The impact of perceived safety on public transport route choice across the day

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Short summary

Public transport (PT) is a key component of sustainable urban mobility. While the effect of perceived safety on satisfaction has been widely studied, its impact on actual passenger behaviour remains largely unexplored. This study combines observed route choices from smart card data in Eastern Denmark with responses from a large-scale survey of 3,583 train passengers to examine how perceived station safety influences route choice. Discrete choice models estimated separately for morning and evening trips show that safety has a significant behavioural impact, equivalent to a perceived reduction of approximately 6–10 minutes of bus in-vehicle time. Demographic interactions reveal no significant differences between men and women, whereas young adults display varying sensitivity to safety throughout the day. Overall, the findings highlight the importance of perceived safety in shaping route choice within multi-modal PT networks.

Keywords: Discrete choice modelling, Multi-modal transport, Perceived safety, Smart card data

1 Introduction

Public transport (PT) plays a crucial role in sustainable urban mobility, and ensuring travellers feel safe is fundamental for an attractive PT system. Perceived safety, i.e. travellers' subjective experience of vulnerability or risk within PT environments (Ceccato et al., 2022), is in fact a significant predictor of PT use (Başaran et al., 2022; Delbosc & Currie, 2012; Ingvardson & Nielsen, 2021), and satisfaction (Başaran et al., 2025; De Oña et al., 2012; van Lierop et al., 2018). However, travellers' safety perceptions are rarely uniform in a PT system: they vary across people, time, and places (Sundling & Ceccato, 2022). Women and LGBTQI+ travellers consistently report feeling less safe than men (Ceccato et al., 2024; Coppola & Silvestri, 2021; Sundling & Ceccato, 2022), fear intensifies during evening and nighttime hours (Sundling & Ceccato, 2022), and environmental conditions such as tunnels, limited natural surveillance or desolate parking lots further reduce perceived safety (Sundling & Ceccato, 2022). These variations can deem parts of the PT system inaccessible for some travellers, constraining their daily mobility (Loukaitou-Sideris, 2014).

Numerous researchers have studied safety-related constraints by conducting surveys on the precautions travellers take in PT. Many travellers state that they avoid travelling during evening and nighttime hours when possible (Ceccato et al., 2024; Ceccato & Loukaitou-Sideris, 2022; d'Arbois De Jubainville & Vanier, 2017; Jaitman, 2020). Similarly, avoiding certain places or routes perceived as unsafe is a common strategy (Ceccato et al., 2024; Ceccato & Loukaitou-Sideris, 2022; d'Arbois De Jubainville & Vanier, 2017; Stark & Meschik, 2018). Beyond these survey findings, a stated-preference study from Fortaleza, Brazil finds that travellers who are more concerned about safety perceive transfers much more negatively, which can in turn have implications for their route choice (Coelho Guimarães & Oliveira-Neto, 2026). While these studies underscore that safety concerns influence the way travellers navigate the PT system, they rely largely on self-reported strategies or preferences. Therefore, there remains still a gap in understanding how perceived safety influences actual route choice behaviour.

Our study addresses this gap by investigating how perceived station safety influences route choice in Eastern Denmark, an area served by metro, regional and suburban rail, and bus services. We

estimate route choice models combining large-scale automated fare card (AFC) data from the region with survey-based perceived safety scores from 184 stations. This approach draws on observed behaviour rather than stated intentions, and allows us to quantify the trade-offs between e.g. travel time and perceived safety. Furthermore, we explicitly consider heterogeneity due to time of day and personal characteristics by comparing morning peak hours with evening off-peak periods, and including interactions between perceived safety and variables of age and gender.

2 Methodology

Case Study Area

In this study, we investigate the influence of perceived safety on route choice behaviour in Eastern Denmark. The region includes 46 municipalities, and is home to approximately 2.7 million residents (Region Østdanmark, 2026), corresponding to about 44% of the Danish population. There is a diverse settlement structure, ranging from the dense urban city of Copenhagen, Denmark's capital, to smaller cities such as Roskilde and Næstved, as well as suburban and rural areas.

An extensive public transport network serves Eastern Denmark. Figure 1 illustrates 279 train stations in the region with four different types, as well as interchange stations. Four metro lines operate in the centre of Copenhagen, and the city is connected to suburban areas with S-train (suburban commuter rail) lines. Regional and intercity trains operate to the north and west of Copenhagen, while the less-populated rural areas are primarily served by local train lines. In addition to the rail network, buses operate throughout the region, with major routes providing direct longer-distance connections and local services enhancing accessibility in towns with shorter distances between stops.

