Transportation Research Interdisciplinary Perspectives 14 (2022) 100589

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

journal homepage: www.elsevier.com/locate/trip

Analysis of initial speed pedelec usage for commuting purposes in Flanders

Bert Herteleer[a,*], Nikolaas Van den Steen[a,b], Lieselot Vanhaverbeke[b], Jan Cappelle[a]

[a] ELECTA Gent, Faculty of Technology Engineering, KU Leuven, Gebroeders De Smetstraat 1, 9000 Gent, Belgium
[b] Department BUTO, Research Group MOBI, Faculty of Social Sciences and Solvay Business School, Vrije Universiteit Brussel, Pleinlaan, 2, B-1050 Brussels, Belgium

ARTICLE INFO

Keywords:
Speed pedelec
Cruising speed
Commuting
Maximum assistance factor
Regulation
Active travel

ABSTRACT

Speed pedelecs, pedal-powered two-wheelers with motor assistance up to 45 km/h, are relatively new vehicles for active travel on European roads, with Flanders at the forefront of adoption. Policies by European and national entities have allowed speed pedelecs to be used, yet the policies have been based on assumptions and modelling about speeds reached, rather than measured data. This paper presents analysis of naturalistic speed pedelec behaviour by 98 individuals at 10 companies in Flanders, who logged commuting and leisure rides with smartphone GPS during three-week test periods as part of the 365SNEL project using fifteen speed pedelecs, ranging in motor power from 250 W to 800 W. The cruising speed, the speed at which the largest distance is covered, and the 95th percentile (P95) speed (as a realistic maximum speed) are proposed as Key Performance Indicators to better evaluate speed pedelec behaviour. Cruising speeds for men were consistently higher than women (mean values: men 38.2 km/h, women 33.5 km/h). For all participants, the mean commuting P95 speed of 40.1 km/h is 5 km/h below the expected 45 km/h, which points to potential over-regulation of speed pedelecs according to their expected maximum speed. Contrasting logged commuting cycling trips with leisure trips indicates that speed pedelecs can be characterised by their speed metrics, regardless of their travel purpose. Policymakers can therefore facilitate active travel with its commensurate physical and mental health benefits by investing in and designating routes for higher-speed (active) travel, and conversely reserve other routes for slower travel modes.

1. Introduction

The uptake of speed pedelecs is rapidly growing in Belgium, from 1600 speed pedelecs registered in 2016 to reaching 46,800 at the end of 2020, with 96 % of all registrations in Flanders (Statbel, 2022). Speed pedelecs make up a small, albeit rapidly growing, portion of the market for bicycles and electric pedal-assisted cycles (EPACs or pedelecs), with approximately 500,000 bicycles sold per year in Belgium (CONEBI - Confederation of the European Bicycle Industry, 2018). Within Belgium, Flanders is a region with very high ownership and use of bicycles, with approximately 1 bicycle per inhabitant (6.5 million), and 14.2 % of all trips (4.65 % of all travel km) done with a bicycle, however, 24 % of families in Flanders own zero bicycles (Janssens et al., 2020a).

Speed pedelecs are classified as L1e-B vehicles subject to type testing in Europe (European Commission, 2014) when the light two-wheel vehicle has electric motor assistance up to 45 km/h and has a maximum nominal motor power of 4 kW. Additional requirements for “cycles designed to pedal” aim at distinguishing between mopeds and bicycles (with motor assistance). These specify a maximum auxiliary motor power or maximum assistance factor (MAF) “less than or equal to four times the actual pedal power”, and are then also exempt from electric range tests for vehicle type testing (European Commission, 2014). Vehicle type testing is a key requirement to obtain a Certificate of Conformity (CoC), which permits a vehicle to be registered and used on the road. When national authorities determine where vehicles are allowed on the roads and what speeds are permitted, vehicle type tests and classifications serve as a starting point for policymaking.

In Belgium, the Royal Decree for road use (Belgian Government, 2019) defines the category of “speed pedelec” and with it the conditions to be permitted on roads such as vehicle registration and having a license plate, and the obligation for the user to wear an appropriate helmet at all times and have a driver’s license. The maximum permitted speed is the minimum of 45 km/h and the local speed limit. On roads with 50 km/h speed limits or lower, speed pedelec users can choose to cycle on the main road, or on the cycle path, whereas they are obliged to cycle on cycle paths if the road has a speed limit of 70 km/h or higher. Local authorities may oblige speed pedelec users to use a cycle path (or

* Corresponding author.
E-mail addresses: bert.herteleer@kuleuven.be (B. Herteleer), nikolaas.vandensteen@kuleuven.be (N. Van den Steen), Lieselot.Vanhaverbeke@vub.be (L. Vanhaverbeke), jan.cappelle@kuleuven.be (J. Cappelle).

https://doi.org/10.1016/j.trip.2022.100589
Received 16 April 2020; Received in revised form 22 March 2022; Accepted 23 March 2022
Available online 11 April 2022

Table 1
Speed pedelec user summary statistics from literature compared to this work.

Source			Schleinitz et al. (2014, 2017)	de Bruijne and v.d. Lindeloof (2016)	Stelling et al. (2017), Twisk et al. (2021)	Rotthier et al. (2017a)	Stelling-Konczak et al. (2017), Stelling et al. (2021)	This work
Country & year of study			Germany 2012	Netherlands 2014	Netherlands 2016	Belgium 2017	Netherlands 2017	Belgium 2019–20
Allowed on road, max speed			Yes, 45 km/h	No	No	Yes, 45 km/h	Yes, 45 km/h	Yes, 45 km/h
Allowed on cycle path, max speed			No	Yes, 25 km/h	Yes, 25 km/h	Yes, 45 km/h	Yes, 40, 30 km/h[e]	Yes, 45 km/h
Speed measurement			Wheel speed sensor	STRAVA on smartphone	Custom GPS DAS[c]	RunKeeper on smartphone	Custom GPS DAS[c]	RunKeeper on smartphone
Testing period			4 weeks		3 weeks		2–4 weeks	3 weeks
Ownership status			owner	owner	borrowed		borrowed	borrowed
Motor rating P_{nom} (W)					250, 350	350, 500	350, 500	250, 350, 500, 800
User age range		All	18–64	30-60[a]	26–55		26–55	23-64
Users (N)		All	9	28[a]	20	31	28	105
Users (N)		Women	0	0[a]	5		3	45
Users (N)		Men	9	28[a]	15		25	60
Summary statistic	Speed metric	Applies to	Speed value in km/h[b]					
Mean	Average	Women			24.2			29.0
Mean	Average	Men	24.5		29.9			32.8
Mean	Average	All	24.5	30.3	30.3, 27.3[e]		31.8	31.1
Mean	Cruising	All		35.2, 32.9[e]				36.3
Median	Cruising	All				37		36.7
Mean	Max[d]	All	31.9					39.7

Empty cell: Not available, not stated, or unknown.
[a]The target group consists primarily of men aged 30–60 years. (Author's translation and summary.)
[b]Metric and summary statistic to be read as "Mean/Median of average/cruising/max speeds of All participants/Only Women/Only Men in study". E.g. "Mean Average speeds for Women is 24.2 km/h in Stelling et al. (2017), Twisk et al. (2021)".
[c]DAS = Data Acquisition System.
[d]As identified by researchers. In this work: P95 speed.
[e]Speeds in rural, respectively urban (city centre) settings.

prohibit it), for which appropriate signage is employed. Nevertheless, speed pedelec users in Belgium generally have more decision leeway as to their position on the road, compared to other countries, such as The Netherlands (Stelling-Konczak et al., 2017).

Observing the trend in rapid uptake of speed pedelecs, the Flemish Government's Department of Environment funded the "365SNEL" project, which ran from Spring 2018 until Spring 2020 as part of its "Clean Power for Transport" action plan. The aim of the 365SNEL[1] project was to evaluate the potential for year-round commuting using speed pedelecs in Flanders, and to address knowledge gaps around their use.

