Acceptance of new technologies affecting safety on electric bicycles: evidence from five European countries

Georgios Kapousizis*[1], Rumana Sarker[2], Baran Ulak[3], Karst Geurs[4]

[1] PhD candidate, Department of Civil Engineering, University of Twente, Netherlands
[2] Research Fellow, Department of Civil Engineering, Monash University, Australia
[3] Assistance Professor, Department of Civil Engineering, University of Twente, Netherlands
[4] Professor, Department of Civil Engineering, University of Twente, Netherlands

SHORT SUMMARY

Electric bicycles (e-bikes) are one of the main solutions towards mitigating transport externalities, such as traffic congestion and emission, and have thus been promoted in many countries. Despite the advantages of e-bikes, users are prone to be involved in crashes, usually due to the high speed. Leveraging new technologies could help reduce such crashes; however, e-bike users' willingness to accept new technologies still needs to be investigated. Hence, this study explores e-bike users' motivation to use smart e-bikes by adopting the extended Unified Theory of Acceptance and Use of Technology (UTAUT2). A cross-national survey was administered in five European countries-Austria, Belgium, Germany, Greece and the Netherlands, differing in sizes and cycling culture. The survey yielded 1116 responses, and the structural equation model (SEM) results indicate that 'performance expectancy', 'hedonic motivation' and 'perceived safety' are the strongest predictors of users' acceptance of new technologies on e-bikes to increase safety and comfort.

Keywords: Cycling safety, E-bikes, UTAUT2, User acceptance, SEM

1. INTRODUCTION

The Covid-19 pandemic and the recent energy crisis have pushed a significant number of people to switch to more active transport modes such as cycling (Nikitas et al., 2021; Shimano, 2022). Despite the numerous benefits of cycling, there are also certain barriers such as low fitness levels, topographical difficulties, and established habits, preventing more people embrace cycling as their everyday transportation (Fishman & Cherry, 2016; Plazier, 2022). E-bikes can help overcome some of these barriers in front of widespread adoption of cycling. Since with an e-bike people can travel faster and longer distances compared to conventional bicycles, several governments worldwide have lately been promoting e-bikes as one of the main measures to mitigate negative transport externalities such as congestion and emission.

Many European countries subsidise the purchase of e-bikes (ECF, 2023) and as a result, there is an increase in the number of e-bikes being sold in Europe in recent years. In 2021, around five million new e-bikes were sold in Europe (Sutton, 2022), which is the highest numbers of bicycles sold in a decade (Statista, 2020). However, this increase in bicycles lead to major safety concerns in many countries which have inadequate cycling infrastructure. Furthermore, e-bikes potentially lead to more severe crashes as they are usually faster than regular bicycles and aging people can also use them more easily (Gadsby & Watkins, 2020; Panwinkler & Holz-Rau, 2021; J. P. Schepers et al., 2014). That is why countries like the Netherlands, with one of the best and well design bicycle network (P. Schepers et al., 2017), still experience many e-bike crashes (Statistics Netherlands (CBS), 2021). One of the ways to address this increasing safety concern is the adoption of new technologies such as sensors on bicycles and Internet of Things (IoT) to prevent crashes and reduce severities. Such systems can be the future of a sustainable cycling environment as they could positively influence and increase cycling safety (Boronat et al., 2021; Oliveira et al., 2021). Kapousizis et al. (2022) showed that in the last decade, there is a plethora of published studies about new technologies that can increase cycling safety, and proposed a classification for the 'bicycle smartness levels' (BSLs) consisting of 6 levels. This study focused on technologies at third level to investigate user acceptance of specific functionalities in their e-bike, considering that the Level 3 involves the most feasible and readily available technology given the highest Technology Readiness. The level 3 consists of surrounding detection, collision avoidance, speed warnings and post-accident notifications.

