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Assessing air quality and physical risks to *E*-scooter riders in urban environments through artificial intelligence and a mixed methods approach

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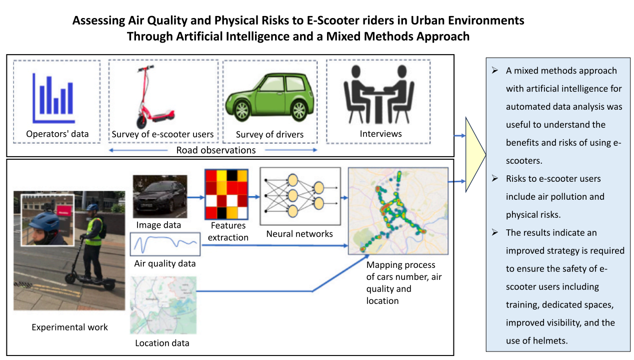
HIGHLIGHTS

- Electric and clean energy transportation technologies are key in future NetZero cities.
- This paper uses a mixed methods approach including Artificial Intelligence to address risks to e-scooter users.
- Risk to e-scooter users include air pollution from fossil-fuel cars and physical risk.
- The results indicate a better strategy is required to ensure the safety of e-scooter users.
- The improved strategy could include training, dedicated spaces, improved visibility, and the use of helmets.

GRAPHICAL ABSTRACT



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ABSTRACT

The need to develop green and smart transport solutions for NetZero cities to reduce carbon emissions through the use of clean energy is driving innovation in cities around the world. A result of this trend is a rise in micro-mobility solutions such as e-scooters in cities around the globe. Nottingham (UK) is one of the cities that conducted an e-scooter pilot scheme permitting the rental of e-scooters to travel around the city in a bid to encourage more sustainable personal transport use. However, to ensure pedestrian safety, e-scooters are required to be ridden on the road network among cars. Hence, giving rise to two potential risks for e-scooter users: the air quality that they breathe and the physical risk of being near cars, whose drivers may be unfamiliar with seeing e-scooters on the road.

This study seeks to explore this interaction using a mixed methods approach to explore the experiences of e-scooter riders in respect to their physical safety and exposure to air pollution. The research makes use of two quantitative surveys an international e-scooter user survey $n = 801$ and a survey of UK car drivers $n = 92$, focussed qualitative e-scooter rider interviews and quantitative in-depth road data collection trials comprising of air quality particulate sensing, video capturing around the rider and GPS tracking. The in-depth road data was analysed using an AI approach utilising the ASPS approach, the automated sensor and signal processing

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approach, implemented for image and signal processing to detect the existence of cars alongside the pollution readings.

The findings show that e-scooter riders are typically aware of physical dangers to their safety from other road users, as well as how their presence among pedestrians can impact on more vulnerable users; however, they were unaware of the prevalence and effects of air pollution on them whilst riding. The study highlights the need for a multifaceted approach to improvements in safety for micro-mobility users, predominately considering suitable infrastructure to sperate them from motor vehicles and pedestrians but also the need to consider the proximity to emission emitting vehicles, developing infrastructure in green spaces to address these air pollution levels.

Nomenclature

Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Network
ASPS	Automated Sensory and Signal Processing Selection System
Chi-square	A statistical test used to determine if there is a significant association between categorical variables.
DfT	UK Department for Transport
DWT	Discrete Wavelet Transform
e-Scooter	Electric Scooter,
FFT	Fast Fourier Transform
GoPro	A high-definition action camera
GPS	Global Positioning System
LogFFT	The logarithmic transformation of the FFT results.
NCC	Nottingham City Council
NetZero cities	Cities with urban areas that balance greenhouse gas emissions with an equivalent amount of carbon removal, achieving net-zero emissions to combat climate change.
NTU	Nottingham Trent University
NVivo	Qualitative data analysis software
PM 10	Particulate matter that is 10 μm or smaller in diameter.
PM 2.5	Particulate matter that is 2.5 μm or smaller in diameter:
SCFs	Sensitive Sensory Characteristic Features

1. Introduction

The drive for cities to utilise clean energy in a journey towards NetZero has numerous benefits, both in respect to the environment and human health, through enhanced air quality in urban environments. Air pollution is a significant life-threatening issue in numerous countries worldwide, posing risks to public health and the environment [1]. International regulations have seen a net decrease in emissions and associated pollutants; however, the traffic sector still has a significant impact on air pollution [2] [3] [4]. In addition to tailpipe emissions from road vehicle through the exhaust, brake dust, tyre particulates and fuel evaporation cause the emission of additional air pollutants [5].

The World Health Organization (WHO) identifies road transport as a significant source of harmful air pollution, along with other transport, power generation, heating systems, industry, and agriculture/waste incineration [6]. Over the past few years, there has been a worldwide demand for the use of electric scooters as micro-mobility devices. Electric scooters offer solutions to a wide range of transport policy goals such as reducing air and noise pollution. Since their introduction in 2017, the US, countries in Europe and large metropolitan cities in New Zealand and Singapore have seen widespread use of electric scooters, benefitting the environment, public transport systems [7] as well as the consumer through increased affordability. Electric scooters (e-scooters) are a new transportation option which offer a disruptive change to travel systems in urban environments. In march 2019, the UK government identified new strategies for greenhouse gas emission saving and transport innovation [8], permitting a pilot scheme allowing the rental of e-scooters in 32 British regions from July 2020 [9]. Under existing legislation privately owned scooters in the UK remain illegal for use on public roads, cycle lanes and pavements, being legally permitted for use on privately owned land only in the UK [10] due to uncertainty over their nature and considerations surrounding insurance. Within the permitted pilot schemes e-scooter riders must be at least 18 years old and hold a driving license, whilst helmets are recommended but not legally required. *E*-scooters riders who violate these rules face the prospect of a £300 fixed penalty notice and six points on their driving license if stopped by the police, with their e-scooter potentially impounded.

However, regulations governing the use of e-scooters vary between countries as shown in Table 1:

Previous research shows that around 65% of current and former e-scooter users in the US considered an e-scooter as a convenient device to ride, reporting feeling 'somewhat' or 'very' safe while riding this device [12]. However, the same study also revealed that the younger generation considered using e-scooters impractical for long distances and difficult to use in hot weather conditions. Further research carried out by Department for Transport [10] investigated the public awareness of e-scooters use in the UK. The results showed that around 50% of respondents had some degree of knowledge on how to use e-scooters and this was higher among males, younger participants, those living in urban areas and from higher social grades. The findings also revealed that the usage of e-scooters was relatively low in the UK with only 7% of participants stating that they had ever used e-scooters [10]. This is expected because they privately owned scooters are illegal for public use.

Cities face growing challenges in managing road sharing between encouraging more sustainable forms of transportation such as e-scooters and active travel alongside traditional motor vehicles, as highlighted in Fig. 1. In addition, the authors have observed many issues with current behaviour of e-scooter users such as the lack of safety helmets, wearing dark clothes, using headphones (Fig. 1-b), and carrying unbalanced load (Fig. 1-b) that place them at greater risk.

There has been a growth in the popularity of e-scooters, but the current research on the safety of electric scooters and effects of air pollution is limited. With most e-scooter studies neglecting consideration of the impact on the environment and health in terms of air pollution exposure [13]. There is also a lack experimental studies that consider individual perspectives from users' and non-users on the benefits and barriers of using e-scooters in comparison to other transport modes. Existing research has found that e-scooters use can be associated with an increased risk of physical injury from cars [14,15] and that parked cars in particular pose hazards for e-scooter users [16]. However, despite these concerns, there is limited research on how drivers perceive or respond to e-scooters on the roads. Furthermore, there is a need for a deeper comprehension of e-scooter safety and their potential roles in advancing zero-carbon initiatives. This paper aims to address such gaps by collecting information on the use and perceptions of e-scooter riders, including the road safety and air quality impacts for vulnerable road users (e-scooter users, cyclists, and pedestrians) during their commutes in urban centres across the UK, EU, USA, and Canada. Additionally, the study aims to explore the perceptions of safety regarding electric scooters among drivers in the UK.

A number of UK studies have considered e-scooter use and its safety impact in different regions [17–19], *E*-scooter crash frequencies were found to be the highest in central London, particularly in the City of London and Westminster, whilst areas that have higher incidents of walking and cycling activities and a higher number of schools are also associated with higher crash frequencies, while areas with greater greenspaces see fewer e-scooter related incidents [19]. Then most common injuries from e-scooter accidents UK were orthopaedic injuries involving the upper (36%,) or lower extremities (33%), followed by facial/head injuries (22%). Injuries to the axial skeleton and torso were much less common: abdominal, back/spine, and thorax (3%) and isolated eye injuries accounted for 2% [17]. Another UK study found that shared e-scooter use across 15 UK cities and towns resulted in positive well-being impacts (higher odds ratio) among users with protected characteristics, such as those from an ethnic minority, those who have lower educational outcomes, mobility issues or those who do not own a car [18].

Although e-scooters are widely used in Nottingham, this city has not been the subject of UK studies so far. The subject of the air pollution and e-scooter user trials in this study, Nottingham City Council (NCC) ran an e-scooter pilot from 2020 to 2023. It was recognised that there was a need to evaluate this trial and a team from Nottingham Trent University (NTU) was selected to conduct the evaluation. This evaluation trial ran from November 2021 to Oct 2022 with the NTU team following the DfT guidelines for e-scooter trial evaluation schemes. The evaluation was conducted through mixed research methods including two survey questionnaires (users and non-users), focus groups of users and, separately, non-users, interviews of users and analysis of the e-scooter data made available by the e-scooter operators Wind and then Superpedestrian's usage data for analysis.

Introduced at the start of the pandemic, the e-scooter trial in Nottingham saw very strong uptake among users as shown in Fig. 2, which illustrates the daily progression of ride numbers from the obtained e-scooter data. Showing a steep increase in the number of scooter rides over a year. Rides surged from 0 to nearly 2000 per day in the first half of the first month, eventually peaking at above 5000 rides by the end of the trial period, with the daily average number of rides during the study period was 2610 rides per day.

The data collection from the e-scooter evaluation resulted in data for 908,234 journeys for the period November 2020 to October 2021. This paper builds upon these earlier evaluations study to explore additional safety factors and user preferences in respect to the use of e-scooters.

2. Methodology

This research study implements a mixed methods approach, incorporating several studies, as shown graphically in Fig. 3. This implemented mixed methods research combines qualitative and quantitative approaches to provide a comprehensive understanding. It enhances the validity of findings through triangulation and integration of information to address any limitations. This approach offers flexibility, enhanced data interpretation, and robust conclusions. Ethical approval and health and safety risk assessment procedures were conducted prior to undertaking the work. In addition to road observations and e-scooter data from operators, an online survey was conducted comprising of both quantitative and qualitative questions addressed to $n = 801$ e-scooter users and $n = 92$ car drivers, this was followed up by detailed qualitative semi-structured interviews of $n = 9$ e-scooter users, who also took part in an quantitative experimental air quality data collection, from their e-scooter rides around the city, this air pollution data (PM 2.5 & PM 10) was captured alongside camera footage and GPS data to permit the environment to be plotted accordingly and analysed using sensor fusion and artificial intelligence. The combination of this experimental and empirical user focussed research methods ensured that the social perspectives and understanding where captured as well as the experimental research fulfilling the study's objective of monitoring air pollution, whilst also understanding the perspectives of the key stakeholders, both users and non-users and capture important findings in respect to physical safety and their perception of their physical and health related safety due to the impact of air pollution.

2.1. Surveys

Two online surveys (e-scooter survey, driver survey) were created using Qualtrics and distributed through social media platforms including Reddit, Prolific, LinkedIn and the 'direct contact' of researchers using a snowball effect. The primary objective of the first questionnaire was to gather perspectives from the public in various countries (UK, EU, USA, and Canada) on the use of e-scooters in comparison to other transportation modes, as well as to assess their perceptions of e-scooter safety.

The second questionnaire exclusively targeted the car driver population aiming to explore their viewpoints regarding e-scooters. Both questionnaires employed a mixed-methods approach, incorporating multiple-choice quantitative questions and open-text qualitative questions. Descriptive statistical analysis has been conducted on quantitative data from the multiple-choice questions and coding and clustering [20] was applied to the qualitative open response questions.

2.2. Interviews

Interviews were undertaken with 9 e-scooter users (8 males, 1 female) (*Mean age*: 25.7) to gather insights on their individual experiences. This sample size was deemed sufficient, as interviews were conducted until the full range of opinions and desired level of detail were captured, ensuring that 'saturation' was achieved [21,22]. The interviews were undertaken prior to the e-scooter riders engagement in the experimental work to ensure that their responses were biased accordingly. The interviews were conducted in English, anonymised,

Table 1
Comparison of e-scooter rules by country, based on data from [11].