1.1. Literature review

To date, relatively little research has been published about speed pedelecs and their speed characteristics while in use, reflecting their novelty, relatively high purchasing cost and the local conditions, such as cycling culture and legislation. Table 1 summarises the key aspects found in literature, compared to this work. As can be seen, the position of the speed pedelec and permitted maximum speeds on the road and cycle paths has been (and still is) subject to discussion among researchers and policymakers. Of the three countries (Germany, The Netherlands and Belgium), Belgium is the most supportive for speed pedelecs, with the most decision freedom for speed pedelec use on roads and providing tax benefits (a tax-free cycling allowance of up to 0.24 €/km (Federale Overheidsdienst Financiën, 2021)), while legislation was changed in the Netherlands, evaluating the speed pedelec as being more similar to a moped, rather than a bicycle.

[1] 365SNEL (365 dagen SNelle ELektrische fiets) = 365 days per year, using a ***snelle*** (fast, or speed) pedelec.

The first major investigation to clarify the safety of speed pedelecs was by Gross et al. who investigated the maximum assistance factor (MAF) for speed pedelecs as part of a broader study into speed pedelec structural safety (Gross et al., 2015) for use as a vehicle on European roads, with the results for the four tested speed pedelecs suggesting that a MAF ≤ 4 as specified by European Commission (2014) is reasonable.

Rotthier et al. (2016) challenged the reasoning and measurement of the MAF, pointing to the "fickleness" (sensitivity to environmental parameters, such as wind speed while cycling) resulting from the MAF. Rotthier et al. then investigated (Rotthier et al., 2017a) cruising speeds with speed pedelec motor power for over 40 speed pedelec users with 350 W or 500 W motors. They developed the distance-based cruising speed (the speed at which the longest distance is travelled) as the relevant metric for comparison. The impact of limiting the MAF to four has further been discussed in Rotthier et al. (2017b), arguing that the speed pedelec is (strongly) susceptible to adverse conditions such as headwind or strong slopes.

Regarding measured speeds of speed pedelec users, Table 1 shows the main results obtained. Of note, the study Stelling et al. (2017) of Dutch commuter cyclists showed a pronounced impact of gender on the average speed, with men achieving a higher mean speed than women by 5.6 km/h (urban) and 7.4 km/h in rural environments.

A follow-up study at SWOV in 2017 performed a first analysis of speed pedelec behaviour with the new law in place in the Netherlands, which permits speed pedelecs to cycle as mopeds (i.e. obligatory helmet use, allowed on road infrastructure as mopeds, with top speed limited to 45 km/h on the road, 40 km/h on cycle lanes outside of city centres and 30 km/h within city centres) (Stelling-Konczak et al., 2017). The speed characteristics were further analysed in Stelling et al. (2021), with a focus on safety, concluding that speed pedelecs are in an uncomfortable middle: too slow for roadways and too fast for cycle paths.

Guy et al. were tasked by the European Commission to study road safety risks for L-category vehicles (Guy et al., 2021), and Guy looked into Maximum Assistance Factors for speed pedelecs (European Commission and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and Guy, 2019). The results of these studies were inconclusive regarding safety aspects of speed pedelecs, although initial statistics suggest that speed pedelec users had proportionally more injuries than (e-)bike users.

1.2. Research questions

Conversations with stakeholders (speed pedelec manufacturers, leasing companies, cyclist organisations and policymakers) further stressed different perceptions around the safety of speed pedelecs, based on their maximum permitted speed. However, sufficient objective data indicating the speeds and their frequency distributions achieved by speed pedelec users in practice has not been available for evidence-based policymaking. This paper therefore aims to address knowledge and data gaps regarding the usage of speed pedelecs in a naturalistic context, with a focus on commuting (regular trips between the home and the workplace), with a comparison against recreational trips, and the key performance indicators of this transportation method, such as the typical maximum and cruising speeds achieved, by gender and speed pedelec motor power. This complements the evaluation of motivations and barriers of speed pedelec users using surveys and focus groups within 365SNEL as discussed in Van den Steen et al. (2019b).

The research questions for this paper are therefore:

- Given that the participants in 365SNEL were selected for least experience with speed pedelecs (and thus approximate a new owner), how do they use these, and is there a difference in use for commuting and for recreation?
- Which key performance indicators (KPIs) around speed pedelecs can and should be used for evidence-based policymaking?
- How fast do speed pedelec users travel, how often do they reach speeds nearing the advertised 45 km/h?

2. Methods and data

2.1. 365SNEL project and experimental evolution

The aim of the 365SNEL project was to have at least ten companies have ten employees exclusively substitute their car by a speed pedelec over the course of three weeks for commuting purposes (Van den Steen et al., 2019a). Companies based in Flanders were invited to participate in 365SNEL via news articles, direct mailings, newsletters, bicycle network organisations, and applied via an online application form in the period September 2018–May 2019. From the 52 applicant companies and institutions, ten were retained for participation in the project.

Three companies were selected prior to the project start, while the remaining seven were contacted and agreed to participate as the project progressed. The selection of the final companies was based on the following criteria:

- Geographical diversity and representation: at least one company for each of the five Flemish provinces.
- Variety of sectors: private sector, healthcare, education, research.
- Difference in organisational scale, from small (<50 employees), medium (<250), to large (>3000).
- Demonstrated willingness and commitment from companies to participate in the project.

2.2. Selection of participants

Within the retained companies and institutions, participants were recruited through various means, which varied according to the company size, with internal emails and newsletters used for larger institutions, and in-person recruitment and emails used at the smallest. Table 2 summarises the participants in the project. Participation by individuals in the 365SNEL project comprised two main components:

- Active and willing participation in focus groups and surveys. Focus group discussions (Breen, 2006) were held before and after the speed pedelec testing period, while surveys were held before, midway and after the testing period. The analysis and results of the focus groups are published in Van den Steen et al. (2019b).
- Commuting between the home and the workplace with a speed pedelec provided within 365SNEL for a testing period of up to three weeks, and voluntarily log each ride's GPS trace using the Runkeeper App (Runkeeper, 2019). Participants used their own smartphone (Android or iOS), or used an Android smartphone provided by 365SNEL.

2.3. Speed pedelec availability and assignment

The availability of speed pedelecs increased during the project; as such, not all speed pedelecs were used equally throughout. The allocation of speed pedelecs within a company during the trial period was based on the following criteria:

1. Height and gender of participant compared to available model types: taller people were provided high instep speed pedelecs ("male" variants), whereas women were predominantly provided with unisex or female variants.
2. Availability: some speed pedelecs became available later in the project, or were temporarily unavailable due to maintenance.
3. Commuting distance: cyclists with longer commuting distances were provided speed pedelecs with larger battery capacities. As can be seen in Table 3, these speed pedelecs with higher battery capacity values generally have higher motor power.
4. User preference: cruising or relaxed cycling posture versus more sporty.

Other than an appropriate speed pedelec, each participant was provided with all legally required (helmet) and optional items (rain-proof jackets and trousers, gloves, bicycle bags) for commuting with speed pedelecs in Belgium. Further information regarding the selection criteria can be found in Van den Steen et al. (2019b).

Table 3 provides an overview of the speed pedelecs used in the 365SNEL project. Some of the speed pedelecs were provided for use in the project by companies participating in the project, such as speed pedelec manufacturers and a bike leasing company, while others had previously been purchased by KU Leuven. The speed pedelecs thus cover a relatively broad range in weight and power categories as commercially available at the time.

The variation among battery guarantees points to a potential area for customer dissatisfaction, as it is not always clear when a battery would be covered and therefore replaced under warranty. Similarly, the mass of speed pedelecs is typically stated by many manufacturers excluding the battery, lock(s) and commuting accessories such as saddle bags, battery chargers or waterproof clothing. Given the high purchase cost of speed pedelecs compared to bicycles, a lock is essential against theft. As such, a speed pedelec used for commuting between the home and office with all necessary (battery and lock) and optional (saddle bag with spare or waterproof clothing, charger) accessories can have a mass that is 3 kg to 7 kg higher than displayed in Table 3. In practice, this means that most speed pedelecs will have a fully laden mass excluding the rider between 30 kg to 40 kg. This can further affect how easily a speed pedelec can be moved, such as for parking, or entering or leaving a house, while the higher total mass may also affect handling while cycling, and especially for (sudden) braking manoeuvres.