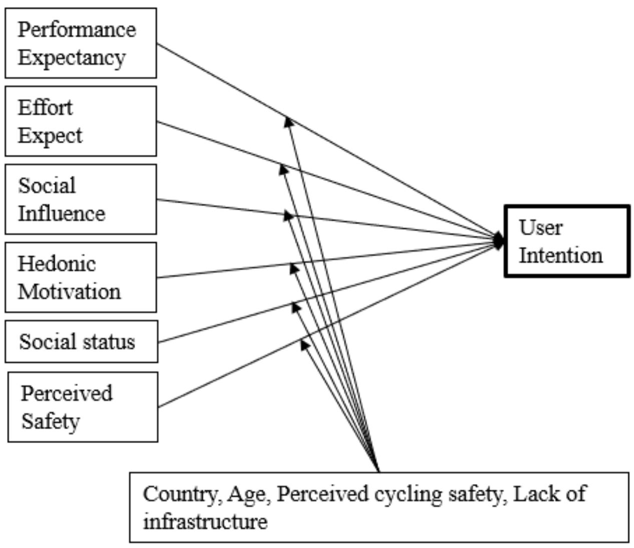
While new bicycle technologies are shown to positively affect cyclists' safety and comfort, less is known about users' acceptance and intention to use these features. There is still scarce literature investigating users' intention to adopt new bicycle technologies to increase safety and comfort. To cover this gap, this study aims to investigate users' intention to accept new technologies on e-bikes by collecting data and comparing factors across different countries.

2. METHODOLOGY

In this study, the framework of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) was adopted (Venkatesh et al., 2012). We used the UTAUT2 as a baseline and adjusted it with most appropriate constructs that fit this study. The conceptual model with the constructs is presented in Figure 1. Adjustments in the UTAUT2 framework are common, especially in transport research such as automated vehicles, since this technology is not available yet and researchers are investigating this a priori (Kapser & Abdelrahman, 2020; Nordhoff et al., 2020). In an attempt to explore specific factors, we adjusted the model to fit this study's aim.

This is the first study that adopted the UTAUT2 framework and tailored it accordingly to examine users' intention to use new bicycle technologies that affect cycling safety and comfort. To develop the hypotheses, we have included psychological constructs from other domains, such as advanced driving assistance systems and automated vehicles.

Figure 1: Conceptual model (Extended UTAUT2)



Following the UTAUT2, it is hypothesised that users' intentions to adopt new technologies in e-bikes are related to performance and effort expectancy, social influences and hedonic motivation. Within this framework, an extended version of the framework is considered by including 'social norm' and 'perceived safety' as factors that could affect people's intention to accept new technologies. We excluded 'facilitating conditions', 'price value', and 'habit' of the UTAUT2 model since these technologies are not commercially available yet. Notably, according to the UTAUT2, the antecedents are independent and directly linked to the behavioural intention of technology adoption in e-bike. The elements in the conceptual framework are as follows:

Performance expectancy relates to individual beliefs concerning a system (Venkatesh et al., 2003). In the context of this study, performance expectancy is defined as the degree of usefulness an individual can get using new technologies on e-bikes. We assume that the performance expectancy construct will be a strong predictor.

Effort expectancy justifies the ease of use of a specific system (Venkatesh et al., 2003) and is also associated with the degree of consumers' ease of use (Venkatesh et al., 2012). In the context of this study, we believe that effort expectancy will positively influence behavioural intention.

Social influence is defined as an individual's perception of what others believe they should use a specific technology and to what extent others' opinion influences an individual to accept and use a specific technology (Venkatesh et al., 2003).

Hedonic motivation proves an individual's enjoyment using technology (Venkatesh et al., 2012). We believe hedonic motivation can be derived from the new technologies on e-bikes and fulfil individual satisfaction.

Social norm refers to individual's behaviour modification based on their belief of what others expect from them.

Perceived safety is frequently used in several studies predicting the influence of an individual to use technology due to their belief that it will improve their safety (Kapser & Abdelrahman, 2020; Nordhoff et al., 2020). Hence, we construct the following hypothesis.

The following research hypotheses are tested from the conceptual model (Fig. 1):

H1: Performance expectancy positively influences behavioural intention to use new technologies on e-bikes.