The metro operates with very short headways of 1.5–3 minutes during peak hours, around 6 minutes in the evening, and approximately 20 minutes late at night. S-trains run every 5–10 minutes between 07:00 and 18:00 and every 10–30 minutes during off-peak hours. Bus services operate every 3–10 minutes in central Copenhagen and every 20–60 minutes in the outskirts. InterCity, regional, and local trains generally operate with headways ranging from 20 to 120 minutes.

Overall, the region's varied settlement structure and extensive multimodal public transport network provide a rich context for examining route choice behaviour.

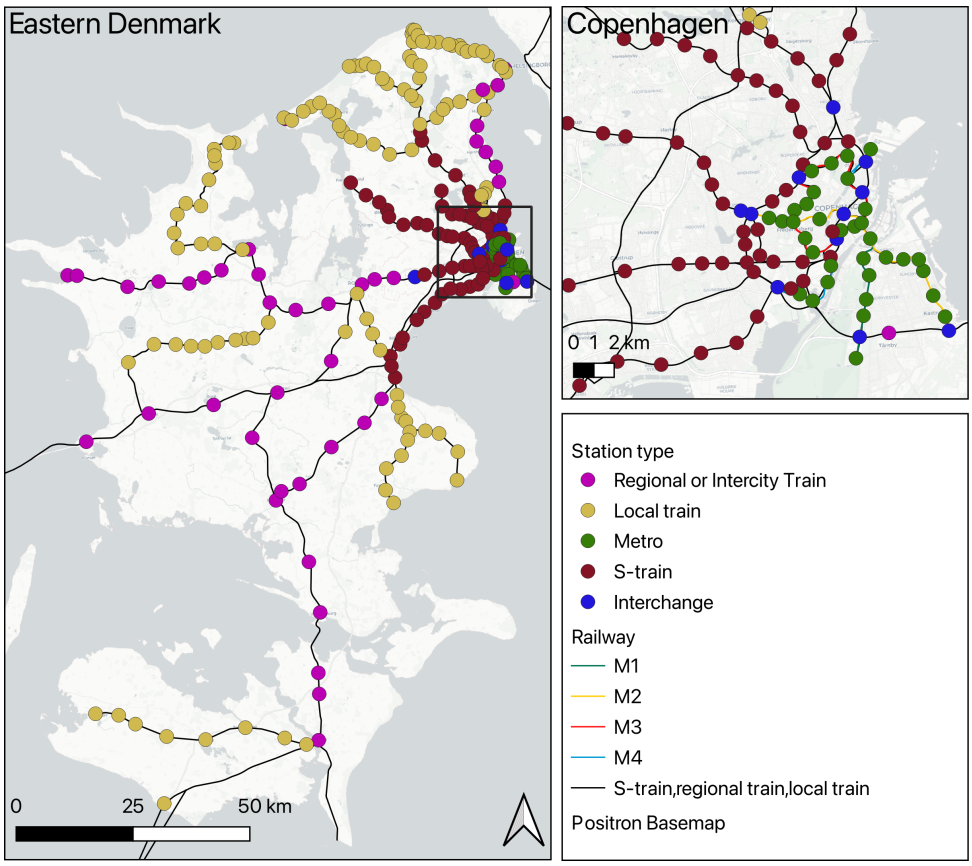


Figure 1: Rail network in Eastern Denmark with 279 train stations

Survey data on perceived safety

We gathered data on perceived safety levels at train stations and in their urban surroundings from an online survey focusing on train journeys in Eastern Denmark (Başaran et al., 2025). The survey targeted residents of Eastern Denmark aged 18 and over, and recorded their perceived safety and satisfaction during their latest journey in the region, along with socio-demographic characteristics.

The survey included two measures of perceived safety: (i) *at* the station and (iii) *around* the station. Respondents were asked: *"How safe would you feel at/around this station at dark when you are alone?"*. Both measures were on a 5-point Likert scale (1= very unsafe, 3= neither safe nor unsafe, 5= very safe). Respondents replied twice to each question, providing their experiences for the start and end station of their journey.