Table 2
Overview of participants in the 365SNEL project.

	Men			Women			Total
Interested	333			187			520
Cycling participants	**60**			**45**			105
Valid[a] GPS data	55			43			98
Commuted home-work	54			42			96
	bicycle	pedelec	speed pedelec	bicycle	pedelec	speed pedelec	
Prior experience[b]	**60**	32	4	**45**	23	4	
	Mean	SD	Range	Mean	SD	Range	
Age	42.7	9.0	23–59	39.8	9.0	25–58	
Mass (kg)	82.4	13.0	52–110	67.9	12.0	51–99	
BMI (kg/m^2)	25.5	3.0	18–33	23.5	4.0	18–33	
Height (m)	1.80	0.08	1.60–2.00	1.70	0.06	1.58–1.83	

[a]Trips excluded when erroneous data had (≥4 %) points per trip, applied per trip. Some participants did not provide GPS trip files.
[b]All pedelec and speed pedelec users had prior bicycle experience.
SD = Standard deviation. BMI = Body Mass Index.

Table 3
Speed pedelecs provided to 365SNEL project participants.

Code	Make	Model	Motor P_{nom}[a]	Battery capacity	Size (Instep)[b]	Battery guarantee	Max range[c]	Mass[d]	Ref
B01	Flyer	TS Serie	250 W	500 Wh	M (High)	60 % ≥ 2 years	N/A	22 kg	Flyer (2019)
B02	Gazelle	CityZen Speed 380 km	250 W	500 Wh	M (High)	2 years[e]	40 km	22.5 kg	Gazelle (2019)
B03	Oxford	S-pedelec	250 W	500 Wh	M (Low)	2 years[e]	50 km	23.3 kg	Oxford Bikes (2019)
B04	Riese & Müller	Cruiser Mixte Vario HS	250 W	500 Wh	S (Low)	min(500 cycles, 60 % ≥ 2 years)	35 km	27.1 kg	Riese & Müller (2019a, 2020b)
B05	Riese & Müller	Roadster Touring	250 W	500 Wh	M (High)	min(500 cycles, 60 % ≥ 2 years)	50 km	23.6 kg	Riese & Müller (2019b, 2020b)
B06	Riese &Müller	Load 75 vario HS	250 W	500 Wh	M (Low)	min(500 cycles, 60 % ≥ 2 years)	30 km	48.2 kg	Riese & Müller (2020a,b)
B07	Kalkhoff	Integrale i11 Speed Trapez	350 W	621 Wh	S (Low)	60 % ≥ 3 years	80 km	25.6 kg	Kalkhoff (2018)
B08	Kalkhoff	Integrale i11 Speed Trapez	350 W	621 Wh	L (Low)	60 % ≥ 3 years	80 km	25.6 kg	Kalkhoff (2018)
B09	Kalkhoff	Integrale i11 Speed Trapez	350 W	603 Wh	M (High)	60 % ≥ 3 years	80 km	25.6 kg	Kalkhoff (2018)
B10	Qwic	Performance RD10 Speed	500 W	735 Wh	M (Low)	2 years[e]	35 km	30.9 kg	Qwic (2018)
B11	Klever	X-Speed	600 W	570 Wh	L (Low)	700 cycles	45 km	28 kg	Klever (2019)
B12	Stromer	ST1x	800 W	814 Wh	L (Low)	75 % ≥ 2 years	50 km	27.4 kg	Stromer (2019a)
B13	Stromer	ST2	800 W	983 Wh	L (High)	75 % ≥ 2 years	60 km	26.6 kg	Stromer (2019b)
B14	Stromer	ST2	800 W	814 Wh	L (High)	75 % ≥ 2 years	50 km	26.5 kg	Stromer (2019b)
B15	Stromer	ST2	800 W	814 Wh	L (Low)	75 % ≥ 2 years	50 km	26.5 kg	Stromer (2019b)

[a]Motor P_{nom} is "30 min continuous rated power", i.e. 30 min average rated power, as set out in UNECE regulation No 85 and referenced in European Commission (2014). By contrast, motor peak power (which can affect maximum speeds) is not explicitly regulated.
[b]Low, high instep: model typically for women, men respectively. Size: S = small, M = medium, L = large.
[c]At maximum support; worst-case value selected per manufacturer.
[d]Measured by the researchers. This includes battery and lock(s), excludes additional accessories.
[e]No information on degradation or criteria, or not covered. The 2-year warranty applies within Europe due to the consumer goods directive (European Commission, 1999).

2.4. Data treatment for analysis

The GPS trace files (GPX format) obtained from Runkeeper were provided by 365SNEL participants to the researchers via email or online storage service links. A total of 2022 rides were provided by the participants for analysis, while the expectation was to have at least 3000 rides.[2] On the other hand, as discussed below, many participants actively logged non-commuting rides, some of which were work-related (but not commuting between home and office), while most of the non-commuting trips were for leisure activities. The data was checked for consistency and quality using various tools, chief among these are python (Van Rossum and Drake, 2009) and pandas (McKinney, 2010). The GPX files were converted to pandas-compatible dataframes based on the gpxpy (Krajina, 2019) module.

The GPX files obtained from Runkeeper do not contain a distance or speed, therefore the distance between points is calculated using the python package vincenty (Pietrzak, 2016) which implements Vincenty's great circle distance calculation algorithm (Vincenty, 1975). The speed is then calculated as distance divided by the time taken between GPS points. An average time resampling of the raw data was done using a five-second median of valid data points, from which the speed is calculated. Compared to using an average value, the median is more robust to outliers. Attempts were made to improve the geospatial accuracy at all times (i.e. ensure that measured points were on roads and paths) of the measured data using the map-matching approach suggested by Schuessler and Axhausen (2009), yet the results were unsatisfactory, as no additional reference or "ground-truthing" measurement was available.[3]

2 100 participants, 15 working days, 2 commuting rides per day.

3 Map-matching typically works well in matching a GPS point to a road feature. Ensuring that the "mapped" speed is correct is a challenge, when reference or calibration data (such as a vehicle's speed reading) measured at the same time is absent.

The resampled data was subsequently cleaned using a filter employed to remove remaining erroneous data points (speed of <0 km/h or >50 km/h). If more than 4 % of data points in one ride were erroneous, the full ride was excluded from further consideration.[4] While the focus of the 365SNEL project was on evaluating speed pedelecs for commuting purposes, users could and did use the speed pedelecs for recreational and non-commuting applications such as client visits, as will be seen further.

The consequence of employing the 50 km/h upper limit for data filtering is that this automatically becomes the maximum speed for all speed pedelecs. This is more than 10 % than the legal limit of 45 km/h, and given the generally flat profile of Flanders and thus the absence of long descents to achieve higher speeds, 50 km/h is an effective maximum limit for filtering. Moreover, as the speed pedelecs were provided to the users on loan for the testing period, the potential for tampering was low.

To then determine the realistic maximum speed that was achieved, the 95th percentile of speeds (i.e. where all rides are appended and sorted by speed, and the 95th percentile speed is taken) was selected. This is consistent with engineering and financial practice, where exceedance probability values (PXX, where XX stands for the percentile) indicate the value at which 100 % - XX% of data will be higher. Statistical analyses were done in R using the stats package and python using pandas, numpy and sci-kit learn packages.

