Understanding shoppers' acceptance of emerging last-mile delivery modes: Drones, ground robots and cargo bikes

Furqan A. Bhat*[1], Abel Kebeda Reda[2], Eva Heinen[3]

[1] Postdoctoral Research Associate, Department of Mobility and Transport, Technical University of Dortmund, Germany

[2] Postdoctoral Research Associate, Logistics City Chair at Gustave Eiffel University, France

[3] Professor, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Switzerland

SHORT SUMMARY

The rapid growth of e-commerce has intensified pressures on urban last-mile delivery, prompting interest in autonomous ground robots, drones, and cargo bikes as alternatives. This study examines stated acceptance of these three modes using survey data from 2,012 respondents across four European cities: Dortmund, Paris, Trondheim, and Zurich, estimated through a multivariate ordered probit model incorporating socio-demographic, attitudinal, behavioural, delivery-related, and contextual variables. Cargo bike delivery receives the highest acceptance across cities, while acceptance of automated modes is lower and varies significantly, with Paris showing notably lower acceptance of robots and drones. Privacy concerns are a significant barrier to automated mode acceptance, whereas environmental concerns positively predict cargo bike acceptance. Shopping frequency and virtual shopping engagement are the most consistent positive predictors across all three modes. The findings underscore the importance of behavioural heterogeneity and urban context for evaluating and promoting sustainable last-mile delivery innovations.

Keywords: City logistics; Consumer acceptance; Discrete choice modelling; Emerging delivery modes; Urban freight transport

1. INTRODUCTION

The rapid expansion of e-commerce has fundamentally altered urban freight activity, making last-mile delivery one of the fastest-growing components of urban transport systems. Over the past two decades, and with a marked increase following the COVID-19 pandemic, online purchasing has become embedded in everyday consumption (Riahi Samani et al., 2024).

This rapid growth has created significant challenges for retailers and logistics providers. Within urban logistics chains, the last mile has consequently emerged as the most resource-intensive stage, accounting for between 28 and 40 % of total delivery costs and a disproportionately high share of freight-related greenhouse gas emissions (Bergmann et al., 2020). In response to these operational constraints, logistics providers and policymakers have increasingly turned their attention to alternative delivery options. Among the most prominent options are cargo bikes, autonomous ground robots, and drones, each offering distinct operational advantages and constraints.

Despite growing research on last-mile delivery innovations, important gaps remain in understanding consumer acceptance of emerging modes. First, existing studies typically examine individual technologies in isolation, limiting insight into how consumers simultaneously evaluate and differentiate between alternatives (Cicek et al., 2025). Whether acceptance is driven by common underlying factors or mode-specific structures therefore remains unclear. Second, empirical work has focused predominantly on socio-demographic characteristics and standard technology acceptance constructs, with limited attention to how acceptance is jointly shaped by attitudinal factors and everyday shopping behaviours such as online engagement, price sensitivity, and delivery expectations (Cicek et al., 2025). Third, comparative evidence across urban contexts remains scarce, making it difficult to disentangle mode-specific acceptance patterns from city-level effects related to infrastructure, regulation, and mode visibility. Together, these gaps motivate a study that jointly examines acceptance across three delivery modes and four European cities: Dortmund, Trondheim. Paris, and Zurich, incorporating socio-demographic, attitudinal, behavioural, delivery-related, and contextual variables within a unified analytical framework.

2. METHODOLOGY

Survey instrument and data collection

An online questionnaire was administered simultaneously across the four cities using a common survey instrument designed to capture multiple dimensions of shopping and mobility behaviour, delivery preferences, and attitudes toward emerging delivery modes.

The survey instrument was first developed in English and subsequently translated into French, Norwegian, and German by native speakers. Translation followed a double-checking procedure to ensure consistency in wording and meaning across language versions, and feedback from local collaborators was used to refine the questionnaire before full deployment. To improve reliability and minimise response bias, several items were reverse-coded, and attention-check questions were embedded within the questionnaire.

Data collection took place in June and July 2025, and was conducted simultaneously across all four cities. The survey was administered through a professional online panel, and recruitment procedures were designed to achieve a sample representative of the adult population in each city, with respect to age and gender distribution. In total, 2,720 responses were obtained. After this cleaning process, 2,012 complete and valid observations were retained for analysis (Table 1).

