

Article

# A Scientometric Review of Powered Micromobility

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**Abstract:** Micromobility is an emerging field of transportation, referring to trips undertaken by a range of microvehicles. Microvehicles encompass both traditional and emerging types of light vehicles from conventional bicycles and powered-two wheelers, through to e-bikes and e-scooters, e-skateboards and “hoverboards”. The recent uptake in powered microvehicles emphasizes the need to understand the knowledge domain of micromobility research. This paper summarises the research status by identifying main contributors to and evolutionary trends in the field. The study applied scientometric analysis techniques to review 474 articles published between 1991 and 2020. The search on Thomson Reuter’s Web of Science database was guided by the Society of Automotive Engineers (SAE) common vocabulary for powered micromobility. Results show a proliferation of research in the field of powered micromobility since 2012, which demonstrates that the growth in research is occurring alongside the increased availability of microvehicles and trips being made using microvehicles. A broad range of research topics including user behaviour, vehicle technology, planning, policy, health and safety were identified with the latter two found to be the most studied areas. Findings suggest many potential benefits of using micromobility and that the field will continue to grow, spurred by the popularity of shared e-scooter schemes. Greater collaboration in the field is desirable to broaden the dissemination of knowledge.

**Keywords:** micromobility; scientometric analysis; e-bikes; e-scooters; powered-two wheelers

## 1. Introduction

Micromobility is an emerging field of transportation that encapsulates travel undertaken using a range of light vehicles, collectively referred to as microvehicles [1]. Microvehicles encompass both traditional and emerging vehicle types, from conventional bicycles and powered-two wheelers, through to power-assisted e-bikes, e-scooters and new vehicles such as electric skateboards and “hoverboards” [2]. The proliferation of shared mobility systems [3], including integration with mobility as a service (MaaS), and improvements in vehicle technology has seen renewed interest in micromobility and microvehicles [4,5], particularly powered microvehicles that are either partially or fully motorised [1].

Despite the recent uptake in powered microvehicles, there has yet to be an analysis of the knowledge domain of powered micromobility research. Recent reports from the International Transport Forum (ITF) and the National Association of City Transportation Officials (NACTO) address specific issues regarding safety [1] and usage trends [3]. However, there is a need for a comprehensive analysis of the scientific outputs to date to provide a holistic representation of the field.

Scientometric analysis is a data driven approach for examining a field of research and is increasingly being used for mapping knowledge domains [6]. Scientometric analysis techniques are commonly employed to demonstrate the scientific development of the knowledge domains within a field of research by exploring relationships through analysis of bibliographic data such as citations and

co-authorship [7]. They are particularly applicable for preliminary investigation of a field due to the ability to rapidly synthesise, sort and analyse bibliographic data and display knowledge [6,7]. Through this process, a comprehensive perspective of the research field can be summarised allowing for knowledge capture and identification of trajectories for future research.

This study provides a review and scientometric analysis of powered micromobility research, with articles identified in the review published between 1991 and 2020. The aim was to provide an overview of the transportation research undertaken to date in this emerging field. The main objectives of the study were to:

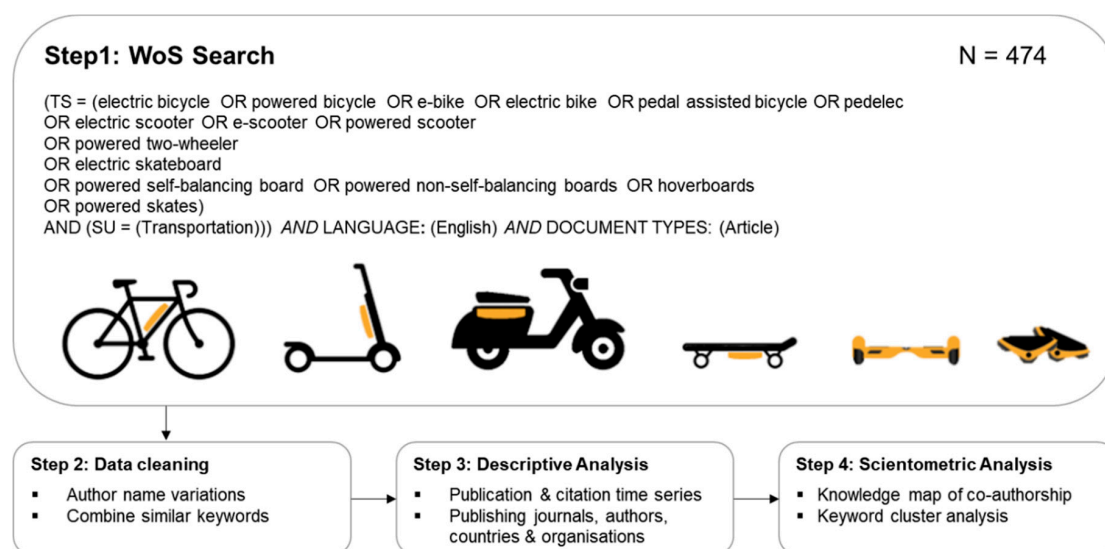
- Summarise published research addressing powered micromobility;
- Understand the overall research status of powered micromobility from the perspective of country, institution, article co-citation and keyword co-occurrence as well as to identify key research topics; and
- Identify the knowledge domain, trends and future directions of powered micromobility research.