2.5. Identification of commuting rides

A commuting ride is defined as a ride in which the speed pedelec user departs from the home or office and arrives at the office or home respectively (Vandenbulcke et al., 2009; Cass and Faulconbridge, 2016), as identified by the start and end GPS coordinates. This excludes recreational and other work-related trips, such as visiting clients. Determining the home and office locations from the GPS data was done as follows:

1. The office location(s) are common, with at least one person visiting this location, whereas the home location is unique to an individual. However, companies may have more than one office, or bicycle storage shed. Thus, the office coordinates (latitude and longitude) were obtained as the mode of all departure and arrival latitude–longitude pairs. The locations of the offices and homes were subsequently visually verified by plotting these on interactive maps using the leaflet package.
2. For each participant, the most or second-most visited location is the home (the other being the office(s)). The mode of latitude–longitude pairs for each individual was calculated, and the office location was then excluded, leaving the remaining most-frequent location to be the home.

As the visual exploration of the data showed that some participants started or ended their GPS tracking belatedly, a tolerance radius of 0.3 km around the home and office coordinates was used to classify trips as being for commuting purposes, or not. A few participants started a limited number of their trip GPS logging up to 3 km from their starting point, likely indicating that they had departed without logging and remembered to do so on the way. The tolerance radius of 0.3 km thus excludes some genuine commuting trips (albeit poorly captured), this is estimated to be fewer than ten trips in the full dataset of 1786 valid trips.

[4] This level allowed a few more rides to be kept for further analysis, compared to the more stringent 1 % erroneous data limit. Rides with large amounts of erroneous data points typically had a multitude of data issues, such as impossible position jumps of multiple kilometres and/or no recorded data for hours.

Table 4
Summary of all analysed GPS trips.

Trip statistics	Valid data[a]	Commute	Leisure
All trips	1786	1413	373
Total distance (km)	35 015	29 353	5663
Mean distance (km)	19.6	20.8	15.2
Mean speed (km/h)	31.0	31.2	30.2
Mean cruising speed (km/h)	36.7	36.6	37.0
Mean P95 speed (km/h)	40.2	40.1	40.5
Mean moving time (min : s)	37:55	39:54	30:11
Mean duration[b] (min : s)	42:43	44:47	34:56

[a] 2022 GPS files received, of which 236 trips (11.7 %) had too many erroneous values (≥4 % of all data points in one trip) and were excluded from further analysis. These erroneous files were mainly from older smartphones (primarily 365SNEL-supplied smartphones).
[b] Door-to-door, as measured by GPS recording start and stop.

3. Results and discussion

3.1. Summary data

The high-level summary of the data analysed is provided in Table 4. Fig. 1 illustrates the speeds of the 365SNEL participants, and their geographic distribution over Flanders.

For all participants in the 365SNEL project, the average P95 speed is 40 km/h, i.e. a full 5 km/h below the rated or advertised maximum speed for speed pedelecs. When looking at the mean cruising speed, this is even lower at 36.7 km/h. Both of these values indicate that the perception of “a speed pedelec is a 45 km/h vehicle” needs to be adjusted downwards. The data from this work confirms the conclusions from the pre- and post-testing focus groups in 365SNEL, where participants mentioned the expectation of being able to move at 45 km/h prior to starting their testing period with the speed pedelecs, and their subsequent disappointment when they could not do so continuously (Van den Steen et al., 2019b).

While commuting travel times are inherently related to the distance travelled, the mean commuting trip duration within 365SNEL of 45 min is higher than the mean commuting time using other transport modes in Flanders in 2019 at 30 min ± 11.5 min, for distances 15 km to 25 km (Janssens et al., 2020b). However, the time travel variability (TTV) for the speed pedelec users reported in the present paper is much lower at 7.2 s/min for each min extra travelled, compared to the 19 s/min for cars as observed by Durán-Hormazábal and Tirachini (2016). This means that, compared to travelling an extra minute (i.e. travelling farther) by car, a speed pedelec user will have greater predictability of travel time estimation. To an extent, this stands to reason, as speed pedelecs are not as impacted by traffic jams as cars. This increased travel time predictability for speed pedelecs versus the previous mode of transport for commuting was identified as a great advantage by 365SNEL participants (Van den Steen et al., 2019b).

Even though the health effects for speed pedelec users have not yet been discussed in literature, normal pedelec users do see health benefits (Bourne et al., 2018). Speed pedelec commuters can thus meet World Health Organisation recommendations (World Health Organisation, 2020; Haskell et al., 2007) for at least 150 weekly activity minutes of medium to vigorous activity, from a total distance 77.5 km/week assuming an average speed of 31 km/h. Assuming five days per week of speed pedelec commuting for full-time employees, this implies that all commuting distances above 7.5 km can confer significant health benefits for this mode of active travel, particularly in light of the Coronavirus-19 pandemic (Jesus et al., 2021).

3.2. Speed values per speed pedelec

Based on the resulting values obtained for each speed pedelec, Fig. 2 shows the overall median and P95 (95th percentile) speeds for each

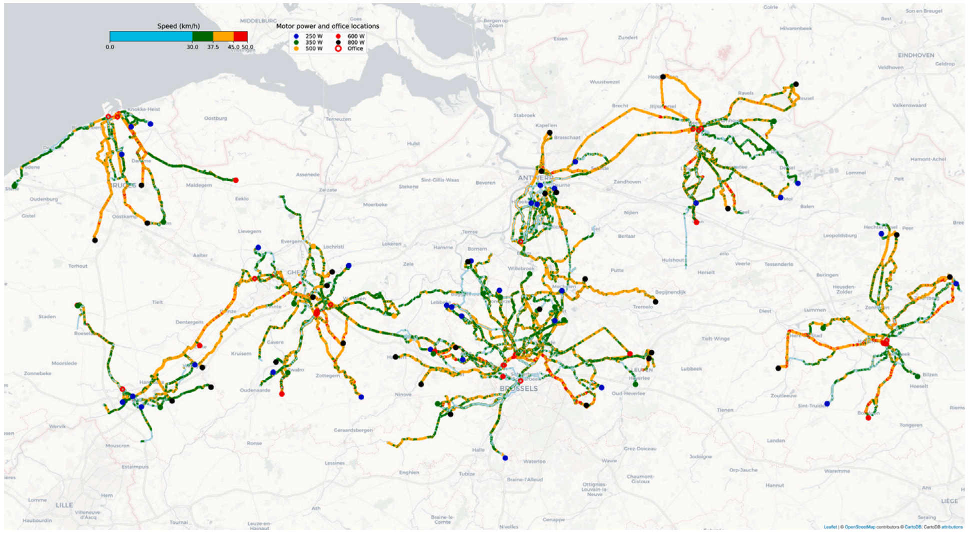

Fig. 1. Map of rides done by 365SNEL participants, colour-coded by speed category and speed pedelec motor power. Note that cyclist speeds are lower in city centres, except when using main thoroughfares. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

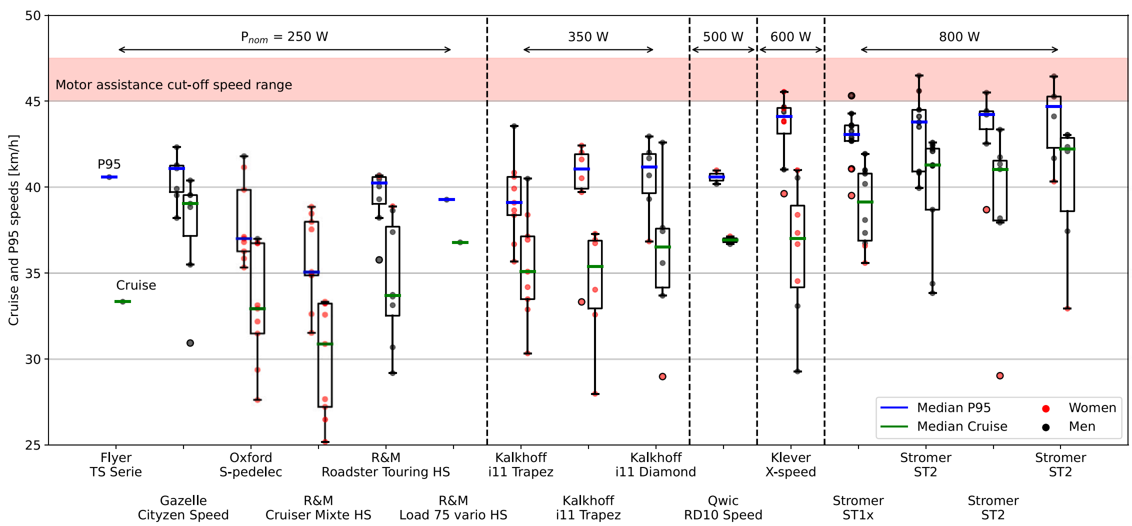

Fig. 2. Resulting overall P95 (i.e. realistic top speed) and cruising speed boxplots for each bicycle used. The box contains the interquartile data (P25 to P75), while the whiskers extend 1.5 times the interquartile range (outliers are points beyond this range). The median value in each boxplot is indicated by a blue (P95) or green (cruising speed) line. The colour of the overlaid dots indicates the gender of the cyclist that achieved those speed values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

speed pedelec as used throughout the 365SNEL project, for commuting purposes.