H2: Effort expectancy positively influences behavioural intention to use new technologies on e-bikes.

H3: Social influence positively influences behavioural intention to use new technologies on e-bikes.

H4: Hedonic motivation positively influences behavioural intention to use new technologies on e-bikes.

H5: Social status positively influences behavioural intention to use new technologies on e-bikes.

H6: Perceived safety positively influences behavioural intention to use new technologies on e-bikes.

Survey

To investigate the aforementioned hypotheses, we conducted an online survey -translated into five languages (English, German, Greek, Dutch and French), which was distributed in five European countries, Austria, Belgium, Germany, Greece and the Netherlands, between November 2022 and January 2023. All constructs are measured by 3-5 standardised items assessed on 5-point Likert scales. The focus group of the survey comprised people who already use an e-bike or are willing to buy one. This group was chosen to collect more realistic results than asking people not interested in cycling. Countries were not selected randomly; on the contrary, they were chosen due to the varying quality of cycling infrastructure and cycling culture to understand users' perceived safety in different scenarios. In total, 1116 responses were collected.

Table 1: Sample

Variable	Austria	Belgium	Germany	Greece	Netherlands
Number of respondents	75	199	115	199	528
Gender					
Male	53	106	79	142	322
Female	18	90	35	56	195
Other	4	3	1	1	11
Age					
18-29	3	10	11	26	24
30-39	16	24	15	54	20
40-49	10	29	17	61	25
50-59	23	37	37	39	80
60-69	18	64	29	19	190
>70	5	35	6	0	189

We performed a Structural Equation Model (SEM) to analyse the behavioural framework. The SEM in this study contains three sets of equations: measurement equations, structural equations linking the latent constructs to observed characteristics of the participants, and structural equations relating the latent constructs to the dependent variables (user intention of new technologies on e-bikes). The model was estimated using the SPSS-AMOS.

3. RESULTS AND DISCUSSION

To investigate users' intention to use new technologies on e-bikes, a SEM model was analysed. Maximum likelihood method was used and the model was assessed through the five most commonly used goodness-of-fit indexes: Chi-square per degree of freedom (CMIN/DF: $1.0 < \chi^2 < 3.0$) (CMIN/DF : 2.80), Comparative Fit Index (CFI: >0.095)(CFI: 0.981), Tucker-Lewis index (TLI: >0.95)(TLI: 0.976), Root Mean Square Error of Approximation (RMSEA:< 0.07) (RMSEA : 0.04) and Standardised Root Mean Square Residual (SRMSR < 0.05) (SRMSR : 0.0266) (Hair et al., 2014; Schumacker & Lomax, 2010). In this study, standardised factor loadings are between 0.638 to 0.949, above the threshold of 0.5 (Hair et al., 2014, p. 618). The model was assessed for convergent and discriminant validity; Average Variance Extracted (AVE) was above the cut-off criterion of 0.50 (Fornell & Larcker, 1981; Hair et al., 2014), which illustrates the convergent validity. Composite reliability (CR) was also above the acceptance threshold of 0.7 (Hair et al., 2014), supporting internal consistency.

A significant positive relationship was found between performance expectancy and behavioural intention, hedonic motivation and behavioural intention, perceived safety and behavioural intention, social influence and behavioural intention, and effort expectancy and behavioural intention. Thus, this shows that performance expectancy, hedonic motivation and perceived safety are the stronger constructs and are important factors in user intention of the new technologies on e-bikes. Social influence is also an important and positive aspect in user intention, while effort expectancy has a mild positive significant role. In contrast, there is no significant relationship between social status and behavioural intention. The hypotheses and their structural results of this study are presented in Table 2.