The manuscript is organised as follows: first, the Background section presents a high-level introduction to micromobility. The Methodology details the data utilised for the study and the scientometric analysis. The Results section presents key findings with the Discussion providing an interpretation of these findings and positing future directions for micromobility research.

### *Background*

The term micromobility has only recently entered the lexicon of transportation with the term popularised around 2016 [1]. Alongside the new terminology, a range of different classifications and definitions for micromobility are emerging. The ITF's recent report, addressing safe micromobility, reviewed various international microvehicle classification systems. The report defined microvehicles as having top speeds of approximately 45 km/h, weighing less than 350 kg and being either human-powered or electrically assisted vehicles [1]. The ITF classification presents a broad taxonomy and considers the full range of light vehicles [1]. Some of the vehicles included in the ITF classification, such as conventional bicycles, are mainstays of the transportation systems and have been the subject of extensive research addressing key issues such as safety, health and how to promote increased usage [8–10]. Recently there has been an increase in the number and range of powered and power-assisted microvehicles. This increase in both the range of different powered microvehicles and their usage has been driven by technological innovations, particularly in regards to power supply, and through shared micromobility schemes that have become popular in cities throughout the world [3,11]. For example, in the United States of America, there are over 100 public shared micromobility schemes in operation, which collectively operate over 85,000 e-scooters and over 84 million trips were made using shared micromobility systems in 2018 [3].

The Society of Automotive Engineers (SAE, Warrendale, PA, USA) established a common vocabulary for powered micromobility in their taxonomy "*SAE J3194—Standard taxonomy of powered micromobility vehicles*" [2]. Within the SAE taxonomy, there are four criteria for classifying powered micromobility vehicles: a weight up to 227 kg, a width of up to 1.5 m, a top speed of 48 km/h and a power source of either an electric motor or a combustion engine [2]. The classification limits a microvehicles kinetic energy to roughly one hundred times less than the kinetic energy reached by a compact car at top speed [1]. Using the four factor taxonomy, SAE distinguishes six types of powered microvehicles: powered bicycles, powered standing scooters, powered seated scooters, powered self-balancing boards, powered non-self-balancing boards, and powered skates [2] (Figure 1).



**Figure 1.** Analysis process.

Powered microvehicles offer a range of transportation alternatives, and have the potential to change the way that people travel, particularly in urban environments [12,13]. Proponents of micromobility highlight that they provide quick, convenient travel and the ability to fill the “last-mile” gap within public transport systems [14,15] or offer an alternative to private transport for short trips [16,17]. Powered microvehicles are also less physically demanding than traditional human-powered counterparts [17,18], which may help to explain their increased usage. For example, research conducted in China demonstrated that e-bike users travel longer distances, yet have shorter travel times, compared to conventional bicycle users [17].

Other suggested benefits of powered micromobility include reduced congestion and carbon emissions due to reduced demand for private vehicle trips and reliance on fossil fuels, however, these benefits are influenced by the underlying power source used by the microvehicle [16,19]. There are also potential public health benefits when using power-assisted microvehicles to replace sedentary travel made using private motor vehicles [4,20]. Research further suggests that usage may also be associated with the enjoyment derived from using these vehicles [14].

Nevertheless, there remain a range of questions regarding the use of microvehicles and their integration into the transportation system. One of the most commonly cited issues is that of road user safety [1]. Currently, there have been few studies investigating the injury epidemiology of the emerging range of powered microvehicles. Albeit, there are studies investigating more established vehicle types within the powered microvehicle taxonomy such as powered two-wheelers. There also exists a range of issues regarding microvehicle user safety and transport planning, including where they should be used within the road reserve [21,22], safe operating speeds [22–24] and use of safety equipment [21].