All speed pedelecs save two (B04 and B06) saw at least some of their users achieve a realistic top speed above 40 km/h. Speed pedelecs with a motor rated at ≤350 W consistently achieved a lower maximum speed than the speed pedelecs with a higher-rated motor. A two-tailed non-parametric Mann–Whitney-U test confirms this (U_{P95} = 2113.5, p = 1.737×10^{-11} < 0.001 with $n_{>350W}$ = 42 and $n_{\leq 350W}$ = 56). Of more interest is the distance between the P95 and P50 speed, and the change in spread of these. Here, it is noteworthy that the median (P50) speed of the higher-power motor speed pedelecs (B11-B15) is closer to their P95 speed. The spread between the P95 and P50 speeds among the ≤350 W-rated speed pedelecs is much more diverse. This implies that:

- Speed pedelecs with lower motor power (≤350 W) see a larger impact of user preferences and physique on the resulting speeds. While maximum speeds above 40 km/h could be achieved, median speeds were in the range of 30 km/h to 35 km/h, i.e. easily 5 km/h slower than speed pedelecs with higher rated motor power. A statistical significant difference is confirmed by a Mann–Whitney-U test (U_{median} = 1973.5, p = 1.056×10^{-8} < 0.001). This points to the high sensitivity of these speed pedelecs to environmental factors (especially wind speed), in line with claims in Rotthier et al. (2017b).
- Higher motor power (≥600 W) typically results in consistently higher speeds achieved by cyclists, as seen by the smaller spread between the peak (P95) and median (P50) speeds. Median speeds were predominantly in the range of 35 km/h to 42 km/h.

Based on focus groups conducted at the start and end of the 365SNEL test periods (Van den Steen et al., 2019b), the main reason given for this difference is the combination of physique and comfort: achieving a consistently higher speed with a ≤500 W speed pedelec required (much) more effort from the cyclist, to the extent that users accepted the lower speed versus the mental goal of 45 km/h and prised other aspects such as the physical effort and freedom as part of their personal mobility.

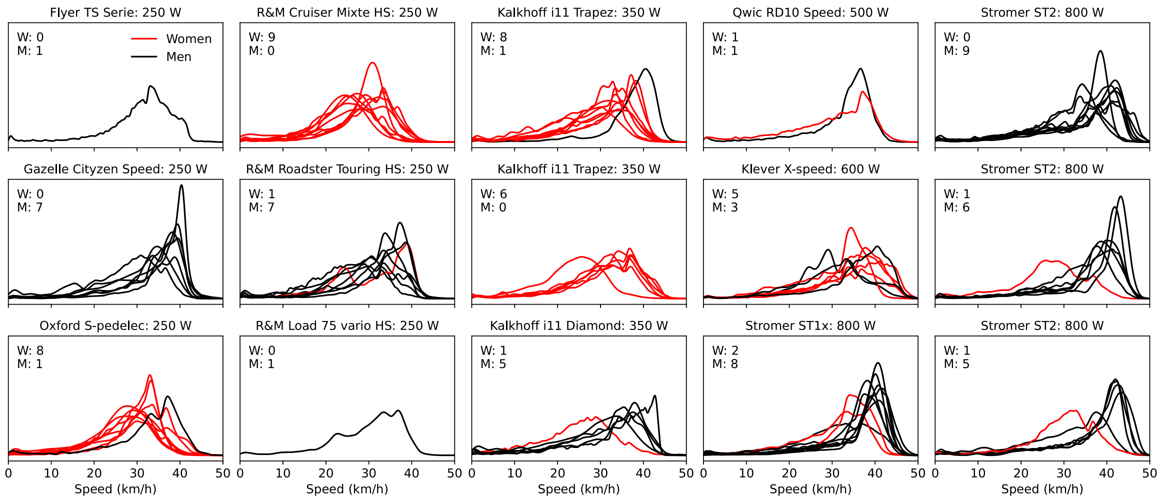

Fig. 3. Distribution of kernel density estimates of speeds for each of the 15 speed pedelecs; each line is the overall speed distribution per person. Number of users with valid data by gender is indicated within each box (W=women, M=men). Most speed pedelec models were used primarily by one gender, as discussed in Section 2.1. These show that not only the speed pedelec or gender plays a role, but that there is also a wide variation as to how people used these.

3.3. Speed distributions among speed pedelec users and speed pedelecs

Fig. 3 shows that the participants exhibit different speed behaviours, even when using the same speed pedelec.

Evaluation of the data did not provide conclusive evidence of speed pedelec users increasing their speed over time (i.e. becoming acclimatized to the speed pedelec). This may point to the testing period being too short to observe these effects, or more likely, that the participants did not have much difficulty adjusting to a speed pedelec from a bicycle or EPAC. This conclusion is applicable to Flanders and may not necessarily translate as well to other regions, given the prior cycling experience of participants, in line with the high incidence of bicycle ownership in Flanders (Fietsberaad, 2019).

From Fig. 3, there are multiple factors that can be identified which may account for these differences among participants and speed pedelec brands and models:

- **Speed pedelec brand and/or model**: higher-powered (≥600 W) speed pedelecs typically see higher peak and cruising speeds than <600 W speed pedelecs. Some models which were designed for a more relaxed (instead of sporty) seating position see slower speeds within the same motor power range, with each model appearing to have a type of speed profile associated with it.
- **Gender**: generally, a significant difference between the speed of men and women can be observed. This is confirmed by Mann–Whitney-U tests for both P50 (median) speeds ($U_{median} = 388$, $n_{male} = 55$, $n_{female} = 43$, $median_{male} = 35.33$ km/h, $median_{female} = 30.2$ km/h, $p = 1.3 \times 10^{-8} < 0.001$) and P95 speeds ($U_{P95} = 437$, $median_{male} = 42.3$ km/h, $median_{female} = 38.75$ km/h, $p = 9.63 \times 10^{-8} < 0.001$). Most men were assigned larger, sportier types of speed pedelec with higher motor power than women, and were thus enabled to cycle faster. Most (but not all) men cycled at higher speeds when using the same speed pedelec as women, which can generally be attributed to their higher mass and absolute power they can generate, which is amplified by the speed pedelec motor. This also points to the speed pedelec assignment and possible selection bias.
- **Fitness and competitiveness**: some participants competed against each other or friends and spouses in their commutes to and from home, as identified in Van den Steen et al. (2019b). This can be seen in Fig. 3 by comparing among the men who used the Oxford S-pedelec and Kalkhoff i11 Trapez, and similarly between the women who used the Riese & Müller Roadster Touring HS and the Qwic RD10 Speed.

