goodness of fit, and AIC/BIC, all six models were fit in terms of overall goodness of fit.

5.1. *Perceived accessibility and revealed travel behavior*

When evaluating the goodness of fit at the equation level, it is evident that the explained variance for travel behavior surpasses that

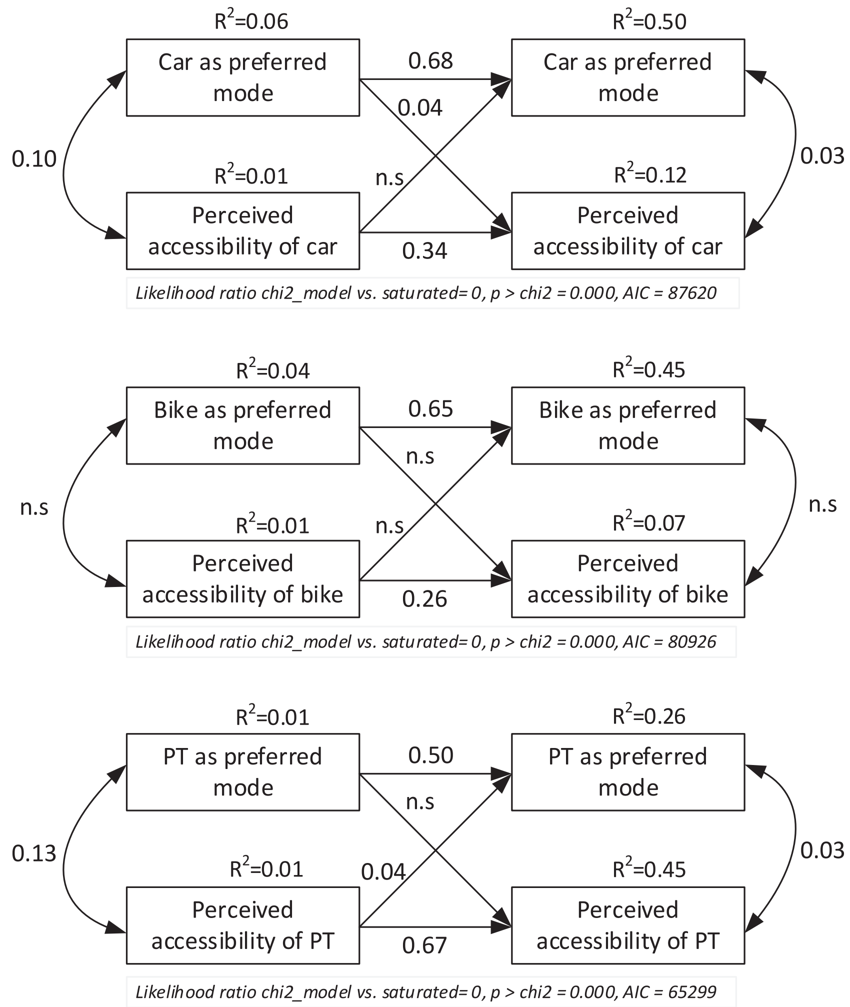

Fig. 3. Standardized effects from the cross-lagged panel model for the relationships between perceived accessibility and *stated travel preferences*. Car (top), bike (middle), and public transport (bottom). n.s means non-significant effect and other values are statistically significant at 95% confidence intervals.

of perceived accessibility for all three modes. For instance, the R-squared value for car use in the second wave stands at 0.48, whereas the R-squared value for perceived car accessibility in this wave is only 0.13.

All stability effects for this set of relationships (perception-travel behavior) were statistically significant at 95 % confidence intervals (or at the 5 % significance level; p-value is less than 0.05 ($p < 0.05$)). According to these stability coefficients, mode use behavior is highly stable for bicycles, PT, and cars, with standardized estimates consistently exceeding 0.64. For all three modes, mode use behavior appears to show greater stability than mode-specific perceived accessibility. Despite the high stability coefficient for car use (0.65), PT use (0.77), and bike use (0.78), the stability effects for the perceived car accessibility (0.34) and perceived bike accessibility (0.26) are relatively low.