The survey was distributed in three waves between June 2022 and February 2024 through online panels and a subsample of the Danish national travel survey ("Transportvaneundersøgelsen"). In total, 3,583 individuals provided perceived safety levels for 237 stations (completion rate = 70%). The final sample was balanced in terms of gender but it slightly overrepresented older adults (60+) and higher-income groups compared with the population of Eastern Denmark. Further details of the sample are provided by Başaran et al. (2025).

Smart Card Data

For our analysis, we used observed passenger journeys recorded through the Danish smart card system, Rejsekort, between 1 and 15 September 2023. The dataset includes all tap-in/tap-out records from weekday morning peak hours (07:00–09:00) and evening off-peak hours (20:00–23:00). Rejsekort operates via an automated fare collection (AFC) system with a zone-based fare structure, where the fare depends only on the number of zones between the origin and destination, regardless of the chosen route. In addition, personalised cards include information on passengers' ages and genders, allowing us to analyse demographic variation in route-choice behaviour.

To prepare the dataset, we first removed incomplete journeys with missing tap-ins or tap-outs. Many intermediate taps were also missing, because passengers often skip tapping, as transfers do not affect the final fare. These transfer points were inferred by identifying all feasible candidate stops and selecting the one with the shortest walking distance. We further excluded implausible trips (shorter than 0.5 minutes or longer than 180 min), loop trips, cross-border journeys to Sweden, and trips involving walking transfers exceeding 1000 metres. In total, these filtering steps eliminated about 16% of all observed journeys. The final dataset comprises approximately 353,000 valid morning-peak trips and 162,000 valid evening off-peak trips.

The route-choice sets were also based on observed smart-card trajectories within the study period. Alternative routes were generated by including stops located within 500 metres of the chosen origin and destination. To ensure an appropriate choice set, we applied two filtering rules: each origin-destination (OD) pair must have more than two route alternatives and at least 25 observed trips during the study period. The final morning dataset consists of 1,959 OD pairs and 141,039 trips from 58,769 personalised cards. The final evening dataset consists of 989 OD pairs and 60,665 trips from 50,023 personalised cards. Overall, 21% of morning trips and 12% of evening trips involve at least one transfer.

Discrete Choice Modelling

The modelling framework follows the Random Utility Maximisation (RUM) paradigm, in which each individual n chooses the route i that maximises their utility. Route utility incorporates observed trip attributes derived from the General Transit Feed Specification (GTFS), including scheduled in-vehicle time for each mode, hidden waiting time, transfer-type penalties (e.g., train-to-train, bus-to-train), transfer waiting time and transfer walking time. The hidden waiting time is calculated as half of the scheduled headway at the origin, with a maximum of 6 minutes, and the transfer waiting time is the average scheduled interval between arrival at the transfer stop and the next departure, assuming passengers board the first available vehicle.

First, we estimated two baseline models (one for each time period) only including trip attributes. Second, we extended these models by including the perceived safety scores. Here, we tested several ways of incorporating safety into the specification: i) an average safety score of all stations in the route, ii) an average safety score of transfer stations, iii) a binary indicator for when passengers encounter at least one unsafe station (i.e. a below-average score). Based on model fit and interpretability, we selected the average safety score of all stations along the route as the preferred measure. Routes consisting exclusively of bus stops were not assigned a perceived safety score, as the survey only provided data on train stations. Third, we included interaction terms between perceived safety and the variables age and gender, to test whether different demographic groups adjust their behaviour differently in response to perceived safety conditions along the route.

We modelled route choice behaviour using the Path Size Logit (PSL) model, an extension of the Multinomial Logit framework that incorporates the Path Size Correction (PSC) term to account for overlapping routes (Bovy et al., 2008). The estimation employs a panel structure to capture correlation in repeated trips by the same passengers. The parameters are estimated by maximum likelihood using the open-source software PandasBiogeme (Bierlaire, 2020).

3 Results & Discussion

Description of the perceived safety score

The perceived safety score is derived from 7,166 survey responses collected at 237 train stations across metro, suburban, regional and intercity lines in Eastern Denmark. To ensure an adequate number of observations, we included only stations with at least 4 responses. Among these 184 stations, the median number of responses was 23, with a maximum of 691.

We calculated each station's perceived safety score as the average of the two indicators (i: at the station, ii: around the station). Across 184 stations, scores range from 2.0 to 4.4 on a 5-point scale, with a mean of 3.4.

Figure 2 visualises the perceived safety score of stations included in our analysis. While the majority

of stations (70%) are perceived as safe, 40 stations are rated as neither safe nor unsafe, and 14 stations are considered unsafe or very unsafe. Two S-train lines to the southwest of Copenhagen have a higher concentration of stations with lower perceived safety scores.