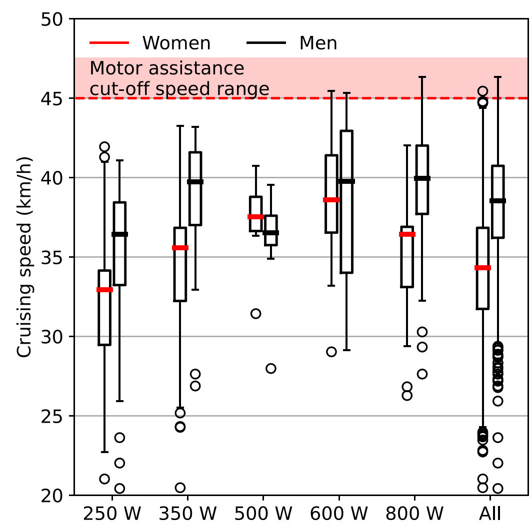

Fig. 4. Commuting cruising speed boxplots per gender and motor assistance power.

- **Personal speed preference**: most men have a higher, thinner peak at a certain speed where they spent most of their time, compared to women, who appear to show broader speed profiles and thus exhibit more variance in their observed speeds.

Fig. 4 summarises the commuting cruising speeds obtained for all participants. Men achieved consistently higher cruising speeds than women ($MWU_{cruise} = 426.5$, $n_{male} = 55$, $n_{female} = 43$, $median_{male} = 38.21$ km/h, $median_{female} = 33.51$ km/h, $p = 6.33 \times 10^{-8} < 0.001$), except for the 500 W category where only one man and one woman cycled.

What Figs. 3 and 4 also clearly illustrate is that women who are unable to consistently generate as much power on the pedals as men are disadvantaged by the European Commission's Regulation 168/2013 (European Commission, 2014) which specifies that the Maximum Auxiliary/Assistance Factor (MAF) must be limited to four times the pedal measured power.

3.4. Exploratory behaviour: commuting versus non-commuting trips

At 20.9 % of all trips, and 74 of the 98 participants with valid data (see Table 2), a sizeable percentage of trips recorded by 365SNEL

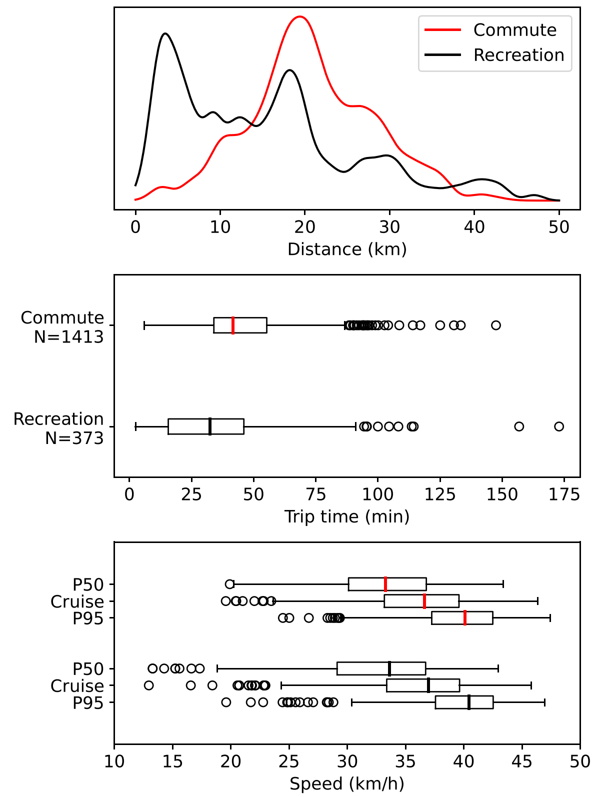

Fig. 5. Comparison of commuting versus recreational trips.

participants were not for commuting between the home and office. Whereas the distance between the home and office (and with it, reasonable possible routes) for commuting is fixed, the non-commuting trips show the behaviour of the user when given free choice of destination and time of day for travel. Fig. 5 illustrates this additional freedom for recreational purposes, with travel distance peaks at 4 km and 18 km and "goal-oriented" (a predefined destination, such as visiting a friend, shop or gym), or longer for "touring" or exploration, with a limited number of trips longer than 40 km. By contrast, the distribution of commuting distances peaks around the mean distance of 20 km, reflecting the effects of participant selection by the researchers.

The middle pane of Fig. 5 reflects this difference in travel purpose between commuting and recreation, with the bulk of travel times for recreation around the median value of 32.5 min, whereas the commuting median trip time is 41.6 min. Interestingly, the speed KPIs (median or P50 speed, cruising speed and P95 speed) for commuting and recreation are nearly identical, showing that the users ended up having a preferred speed, regardless of travel purpose. This has a number of policy implications, as it means that speed pedelecs can be characterised by their speed metrics regardless of their travel mode. Consequently, the position on the road or cycle path will have different safety implications, and decisions by policymakers can encourage or discourage the uptake of speed pedelecs for commuting travel.

3.5. Study limitations

The limitations of this study stem primarily from the following points:

- The project progression and how this informed speed pedelec assignment to participants affects sample sizes for subsequent analyses and their respective statistical power. For example, as some speed pedelecs became available at a late stage of the project, their use by multiple cyclists is limited, with three out of the twelve speed pedelec models (B01, B06 and B10) having just one or two users.
- Similarly, the statistics analysed within this work were defined and informed by the data a posteriori, instead of being done so before the study and participants were selected. This among others affected the resulting sample sizes for statistical analyses.
- The use of (primarily) participant smartphones for GPS tracking, instead of using (custom) Data Acquisition Systems with GPS which automatically record trips once movement is detected, affected when trips were recorded, and the accuracy of the data points in space and time is lower than with higher-precision GPS chips in use, which would provide increased repeatability across the full dataset.
  At least 10 trips were excluded from data analysis where the user started recording after having left the home or office, as this would have affected trip times, distances and other summary statistics. (Such analyses were visually confirmed in zoomed-in images similar to Fig. 1, where the participant started recording on the commuting trajectory, yet beyond the distance filter set to identify the home or office.)
  While some participants diligently recorded all trips (commuting and recreation), others did not. As such, these participants are over-represented in the recreation dataset.
- The study was performed in Flanders, which has generally a well-developed cycling infrastructure and culture. While the study aimed to select participants with limited experience using pedelecs and speed pedelecs, a few did have prior experience.

4. Conclusions

The initial speed pedelec usage by 365SNEL participants indicates that their speed characteristics differed little for commuting and leisure activities. The policy implications of this are that speed pedelecs can be characterised by their speed metrics, regardless of their travel purpose (commuting or leisure). As such, policymakers can actively encourage or discourage speed pedelec traffic along certain routes, with commensurate implications ranging from enabling active travel (or not), to prioritising infrastructure investments and legislation changes if speed pedelecs are to safely coexist on roads and cycle paths.

As discussed in this work, the following key performance indicators for speed pedelecs should be interpreted for the following purposes:

- **Average speed:** this is a measure for door-to-door travel, but is a poor indicator for speed-related risks, as it fails to capture either free-flow speed or realistic maximum speeds. Nevertheless, the observed average speeds for all participants (31.0 km/h) in this work are in line with previously published studies.
- **Cruising speed:** this indicates the speed at which speed pedelecs can be encountered in traffic, as it is the speed at which the largest distance is travelled, and serve as a proxy for risk (time or distance travelled at a certain speed) and consequence (speed in event of an accident). The mean cruising speed for all 365SNEL participants are significantly higher than the average speed, reaching 36.7 km/h.
- **P95 speed:** this is a realistic estimate for the maximum speed that can be observed for speed pedelec users. It avoids outliers in data, yet meaningfully captures the likely maximum speed at which speed pedelecs travel. In this work, the mean commuting P95 speed for all participants is 40.1 km/h, which is 5 km/h below the perception of speed pedelecs being 45 km/h vehicles.

There is as large a diversity among speed pedelec users for commuting purposes as there are individuals, as each user interacts with the selected speed pedelec, has their personal route between home and office, and is impacted differently by the environment, the infrastructure and applicable speed limits. Nevertheless, over the selected sample, noteworthy trends have been observed.