Regarding cross-lagged effects, out of the six cross-lagged effects, all effects are statistically significant. In general, this means that the bidirectional effects between perceived accessibility and travel behavior exist, and they follow a specific pattern. The effect of travel behavior on perceived mode-specific accessibility is consistently larger than the reverse (more expected) effect (i.e., from perceived accessibility to travel behavior). For example, the effect of car use on perceived car accessibility (0.06) is two-fold greater than the effect of perceived car accessibility on car use (0.03).

According to the results of the estimated correlations, mode-specific perceived accessibility and mode use behavior are weakly correlated for each mode ($r < 0.1$). Notably, there is a slightly stronger but still weak correlation between PT use and perceived PT accessibility in the first wave ($r = 0.22$).

Table 3 outlines the impact of the four exogenous variables on the four endogenous variables. While we refrain from delving into the specifics of these findings, as they are not central to the primary research questions of this study, we assert that the observed signs of the effects appear generally reasonable. To illustrate, there is an observable increase in car use associated with variables such as gender (being male), older people, and employed ones. In summary, the exogenous variables exert a small influence on many of the time 1 endogenous variables, yet their impact on only a few of the time 2 endogenous variables is evident. This suggests a limited capacity for these exogenous variables to elucidate changes in mode use and perceived mode-specific accessibility over time. Appendix A in the supplementary material file contains the full results.

5.2. *Perceived accessibility and stated travel preferences*

When it comes to the equation-level goodness of fit, the explained variance for stated travel preferences was higher than the perceived accessibility for car (R-squared for car preference in the second wave is 0.50 compared with 0.12 for perceived car accessibility) and bike (R-squared for bike preference is 0.45 compared with 0.07 for perceived bike accessibility). However, the explained variance for PT preference is lower than the perceived PT accessibility.

All stability effects were found to be statistically significant. The stability coefficients suggest that mode preference exhibits strong stability for cars, bicycles, and PT consistently surpassing standardized estimates of around 0.50. For cars and bikes, mode preference appears to show greater stability than mode-specific perceived accessibility. In terms of stability coefficients for mode-specific perceived accessibility, it is noteworthy that PT accessibility (with a coefficient of 0.67) exhibited a higher degree of stability over time.

In analyzing the cross-lagged effects, out of six effects, only two effects are found to be statistically significant. For the car, it is evident that there is only a unidirectional effect from car preference on perceived car accessibility, while the reverse effect is insignificant. As for the PT, there is a significant effect of perceived PT accessibility on PT as the preferred mode, while there is no effect from PT preference on PT perceived accessibility. Furthermore, no directional cross-lagged effects are found between bike-perceived accessibility and bike preference.

Moreover, regarding the results of the estimated correlations, mode-specific perceived accessibility and mode preferences are weakly correlated for each mode ($r < 0.14$). The full results are available in Appendix B (the supplementary material file). When it comes to the effects of four exogenous variables on four endogenous variables, we observe relatively poor effects (see Table 3).

5.3. *The degree of dissonance*

According to Fig. 4, the degree of dissonance between perceived accessibility and travel behavior, as well as between perceived accessibility and travel preferences, is monitored over time per mode. There is a higher degree of dissonance per mode when we target travel preferences instead of travel behaviors. In other words, a perception-behavior relationship is more consonant than a perception-preference relationship. The least dissonance is seen among car users (the score is around 0.85 out of 4), while the greatest dissonance is seen among people who prefer PT (around 3.52–3.55). The dissonance between perceived accessibility and mode use behavior and preferences increased steadily over time, underscoring the necessity of aligning perception and behavior. The *t*-test results indicate that in both cases, namely travel behavior and preferences, there is a statistically significant increase in dissonance over time (from wave 1 to 2) for public transport (PT) use and all three mode preferences, as evidenced by a 95 % confidence interval. There is no statistically significant change at the 5 % significance level in car and bike use over time.

Concerning differences between travel behavior and preferences, the *t*-test reveals that, in both waves, the level of dissonance between perceived accessibility and travel preference is statistically significantly (at the 5 % significance level) higher than the dissonance observed between perceived accessibility and travel behavior for each mode.