Country	Age	License Required	Helmet required	Max Speed	Pavement/Road
UK (pilot)	18+	Provisional	No	15 mph	Road/cycle path
USA	16+	n/a	Under 18's	15 mph	Road/cycle path
Canada	16+	Permit	Yes** Toronto ⟨18	20–24 kmph**	Road/cycle path
Germany	14+	No	No	20 kmph	Road/cycle path
France ⋄	12/14+ post 2023	No	No	25 kmph	Road/cycle path
Spain	14+	No	Yes	25 kmph	Road/cycle path
Netherlands	16+	Yes	Yes	25 kmph	Road/cycle path
Australia	16+ 12+ with supervision	None	Yes	10–25**kmph	Pavement** shared & cycle paths not roads

** Depending on state, ⋄ banned in Paris from Sept 2023.

Fig. 1. Examples of road observations of e-scooter users on the road; note the low visibility clothes, the lack of safety helmets, the low level of the e-scooter's rear lights and the close proximity of e-scooters from cars.

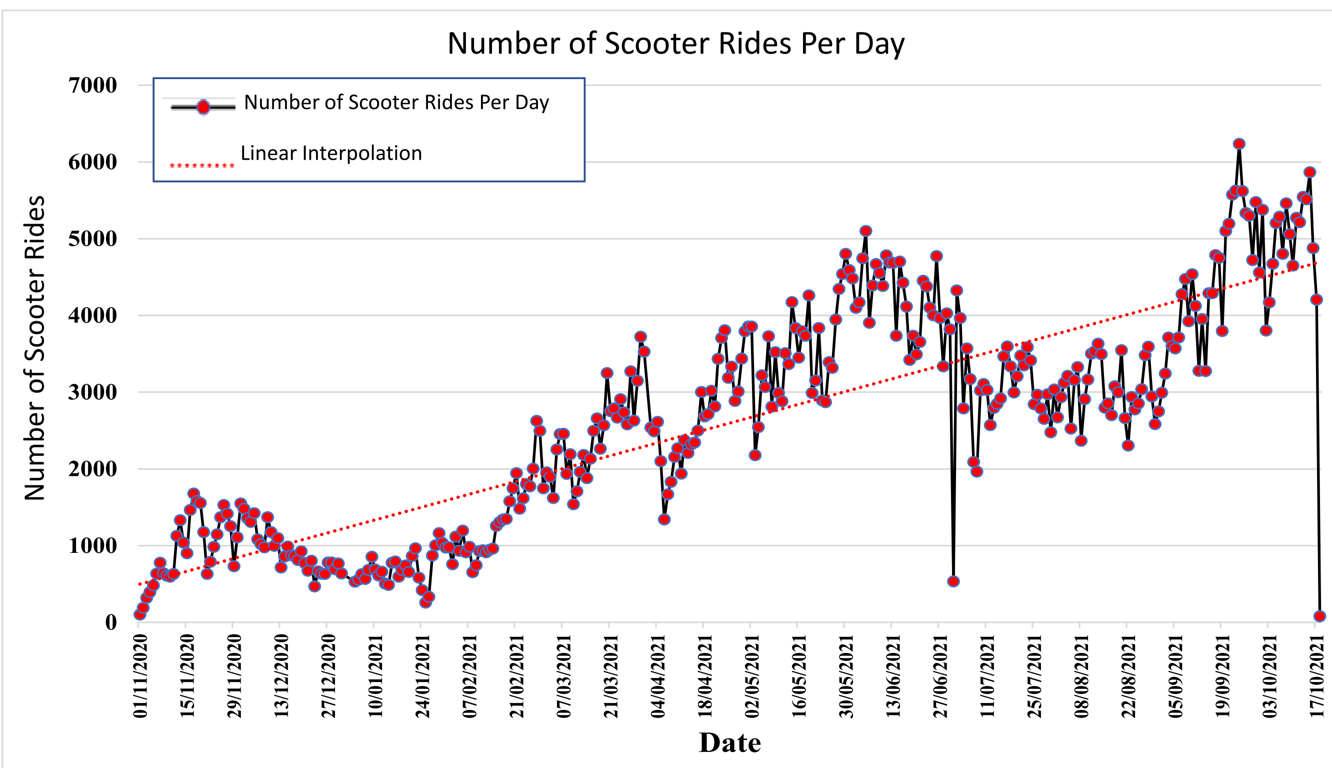

Fig. 2. Number of rides per day during the trial period from Nov 2020 to Oct 2021.

transcribed verbatim and analysed using content analysis in NVivo software. A content analysis approach was used by first defining the research objectives and then developing a coding scheme that represent the key concepts [23]. The coding scheme then works as a framework to help organise and analyse the data systematically. Once complete, data is quantified and summarised by the frequency of different codes or categories, allowing for the identification of patterns, trends, and relationships within the data [20].

2.3. *Experimental work*

Following the interviews seven of the e-scooter users were further involved in the collection of real time data whilst using standard e-scooters available as part of the NCC pilot. Participants were instructed to use the e-scooters as they would usually to travel but to use main roads were possible as part of their typical routes. Hence, the volunteers used the common commuting main roads between the city centre and key locations within the outskirts of the city. In addition, the riders were required to carry a rucksack containing the air pollution sensor and data logger and GPS and wear a helmet that held a Go Pro camera and a

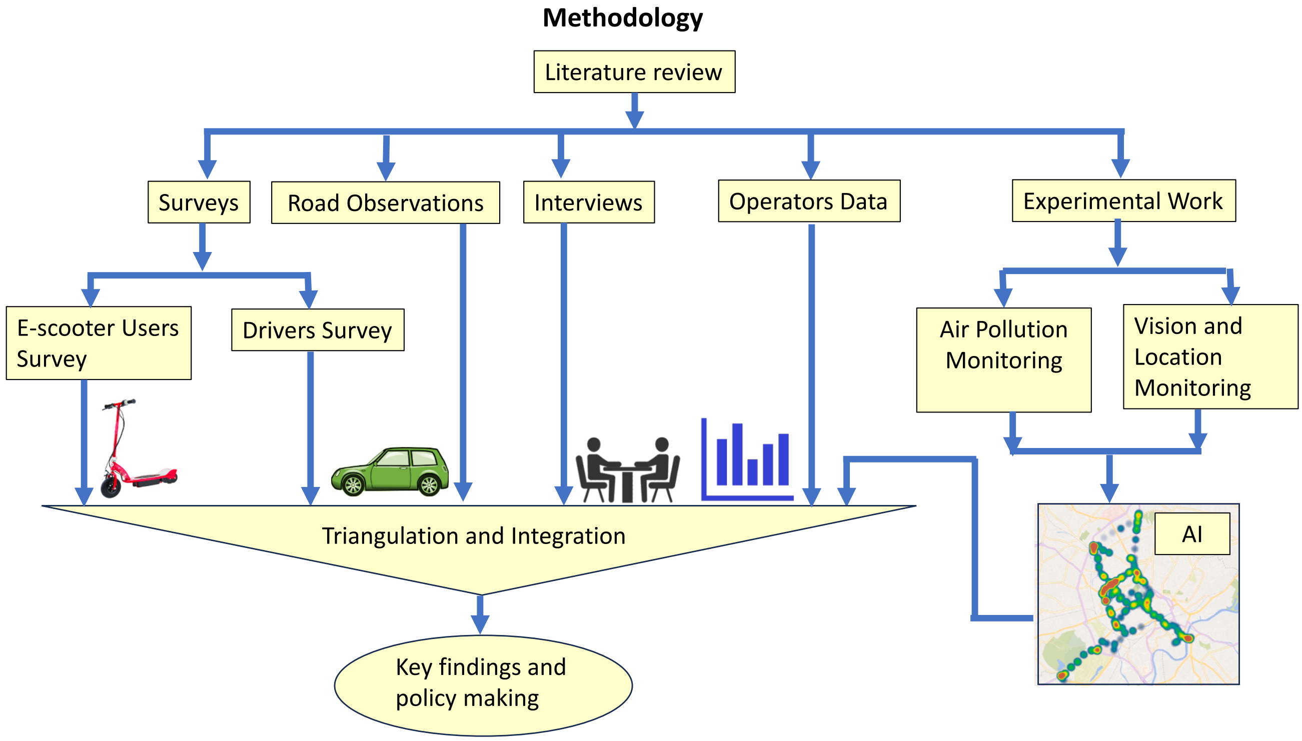

Fig. 3. The methodology of this research work.

separate 360-degree camera. The researchers developed an AI algorithm capable of using the footage obtained to count the number of cars passing nearby e-scooter users by processing images extracted from a 360-degree camera. This enabled the relationship between number of cars passing and air quality in the local area to be investigated and reveal the relationship between car volume and the pollution levels as experienced by e-scooter users. Further details are described in the following sections.

2.3.1. Pollution data collection

This study sought to collect real-time air quality and road safety data, through the use of an Aeroqual 500 data logger with a sensor head capable of measuring PM 2.5 and PM 10 particulates, a GPS iTrail tracker, a GoPro for video for enhanced forward facing video and a 360 camera to capture all round situational video. This setup permitted the allows to location, air quality and proximity to cars and road users to be captured for analysis as shown in Fig. 4.

Fig. 5 illustrates the routes taken by the volunteers during the experimental work, the participants were instructed to drive around Nottingham to capture the proximity to cars and measure air quality using the common commuting main roads between the city centre and key locations within the outskirts of the city. This instruction aimed to enhance the reliability of the comparisons made in the study.

2.3.2. Automated recognition and counting of cars

To investigate the correlation between the number of cars and the level of pollution that e-scooter users are exposed to, an innovative approach to counting cars near to e-scooter riders was developed using the 360-degree camera images. The camera captures everything happening around the rider, including behind them and in their blind spots. While the e-scooter is in use, the camera continuously records video.

In the analysis at set intervals of 3 s, images were extracted from the video to identify and count nearby cars. The 3-s interval was chosen as the average time it takes for cars to pass near e-scooter users and this method ensures no cars are missed, regardless of their location relative to the rider. These extracted frames from the 360-degree camera video were further processed using an artificial intelligence (AI) approach to detect cars and count them. The AI algorithm was based on the Automated Sensory and Signal Processing Selection System (ASPS) approach, which is an engineering optimization method for feature extraction. The ASPS approach aims to design and enhance quality by systematically applying design and analysis of experiments, resulting in a high-quality and cost-effective monitoring system [25, 26 27 and 28].

Fig. 6 present two examples of the 360-degree camera image, which displays all 4 sides around an e-scooter user when attached to the helmet. Such data was analysed by AI through the ASPS approach and MATLAB deep learning toolbox [24] to count the number of cars per minute that the e-scooter user passes, whilst the GPS module determined the location, and the PM sensor measured the air quality.

The process of car recognition and counting involved training a neural network to differentiate cars from other objects in images. Initially, a set of both car and non-car images was manually extracted from the 360-degree images to capture essential features that distinguish between cars and non-car objects. The Automated Sensory and Signal Processing Selection System (ASPS) approach is employed for this purpose. This approach concentrates on extracting sensitive sensory characteristic features (SCFs) by applying statistical/mathematical functions on multiple transformations of the targeted images. Further information about the ASPS approach and its details can be found in [25–28].

Fig. 7 showcases car images and non-car images extracted from 360-degree images, intended for use in the ASPS approach to extract key features for distinguishing between car and non-car images. This approach recognises car images irrespective of their position or orientation. Training the neural network with diverse car images of varying positions and orientations allows the model to learn and generalize features indicative of cars, ensuring accurate identification and differentiation regardless of their specific posture, size, or shape within the input image.