The full picture of speed pedelec users only appears when comparing and contrasting along multiple dimensions, as seen in variations among users for a single speed pedelec (inclusive of gender), and variance due to model and power. In general terms, speed pedelecs as vehicles permit reaching speeds of 45 km/h, if (a) the user has sufficient (leg) power, (b) the speed pedelec can provide sufficient motor assistance, (c) that the local infrastructure and traffic conditions allow these top speeds to be reached and (d) that the user wants to reach this speed. As seen within the 365SNEL project, the higher-powered brands and/or sportier models enable higher cruising and median speeds than the lower-powered models (<600 W motors).

This work showed that women, and participants assigned lower-powered speed pedelecs fail to consistently achieve speeds above 40 km/h. Overall, women have a 5 km/h cruising speed deficit compared to men. Taking into consideration the observed sensitivity of speed pedelecs to environmental variables, it may be an avenue worthy of exploration to identify whether Maximum Assistance Factor values higher than four can be allowed within the European Commission's regulation for speed pedelecs, by instead opting for a design speed for motor assistance levels. This would facilitate communication and testing of speed pedelecs, as the motor assistance level names can change from otherwise unclear names such as "assistance level 3" and "turbo" to "35 km/h" and "45 km/h".

This recommendation is then also in line with the findings of the present work where speed characteristics according to travel purpose (work or leisure) appear identical. As such, policymakers can decide where, and what type, of changes to infrastructure should be done to encourage higher speed active travel with speed pedelecs, and conversely, to designate other routes for slower speed mobility. As such, speed differential conflicts could be reduced, while further supporting active travel with its physical and mental health benefits.

CRediT authorship contribution statement

Bert Herteleer: Methodology, Data analysis – descriptive statistics, Data curation, Writing – original draft, Visualisation. **Nikolaas Van den Steen:** Investigation, Methodology, Data analysis –statistics, Data curation, Writing – original draft. **Lieselot Vanhaverbeke:** Conceptualisation, Project administration, Resources, Funding acquisition, Writing – review & editing. **Jan Cappelle:** Conceptualisation, Project administration, Resources, Funding acquisition, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bert Herteleer reports a relationship with Body Rocket that includes: equity or stocks.

Acknowledgements

The project 365SNEL was funded by the Flemish Government's Department of Environment. The authors wish to thank Bram Rotthier for his contribution to the conception of the 365SNEL project and Annick Roetinck for her insightful contributions. The user group of the 365SNEL project as well as the mobility managers of the participating companies are thanked for their contributions to the project. The following parties provided speed pedelecs for use in the project: o2o provided 7 out of 15 speed pedelecs. The following manufacturers also provided speed pedelecs on loan for the project duration: Stromer, Riese & Muller, Klever, Qwic and Oxford. The bike accessory manufacturers who lent or provided discounts on clothing and bicycle bags were Vaude, Basil and Willex.

Table 5
Accuracy of GPS values as tested at the same time.

RMSE metric	Value
Instantaneous speed	1.33 km/h
P50 summary speed	0.42 km/h
P95 summary speed	0.24 km/h
Total distance[a]	0.7 m/km

[a]An RMSE of 0.7 m/km results in 7 m distance error over 10 km travel distance, or 14 m for 20 km.

Appendix. Accuracy of GPS speeds and distances using smartphones

To estimate the accuracy of calculated speeds and distances as discussed in this article, seven calibration runs on a speed pedelec were performed on a defined route with km markers. Of these, two return trips (4 km and 12.95 km) were identical. Six GPS devices (four smartphones from different manufacturers using Runkeeper, a Garmin 235 GPS running watch and a Garmin 510 Edge GPS cycling computer) logged the same route at the same time. This addresses the issue that the measurements captured by 365SNEL participants were done without a comparator or "ground-truthing" device. The GPX data files were processed as described in Section 2. The resulting speed error metrics expressed as root mean squared error (RMSE) are summarised in Table 5. By contrast, Twisk et al. (2021) gives 0.1 m/s (0.36 km/h) for instantaneous data,[5] using a custom data acquisition system. The very low distance error over the cycled routes compared to the speed metrics in this work suggests that the speed uncertainty issue is primarily due to the combined uncertainty of positional error and timestamp recording by the instrument (hardware and software), whereas distance errors cancel out over the route.

Based on this, instantaneous data for individual rides can show significant deviations, yet the uncertainty on summary statistics is significantly lower (<0.5 km/h). For example, the mean P95 speed for all 365SNEL participants as shown in Table 4 can then be read as (40.2 ± 0.3) km/h.

References

Belgian Government, 2019. Koninklijk besluit houdende algemeen reglement op de politie van het wegverkeer [en van het gebruik van de openbare weg] (WEGCODE) (Royal Decree on general regulations for the police of road traffic [and of the use of public roads]). Belgisch Staatsblad http://www.ejustice.just.fgov.be/eli/besluit/1975/12/01/1975120109/justel.

Bourne, J.E., Sauchelli, S., Perry, R., Page, A., Leary, S., England, C., Cooper, A.R., 2018. Health benefits of electrically-assisted cycling: a systematic review, 15 116 http://dx.doi.org/10.1186/s12966-018-0751-8.

Breen, R.L., 2006. A practical guide to focus-group research. J. Geogr. Higher Edu. 30 (3), 463–475. http://dx.doi.org/10.1080/03098260600927575.

de Bruijne, R., v.d. Lindeloof, M., 2016. Revolutie of risico? URL https://www.fietsberaad.nl/CROWFietsberaad/media/Kennis/Bestanden/Speed_pedelec_onderzoek.pdf?ext=.pdf.

Cass, N., Faulconbridge, J., 2016. Commuting practices: New insights into modal shift from theories of social practice. Transp. Policy 45, 1–14. http://dx.doi.org/10.1016/j.tranpol.2015.08.002.

CONEBI - Confederation of the European Bicycle Industry, 2018. European bicycle market. http://www.conebi.eu/wp-content/uploads/2018/09/European-Bicyle-Industry-and-Market-Profile-2017-with-2016-data-update-September-2018.pdf.

Durán-Hormazábal, E., Tirachini, A., 2016. Estimation of travel time variability for cars, buses, metro and door-to-door public transport trips in santiago, Chile. Res. Transp. Econ. 59, 26–39. http://dx.doi.org/10.1016/j.retrec.2016.06.002.

European Commission, 1999. Directive 1999/44/EC of the European parliament and of the council of 25 May 1999 on certain aspects of the sale of consumer goods and associated guarantees. OJ L 171, 12–16.

European Commission, 2014. Commission Delegated Regulation (EU) no 3/2014 of 24 October 2013 supplementing Regulation (EU) no 168/2013 of the European Parliament and of the Council with regard to vehicle functional safety requirements for the approval of two- or three-wheel vehicles and quadricycles. Text with EEA relevance. OJ L 7, 1–12.

[5] It is unclear whether this is RMSE or raw data.

European Commission and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Guy, I., 2019. Study on the assistance factor (ratio of auxiliary propulsion power and actual pedal power) for cycles designed to pedal of vehicle sub-category l1e-b. Publications Office, http://dx.doi.org/10.2873/085443.

Federale Overheidsdienst Financiën, 2021. Fietsvergoeding. URL https://financien.belgium.be/nl/particulieren/vervoer/aftrek_vervoersonkosten/woon-werkverkeer/fiets.

Fietsberaad, 2019. Fiets DNA. https://fietsberaad.be/wp-content/uploads/FietsDNA_2018_A5_lwr.pdf.

Flyer, 2019. Flyer B serie, TS serie, Tx serie. https://media.flyer-bikes.com/web/18a987c457a5a30/flyer-bedienungsanleitung---flyer-instructions/?mediaId=D7884C93-5CD9-471E-9A872B3E9C74C68D#.

Gazelle, 2019. Cityzen speed 380. https://www.gazellebikes.com/nl-be/cityzen-speed-380-v2.