6. Discussion

We find that the relationship between perceived accessibility and travel-related decisions varies depending on the mode of

Table 3
Standardized effects of exogenous variables on endogenous variables.

		Car				Bicycle				Public transport			
		T1		T2		T1		T2		T1		T2	
		RP	P_ACC	RP	P_ACC	RP	P_ACC	RP	P_ACC	RP	P_ACC	RP	P_ACC
Age	Ordinal	0.09	0.09	0.03		−0.26	0.08	−0.07	0.04	−0.23		−0.07	
Gender	male = 1, female = 0	0.07	0.04	0.02				0.02		−0.03			0.02
Education	university = 1, other = 0					0.11		0.03	0.04	0.10			
Job status	employed = 1. Other = 0	0.25	0.03	0.10					0.03	−0.17		−0.06	
		Car				Bicycle				Public transport			
		T1		T2		T1		T2		T1		T2	
		SP	P_ACC	SP	P_ACC	SP	P_ACC	SP	P_ACC	SP	P_ACC	SP	P_ACC
Age	Ordinal		0.09			−0.14	0.08	−0.04	0.03	−0.04		−0.02	
Gender	male = 1, female = 0	0.09	0.04	0.03									0.02
Education	university = 1, Other = 0	−0.05				0.15		0.04	0.04				
Job status	employed = 1. Other = 0	0.23	0.03	0.08		−0.05	0.03			−0.06		−0.06	

Note. RP = Revealed travel behavior; P_ACC = Perceived accessibility; SP: Stated travel preference.
Only significant effects at $p < 0.05$ are shown.

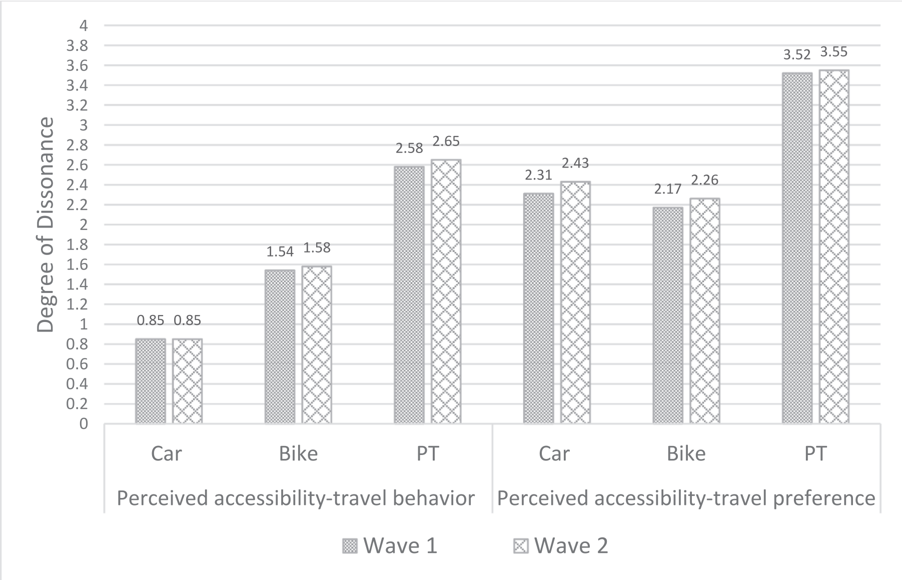

Fig. 4. The degree of perception-behavior/preference dissonance per mode over time.

transport and whether it is about travel behavior or travel preference. There are bidirectional effects, unidirectional effects, or no effects. Policymakers could consider these complex relationships when designing transport policies and interventions. It is essential to recognize that the effects between perceived accessibility and travel decisions may not necessarily follow a uniform pattern. This suggests the need for tailored strategies for each mode and travel context. Public transportation accessibility perception, for example, has a significant impact on PT behavior and stated PT preferences, therefore improving perceived accessibility can have an impact on both PT use behavior and PT preference, so investments could focus on alleviating biases in public transport accessibility perceptions.