Once selected, the images of cars and non-cars undergo a series of transformative processes aimed at enhancing their informational value and consequently extracting hidden key features. These transformations

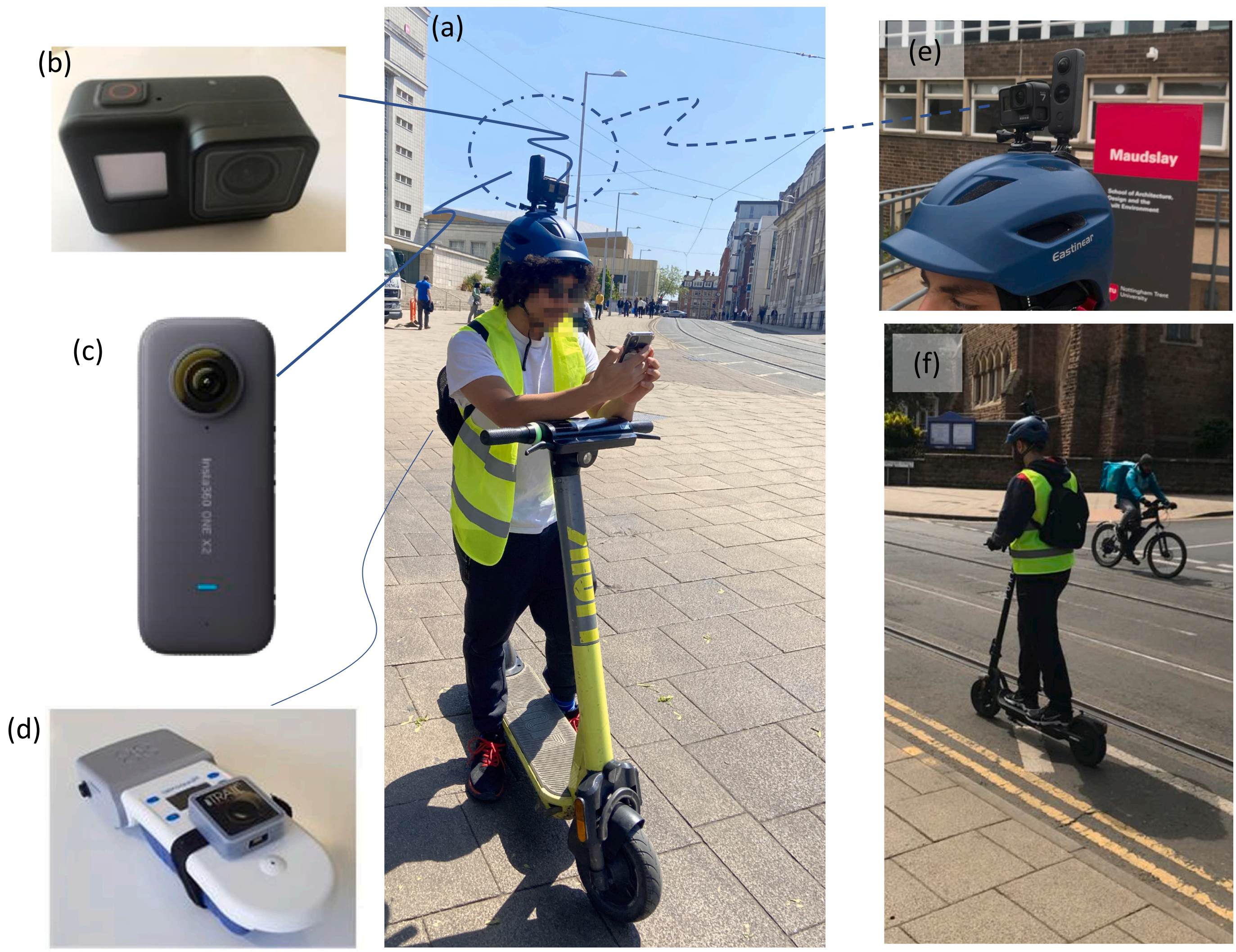

Fig. 4. The sensor fusion setup (a) includes a GoPro camera (b), 360-degree camera (c), PM 2.5 and PM 10 particulates data logger (d) and a GPS logger (d).

are designed to maximise the amount of useful information that can be extracted from each image. Figs. 8 and 9 visually represent an example of the transformations applied to the car and non-car images, respectively. The figures provided serve as illustrations of the transformation processes applied to the car and non-car images. However, the actual number of transformations may vary depending on the desired usefulness and requirements. The goal is to generate a sufficient number of newly transformed images to extract valuable information.

To extract hidden features, the ASPS approach [25–28] recommends applying various functions to each image and its transformations. These functions include but are not limited to Max, Min, Mean, STD (Standard Deviation), Absolute Mean, RMS (Root Mean Square), Absolute Max, Variance, Skewness, Kurtosis, RSS (Root Sum of Squares) level, Covariance, IQR (Interquartile Range of time), Range (Range of radio wave propagation), Crest Factor, Clearance Factor, as well as other relevant and useful functions. By applying these functions to every single image and its corresponding transformations, valuable information can be extracted from the data. This approach allows for a comprehensive analysis of the images, enabling the identification and utilization of hidden features.

In Fig. 10, the application of the minimum function to the DWT transformation (high pass decomposition) is depicted. This feature is highly valuable as it effectively discriminates between the two types of images. Specifically, car images exhibit a higher minimum value compared to non-car images. This observation highlights the utility of the minimum feature in accurately distinguishing between car and non-car images, see Fig. 11.

The schematic diagram shown in Fig. 11 illustrates the structure of the ASPS approach where the images (car images and non-car images) are initially transformed into three shapes (original, greyscale, and edge). Each one of these three images was transformed into another format by applying FFT and DWT on them. The fast Fourier transformation (FFT) was divided into two different shapes (FFT and LogFFT) each one divided into smaller parts and the discrete wavelet transform (DWT) into cA and cD twice. This journey of transformation produced 16 new images. Each one of the sixteen images was exposed to extensive feature extraction by applying multiple statistical/mathematical functions to create a list of the sensitive features (SCF's). As recommended by the ASPS approach the list of the sensitive features produced by applying the statistical/mathematical functions was sorted in descending order based on their values. The highest values features being the most sensitive [25–28].

2.3.2.1. Deep learning neural networks. The utilization of the ASPS approach has returned a collection of useful features, from which thirty highly sensitive features (SCFs), that can discriminate easily between cars and non-cars images, have been chosen. These selected features will serve as inputs to the developed deep learning Artificial Neural Network (ANN) algorithm, illustrated in Fig. 12, to ascertain whether the image depicts a car or not.

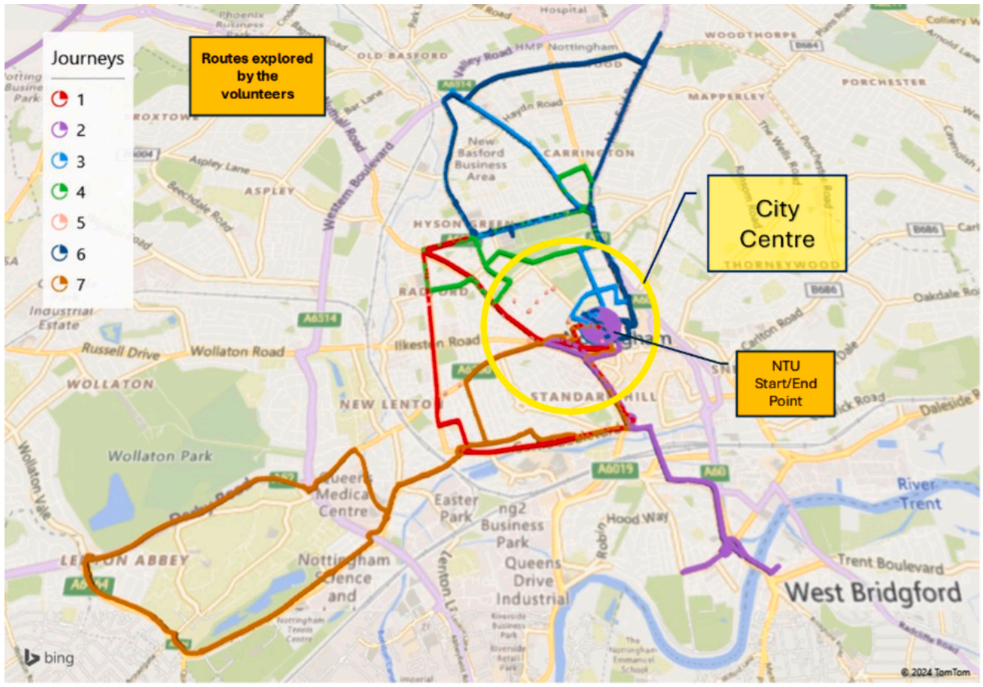

Fig. 5. Map of routes explored on e-scooters during data collection (background map source: TomTom, Microsoft Bing).

The function tool used in the algorithm of the neural network is the *newff* function. The *newff* function creates a feed-forward back-propagation network with specific nodes and hidden layers based on the provided inputs. It allows customisation of the transfer functions, training functions, learning functions, performance functions, and data division functions used in the network, see Figs. 12 and 13.

Fig. 13 illustrates the diagram of the neural network structure that has been automatically generated by Matlab software. This diagram provides visual confirmation of the number of inputs, the number of hidden layers, and the output layer of the neural network.

Fig. 14 displays the fresh results of the ANN before any post-processing operation and illustrates that the images with cars have been recognised with very high accuracy and matched the target exactly. This indicates the successful learning of patterns and characteristics unique to both car and non-car images, allowing for accurate recognition. During training, a dataset comprising 450 images was utilised, while the test set comprised 600 images, equally divided between car and non-car images.

It is worth mentioning that the achieved high accuracy was attained after numerous iterations during the training of the Artificial Neural Network (ANN), as illustrated in Fig. 15. This success of high accuracy underscores the success of the ASPS approach in extracting the most sensitive features, with the ANN effectively learning from the training dataset.

Table 2 shows the outcomes of utilising AI for car counting, as previously described. It presents the car counts for each of the journeys conducted by the seven volunteers. Additionally, the table displays the distance covered in each journey. The average travel distance per trip was recorded as 10.6 km, and the total distance covered by all journeys amounts to 73.910 km. These journeys took place on the main busy roads of Nottingham, spanning the entire city centre, as depicted in Fig. 5.

3. Results

The results of the three research instruments are presented separately in the following sections with parallels between them drawn in the discussions. Whilst the survey findings informed the interviews they were analysed distinctly from the interviews and the experimental trials that were conducted together with the same participants.

3.1. E-scooter survey

$N = 801$ respondents completed the e-scooter survey, comprising 373 males (46.6%) and 415 females (51.8%). UK residents had the highest response (48.94%), with additional responses from the EU (24.97%), USA (12.73%), and Canada (13.36%). The age of the respondents ranged from 18 to 77 years, ($Mean = 35.24$, $SD = 11.66$). In terms of employment status, the breakdown was as follows: full-time (56.7%), part-time (14.7%), retired (2.9%), not working (8.4%), students (12.9%), prefer not to say (1.2%), and other (3.2%). The “other” category encompassed responses such as those who were both students and working simultaneously, self-employed individuals, stay at home parents, family carers, individuals on maternity leave, those on sick leave, and housekeepers.

Respondents were asked questions relating to both bicycle and e-scooter use to permit comparison and there were notable differences in their perspectives, preferences, and perceptions. For bicycle usage, 61% of participants had never used them for commuting, while <10% stated they always or usually use bicycles for commuting. In contrast, a smaller portion of participants (47.3%) had never used e-scooters for commuting, whilst 7.5% and 9.3% always or usually used e-scooters for commuting, respectively.

In respect to of leisure use, 5% of participants always used bicycles, whereas 32.2% sometimes did, 13.4% usually did and 25.7% had never used them for leisure. Conversely, with e-scooters, 7.5% always used them for leisure, 27% sometimes did, 14.6% usually did, while 17.3% had never used them for leisure activities. This is to some extend expected as the respondents identified as e-scooter users for participation in the survey. Considering perceived safety, 35.3% felt a bit unsafe while riding bicycles, and 31% felt quite safe, whilst, for e-scooters, 39.4% found them a bit unsafe and 36.7% considered them quite safe, as shown in Fig. 16.

Furthermore, for commuting, most participants (67.9%) believed cyclists should wear helmets all the time, compared to 75.5% for e-scooters. A Chi-Square test was conducted to test for an association

(a)

(b)

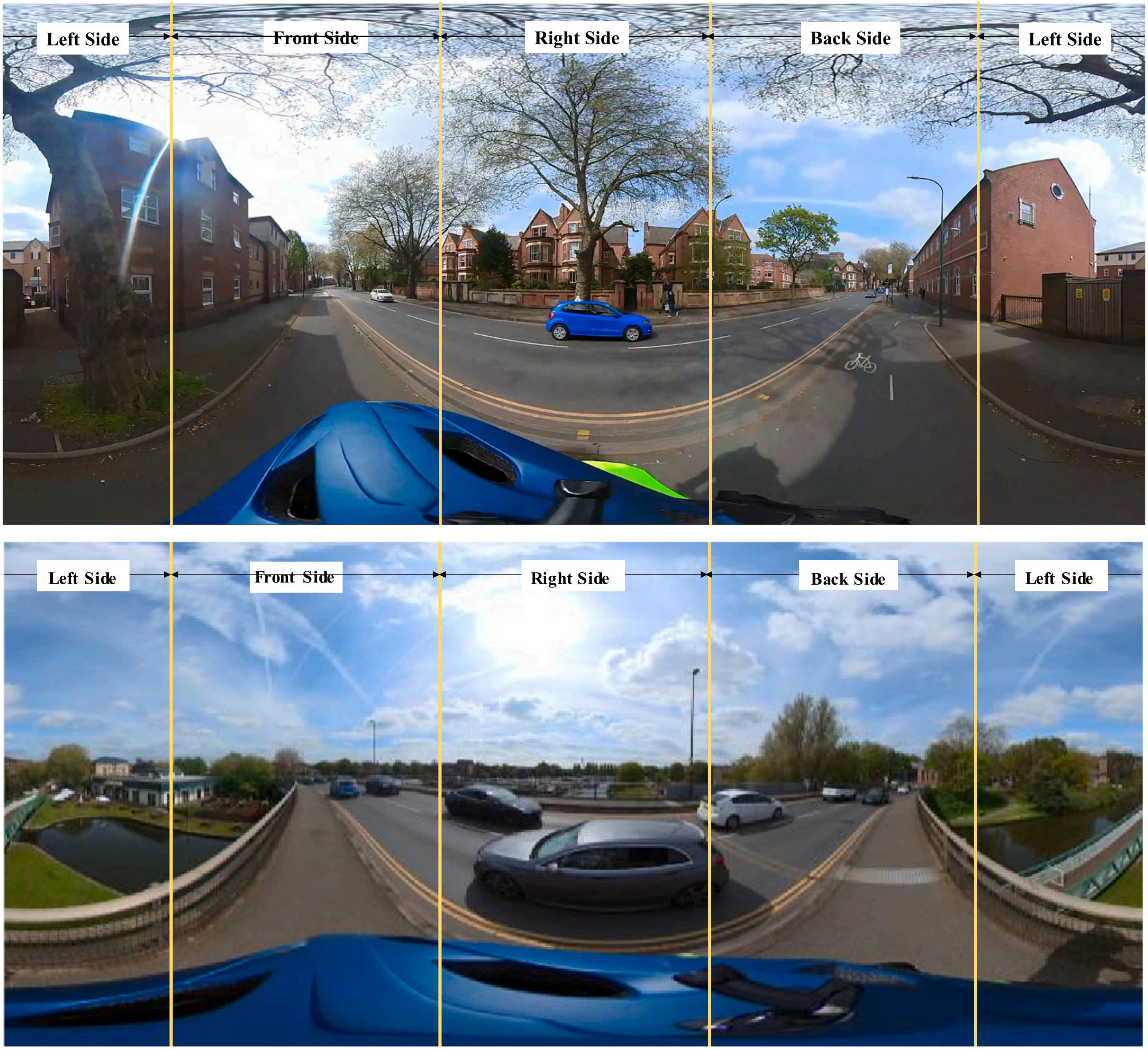

Fig. 6. Examples of 360-degree captured images.