Table 1: Socio-demographic characteristics of the sample

		Dortmund	Paris	Trondheim	Zurich	Full sample
Gender	Men	232	226	270	276	1004
	Women	242	277	252	228	999
Age	Less than 25 years	51	30	31	57	169
	25 to 34 years	100	82	116	89	387
	35 to 44 years	85	75	91	134	385
	44 to 60 years	137	144	129	142	552
	Above 60 years	95	170	155	82	502
Monthly income	Low	170	108	218	164	660
	Middle	176	201	128	181	686
	High	103	152	98	105	458

Education	No university degree	303	145	169	224	841
	University degree	156	354	327	271	1108
Overall Sample		475	504	526	508	2012

Variables

Outcome variables

The present study draws specifically on a subset of variables relevant to understanding consumer acceptance of emerging delivery modes. Respondents indicated their willingness to accept deliveries by three emerging last-mile delivery modes: cargo bikes, autonomous ground robots, and drones. Acceptance is measured using a five-point Likert scale ranging from 'very unlikely' to 'very likely'. The three acceptance ratings serve as the dependent variables.

Explanatory variables

The explanatory variables fall into four groups: attitudinal constructs, shopping behaviour measures, delivery-related attributes, and socio-demographic characteristics.

Two attitudinal constructs are included as latent variables in the model. Environmental concern is measured by five items on a five-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. Social activity engagement was assessed by seven items on a seven-point scale ranging from ‘never’ to ‘daily’. Items for both constructs were adapted from an established questionnaire to ensure conceptual validity (Smith et al., 2023).

Shopping behaviour is captured through detailed measures of shopping frequency across major product categories, including takeaway meals, home-delivered meals, groceries and everyday household items, healthcare and personal hygiene products (including pharmacy items), clothing and footwear, electronic goods, leisure and sports items, and furniture and do-it-yourself (DIY) products. Shopping frequency for all categories is measured using seven-point ordinal scales. Respondents also reported the distribution of purchases between online and in-store channels on a five-point scale ranging from “always online” to “always in store” and how frequently they compared prices online or across stores before making purchases, providing a measure of price sensitivity. Factor scores are extracted through confirmatory factor analysis for attitudinal constructs and behavioural variables and entered as continuous variables in the model.

Additionally, respondents rated the importance of delivery-related attributes such as delivery cost, delivery time, environmental impacts, privacy, effort required for pickup, and availability of delivery updates on five-point Likert scales ranging from “not important” to “very important” when purchasing products online.

Finally, standard socio-demographic variables, including age, gender, education, monthly income, and employment status, were collected.

Analyses

Confirmatory factor analysis

Confirmatory factor analysis was conducted in R using the lavaan package in R to assess the reliability and validity of five latent constructs: environmental concern, social activity engagement, shopping frequency, virtual shopping engagement, and price sensitivity.

All reliability values exceeded 0.60 and the average variance extracted surpassed 0.50 for each construct, supporting internal consistency and convergent validity respectively (Ab Hamid et al., 2017). All indicators showed statistically significant loadings ranging from 0.594 to 0.881, above the commonly cited minimum of 0.50. One indicator, grocery and household shopping frequency, showed an insufficient loading of 0.369 and was dropped from further analysis. Model fit was satisfactory across all indices: RMSEA = 0.06, TLI = 0.976, CFI = 0.974, and SRMR = 0.062 (MacCallum et al., 1996).

Multivariate ordered probit model

Consumer acceptance of cargo bikes, autonomous ground robots, and drones is modelled jointly using a multivariate ordered probit (MVOP) framework estimated simultaneously using the mvord package in R. This joint estimation is preferred over three separate ordered probit models, which would ignore the correlations across the three modes and would yield incomplete insights into shared behavioural drivers.

3. RESULTS AND DISCUSSION

Socio-demographic characteristics, delivery-related preferences, attitudinal and behavioural factors, and city-level context are associated with acceptance of emerging delivery modes (Table 2).

Socio-demographic influences on acceptance

Age is a strong and consistent determinant of acceptance across all three delivery modes. Relative to respondents below 25 years, older individuals show significantly lower acceptance, with the negative effect increasing progressively with age. The effect is most pronounced for drone delivery, where coefficients range from -0.29 ($p < 0.01$) for the 25–34 group to -0.52 ($p < 0.001$) for those above 60, compared to -0.22 ($p < 0.05$) and -0.47 ($p < 0.001$) for cargo bike delivery in the same groups. Age effects are consistently stronger for drone and robot delivery than for cargo bikes, suggesting that age is a more decisive barrier for automated modes than for the more familiar cargo bike. These findings align with evidence that younger cohorts exhibit greater openness to technology-intensive delivery solutions, reflecting higher familiarity with digital platforms and automation (Said et al., 2023). Lower acceptance among older respondents may reflect higher risk aversion, lower trust in automation, or reduced perceived benefit from technological innovation.