Gross, E., Lund, J., Petershagen, C., Schröder, A., Power measurement and road load data acquisition for Speed EPACs URL https://circabc.europa.eu/sd/a/e34b42a6-09b4-46e0-bc6e-32ee3aeaceb5/03.c.2.%20TUHH%20Research%20Final%20Report%20Cycles%20designed%20to%20pedal%20-%20Vehicle%20structure%20integrity.pdf.

Guy, I., Appleby, J., Ball, P., But, B., Chowdhury, S., Jenkins, D., Kent, J., Obazele, I., Radcliffe, J., Sharp, R., Wardle, A., 2021. New PMD and L-Cat vehicles: market development and road safety risks. European Commission, URL https://trl.co.uk/uploads/trl/documents/ET0221146ENN.en.pdf.

Haskell, W.L., Lee, I.-M., Pate, R.R., Powell, K.E., Blair, S.N., Franklin, B.A., Macera, C.A., Heath, G.W., Thompson, P.D., Bauman, A., 2007. Updated Recommendation for Adults from the American College of Sports Medicine and the American Heart Association, 39 1423–1434 http://dx.doi.org/10.1249/mss.0b013e3180616b27.

Janssens, D., Paul, R., Wets, G., 2020a. Onderzoek verplaatsingsgedrag vlaanderen 5.5 (2019–2020) analyserapport. URL https://assets.vlaanderen.be/image/upload/v1608199124/Analyserapport_OVG_5.5_def2_mkh0go.pdf.

Janssens, D., Paul, R., Wets, G., 2020b. Onderzoek verplaatsingsgedrag vlaanderen 5.5 (2019–2020) tabellenrapport. URL https://assets.vlaanderen.be/image/upload/v1606421215/OVG_5.5_-_Tabellenrapport.pdf.

Jesus, I., Vanhee, V., Deramaudt, T.B., Bonay, M., 2021. Promising effects of exercise on the cardiovascular, metabolic and immune system during COVID-19 period. J. Hum. Hypertens. 35 (1), 1–3. http://dx.doi.org/10.1038/s41371-020-00416-0.

Kalkhoff, 2018. Kalkhoff INTEGRALE SPEED i11. https://www.kalkhoff-bikes.com/de_de/kh0010005v2018-kalkhoff-integrale-speed-i11.

Klever, 2019. Klever x speed. https://www.klever-mobility.com/e-bikes/x-range/x-speed.

Krajina, T., 2019. Gpxpy. https://pypi.org/project/gpxpy/.

McKinney, W., 2010. Data structures for statistical computing in python. In: Proceedings of the 9th Python in Science Conference, vol. 445. Austin, TX, pp. 51–56.

Oxford Bikes, 2019. S-pedelec. https://www.oxfordbikes.be/producten/s-pedelec/.

Pietrzak, M., 2016. Vincenty. https://github.com/maurycyp/vincenty.

Qwic, 2018. Qwic. https://qwic.eu/qwic-catalogue-2020/.

Riese & Müller, 2019a. Cruiser mixte HS. https://www.r-m.de/en-en/models/cruiser-mixte/cruiser-mixte-vario-hs/#F00275_0402.

Riese & Müller, 2019b. Roadster touring HS configurator. https://www.r-m.de/en-en/models/roadster/roadster-touring-hs/#F00029_0501.

Riese & Müller, 2020a. Load 75 vario HS. https://www.r-m.de/en-en/models/load-75/load-75-vario-hs/#F00389_020307.

Riese & Müller, 2020b. Warranty. https://www.r-m.de/en-en/service/warranty/.

Rotthier, B., Huyck, B., Dikomitis, L., Motoasca, E., Cappelle, J., 2016. Social benefits and legislative challenges of speed pedelecs. Velo-City Global.

Rotthier, B., Stevens, G., Dikomitis, L., Huyck, B., Motoasca, E., Cappelle, J., 2017a. Typical cruising speed of speed pedelecs and the link with motor power as a result of a belgian naturalistic cycling study. In: 2017 International Cycling Safety Conference.

Rotthier, B., Stevens, G., Huyck, B., Motoasca, E., Cappelle, J., 2017b. The rise of the speed pedelec, restrained by legislation? In: Proceedings of the 30th International Electric Vehicle Symposium and Exhibition.

Runkeeper, 2019. Runkeeper. https://runkeeper.com.

Schleinitz, K., Franke-Bartholdt, L., Petzoldt, T., Schwanitz, S., Gehlert, T., Kühn, M., 2014. Pedelec-Naturalistic Cycling Study URL https://udv.de/sites/default/files/tx_udvpublications/fb_27_pedelec.pdf.

Schleinitz, K., Petzoldt, T., Franke-Bartholdt, L., Krems, J., Gehlert, T., 2017. The german naturalistic cycling study – comparing cycling speed of riders of different e-bikes and conventional bicycles. Saf. Sci. (ISSN: 0925-7535) 92, 290–297. http://dx.doi.org/10.1016/j.ssci.2015.07.027, URL http://www.sciencedirect.com/science/article/pii/S0925753515001976.

Schuessler, N., Axhausen, K.W., 2009. Map-matching of GPS traces on high-resolution navigation networks using the multiple hypothesis technique (MHT). Arbeitsberichte Verkehrsund Raumplanung 568, 1–22.

Statbel, 2022. Registration of motor vehicles URL https://statbel.fgov.be/en/themes/mobility/traffic/registration-motor-vehicles#figures.

Van den Steen, N., Cappelle, J., Vanhaverbeke, L., 2019a. Can speed pedelecs really fulfil the mobility needs of daily commuters? In: 32nd Electric Vehicle Symposium (EVS32).

Van den Steen, N., Herteleer, B., Cappelle, J., Vanhaverbeke, L., 2019b. Motivations and barriers for using speed pedelecs for daily commuting. World Electr. Veh. J. 10 (4), 87. http://dx.doi.org/10.3390/wevj10040087.

Stelling, A., Gent, P.V., Groot, J.D., Twisk, D., Vlakveld, W., 2017. Naturalistic cycling study among Dutch commuter cyclists : comparing speeds on pedelecs, speed-pedelecs and conventional bikes. In: 6th International Conference on Road Safety & Simulation (RSS).

Stelling, A., Vlakveld, W., Twisk, D., 2021. Influencing factors of observed speed and rule compliance of speed-pedelec riders in high volume cycling areas: Implications for safety and legislation. Accid. Anal. Prev. 159, 106239. http://dx.doi.org/10.1016/j.aap.2021.106239.

Stelling-Konczak, A., Groot-Mesken, J.d., Vlakveld, W., Wesseling, S., 2017. Speed-pedelec op de rijbaan URL https://www.swov.nl/en/file/16744/download?token=MwiwC8RT,

Stromer, 2019a. ST1X. https://www.stromerbike.com/sites/default/files/2019-08/myStromer_Tech_Sheet_MY20_Sales_ST1_X_web_EN_1.pdf.

Stromer, 2019b. Stromer ST2. https://stromeruk.com/products/stromer-st2.

Twisk, D., Stelling, A., Van Gent, P., De Groot, J., Vlakveld, W., 2021. Speed characteristics of speed pedelecs, pedelecs and conventional bicycles in naturalistic urban and rural traffic conditions. Accid. Anal. Prev. 150, 105940. http://dx.doi.org/10.1016/j.aap.2020.105940.

Van Rossum, G., Drake, F.L., 2009. Python 3 Reference Manual. CreateSpace, Scotts Valley, CA, ISBN: 1441412697.

Vandenbulcke, G., Thomas, I., de Geus, B., Degraeuwe, B., Torfs, R., Meeusen, R., Panis, L.I., 2009. Mapping bicycle use and the risk of accidents for commuters who cycle to work in Belgium. Transp. Policy 16, 77–87. http://dx.doi.org/10.1016/j.tranpol.2009.03.004.

Vincenty, T., 1975. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. Surv. Rev. 23 (176), 88–93.

World Health Organisation, 2020. Physical activity URL https://www.who.int/news-room/fact-sheets/detail/physical-activity.