As for revealed travel behavior, we find a bidirectional or mutual perception-behavior relationship. Unlike conventional wisdom and commonly used theoretical links, however, we find that travel mode use behavior had a larger impact on perceived mode-specific accessibility than the reverse effect (the more expected link). The finding that people, who repeatedly use a transport mode, develop better accessibility perceptions toward those modes over time may suggest that familiarity and habituation play a significant role in shaping individuals' perceptions of mode accessibility. People tend to confirm their existing travel behavior through repeated experiences. For example, in the case of car users, the more they rely on their cars, the more they may notice and appreciate the convenience and accessibility of car travel, reinforcing their positive perception of it. Repeated car use might lead to the formation of strong habits (Eriksson et al., 2008). Individuals who have established routines centered around driving may find it difficult to break away from these habits and consider alternative sustainable modes as equally accessible. Car-dependent individuals may have limited exposure to other transport options. This lack of exposure can result in a skewed perception of accessibility, as they may not be aware of or familiar with the convenience and efficiency of sustainable alternatives like public transport or biking. Changing travel behavior can be challenging due to inertia. Even if individuals recognize the benefits of alternative modes, they may be resistant to change because it disrupts their established routines and comfort zones.

According to previous empirical research and the most widely expected direction of the perception-behavior relationship (Scheepers et al., 2016; Lättman et al., 2020; Blandin et al., 2023), perceptions of accessibility influence mode use behavior in car, bike, and public transport use. Our findings provide new insights into the bidirectionality of these elements, as also conceptually acknowledged by Pot et al. (2021). As discussed earlier, these effects (perception ⇨ behavior), however, are smaller than the reverse effects (i.e., behavior ⇨ perception). Among different modes, the expected relationship (perception ⇨ behavior) holds for both revealed and stated travel behaviors for public transport. Moreover, the unexpected relationship (behavior ⇨ perception) holds for both revealed and stated travel behaviors for cars.

The high stability coefficients for travel behavior and preference for all three modes indicate that people tend to stick with these modes of transport. Despite a high stability coefficient for bicycle use/preferences, the stability coefficient for perceived accessibility of bikes remains notably low. This result along with another finding that perceived bike accessibility does not influence biking preferences (or affects bike use slightly) raises some policy considerations. Policymakers could implement campaigns and initiatives aimed at dispelling misconceptions and raising awareness about the benefits and accessibility of cycling paths. These efforts can work to close the gap between perceived and actual accessibility. One key factor influencing the perceived accessibility of bicycles is the availability of safe and convenient cycling infrastructure. Investing in bike lanes, bike-sharing programs, and bike storage facilities could make cycling more accessible and appealing, thus aligning perceptions with actual behavior.

For stated travel preferences, neither the (causal) effect (cross-lagged effect) of perception of bicycle accessibility nor the preference for bicycle worked. The perception-behavior effects observed for bicycle use behavior, however, were bidirectional. Observing bidirectional perception-behavior effects for bicycle use, but not for bicycle preference, may suggest a multifaceted approach to bicycle promotion. Stated travel preferences may be influenced by a different set of factors compared to travel behavior. While travel behavior is often influenced by practical considerations like infrastructure and accessibility, preferences may be influenced by personal motives, cultural factors, and perceptions of what is socially desirable. Individuals may hold preferences that are incongruent with their actual behavior due to various cognitive factors. This phenomenon can lead to a gap between stated preferences and revealed behavior. For example, individuals might express a preference for cycling for health or environmental reasons but not engage in cycling due to poor perceived accessibility. It is possible that people perceive bicycles as accessible but still prefer other modes of transport for various reasons, such as comfort or speed. Preferences can also be influenced by a wide range of factors beyond mere accessibility.

As for stated travel preferences for car and public transportation, we find only unidirectional effects: from preference to perception for car, and from perception to preference for public transport. Accordingly, this finding may highlight the fact that the perception-behavior theory is primarily consistent with actual/revealed behavior as opposed to stated preferences. Therefore, it is advisable for researchers in the field of travel behavior to prioritize the use of revealed behavior data when it comes to the application of perception-behavior theory. This emphasizes the need to rely on tangible, observed travel choices over what individuals state as their preferences.