Gender is significantly associated with acceptance of autonomous ground robots and drones, but not cargo bike delivery. Male respondents show higher acceptance of robot ($\beta = 0.15$, $p < 0.01$) and drone delivery ($\beta = 0.21$, $p < 0.001$) than female respondents, with no significant gender difference for cargo bikes. This pattern aligns with evidence of higher male acceptance of

automated and aerial technologies, potentially reflecting differences in technology affinity or safety perceptions (Said et al., 2023). The insignificance of gender for cargo bike delivery suggests this mode is perceived as more familiar, reducing gender-based differences in acceptance.

Holding a university degree is positively associated with acceptance across all three modes (robot: $\beta = 0.20$, $p < 0.001$; drone: $\beta = 0.17$, $p < 0.01$; cargo bike: $\beta = 0.15$, $p < 0.01$), with slightly stronger effects for robot and drone delivery. Higher education may be associated with greater exposure to sustainability discourse, higher trust in innovation, and better understanding of alternative delivery systems (Pani et al., 2020; Said et al., 2023).

Table 2: Results from the multivariate ordered probit model

	Ground Robot Delivery	**Drone Delivery**	**Cargo-Bike Delivery**
Intercept	$\mathbf{0.778}^{***}$	$\mathbf{1.037}^{***}$	$\mathbf{0.881}^{***}$
Age (Base: Less than 25)			
25 to 34 years	$-0.137^{n.s.}$	$\mathbf{-0.288}^{**}$	$\mathbf{-0.219}^{*}$
35 to 44 years	$\mathbf{-0.206}^{*}$	$\mathbf{-0.325}^{**}$	$\mathbf{-0.208}^{*}$
45 to 60 years	$\mathbf{-0.352}^{***}$	$\mathbf{-0.544}^{***}$	$\mathbf{-0.371}^{***}$
Above 60 years	$\mathbf{-0.336}^{**}$	$\mathbf{-0.521}^{***}$	$\mathbf{-0.470}^{***}$
Gender (Base: Female)			
Male	$\mathbf{0.147}^{**}$	$\mathbf{0.209}^{***}$	$0.006^{n.s.}$
Education (Base: No university degree)			
University degree	$\mathbf{0.200}^{***}$	$\mathbf{0.167}^{**}$	$\mathbf{0.152}^{**}$
Delivery features (Base: Low)			
Delivery cost: Medium	$0.213^{n.s.}$	$-0.041^{n.s.}$	$0.044^{n.s.}$
Delivery cost: High	$0.204^{n.s.}$	$0.034^{n.s.}$	$0.132^{n.s.}$
Delivery speed: Medium	$-0.048^{n.s.}$	$-0.070^{n.s.}$	$-0.029^{n.s.}$
Delivery speed: High	$0.053^{n.s.}$	$0.009^{n.s.}$	$0.064^{n.s.}$
Time flexibility: Medium	$0.088^{n.s.}$	$0.057^{n.s.}$	$-0.026^{n.s.}$
Time flexibility: High	$0.166^{n.s.}$	$0.115^{n.s.}$	$0.038^{n.s.}$
Privacy: Medium	$\mathbf{-0.364}^{**}$	$\mathbf{-0.211}^{\dagger}$	$-0.174^{n.s.}$
Privacy: High	$\mathbf{-0.383}^{***}$	$\mathbf{-0.248}^{*}$	$\mathbf{-0.189}^{\dagger}$
Environmental impacts: Medium	$0.016^{n.s.}$	$-0.047^{n.s.}$	$\mathbf{0.252}^{*}$
Environmental impacts: High	$0.148^{n.s.}$	$0.023^{n.s.}$	$\mathbf{0.508}^{***}$
Efforts to pick up: Medium	$0.022^{n.s.}$	$0.109^{n.s.}$	$-0.087^{n.s.}$
Efforts to pick up: High	$0.066^{n.s.}$	$0.176^{n.s.}$	$0.009^{n.s.}$
Delivery updates: Medium	$-0.040^{n.s.}$	$-0.160^{n.s.}$	$-0.002^{n.s.}$
Delivery updates: High	$0.119^{n.s.}$	$0.094^{n.s.}$	$0.149^{n.s.}$
Latent Variables			
Environmental concerns	$\mathbf{-0.021}^{\dagger}$	$-0.016^{n.s.}$	$\mathbf{0.041}^{***}$
Social activity engagement	$\mathbf{0.046}^{***}$	$\mathbf{0.037}^{**}$	$\mathbf{0.050}^{***}$
Shopping frequency	$\mathbf{0.138}^{***}$	$\mathbf{0.109}^{***}$	$\mathbf{0.062}^{***}$