between the mode of transportation (bicycle vs. e-scooter) and opinions on helmet usage. The results showed that the differences in opinions on helmet usage between bicycle and e-scooter users are statistically significant (X^2 (4) = 664.50, $P < 0.05$). Fig. 16 presents the perception of safety between bicycles and e-scooters.

Participants were asked about the potential safety risk of using e-scooters on pavements for pedestrians, a considerable proportion, 43.7% expressed strong agreement and 34.2% of participants agreed that they are a hazard. Furthermore, 34.5% strongly agreed that e-scooters parked on sidewalks obstruct pedestrians' paths, with an additional 33.1% in agreement. Over half of the respondents agreed with the statement that e-scooter users ride dangerously and pose risk of injury to themselves or others. With 31.8% of participants agreeing and 19.9% of participants strongly agreeing with this statement.

Participants expressed agreement on a variety of e-scooter risks, with 47.2% agreeing that e-scooters are risky, 67.3% agreeing that they pose hazards to visually impaired pedestrians, and 60.9% agreeing that they can be a hazard for hearing-impaired pedestrians. Fig. 17 presents the perceived risks of e-scooters.

Participants' perspectives on bicycle and e-scooter infrastructure revealed distinct challenges and concerns. Regarding bicycles, 26.6% acknowledged suitable infrastructure in their cities, but 22.3% reported inadequate facilities, citing infrastructure quality, the need for expansion and improvement, safety issues, and the importance of additional parking and storage. For example, a participant mentioned:

"Not very many dedicated cycle lanes, lanes are very narrow in some place, it is difficult as a driver to safely overtake cyclists."

For e-scooters, 33.1% stated the absence of appropriate infrastructure, while 21.3% believed there is suitable infrastructure. Safety concerns included rider awareness, inadequate infrastructure, traffic, and unsafe riding practices. The mixing of e-scooters with pedestrians on sidewalks raised safety issues, as does their use on roads and cycle lanes without dedicated spaces. Parking challenges and a lack of regulations and education further compound the issue. Participants also highlighted design-related concerns like low visibility at night. For example, a participant mentioned:

"The e scooters need better lights; it is hard for me to see riders while driving on a university poorly lit campus at night."

Concerning the impact of improved infrastructure for e-scooters on individual preference for use, 25% of participants expressed their

Fig. 7. Samples of car and non-car images extracted from the 360-degree image to train the neural network.

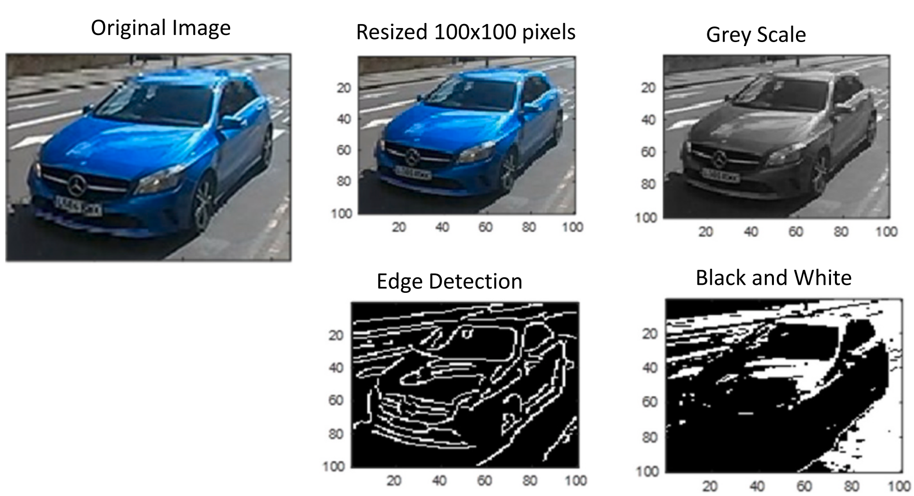

Fig. 8. Image processing and transformation (an example for an image containing a car).

inclination to start using e-scooters or increase their usage if infrastructure were improved.

Inquiring about air quality awareness, 41.7% of participants described their area as rarely polluted, while 35.5% considered their area polluted. Only 4.7% found their surroundings very polluted, but surprisingly 12.5% believed their city was entirely free from pollution and 5.6% admitted to being unaware of their city's air pollution condition. Participants were asked about the extent of air pollution's impact on them, 3% said it always affects them, while 21.7% claimed it never does. Furthermore, 38.5% reported rare effects, 28.2% occasional impacts, and 8.6% usual experiences of air pollution's effects.

Participants were further prompted about the effects of air pollution on their lives, including breathing difficulties, reduced outdoor activity, eye/nose/throat irritation, skin issues, relocation considerations, asthma, visibility problems, and long-term health concerns. The results showed 15.1% experienced breathing difficulties, 17.5% reduced their outdoor activity, 31.3% experienced eye/nose/throat irritation, 10% experienced skin problems, 17.1% considered relocating, 9.4% had asthma incidents, 7.7% faced visibility issues, and 39.2% worried about the long-term health effects. Participants also mentioned odours, headaches, migraines, hair loss, and allergic rhinitis as additional air pollution impacts. Fig. 18 presents the response in relation to the effect

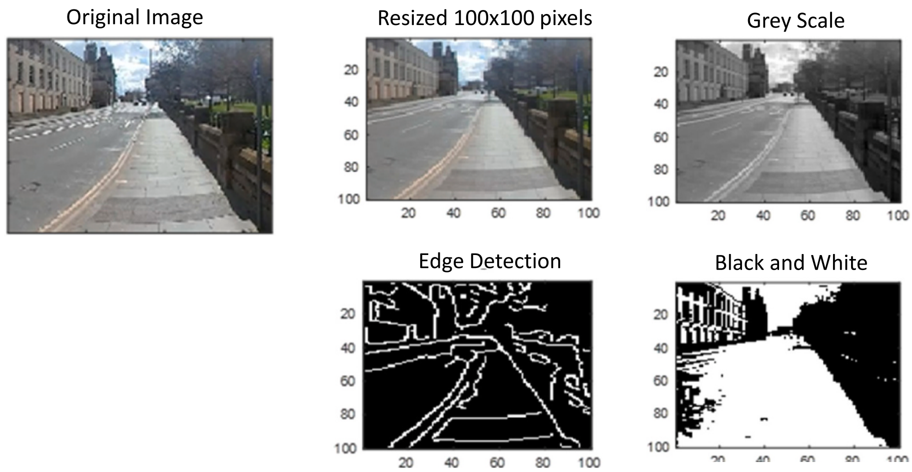

Fig. 9. Image processing and transformations (example for a non-car image).

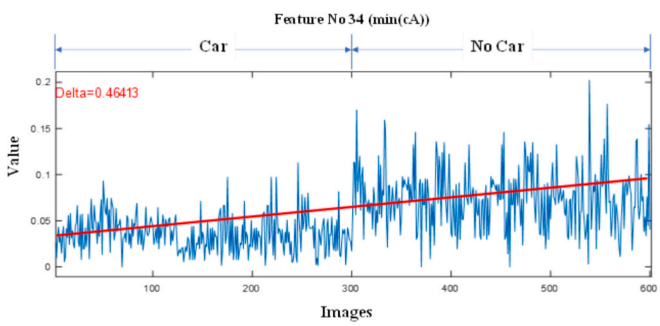

Fig. 10. Clear distinction between Images containing cars and images with no cars.

of air pollution on health.

This study investigated participants' views on electric scooters as an environmentally preferrable transport option. Among the 801 participants, 56.2% responded affirmatively (yes), 33.6% expressed uncertainty (maybe), and 10.2% responded negatively (no). Furthermore, participants agreed that e-scooters were beneficial for the environment, with 17% strongly agreeing and 48.4% in agreement. Although Life Cycle Analysis studies find the opposite to be the case [29].

In relation to the potential for e-scooters to improve air quality, 22.8% of participants strongly agreed and 52.3% of participants agreed with the statement. In addition, 50.4% and 19.5% of participants agreed and strongly agreed that e-scooter use can ease traffic congestion.

Regarding the usefulness of e-scooters as mobility options, most participants 81.8% agreed (56.8%) that e-scooters provide useful mobility options with 25% of participants expressing strong agreement with this statement. When participants were asked whether e-scooters would help improve balance and co-ordination a notable percentage of 38.6% expressed agreement with this statement and a further 13% strongly agreed. In terms of the potential for e-scooters to replace some taxi/Uber/Lyft rides, 39.2% of participants agreed with this notion and a further 19.4% of participants strongly acknowledged the possibility.

3.2. *Driver survey*

The driver survey conducted with UK drivers had $N = 92$ respondents, 66.3% as male, 31.5% as female and 1.1% "Other," and a further 1.1% who chose not to disclose their gender. For age distribution, the largest group was 31–40 (28.3%), followed by 26–30 (19.6%), 41–50 (19.6%), 18–25 (15.2%), 51–60 (12%), and those 61 and older (3.3%). Almost all respondents (98.9%) reported being regular drivers. The majority (64.1%) of respondents had held a full driving license for over 10 years, 14.1% for 2 years or less, 9% for 3–6 years and 12% for 7–10 years.

Car drivers' opinions on e-scooter visibility on roads varied, with 27.2% agreeing and 3.3% strongly agreeing that e-scooters are fully visible on roads, whilst 12% were neutral, 39.1% disagreed and 18.5% strongly disagreed. Participants were asked to assess whether e-scooter users are taking adequate safety measures.

Only 2.2% fully agreed, while 51.1% strongly disagreed, 26.1% disagreed, 18.5% were *neutral*, and 2.2% strongly agreed. When it came to perceiving e-scooters as potential hazards for car drivers and other road users, 33.7% agreed, 35.9% strongly agreed, 7.6% disagreed, 8.7% strongly disagreed, and 14.1% were neutral. Lastly, in terms of e-scooters being a convenient mode of transportation that can reduce traffic congestion and air pollution, 34.8% agreed, 30.0% strongly agreed, 9.8% disagreed, 5.4% strongly disagreed, and 19.6% were neutral. Fig. 19 presents e-scooter perceptions among drivers.

Furthermore, driver's general comments revealed important findings: drivers are worried about e-scooter safety, want clearer rules and training for e-scooter users, suggest better visibility, call for improved infrastructure, have mixed feelings about e-scooters in cities, and have different opinions on whether to ban or allow them. For instance, a participant mentioned:

"Scooter drivers should have some form of road teaching if they have to ride on the road. But the scooter company doesn't provide this! Yet expect them not to drive on the pavement! E-scooters are a great concept but poorly executed."

Another participant mentioned:

"*Better bike infrastructure would provide a safer space for e-scooter users and reduce incidence of collision with cars. I think most e-scooter riders try their best to be safe but have limited space to move freely in cities safely*."

3.3. *E-scooter user interviews*

Detailed semi-structured interviews were conducted with 9 e-scooter users from Nottingham to gain deeper and richer insights than the survey could achieve. Interviewees were asked their opinion on the advantages and disadvantages of e-scooters, their impact on traffic and air quality, overall safety, their accessibility and inclusion, regulatory concerns, and their feasibility as a transport mode replacement.