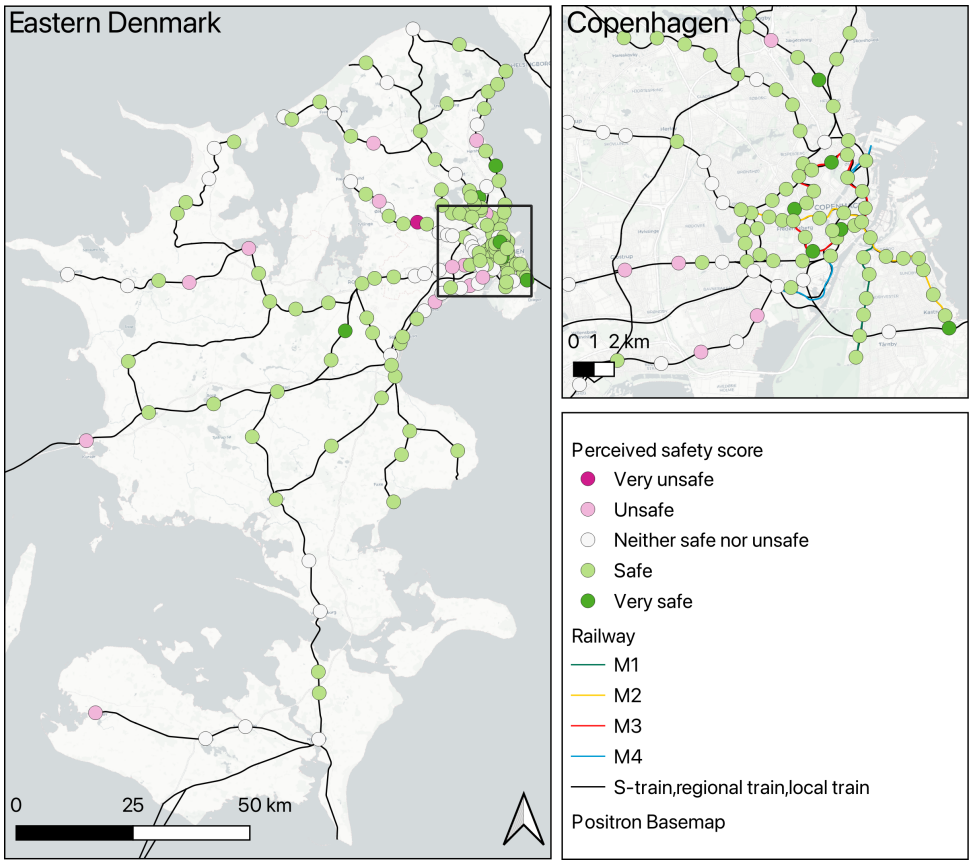


Figure 2: Average perceived safety score of 184 train stations in Eastern Denmark. Note that we only show stations with 4 or more observations.

For modelling purposes, we centred the score of each station around the mean by subtracting the overall average rating (3.4), so that a value of 0 corresponds to an average train station or to a bus stop without a perceived safety evaluation.

Route Choice Modelling

This section presents two baseline discrete-choice models: one for morning peak hours and one for evening off-peak hours. These baseline models are later extended with two specifications: one that incorporates the safety component and another that additionally interacts this component with age and gender. Table 1 provides an overview of the demographic composition of the smart card observations. Women account for slightly more trips in both periods, resulting in a similar gender distribution across the day. Regarding age distributions, passengers aged 18-34 and 35-64 are equally prominent in the morning (together representing around 88%), while evening travel is more dominated by younger adults.

Tables 2 and 3 present the estimated coefficients and the corresponding substitution rates in relation to bus in-vehicle time for the morning and evening baseline models. All in-vehicle time coefficients are negative and statistically significant. Metro travel shows the lowest disutility among modes, with one minute on the metro equivalent to approximately 6 minutes on the bus in the morning and 4 minutes in the evening. This indicates that travellers perceive metro travel time as substantially less burdensome, especially during the morning peak, when services are more frequent and reliable. Differences between rail modes are more pronounced in the morning, whereas in the evening, travellers value in-vehicle time more similarly across rail services, reflecting more relaxed time constraints during off-peak periods.