Other issues are the lack of consistency regarding regulation, which has already been shown to lead to differing road rules for powered microvehicles in different jurisdictions [25,26]. There further remain questions regarding the sustainability and public health benefits of these modes, with health benefits largely dependent on if trips are being diverted from private motorised travel or more sustainable active modes [27,28]. The amalgamation of these issues are leading some to question if microvehicles are here to stay or if they are merely a passing trend [14], and if microvehicles do remain part of the transport system, what modes and aspects will be retained?

In summary, there are a range of research questions to address, regarding this emerging field of transportation. Globally, evidence suggests that powered micromobility is here to stay, and the proliferation of these modes of transport appear to have outpaced the academic research. As such,

there is a need to understand the research undertaken to date to develop a comprehensive understanding of the field, highlight gaps in the current research and identify avenues for future research to address concerns regarding issues including, usage, safety and legislation.

## 2. Methodology

### 2.1. Data Processing

The analysis followed the process depicted in Figure 1. Bibliographic data retrieved from Thomson Reuters' Web of Science (WoS) database core collection provided the data source for this study. The WoS core collection contains articles from over 21,000 journals and is the most frequently used database for analysis of scientific publications [29].

The search topic (TS) was developed based on the classification of powered micromobility vehicles as specified in "SAE J3194: taxonomy and classification of powered micromobility vehicles" [2]. The search topic used the logical combination of search terms: "electric scooter OR e-scooter OR powered scooter OR pedelec OR electric bicycle OR powered bicycle OR e-bike OR electric bike OR self-balancing board OR powered skates OR powered two-wheeler OR pedal assisted bicycle OR powered seated scooter OR electric skateboard OR non-self-balancing boards OR hoverboard". The search was restricted to the "transportation" research category (SU). Additional inclusion criteria included that the document was a journal "article", written in English with the search spanning 1900 to 2020; however, the first article was identified in 1991.

Results presented in this manuscript are from a search conducted on 25 September 2020. Full citations for each publication were exported. Manual cleaning of the data removed slight variations in author names, combined keywords (e.g., electric scooter and electric scooters) and removed articles not related to micromobility. This yielded 474 unique publications for analysis.

### 2.2. Analysis

Summary descriptive statistics are reported for the identified manuscripts including; year of publication, citations per year, and most productive publishing journals, countries, research organisations and authors.

VOSviewer, a tool to assist with scientometric analysis developed by van Eck and Waltman (Leiden University, Leiden, The Netherlands) in the Netherlands [30], was used to analyse and visualise relationships between authors, articles and keywords. Three types of analysis were performed using the software. Analysis of co-authorship was undertaken to identify clusters of researchers and demonstrate collaboration in the field. Citation analysis was performed based on the number of citing articles to identify the key publications in the field. Finally, keyword co-occurrence analysis based on the author keywords were performed to condense the authors' academic viewpoints and keyword clusters were built to provide an indicator of key domains of research as well as to explore the research domain development over the last decade.

## 3. Results

In total, 474 publications were identified using the WoS search. The identified articles received a combined 5697 citations ( $m = 12.0$   $SD = 21.5$ ). The most cited article received 253 citations, while 93 manuscripts had received no citations at the time that the search was conducted. Figure 2 provides a summary of the number of publications and citations by year. The distribution of publications demonstrates a proliferation of powered micromobility research from 2012. The field has shown a sustained growth with the most publications to date in 2019. The citation heatmap shows citations increasing from 2009, for manuscripts published from the early 2000s and onwards.