Virtual shopping engagement	$\mathbf{0.133}^{***}$	$\mathbf{0.121}^{***}$	$\mathbf{0.100}^{***}$
Price sensitivity	$\mathbf{0.033}^{***}$	$\mathbf{0.041}^{***}$	$\mathbf{0.029}^{***}$
City (Base: Dortmund)			
Paris	$\mathbf{-0.178}^{*}$	$\mathbf{-0.181}^{*}$	$\mathbf{0.189}^{**}$
Trondheim	$0.017^{n.s.}$	$\mathbf{0.092}^{\dagger}$	$\mathbf{0.118}^{\dagger}$
Zurich	$-0.050^{n.s.}$	$-0.059^{n.s.}$	$-0.063^{n.s.}$
Correlations			
Ground robot delivery	1	0.871	0.632
Drone delivery		1	0.615
Cargo-bike delivery			1

Note: Correlation coefficients capture the correlation between unobserved components across the three modes

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $^{n.s.}$ not significant.

Delivery-related preferences and perceived attributes

Among the delivery-related attributes, privacy concerns are a strong negative determinant of acceptance for robot and drone delivery, with effects intensifying progressively as concern increases (robot: $\beta = -0.38$, $p < 0.001$; drone: $\beta = -0.25$, $p < 0.05$ for high importance). This indicates that as privacy concern intensifies, the negative effect on acceptance propensity grows progressively stronger, pushing respondents increasingly toward the lower acceptance categories. This finding aligns with a growing body of literature highlighting privacy and surveillance concerns as key barriers to public acceptance of autonomous and aerial delivery technologies (Berke et al., 2023; Leon et al., 2023). In contrast, effects are marginal for cargo bikes, perceived as closer to conventional courier services.

While environmental importance does not significantly influence acceptance of robot or drone delivery, it is positively and significantly associated with cargo bike acceptance, with coefficients of 0.25 ($p < 0.05$) for respondents who place medium importance and 0.51 ($p < 0.001$) for respondents who place high importance. This suggests that cargo bikes are evaluated through a sustainability lens in ways automated modes are not.

Role of latent behavioural and attitudinal factors

Environmental concern shows a clearly differentiated effect across modes. It is positively and significantly associated with cargo bike acceptance ($\gamma = 0.04$, $p < 0.001$), suggesting that environmentally oriented consumers are more receptive to this visibly low-emission mode. By contrast, the effect on robot acceptance is negative and marginal ($\gamma = -0.02$, $p < 0.10$), and not significant for drone delivery ($\gamma = -0.02$, $p > 0.10$). This pattern reinforces the interpretation that cargo bikes are perceived as an environmentally-friendly option, whereas perceptions of technology, risk, and privacy more strongly shape acceptance of automated modes.

Shopping frequency and virtual shopping engagement are among the strongest and most consistent predictors across all three modes. Shopping frequency coefficients are 0.14 for robot delivery, 0.11 for drone delivery, and 0.06 for cargo bike delivery, all significant at $p < 0.001$. This indicates that more frequent shoppers are systematically shifted toward higher acceptance categories across all three modes, with the effect being most pronounced for automated modes. Virtual shopping engagement shows a similar pattern, with coefficients of 0.13, 0.12, and 0.10,

respectively. These results indicate that the individuals with greater exposure to e-commerce and delivery services are more likely to perceive potential benefits from emerging last-mile solutions and are less resistant to changes in delivery formats.

Similarly, price sensitivity and social activity engagement also have a significant impact on the acceptance of emerging delivery modes.

City-level effects and contextual differences

City-level effects persist even after controlling for a wide range of individual characteristics and attitudes. Relative to Dortmund, respondents in Paris exhibit significantly lower acceptance of autonomous ground robots ($\beta = -0.18$, $p < 0.05$) and drone delivery ($\beta = -0.18$, $p < 0.05$), while showing higher acceptance of cargo bike delivery ($\beta = 0.19$, $p < 0.01$). This pattern is consistent with the higher visibility of cargo bike logistics in Paris and the comparatively lower familiarity with autonomous delivery systems in the city. Respondents in Trondheim show marginally higher acceptance of drone delivery ($\beta = 0.09$, $p < 0.10$) and cargo bike delivery ($\beta = 0.12$, $p < 0.10$) relative to Dortmund. At the same time, no significant difference is observed for ground robot delivery. The marginal significance of the Trondheim effects may reflect the city's relatively greater exposure to drone delivery pilots, though the effect remains modest. Zurich does not differ significantly from Dortmund across any of the three modes, indicating broadly comparable acceptance levels once individual characteristics are accounted for. These findings echo the importance of city-specific context in shaping public attitudes towards urban logistics innovations.