Transfer penalties are high in both models, but consistently higher in the morning, suggesting a

Table 1: Demographic Composition of Smart Card Observations

	Morning (07:00–09:00)	Evening (20:00–23:00)
Gender (%)		
Women	54.05	54.21
Men	45.95	45.79
Age Group (%)		
<18	8.14	4.10
18–34	43.21	51.55
35–64	44.45	33.85
65+	4.21	10.50

stronger aversion to multimodal trips and to the additional transfer waiting time. In contrast, hidden waiting time is valued more negatively in the evening, when service frequencies are lower. Interestingly, the PSC factors change sign between the two periods, suggesting that in the evening, passengers may prefer routes with overlapping services, possibly as a strategy to mitigate the risk of long waits.

Introducing the average perceived safety along the route improved fit in both time periods, confirming that safety is an important determinant of route choice. As expected, its influence is substantially stronger in the evening. The substitution rate increases from approximately 6 minutes in the morning to about 10 minutes in the evening (relative to bus in-vehicle time), indicating that travellers place a higher value on safety when travelling after dark. Consequently, improving the average perceived safety of stations along the route by 1 unit, i.e., moving from average to good-quality stations, corresponds to an additional perceived time saving of about 4 minutes in the evening.

Adding safety to the morning model explains some of the variation in in-vehicle time valuations and hidden waiting time, and leads to slight increases in the transfer penalties. In the evening, however, safety has a much stronger structural effect. Once introduced, it absorbs much of the originally strong preference for trains, indicating that part of the evening rail advantage is driven by higher perceived station safety. At the same time, transfer penalties increase substantially, while transfer walking time becomes more costly.

Incorporating individual characteristics, such as gender and age, allows us to examine heterogeneity in safety preferences. Men and adults aged 35–64 serve as the reference groups. Based on likelihood ratio tests, models that include both safety and demographics outperform the baseline models, but do not significantly improve upon the safety-only specifications. Gender effects are not significant in either period, suggesting that there are no systematic safety-related differences in route choice behaviour between men and women. However, gender-related differences in safety perceptions may be more pronounced in other parts of the trips, such as access and egress, outside the stop-to-stop components considered here. Therefore, further investigation is needed.

Age effects, however, reveal distinct patterns in route choice behaviour. Young adults value station safety less during the morning peak but more during the evening, suggesting that safety considerations may vary with trip purpose and travel context. Morning journeys for work, school, or other scheduled activities often follow familiar routes in daylight, which may reduce perceived safety concerns. In contrast, evening trips might be associated with leisure activities or with accompanying others through unfamiliar stations in darker conditions. Older adults (65+) value station safety less than the reference group does during the evening.

Table 2: Estimated Parameters for Morning Observations (07:00–09:00)

Parameter	Baseline Model	Subst. Rate	Only Safety	Subst. Rate	Safety with Age and Gender	Subst. Rate
In-vehicle time						
Bus	-0.497	1.00	-0.453	1.00	-0.454	1.00
Reg. & Intercity train	-0.227	0.46	-0.226	0.50	-0.226	0.50
S-train	-0.150	0.30	-0.132	0.29	-0.132	0.29
Metro	-0.085	0.17	-0.100	0.22	-0.099	0.22
Transfer components						
Bus → Bus	-7.001	14.09	-6.380	14.08	-6.540	14.41
Bus → Train	-7.340	14.77	-7.280	16.07	-7.280	16.04
Train → Bus	-8.170	16.44	-8.160	16.98	-8.120	17.89
Train → Train	-4.790	9.64	-4.750	10.49	-4.750	10.46
Transfer waiting time	-0.075	0.15	-0.117	0.26	-0.117	0.26
Transfer walking time	-0.571	1.15	-0.573	1.26	-0.576	1.27
Safety components						
Safety	—	—	2.82	-6.23	3.010	-6.63
Female × Safety	—	—	—	—	-0.008*	—
(< 18)× Safety	—	—	—	—	0.421*	—
(18–34)× Safety	—	—	—	—	-0.553	1.22
(65+)× Safety	—	—	—	—	0.107*	—
Other components						
Hidden waiting time	-0.310	0.62	-0.315	0.70	-0.316	0.70
PSC	-0.138	0.27	-0.191	0.42	-0.194	0.43
Sample Size	58,769		58,769		58,769	
Observations	141,039		141,039		141,039	
Number of Parameters	12		13		17	
Final Log-likelihood	-35,243		-34,824		-34,815	
Rho-square	0.837		0.839		0.839	
AIC	70,511		69,674		69,664	
BIC	70,618		69,790		69,817	
LRT compared to	—		838		856	
the Baseline model	—		(p<0.0001)		(p<0.0001)	

* Not significantly different from zero at a 90% confidence level.