In respect to the advantages, the rider's experience featured strongly, with the responses describing e-scooters as convenient and fun, with a sense of genuine freedom to navigate the city and the flexibility being available 24/7. Whilst the most noted advantage was their efficiency, coupled with low cost, especially at night and in the early hours:

"When I finish work at approximately 1:00am, there is no bus. So, the

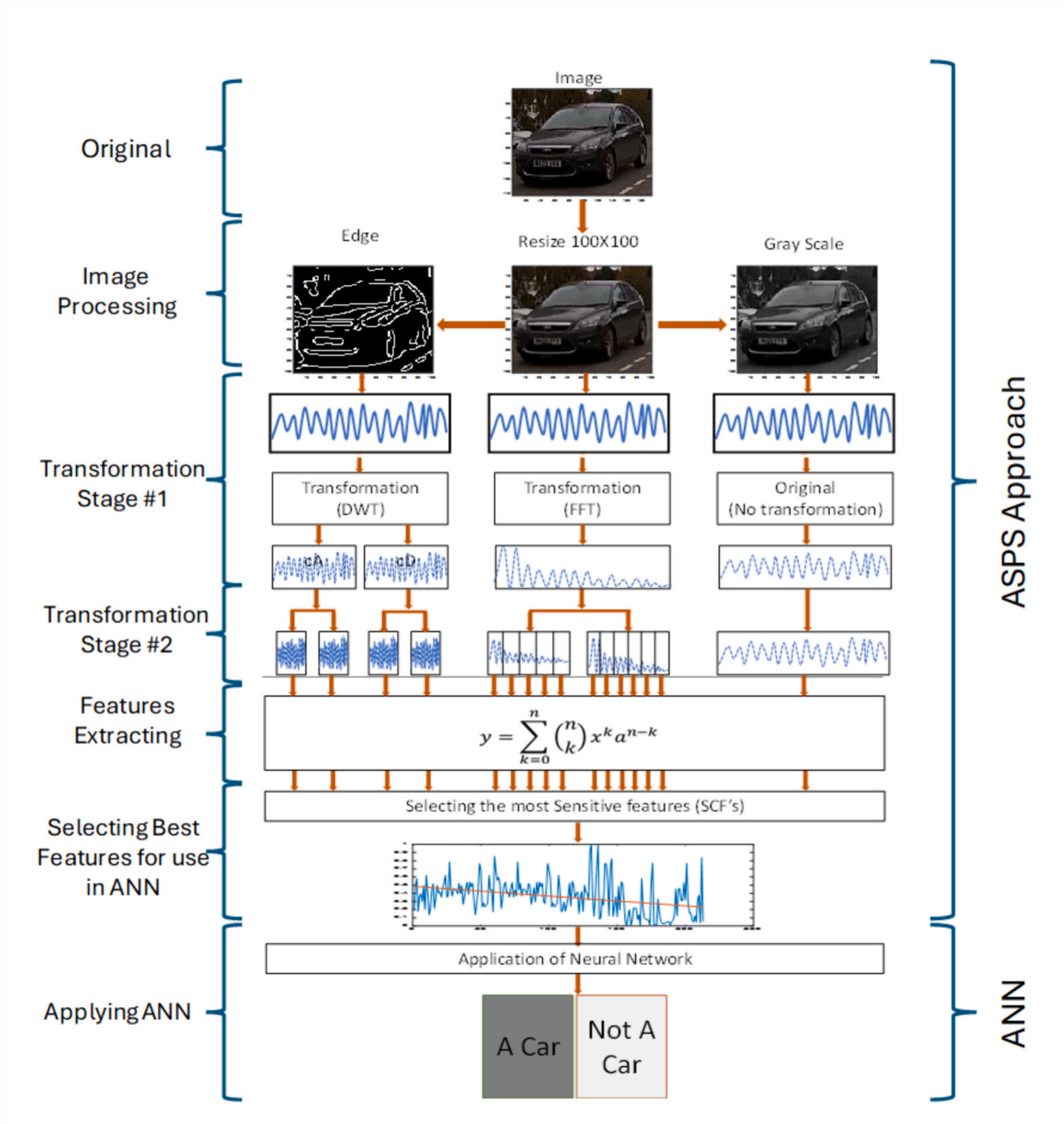

Fig. 11. Schematic Diagram of the ASPS approach including the ANN using car and non-car images.

only choice is to take an electric scooter. So, I take it, I pay for it, and I go straight to home it will cost me less than £2.50 and it will take me 10 minutes to be home."

Discussing the disadvantages, limitations of the design of e-scooters heavily featured, such as the small wheels, limited weight, speed restrictions, lack of weather protection and mirrors. Others related to battery range and charging infrastructure. Also noted was the lack or specific road infrastructure or lanes for e-scooters and the limited areas in which they will operate.

"*Honestly, I just think it's lack of space, like the lack of it for e-scooter users, I think it's a very similar issue with cyclists, like there's no designated area for it.*"

Considering the impact of e-scooters on the urban environment, riders were quick to highlight their potential to reduce congestion due to their smaller footprint on roads. Discussing their impact on air pollution some were keen to highlight their lack of emissions, whilst some questioned whether this was being offset though in their electricity generation.

"*You're not really reducing carbon. Your kind of offsetting it to someone else. So, I think that's still a big thing with all electric things in general. But if the future, you know, if we're getting more and more renewable energy, I think electric scooters, electric bikes, sort of electric vehicles is the way to go.*"

When asked about their safety concerns, many referred to individual e-scooter riders' poor behaviour such as reckless riding, failing to follow the traffic rules and disregarding pedestrian safety. In relation to the rider's safety the lack of specific infrastructure on the roads, lack of e-scooter parking and the poorly maintained road surfaces such as potholes that impact e-scooters more due to their small wheels. Visibility on the road was mentioned many times with the suggestions of high visibility clothing being required especially in low light heavy traffic areas. The importance of wearing safety helmets was also noted for safety but some preferred not to wear helmets due to comfort issues or perceived visibility.

When questioned about whether e-scooters are suitable for older

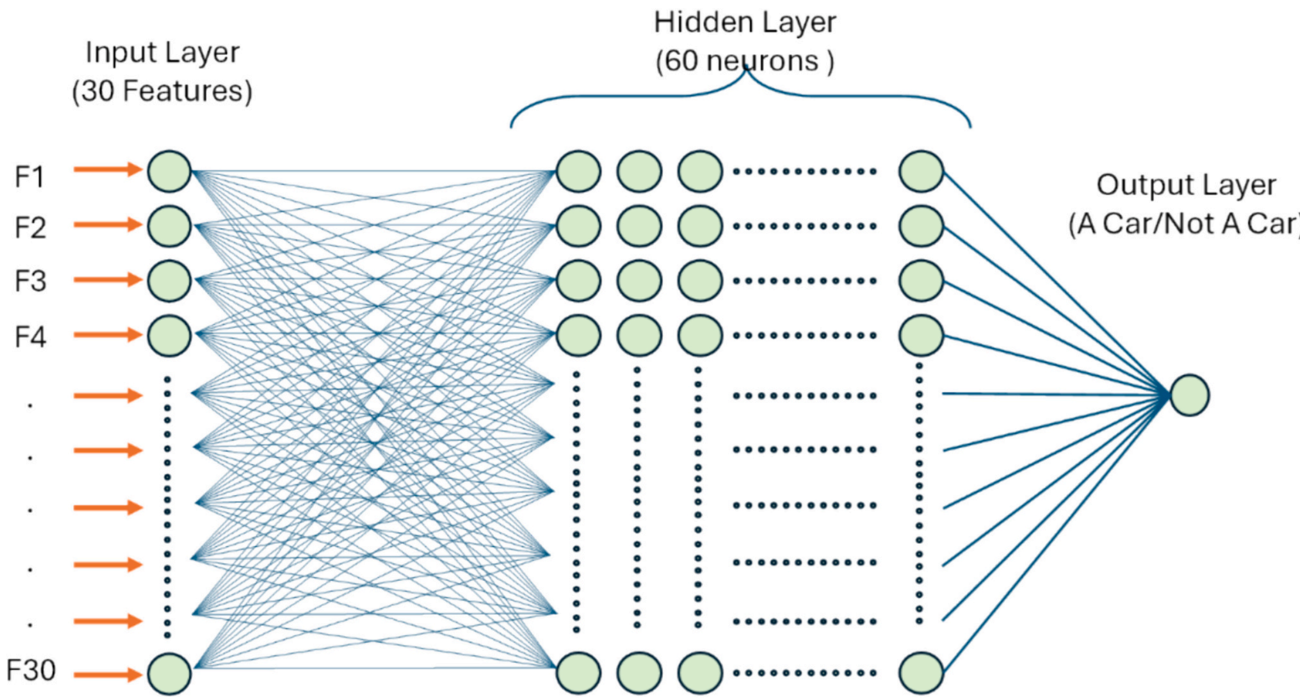

Fig. 12. The architecture diagram of the generated neural network.

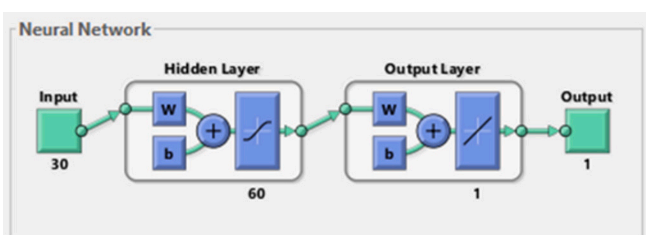

Fig. 13. The structure of the developed supervised neural network generated by Matlab softare, with 30 inputs, 60 hidden nodes and one output layer.

adults, persons with disabilities and those on low incomes. The users noted the importance of manoeuvrability in use that could be an obstacle to older and disabled users:

"Accessibility of transportation. I think these groups are less likely to use electric scooters, older adults, people, disabilities. That if you have more e-scooters on the road, maybe older adults or people with disabilities might find it annoying or find it like it's an extra obstacle they need to navigate."

Regarding affordability, e-scooters were noted as a cost-effective solution for all, that may be more economical for those with limited incomes. Users described the need for greater regulations and policies governing e-scooters, highlighting the potential for laws on wearing helmets, penalties for traffic offences and for non-compliance and the use of cycle lanes.

Concerning the use of e-scooters as a replacement mode of transport,

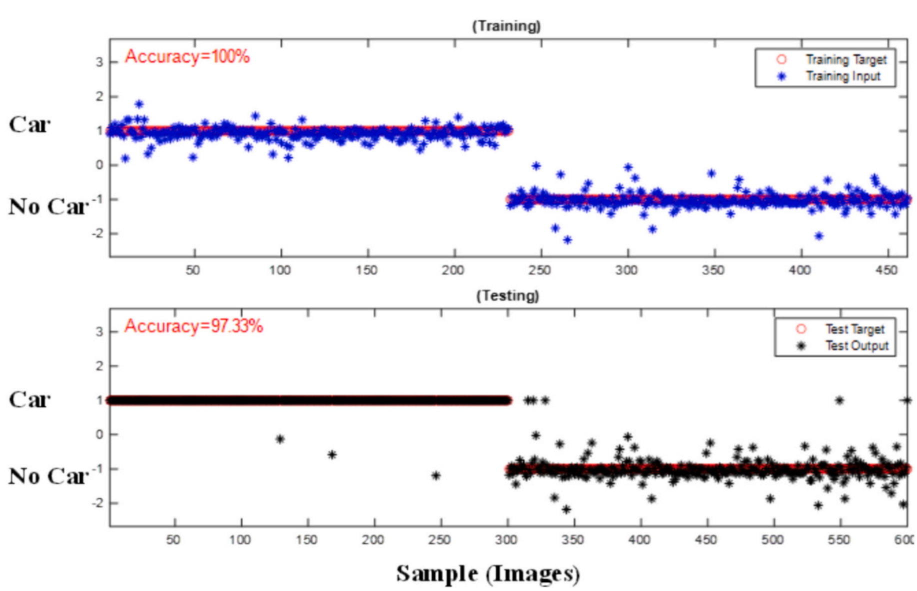

Fig. 14. Accuracy progress graph for the detection of car images and non-car images.

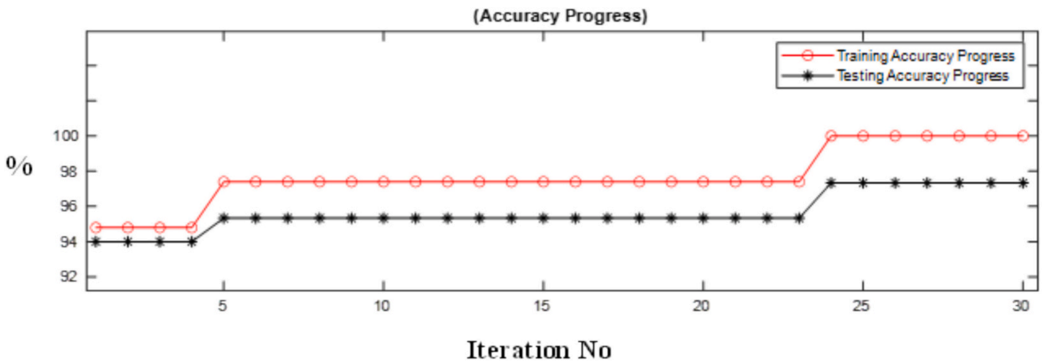

Fig. 15. Accuracy progress graph.