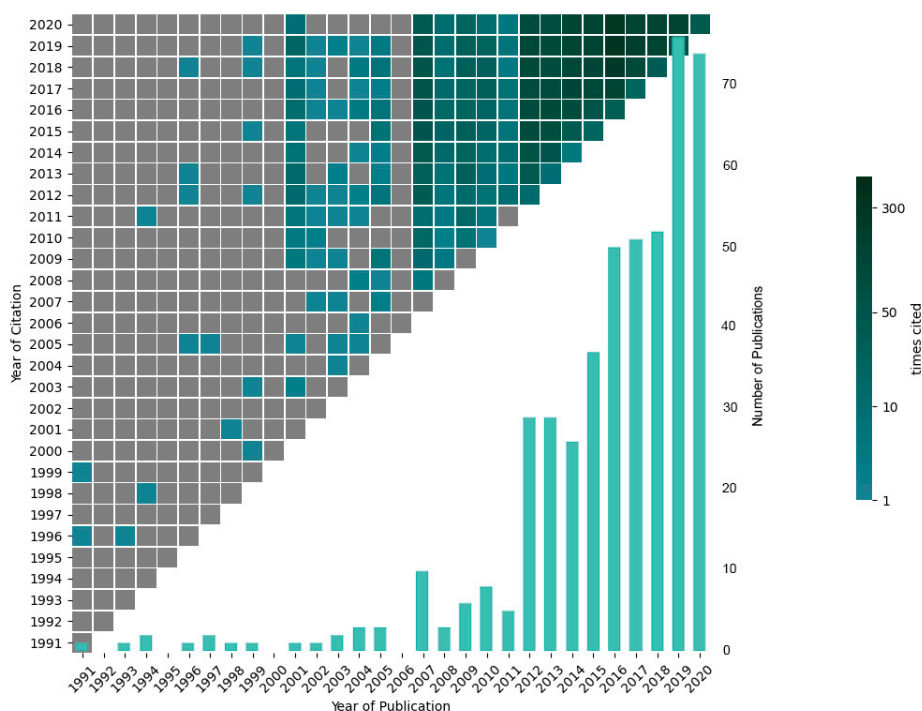


Figure 2. Publications and Citations by year.

Unsurprisingly, the most citations of the identified articles also occurred in 2019, demonstrating the increased research being undertaken within the field and the relationship between publications and citations. The reduction in publications and citations in 2020 is a reflection of the search being conducted mid-year.

### 3.1. Modes of Transport

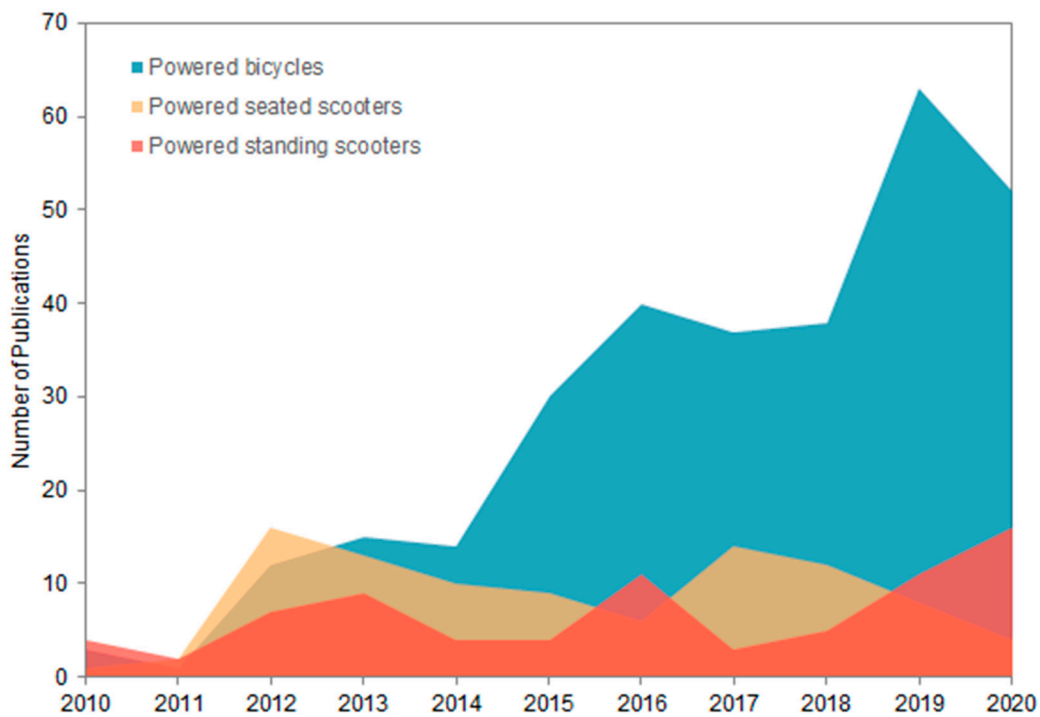
Table 1 presents stratification of the search term results using the SAE typology. The research to date has focused generally on three of the broader classifications of powered micromobility within the SAE typology; powered bicycles, powered standing scooters, and powered seated scooters. Only one of the identified articles in the search addressed “self-balancing boards”, while the search term “powered skates” and search terms related to “non-self balancing boards”, did not identify any published articles.

The findings demonstrate the maturity of each mode and indicate prevalent and niche modes encompassed within the powered micromobility typology. The search also highlighted some ambiguity regarding the use of the term powered scooter, which referred to both seated and standing scooters. Figure 3 demonstrates time series analysis of publications by typology for powered bicycles, powered standing scooters, and powered seated scooters. The temporal distribution of publications indicates the growth in research into powered bicycles over the past decade. There has been a slight growth in research addressing powered standing scooters, while research investigating powered seated scooters remains constant.