Table 2: Results of structural relationships

Hypothesis	β	Significance	Results
H1	0.398	< 0.001	supported
H2	0.039	0.017	supported
H3	0.068	< 0.001	supported
H4	0.326	< 0.001	supported
H5	0.027	0.220	rejected
H6	0.134	< 0.001	supported

The variability of behavioural intention to use new technologies on e-bikes is explained by 84% of the proposed model. Investigating cross-country differences is evidence that performance expectancy has a strong and positive impact on user intention across all countries, while hedonic motivation has no significant impact in the Austrian sample. Additionally, perceived safety positively influences user intention in Belgium, Germany, and Netherlands. Social influence has a stronger relationship and is significant to the Dutch and Austrian responders. Finally, there is no significance on social status construct; this tendency is similar in all five countries. These results are presented in Table 3.

This model was also tested with a series of controls against user intention. In this attempt, we controlled our model to gender, age, lack of infrastructure, and perceived cycling safety (see Table 3). Note that age was tested as continuous while the rest variables were dummy coded. Results show that user intention significantly increases with increasing age in all counties except Belgium. Gender significantly impacts user intention in Belgium, while the rest variables are not statistically significant across all countries.

Table 3: Results of cross-country analysis

Variables	Austria	Belgium	Germany	Greece	Netherlands
Dependent variable: Intention					
Performance expectancy	0.455***	441***	0.461***	0.444***	0.369***
Effort expectancy	0.114	0.026	0.043	0.047	0.050*
Social influence	0.160**	0.004	-0.085	0.069	0.120***
Hedonic motivation	0.113	0.273**	0.284**	0.276***	0.359***
Social status	0.068	0.032	0.099	0.077	-0.016
Perceived safety	0.115	0.190**	0.186**	0.077	0.129***
Age	0.045*	0.027	0.059**	0.069**	0.066***
Gender (male)	0.044	0.044	0.035	- 0.002	- 0.003
Perceived cycling safety (high)	- 0.043	- 0.019	- 0.040	0.051	- 0.027
Lack of cycling infrastructure (yes)	0.006	- 0.012	- 0.021	- 0.026	0.007

***: p-value < 0.001, **: p-value < 0.05, *:p-value < 0.1

4. CONCLUSIONS

This study provides novel results for the user acceptance of new technologies on e-bikes as a potential solution to improve e-bike safety and comfort. We employed an extended framework of the UTAUT2, which applied to survey data from five European countries. We tested six constructs, while only five were supported (Performance expectancy, Social influence, Hedonic motivation, Perceived safety and Effort expectancy), with Performance expectancy, Hedonic motivation and Perceived safety having a strong relationship with users' intention to use new technologies on e-bikes in the aggregated sample.

Regarding the cross-country analysis, performance expectancy has a higher impact across all countries. The Netherlands shows a high impact on hedonic motivation and social influence, while there is a negative impact and no significance on social status. Perceived safety remains a strong impact in the Netherlands, Belgium and Greece. Additionally, we controlled the model with socio-demographic, infrastructure and safety variables. We found that user intention increases with increasing age in all countries but not in Belgium. However, no significant effects were found for the rest variables.

The findings from this study are an important added value to the literature since it lacks user acceptance. In addition, it offers new insights into deploying new technologies on e-bikes and can benefit different stakeholders, such as bicycle manufacturers and cities. While bicycle manufacturers and designers of such innovative systems are investigating these features to bring them into the market, they can integrate these insights to optimise and develop them better. Also, cities can develop and implement new policies for these emerging technologies for a smooth transition.

ACKNOWLEDGEMENTS

This work is supported by Accell Group.

REFERENCES

Boronat, Pérez-Francisco, Calafate, & Cano. (2021). Towards a sustainable city for cyclists: Promoting safety through a mobile sensing application. *Sensors (Switzerland), 21*(6), 1-18. doi:10.3390/s21062116

ECF. (2023). Money for bikes: Tax incentives and purchase premiums for cycling in Europe. Retrieved from https://ecf.com/resources/financial-incentives

Fishman, & Cherry. (2016). E-bikes in the Mainstream: Reviewing a Decade of Research. *Transport Reviews, 36*(1), 72-91. doi:10.1080/01441647.2015.1069907

Fornell, & Larcker. (1981). Evaluating Structural Equation Models with Unobservable Variables and Measurement Error. *Journal of Marketing Research, 18*(1), 39-50. doi:10.2307/3151312

Gadsby, & Watkins. (2020). Instrumented bikes and their use in studies on transportation behaviour, safety, and maintenance. *Transport Reviews*. doi:10.1080/01441647.2020.1769227

Hair, Black, Babin, & Anderson. (2014). *Multivariate data analysis* (Fifth Ed. ed.). Prentice Hall.