Table 2
Number of cars observed per trip.

Journey No	Date	Distance Covered (km)	No of Cars	Average Cars per Minute
1	24/05/2023	8.284	1209	42
2	06/06/2023	8.622	946	33
3	08/06/2023	10.571	759	26
4	14/06/2023	12.006	1132	39
5	15/06/2023	9.006	1962	68
6	21/06/2023	11.985	1400	48
7	22/06/2023	13.437	1883	65
	Total	73.9	9291	

the users highlighted key benefits already noted such as convenience, suggesting that e-scooters could replace shorter bus or car journeys, although there were reservations around the suitable distance due to the battery range, built in boundary limitations and the fact that it is an individual only mode of transport not suitable for groups, or families.

"I feel like for certain destinations, it could, but for other destinations it couldn't because buses and other forms of transportations would take you to further. I would rather take (an e-scooter) a shorter destination about 15 to 20 minutes."

3.4. Air pollution levels and mapping

The number of riders varied throughout the day, with the highest intensity observed during afternoon rush hours, raising concerns about

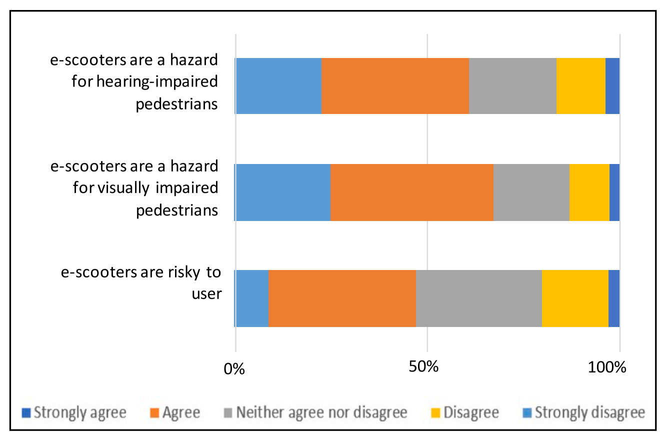

Fig. 17. Participant agreement on e-scooter risks.

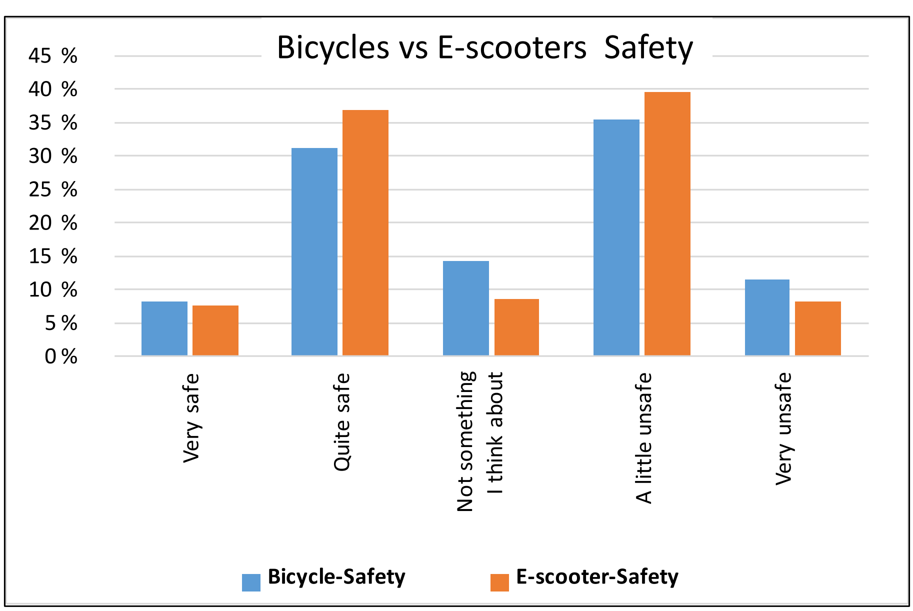

Fig. 16. Bicycle vs e-scooter safety.

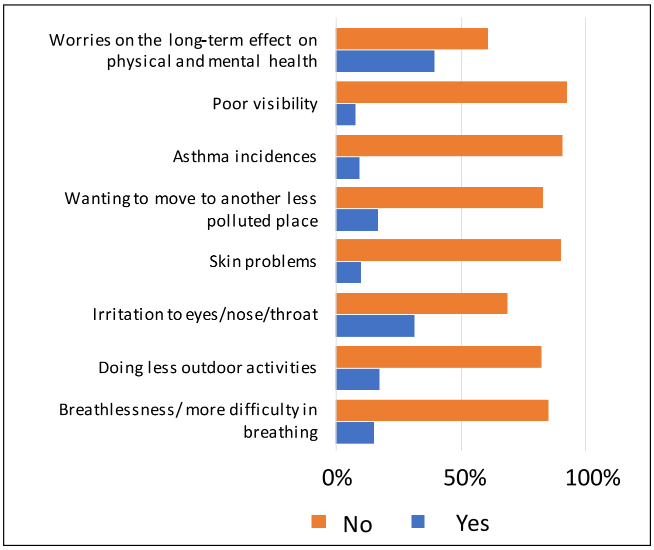

Fig. 18. Effects of air pollution on health and well-being.

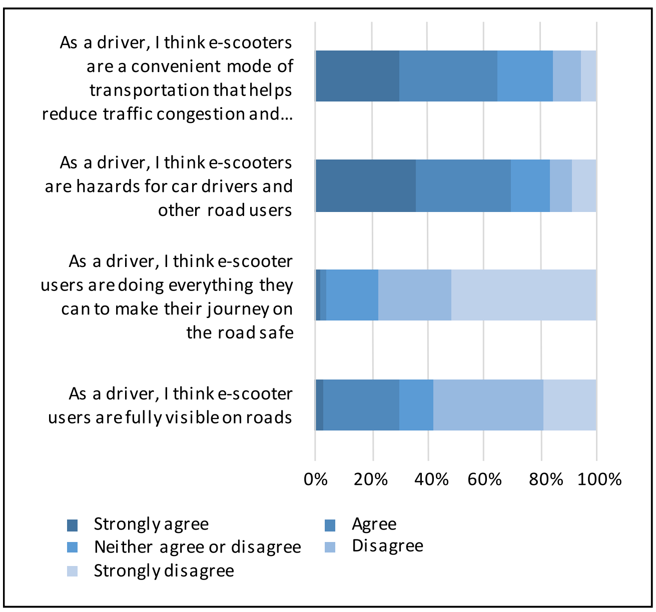

Fig. 19. Key findings on e-Scooter perceptions among drivers.

potential air pollution exposure for e-scooter users at these busy times. Fig. 20 displays the user count across six different time zones over the course of a day. Analysis of the time zone categories reveals that e-scooter usage peaks during afternoon rush hours, constituting 30.7% of total rides, followed by the mid-day period at 23.7%.

Fig. 21 presents an example of the air pollution monitoring conducted during the study. The PM10 readings are found to be higher than the PM2.5. The Air Quality Standards Regulations 2010 require that concentrations of PM in the UK must not exceed: an annual average of 40 μg/m3 for PM10; and an annual average of 20 μg/m3 for PM2.5. The Environmental Targets (Fine Particulate Matter) (England) Regulations 2023 require that in England by the end of 2040: An annual average of 10 $\mu g/m^3$ for PM2.5 is not exceeded at any monitoring station. And population exposure to PM2.5 is at least 35% less than in 2018. We have found that the readings from the rides within the sample are within the expected limits.

Fig. 22 presents an air pollution map of all e-scooter users in the test for PM10 and PM2.5, indicating the city centre has higher concentrations of particulates, compared to areas further away from the centre. These areas are understandably related to the number of cars counted in these regions.

Fig. 23 presents the number of cars (N) that the e-scooter users have passed by during their journeys.

Fig. 24 presents the relationship between air quality and the number of cars where there is a clear association.

Fig. 25 shows that road crossings are the most critical part of relatively higher number of cars and lower air quality. This indicates that electric cars or cars with auto-top could help in enhancing air quality at junctions.

Fig. 26 presents a comparison between different modes of transportation. The data from walking, bikes, cars, buses and trams are based on reference [39] by the authors using the same sensors and methods. For MP10, the air quality of e-scooters seems to be slightly worse than using the bike or walking. But for PM2.5, the use of e-scooters seems to be comparable to being in a car and better than walking or using the bicycle.

4. Discussions & conclusions

There have been significant questions about the safety of e-scooter users in cities due to their proximity from cars, their low visibility, and the potential poor air quality that riders inhale around fossil fuel vehicles. A mixed methods approach has been used in this paper to capture information about e-scooter use as a case study. The positive response to e-scooters from their users matches that found in other studies as noted in the introduction in both the US and the UK [10,12]. However, this outcome is expected as most respondents except in the driver survey are self-identified e-scooter users and have chosen this form of transportation over others. What this study adds to existing studies is the perspectives of users and drivers around core issues such as safety, inclusivity and the uniqueness and drawbacks of this new mode of urban transport. Furthermore, the experimental data on air pollution and safety through air pollution monitoring and car identification and counting adds an additional dimension with findings that are contrary to the survey respondents' expectations on air pollution but affirms e-scooter riders and more, so drivers concern around safety.

This study highlights perceived advantages and disadvantages of using e-scooters. *E*-scooters are viewed as convenient and affordable transportation solution for short trips, particularly during off-peak hours when other public transport options are limited. Such findings align with literature which emphasize that e-scooters are a suitable solution for "first" and "last" mile travel [30,31]. Participants also believe that e-scooters can help the environment, although scientific studies differ on their overall impact [29]. Disadvantages concerned safety, with users and non-users worried about accidents involving riders and pedestrians, particularly on crowded pavements. There is also a lack of proper infrastructure such as dedicated lanes and parking spaces, which makes using e-scooters in cities challenging, as noted in other studies, which indicate that e-scooter riders have specific infrastructure preferences [32], favouring infrastructure that is separated from cars, such as dedicated cycle lanes, with minimal obstacles along their route.

The results show that e-scooter users and drivers view the concept differently with e-scooters users viewing the transport mode more favourably than the car drivers that they share the road with. However, car drivers do see positives from e-scooter integration particularly through the potential to reduce congestion. Whilst both riders and drivers perceive issues with infrastructure and road sharing, which can lead to greater concerns around safety of both riders and pedestrians.

Interestingly the comparisons to bicycle use and safety suggest that e-scooters are slightly more popular among those who have used an e-scooter but are still are viewed as less safe by comparison. Previous research has shown that e-scooter users were more likely to be admitted to a major trauma centre or a critical care unit [33], with serious head and limb trauma being more common among the e-scooter cohort

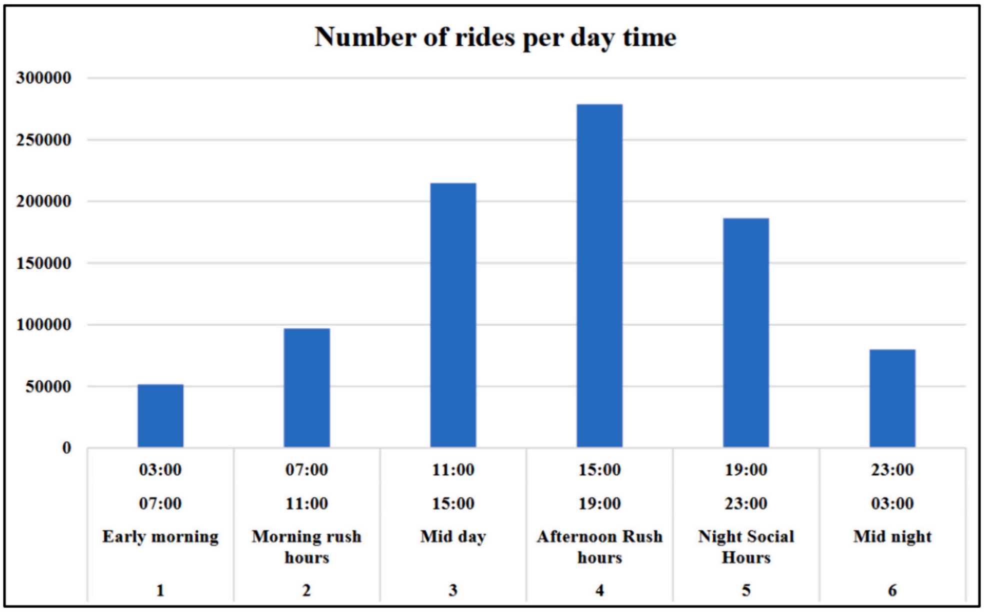

Fig. 20. Air quality monitoring during the 24 h period (one-minute sampling rate).