Table 3: Estimated Parameters for Evening Observations (20:00–23:00)

Parameter	Baseline Model	Subst. Rate	Only Safety	Subst. Rate	Safety with Age and Gender	Subst. Rate
In-vehicle time						
Bus	-0.623	1.00	-0.527	1.00	-0.527	1.00
Reg. & Intercity train	-0.196	0.31	-0.231	0.44	-0.231	0.44
S-train	-0.169	0.27	-0.149	0.28	-0.149	0.28
Metro	-0.142	0.23	-0.151	0.29	-0.151	0.29
Transfer components						
Bus → Bus	-4.010	6.44	-3.990	7.57	-4.020	7.63
Bus → Train	-7.280	11.69	-6.950	13.19	-6.990	13.26
Train → Bus	-6.540	10.50	-7.240	13.74	-7.230	13.72
Train → Train	-4.610	7.40	-4.820	9.15	-4.830	9.17
Transfer waiting time	-0.446	0.72	-0.413	0.78	-0.411	0.78
Transfer walking time	-0.606	0.97	-0.588	1.12	-0.578	1.10
Safety components						
Safety	—	—	5.030	-9.54	4.81	-9.13
Female × Safety	—	—	—	—	0.002*	—
(< 18)× Safety	—	—	—	—	0.297*	—
(18–34)× Safety	—	—	—	—	0.556	-1.06
(65+)× Safety	—	—	—	—	-0.984	1.87
Other components						
Hidden waiting time	-1.040	1.67	-0.912	1.73	-0.912	1.73
PSC	0.092	-0.15	-0.010*	—	-0.010*	—
Sample Size	50,023		50,023		50,023	
Observations	60,665		60,665		60,665	
Number of Parameters	12		13		17	
Final Log-likelihood	-24,576		-24,279		-24,275	
Rho-square	0.786		0.789		0.789	
AIC	49,177		48,583		48,584	
BIC	49,283		48,698		48,733	
LRT compared to	—		594		602	
the Baseline model	—		(p<0.0001)		(p<0.0001)	

* Not significantly different from zero at a 90% confidence level.

4 Conclusions

This study investigated how station safety influences public transport route choices within a multimodal network by combining large-scale smart card data with user-reported safety perceptions. First, we gathered average perceived safety scores at train stations across Eastern Denmark from a tailor-made survey with 3,583 responses. Second, we incorporated the average perceived safety score of all stations along the route into a discrete-choice model estimated from 141,039 morning and 60,665 evening routes observed between September 1-15, 2023. Lastly, we explored interactions between safety and passengers' characteristics, such as gender and age, to examine heterogeneity in preferences across demographic groups.

Our findings highlight the crucial role of safety in shaping actual passenger behaviour. This aligns with previous evidence showing that passengers may alter their routes due to safety concerns (Ceccato et al., 2024; Ceccato & Loukaitou-Sideris, 2022; d'Arbois De Jubainville & Vanier, 2017; Stark & Meschik, 2018). In addition, we provide empirical evidence on the magnitude of safety-related trade-offs in route choice. Improving all stations along the route from average to good safety conditions corresponds to a perceived reduction of about 6-10 minutes of bus in-vehicle time, depending on the time of the day. Safety is particularly influential at night, when it becomes an even stronger determinant of route choice. Incorporating safety into the model also narrows the differences in in-vehicle time disutility across modes, explaining part of the strong preference for metro and S-train services. At the same time, perceived safety along the route may additionally reflect broader aspects of comfort and station quality more commonly associated with rail than

with bus services.

The interaction effects between safety, age and gender reveal several interesting patterns. Women do not appear to adjust their route choices in response to the average perceived safety of stations along the route, a finding that merits further examination, particularly in relation to the waiting or access/egress components. Young adults, however, show clear temporal differences, being less sensitive to safety in the morning and more responsive in the evening. Our ongoing work explores a latent-class approach to identify whether distinct traveller segments with varying safety sensitivities exist, which might help better capture heterogeneity in route choice behaviour. Demonstrating how safety along the route shapes these behavioural patterns will deepen our understanding of passenger route choice in multi-modal public transport systems.

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