Mode-use behavior exhibited greater stability compared to mode-specific perceived accessibility. While mode use is stable, it may not necessarily align with the perceived accessibility of a mode. We observe the evolving trends of dissonance between perceived accessibility and travel decisions (travel behavior and preferences). One key insight is the variation in dissonance levels when focusing on travel preferences versus travel behavior. It is evident that the degree of dissonance is consistently higher when we examine travel preferences. This observation suggests that individuals tend to use travel modes that align more closely with their perceived accessibility, which in turn influences their behavior. This result is in line with the idea that individuals are more likely to act in accordance with their perceived opportunities and constraints, which are reflected in their accessibility perception. Furthermore, the marked difference in dissonance levels across various modes of transportation is intriguing. Car users, for instance, exhibit the least dissonance. This might be attributed to the relatively high perceived accessibility associated with car use, leading to a strong alignment between perception and behavior. On the other hand, individuals who prefer public transport display the highest level of dissonance. This could be due to factors such as perceived convenience, cost, and scheduling conflicts, which may not align with their accessibility perceptions. Another finding is the consistent growth of dissonance over time for all mode preferences and for PT use. This trend underscores the importance of continually monitoring and aligning perception with behavior/preference to promote more sustainable and efficient travel choices. As dissonance grows, there may be an increasing need for interventions and policies aimed at bridging the gap between perceived accessibility and actual travel behavior and preferences.

The findings suggest a key insight regarding public transport in comparison to other transport modes. The study reveals that the effect of perception on public transport use behavior and preferences is more consistent than the reverse effect. However, we did not find such a consistent effect from perception on the use/preference of cars and bicycles. In practical terms, this implies that efforts aimed at correcting misperceptions about the accessibility and quality of public transport facilities can have a substantial impact on individuals' decisions to choose public transport. This observation underscores the importance of addressing public perceptions and providing accurate information to encourage the use of public transport as a sustainable and efficient mode. Ultimately, prioritizing efforts to enhance public transport perception can contribute significantly to encouraging its adoption when compared to other alternatives.

7. Conclusions

Our study tested bidirectional effects between perceived accessibility and travel decisions (i.e., revealed travel behavior and stated travel preferences) in a general Dutch sample, using panel data. Conventional wisdom suggests that our perceptions influence our behaviors, yet our study investigates the possibility of a reverse effect—whether our behaviors shape our perceptions over time. In our investigation of bidirectional effects between "perceived accessibility" and travel-related decisions (both "revealed travel behavior" and "stated travel preferences"), we aimed to offer fresh insights into perception-behavior theory in the travel behavior modeling context.

Our panel analysis reveals several key findings:

(i) The relationship between perceived accessibility and travel decisions varies depending on the transport mode and whether it pertains to behavior or preference.
(ii) We observed that the perception-behavior theory aligns more closely with "revealed behavior" than with "stated preferences." This suggests that prioritizing the use of observed behavior data is crucial in applying perception-behavior theory.
(iii) Contrary to conventional wisdom, we found that travel behavior has a greater impact on perceived accessibility over time (behavior ⇨ perception) than the expected reverse effect (perception ⇨ behavior).
(iv) Notably, "travel behavior" consistently shows lower levels of perception-behavior "dissonance" compared to "preferences".

In summary, the findings highlight the need for nuanced and mode-specific transport policies. In both realms of travel decisions—behavior and preferences—it appears that car use or preferences have a greater influence on shaping perceived car accessibility than the reverse. As a result, individuals' perceptions of how easily they can access cars are highly influenced by their existing car use habits. Consequently, interventions aimed solely at reducing car accessibility perception may not effectively decrease car use. Therefore, alternative strategies beyond simply altering perceptions of car accessibility may be required to reduce reliance on cars effectively.

Conversely, the impact of perception on public transport use behavior and preferences seems to be more consistent than the reverse effect. Policies could aim to enhance the perceived accessibility of public transport, address the unique challenges faced by public transport, and recognize that stability in mode choice does not necessarily imply alignment with perceived accessibility. Tailored interventions can encourage sustainable and efficient transport choices.

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CRediT authorship contribution statement

Milad Mehdizadeh: Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Idea. **Maarten Kroesen:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Data curation.

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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Appendix A. Supplementary data

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