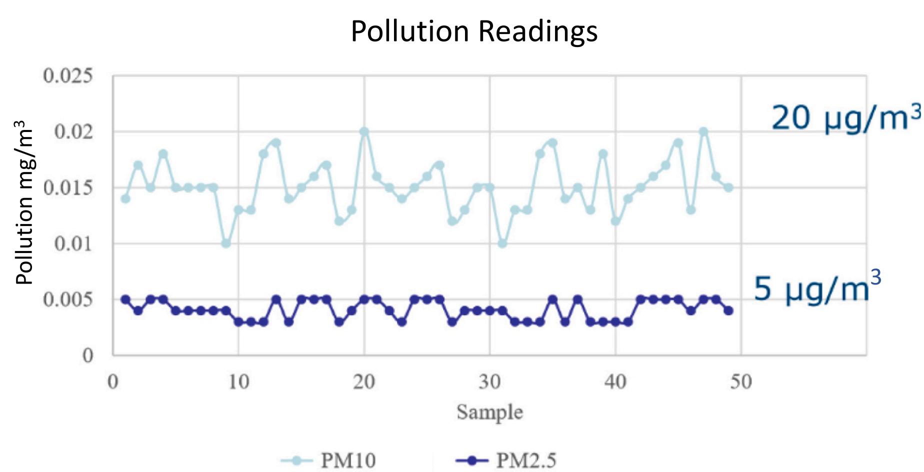

Fig. 21. Air quality monitoring (one-minute sampling rate).

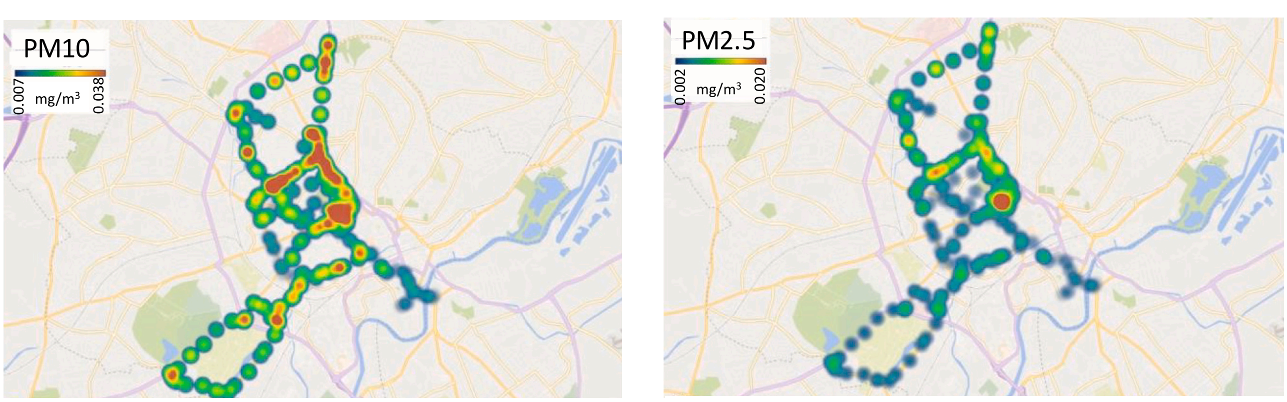

Fig. 22. Air pollution map as experienced by e-scooter users (PM10 and PM2.5 respectively).

compared to bicycle users (35.2% vs 19.7%) respectively. Most interestingly for e-scooters riders there is significant difference $P < 0.05$ in their views on wearing helmets between bicycles and e-scooters deeming them more necessary on e-scooters. Whether this is related to the existing research findings above [33] or the rider's own perception of the smaller wheels or a higher likelihood of falling off, was not clear

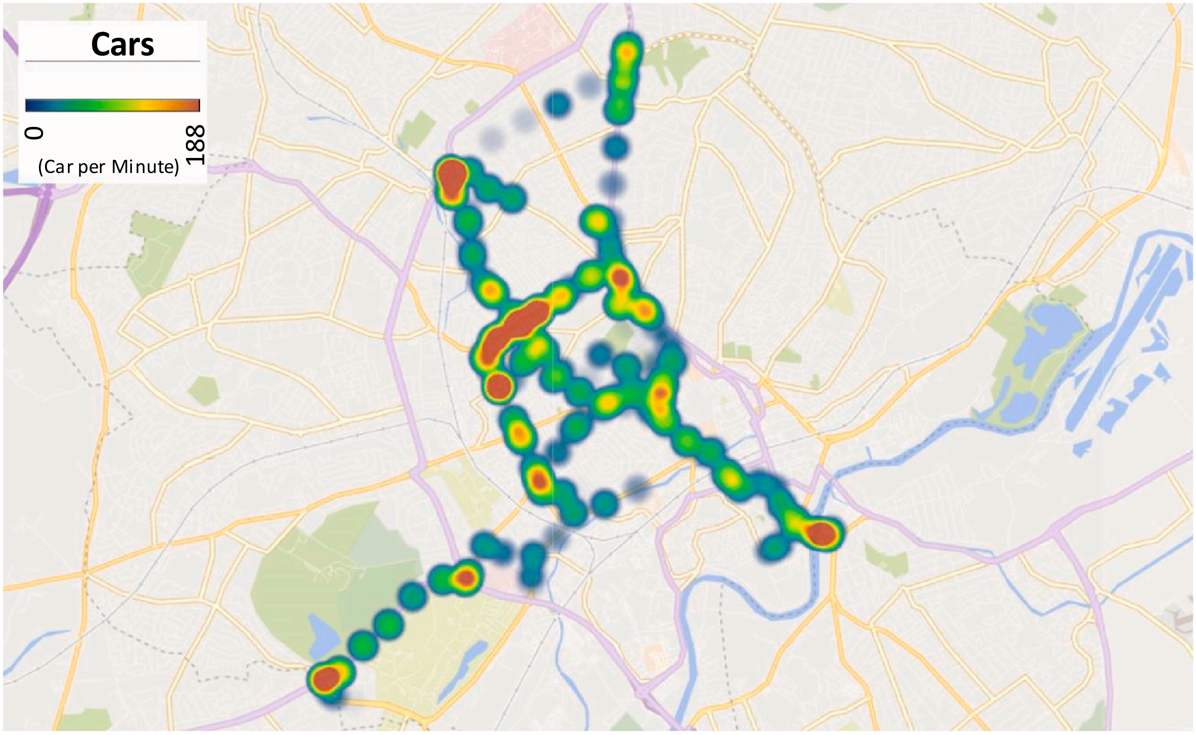

Fig. 23. Number of cars passed by the e-scooter users (per minute).

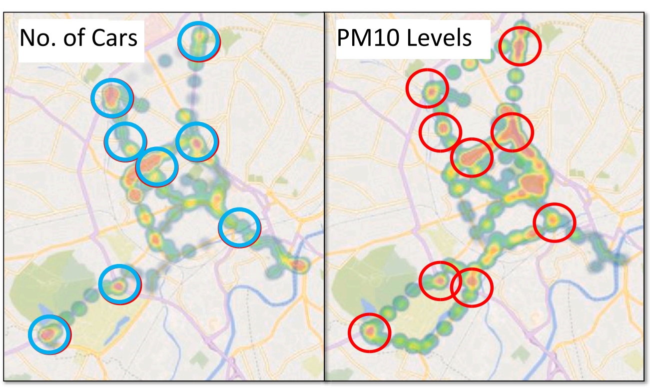

Fig. 24. The majority of elevated levels of pollution areas are related to high number of cars passing by the area.

but it agrees with empirical studies on the higher incidence of injuries and trauma from e-scooters in relation to bicycles [33–35]. Although typically e-scooter users were more concerned with the risks that e-scooters can pose to the visually [36] and hearing impaired [37] [38] than themselves. These findings in respect to the self-identification among e-scooter users that helmets are more necessary for e-scooters than bicycles and the reflection on the safety issues that e-scooters pose to other vulnerable users, pose questions that require further investigation. Combined with the extensive literature on the safety of e-scooters, the overall research findings question the existing approach of shared roads and even shared pavements. Incremental solutions such as increased visibly through larger or more prominently displayed lights on e-scooters, high visibility clothing and helmets could have their place for improving the visibility of the e-scooter riders. Combining such design improvements for the users with projection lights to alert hearing impaired and artificial noises to alert the visually impaired pedestrians could also improve the experience of shared spaces and paths for pedestrians. However, to ensure the safety of both groups dedicated comprehensive training of riders would also be desirable. However, all these key issues all arise from the limitations of the existing infrastructure that requires the sharing of spaces, with e-scooters sharing roads and where permitted pavements which is clearly not ideal.

For the case of the UK, see Fig. 27, given the specific infrastructure in the UK, where roads and pavements are very narrow and there are limited cycle lanes, we sought the opinions of UK respondents on these conditions. Our findings as shown in Fig. 27 revealed that about 83% (Strongly agree + Agree) believe that e-scooters on sidewalks pose a safety risk to pedestrians. Additionally, 68.4% (Strongly agree + Agree) think that parked e-scooters obstruct pedestrian paths. However, 56.3% (Strongly agree + Agree) of respondents believe that improved infrastructure would encourage them to use e-scooters more.

Further work is needed to understand further the effect of different modes of transportation on air quality for PM10 and PM2.5 as the findings show variation between PM10 and PM2.5 with consistency between the use of the tram as being the best option for better air quality due to the use of electricity (Zero emission) and the closed windows of the trams used in the studies.

The novel approach that has been implemented in this study to allow the monitoring and prediction of air quality based on GPS data, air quality monitoring and the existence of cars, found particulates to be within the required range, but still a present reality for e-scooter users due to their greater proximity to cars and is in line with a previous study on cycling [25]. However, the perceptions of air pollution and the e-scooter impact on the environment [29] were seen more favourable from the user's perspective than reality when measured, suggesting that the physical seen dangers are more emotive and relevant to e-scooter riders than the unseen impact of air pollution, however when prompted by the physical symptoms that could arise from air pollution exposure, e-scooter riders did recognise these.

AI (Neural networks and ASPS approach) techniques were used to estimate the number of cars using image processing. The results indicate that cars play a significant role in increasing or decreasing air pollution levels. It was essential, to understand the air quality during commuting periods, to fully understand the variables affecting the process. These

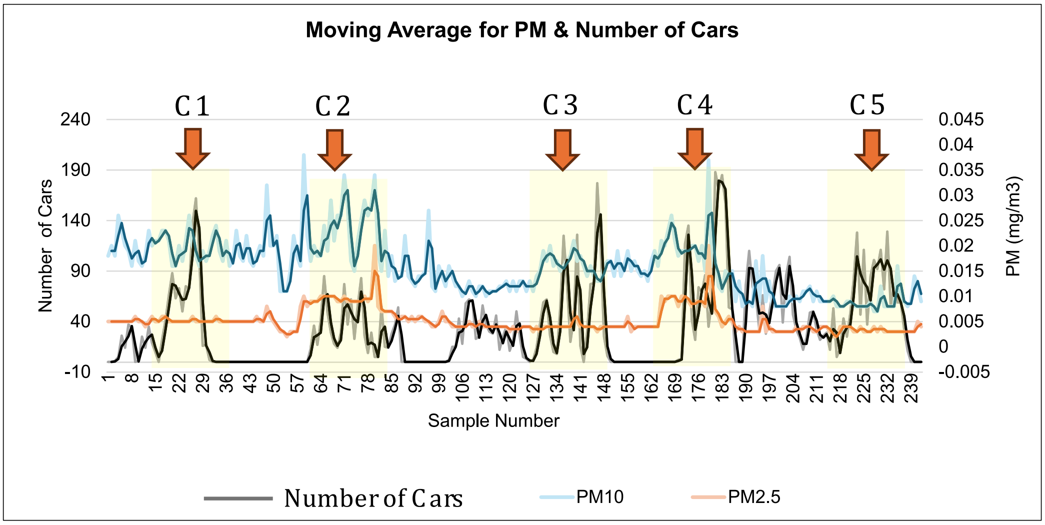

Fig. 25. The effect of road crossings (junctions) on air quality and number of cars.

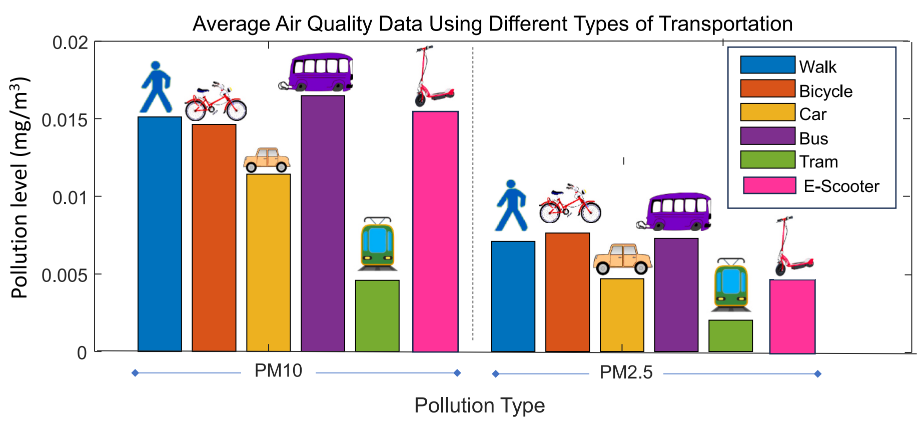

Fig. 26. Average air quality data using different types of transportation (based on data collected from this work for the e-scooter and reference [39] for other types of transportation).