Correlation structure

The estimated correlations between the unobserved components of the three acceptance equations are positive and substantial, confirming that unobserved factors influencing acceptance are correlated across delivery modes. The strongest correlation is observed between autonomous ground robots and drone delivery ($\rho = 0.87$), suggesting that these technologies are perceived as closely related in terms of novelty, automation, and perceived risk. The correlations involving cargo bike delivery are positive but smaller ($\rho = 0.63$ with robot delivery and $\rho = 0.62$ with drone delivery), indicating that while general openness to alternative delivery solutions contributes to cargo bike acceptance, this mode is also shaped by a distinct set of considerations that do not apply equally to automated modes.

4. CONCLUSIONS

The most practically significant finding is that consumer readiness is not a fixed property of a technology but a function of its social legibility, its fit with existing routines, and the degree to which its presence in public space feels legitimate and trustworthy. Cargo bikes have largely cleared these thresholds; they are visible, human-mediated, and environmentally intuitive. Automated modes have not, and closing that gap will require more than technical improvement or operational scaling. A second implication concerns the consumer segments most likely to drive early adoption. The consistent positive role of shopping frequency and virtual engagement across all three modes points to another practical insight: the e-commerce ecosystem itself is generating the conditions for acceptance. Frequent delivery recipients are both the primary market and the most behaviourally ready adopters, creating a natural alignment between demand and receptiveness that operators and policymakers can build on. Ultimately, the transition toward more

sustainable last-mile delivery will not be driven solely by technology. Consumer behaviour, local context, and public trust are equally important.

REFERENCES

Ab Hamid, M.R., Sami, W., Mohmad Sidek, M.H., 2017. Discriminant Validity Assessment: Use of Fornell & Larcker criterion versus HTMT Criterion. J. Phys. Conf. Ser. 890, 012163. https://doi.org/10.1088/1742-6596/890/1/012163

Bergmann, F.M., Wagner, S.M., Winkenbach, M., 2020. Integrating first-mile pickup and last-mile delivery on shared vehicle routes for efficient urban e-commerce distribution. Transportation Research Part B: Methodological 131, 26–62. https://doi.org/10.1016/J.TRB.2019.09.013

Berke, A., Ding, G., Chin, C., Gopalakrishnan, K., Larson, K., Balakrishnan, H., Li, M.Z., 2023. Drone delivery and the value of customer privacy: A discrete choice experiment with U.S. consumers. Transp. Res. Part C Emerg. Technol. 157, 104391. https://doi.org/10.1016/J.TRC.2023.104391

Cicek, D., Kantarci, B., Schillo, S., 2025. A comparative review of user acceptance factors for drones and sidewalk robots in autonomous last mile delivery. Green Energy and Intelligent Transportation 4, 100310. https://doi.org/10.1016/J.GEITS.2025.100310

Leon, S., Chen, C., Ratcliffe, A., 2023. Consumers' perceptions of last mile drone delivery. International Journal of Logistics Research and Applications 26, 345–364. https://doi.org/10.1080/13675567.2021.1957803

MacCallum, R.C., Browne, M.W., Sugawara, H.M., 1996. Power analysis and determination of sample size for covariance structure modeling. Psychol. Methods 1, 130–149.

Pani, A., Mishra, S., Golias, M., Figliozzi, M., 2020. Evaluating public acceptance of autonomous delivery robots during COVID-19 pandemic. Transp. Res. D Transp. Environ. 89, 102600. https://doi.org/10.1016/J.TRD.2020.102600

Riahi Samani, A., Riahisamani, R., Mishra, S., Golias, M.M., Jung-Hwi Lee, D., 2024. Evaluating relocation behavior of establishments: Evidence for the short-term effects of COVID-19. Environ. Plan. B Urban Anal. City Sci. 51, 2012–2030. https://doi.org/10.1177/23998083241230580/SUPPL_FILE/SJ-PDF-1-EPB-10.1177_23998083241230580.PDF

Said, M., Aeschliman, S., Stathopoulos, A., 2023. Robots at your doorstep: acceptance of near-future technologies for automated parcel delivery. Scientific Reports | 13, 18556. https://doi.org/10.1038/s41598-023-45371-1

Smith, J., Ryan, L., Larkina, M., Sonnega, A., Weir, D., 2023. Psychosocial and Lifestyle Questionnaire 2006-2022. University of Michigan.