Kapousizis, Ulak, Geurs, & Havinga. (2022). A review of state-of-the-art bicycle technologies affecting cycling safety: level of smartness and technology readiness. *Transport Reviews*, 1-23. doi:10.1080/01441647.2022.2122625

Kapser, & Abdelrahman. (2020). Acceptance of autonomous delivery vehicles for last-mile delivery in Germany – Extending UTAUT2 with risk perceptions. *Transportation Research Part C: Emerging Technologies, 111*, 210-225. doi:10.1016/j.trc.2019.12.016

Nikitas, Tsigdinos, Karolemeas, Kourmpa, & Bakogiannis. (2021). Cycling in the Era of COVID-19: Lessons Learnt and Best Practice Policy Recommendations for a More Bike-Centric Future. *Sustainability (Switzerland), 13*(9). doi:10.3390/su13094620

Nordhoff, Louw, Innamaa, Lehtonen, Beuster, Torrao, . . . Merat. (2020). Using the UTAUT2 model to explain public acceptance of conditionally automated (L3) cars: A questionnaire study among 9,118 car drivers from eight European countries. *Transportation Research Part F: Traffic Psychology and Behaviour, 74*, 280-297. doi:10.1016/j.trf.2020.07.015

Oliveira, Nery, Costa, Silva, & Lima. (2021). A survey of technologies and recent developments for sustainable smart cycling. *Sustainability (Switzerland), 13*(6). doi:10.3390/su13063422

Panwinkler, & Holz-Rau. (2021). Causes of pedelec (pedal electric cycle) single accidents and their influence on injury severity. *Accident Analysis and Prevention, 154*. doi:10.1016/j.aap.2021.106082

Plazier. (2022). E-bikes in rural areas: current and potential users in the Netherlands. *Transportation*. doi:10.1007/s11116-022-10283-y

Schepers, Fishman, Den Hertog, Wolt, & Schwab. (2014). The safety of electrically assisted bicycles compared to classic bicycles. *Accident Analysis and Prevention, 73*, 174-180. doi:10.1016/j.aap.2014.09.010

Schepers, Twisk, Fishman, Fyhri, & Jensen. (2017). The Dutch road to a high level of cycling safety. *Safety Science, 92*, 264-273. doi:10.1016/j.ssci.2015.06.005

Schumacker, & Lomax. (2010). *A Beginner's Guide to Structural Equation Modeling: Third Edition (3nd ed.)*. New York: Tayler and Francis Group, LLC.

Shimano. (2022). *State of the Nation 2022*. Retrieved from https://lifestylebike.shimano.com/uk/stories/shimano-state-of-the-nation-2022

Statista. (2020). Number of e-bikes sold in Europe from 2009 to 2019. In (pp. CONEBI).

Statistics Netherlands (CBS). (2021). 610 traffic deaths in 2020. Retrieved from https://www.cbs.nl/en-gb/news/2021/15/610-traffic-deaths-in-2020

Sutton. (2022). European electric bike sales pass 5 million, all bikes 22 million. *cyclingindustry.news*. Retrieved from https://cyclingindustry.news/european-electric-

bike-sales-pass-5-million-all-bikes-22-million/#:~:text=New%20data%20published%20this%20week,%25%20year%2Don%2Dyear.
Venkatesh, Morris G, Davis B, & Davis D. (2003). User Acceptance of Information Technology: Toward a Unified View. *27. No.3*, pp. 425-478 (454 pages). doi:https://doi.org/10.2307/30036540
Venkatesh, Thong, & Xu. (2012). Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *JSTOR, 36*, 157-178. doi:https://doi.org/10.2307/41410412