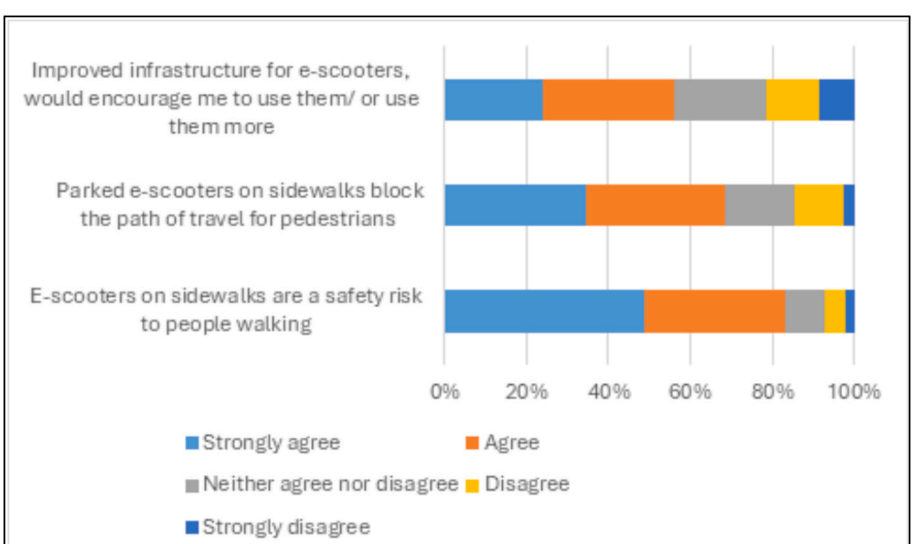

Fig. 27. UK Respondents' Views on *E*-Scooter Safety and Infrastructure.

variables include the time of day, related concentration, and the proximity from cars. Individual sensors in this context have limitations, and do not give the full picture, for example an e-scooter rider parked stationary next to a car at traffic lights would give a far higher reading than one that is moving, but this has been addressed through the integration of multiple data sources that permit the visual proximity of cars to be considered alongside the air pollution data through sensor fusion, which when combined with Artificial Intelligence can provide an enhanced analysis of complex data. This paper has explored the wider safety concerns around the use of e-scooters and found that both users and drivers are mostly aware of the physical hazards that e-scooters can pose, but less aware of the impact of air pollution on riders. The paper notes that whilst fossil fuel cars are still a predominant source of air pollution in urban environments, fully electric cars will still present particulates from brake and tyre wear in addition to physical safety concerns to active and micro-mobility users. So, to fully develop NetZero and sustainable cities of the future and to encourage cleaner forms of transport and energy, safety issues and the risks to the proposed micro-mobility solutions, such as e-scooters, need to be addressed to provide sustainable and comprehensive solutions. Such solutions are complex and even if addressed through improved shared spaces infrastructure with dedicated paths and cycle lanes, problems persist. If such infrastructure remains parallel to roads the air pollution impact upon users remains, so thorough planning of routes with green spaces require exploration, alongside final mile solutions that remove not only the physical proximity risk but also the wider health implications of air pollution. For future work, the team aims to investigate e-scooter use in other global cites to examine common and unique features between different cities. And to also investigate further the effect of the type of transportation on air quality. It is essential, therefore, to further integrate AI and data science [40] to address climate change and variables that affect air quality and carbon emission towards sustainable and safe transportation.

CRediT authorship contribution statement

Amin Al-Habaibeh: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Matthew Watkins:** Writing – review & editing, Validation, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Bubaker Shakmak:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Maryam Bathaei Javareshk:** Writing – original draft, Visualization, Validation, Software, Investigation, Formal analysis, Data curation, Conceptualization. **Seamus Allison:** Writing – review & editing, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that there is no other conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

Data availability

Data will be made available on request.

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References

[1] Bekkar A, Hssina B, Douzi S, Douzi K. Air pollution prediction in smart city, deep learning approach. J Big Data 2021;8(1):1–21.
[2] Silva LT, Mendes B, Oliveira C, Reis C, Silva P, Silva JF. Contribution of an environmental monitoring system to evaluate the potential effect of urban air pollution. Procedia Structural Integrity 2019;22:130–6.
[3] Cabaneros SMS, Calautit JKS, Hughes BR. Hybrid artificial neural network models for effective prediction and mitigation of urban roadside NO2 pollution. Energy Procedia 2017;142:3524–30.
[4] Madaniyazi L, Xerxes S. Outdoor air pollution and the onset and exacerbation of asthma. Chronic Diseases Trans Med 2021;7(2):100–6.
[5] EEA. Explaining Road transport emissions. European Environment Agency Report. Available at. https://www.eea.europa.eu/publications/explaining-road-transport-emissions; 2016. Accessed 26th April 2024.
[6] Huang FH. Influence of reduced air pollution source emission information on user Behavioural intention towards E-scooter products. PROMET-Traffic & Transportation 2022;34(1):53–67.
[7] Dias, G., Arsenio, E., & Ribeiro, P. (2021). The Role of Shared E-Scooter Systems in Urban Sustainability and Resilience during the Covid-19 Mobility Restrictions. In Sustainability (Vol. 13, Issue 13). doi:https://doi.org/10.3390/su13137084.
[8] Cruz ND, Morgan C, Morgan RV, Tanna S, Talwar C, Dattani R, et al. Injury patterns of e-scooter-related orthopaedic trauma in Central London: a multicentre study. The Annals of the Royal College of Surgeons of England 2022;104(3):187–94.
[9] Department for Transport. *Government response to the e-scooter trials evaluation report. Policy paper.* Available at. https://www.gov.uk/government/publications/government-response-to-the-e-scooter-trials-evaluation-report/government-response-to-the-e-scooter-trials-evaluation-report; 2022. Accessed 15th September 2023.
[10] Department for Transport. *Perceptions of current and future e-scooter use in the UK. Summary report.* Available at. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1024151/perceptions-of-current-and-future-e-scooter-use-in-the-uk-summary-report.pdf; 2021. Accessed 15th September 2023.
[11] Aurora. A Comprehensive Guide to Shared E-Scooter Regulations Around the World. Available at. https://auroraelectrico.com/a-comprehensive-guide-to-shared-e-scooter-regulations-around-the-world/; 2023.
[12] Sanders RL, Branion-Calles M, Nelson TA. To scoot or not to scoot: findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders. Transportation research. Part A, Policy, and Practice 2020;139:217–27.
[13] Vallamsundar S, Jaikumar R, Venugopal M. Exploring the spatial-temporal dynamics of travel patterns and air pollution exposure of E-scooters. J Transp Geogr 2022;105:103477.
[14] Hourston George JM, Ngu Albert, Hopkinson-Woolley James, Stöhr Kuldeep. Orthopedic injuries associated with use of electric scooters in the UK: a dangerous trend? Case series and review of the literature. Traffic Inj Prev 2021;22(3):242–5.
[15] Störmann P, Klug A, Nau C, Verboket RD, Leiblein M, Müller D, et al. Characteristics and injury patterns in electric-scooter related accidents—a prospective two-center report from Germany. J Clin Med 2020;9(5):1569.
[16] Bentham MJ, Christopher HW, Borchert RJ, Thavakumar A, Riede P, Sadler TJ. Incidence and distribution of injuries associated with e-scooter use: a radiological perspective. Br J Radiol 2024;97(1155):567–73.
[17] Ahluwalia R, Grainger C, Coffey D, Malhotra PS, Sommerville C, Tan PS, et al. The e-scooter pandemic at a UK major trauma Centre: a cost-based cohort analysis of injury presentation and treatment. Surgeon 2023;21(4):256–62.
[18] Grant-Muller S, Yang Y, Panter J, Woodcock J. Does the use of E-scooters bring well-being outcomes for the user? A study based on UK shared E-scooter trials. Active Travel Studies: An Interdisciplinary J 2023;3(1).
[19] Heydari S, Forrest M, Preston J. Investigating the association between neighbourhood characteristics and e-scooter safety. Sustain Cities Soc 2022;83:103982.
[20] Drisko JW, Maschi T. Content analysis. USA: Oxford University Press; 2016.
[21] Cobern W, Adams B. When interviewing: how many is enough? Int J Assess Tools in Edu 2020;7(1):73–9.
[22] Seidman I. Interviewing as qualitative research: A guide for researchers in education and the social sciences. Teachers: college press; 2006.
[23] Miles MB, Huberman AM, Saldaña J. Qualitative data analysis: A methods sourcebook. 4th ed. Los Angeles: SAGE; 2020.
[24] MATLAB Deep Learning Toolbox. (2023). MathWorks. Available at: https://uk.mathworks.com/products/deep-learning.html? [Accessed 13/06/24].
[25] Al-Habaibeh A, Shakmak B, Watkins M, Shin HD. A novel method of using sound waves and artificial intelligence for the detection of vehicle's proximity from cyclists and E-scooters. Methods X Jun 2024;1:12.
[26] Al-Azmi A, Al-Habaibeh A, Abbas J. Sensor fusion and the application of artificial intelligence to identify tool wear in turning operations. Int J Adv Manuf Technol 2023;126:429–42. https://doi.org/10.1007/s00170-023-11113-w.
[27] Alkhadafe H, Al-Habaibeh A, Lotfi A. Condition monitoring of helical gears using automated selection of features and sensors. Measurement 2016;93:164–77 [ISSN 0263-2241.].

[28] Al-Azmi A, Al-Habaibeh A, Abbas J. Sensor fusion and the application of artificial intelligence to identify tool wear in turning operations. Int J Adv Manuf Technol 2023;126:429–42. https://doi.org/10.1007/s00170-023-11113-w.

[29] Hollingsworth J, Copeland B, Johnson JX. Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. Environ Res Lett 2019; 14(8):84031. https://doi.org/10.1088/1748-9326/ab2da8.

[30] Glavić D, Trpković A, Milenković M, Jevremović S. The e-scooter potential to change urban mobility—Belgrade case study. Sustainability 2021;13(11):5948.

[31] Hardt C, Bogenberger K. Usage of e-scooters in urban environments. Transportation research procedia 2019;37:155–62.

[32] Zhang W, Buehler R, Broaddus A, Sweeney T. What type of infrastructures do e-scooter riders prefer? A route choice model. Transp Res Part D: Transp Environ 2021;94:102761.

[33] Benhamed A, Gossiome A, Ndiaye A, Tazarourte K. Characteristics and comparison between e-scooters and bicycle-related trauma: a multicentre cross-sectional analysis of data from a road collision registry. BMC Emerg Med 2022;22(1):164. https://doi.org/10.1186/s12873-022-00719-0.

[34] Posirisuk P, Baker C, Ghajari M. Computational prediction of head-ground impact kinematics in e-scooter falls. Accid Anal Prev 2022;167:106567. https://doi.org/10.1016/j.aap.2022.106567.

[35] Clough RA, Platt E, Cole E, Wilson M, Aylwin C. Major trauma among E-scooter and bicycle users: a nationwide cohort study. Inj Prev 2023;29(2):121–5. https://doi.org/10.1136/ip-2022-044722.

[36] Hardinghaus M, Oostendorp R. In: Nathanail EG, Gavanas N, Adamos G, editors. Feelings of insecurity, obstacles and conflicts: Issues blind people have with e-scooters in public space and potential improvements BT - smart energy for smart transport. Springer Nature Switzerland; 2023. p. 991–1000.

[37] Sikka N, Vila C, Stratton M, Ghassemi M, Pourmand A. Sharing the sidewalk: a case of E-scooter related pedestrian injury. Am J Emerg Med 2019;37(9):1807.e5–7. https://doi.org/10.1016/j.ajem.2019.06.017.

[38] Sherriff G, Lomas M, Blazejewski L, Larrington-Spencer H. A micromobility buffet: e-scooters in the context of multimodal spaces and practices in greater Manchester. Active Travel Studies: An Interdisciplinary J 2023;3(1). https://doi.org/10.16997/ats.1194.

[39] Shakmak B, Watkins M, Al-Habaibeh A. How clean is the air you breathe? Air quality during commuting using various transport modes in Nottingham. In: Mporas I, Kourtessis P, Al-Habaibeh A, Asthana A, Vukovic V, Senior J, editors. Energy and sustainable futures. Proceedings of 2nd ICESF 2020. Springer proceedings in energy. Cham: Springer; 2021. p. 247–56. ISBN 9783030639150; available on-line at: https://link.springer.com/book/10.1007/978-3-030-63916-7.

[40] Ali AH, Thakkar R. Climate changes through data science: understanding and mitigating environmental crisis. Mesopotamian J Big Data 2023;2023:125–37. https://doi.org/10.58496/MJBD/2023/017.