**Table 1.** Publications statistics by typology.

SAE Typology Group	Search Term	<i>n</i> (%) <sup>1</sup>
Powered bicycle	Pedelec	18 (3.8)
	Electric bicycle	180 (38.0)
	Electric bike	140 (29.5)
	Powered bicycle	92 (19.4)
	Pedal assisted bicycle	12 (2.5)
	E-bike	140 (29.5)
Powered standing scooter	Electric scooter	58 (12.2)
	E-scooter	19 (4.0)
Powered seated scooter	Powered scooter <sup>2</sup>	52 (11.0)
	Powered seated scooter	2 (0.4)
	Powered two-wheeler	100 (21.1)
Powered self-balancing board	Powered self-balancing board	0 (0.0)
	Hoverboard	0 (0.0)
Powered non-self-balancing boards	Powered non-self-balancing board	0 (0.0)
	Electric skateboard	1 (0.2)
Powered skates	Powered skates	0 (0.0)

1: Some publications consider multiple modes of transport, 2: Term used for both seated and standing scooters.

**Figure 3.** Publications by SAE typology.



### 3.2. Journals

Analysis of publishing journals demonstrates the varied research domains studying powered micromobility. The majority of the 289 articles (60%) were published in the ten journals listed in Figure 4 and the remaining 195 articles were distributed over 50 other journals.

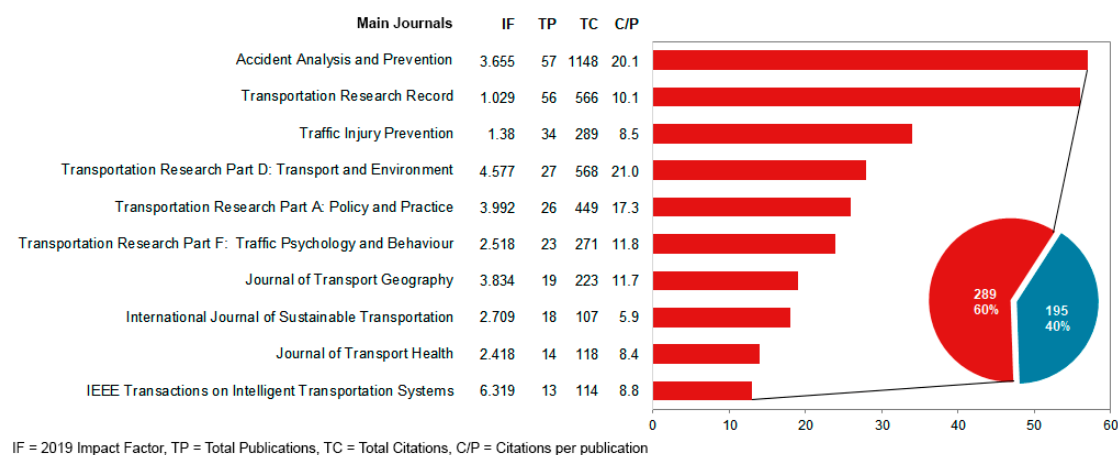


Figure 4. Publications by journal.

Accident Analysis and Prevention was the most prolific journal in terms of total publications and citations. This was followed by Transportation Research Record (TRR), which publishes research from the Annual Transportation Research Board conference. Traffic Injury Prevention was the next most common journal, with articles in this journal and Accident Analysis and Prevention tending to focus on injury epidemiology and issues of road safety. Articles published in Transportation Research Part D had the highest number of citations per publication. The journal IEEE Transactions on Intelligent Transportation Systems has the highest impact factor, but also the lowest number of publications amongst the top ten journals addressing micromobility. A diverse range of articles were identified in other key journals covering the various dimensions of transportation including; psychology, health, geography, technology, policy and the environment.

The WoS database classifies each article into research categories. The search term for this study restricted findings to articles in the transportation category and therefore all articles fell under this category. Besides Transportation (474), the most common research categories were Engineering (203), Public, Environmental and Occupational Health (109) and Social Science and Psychology (84). Other categories which were each addressed by less than 50 articles are Business and Economics, Science and Technology, Environmental Science and Ecology as well as Geography.

Figure 5 shows differences in research focus between the three main categories of powered bicycles, seated and standing scooters, respectively. The general distribution remains similar for the three mode categories, with the majority of articles concerning the research area of Engineering, Public, Environmental and Occupational Health as well as Social Sciences and Psychology. While Business and Economics was one of the key aspects for almost 15% of published articles regarding powered bicycles and standing scooters, only 5% of publications regarding seated scooters were concerned with this research area. Research on powered standing scooters also had a relatively strong focus on Environmental Sciences and Ecology (14%), compared to the two other mode groups. Behavioural aspects, summarised in the research category Social Sciences and Psychology, are less studied for powered standing scooters and powered bicycles.

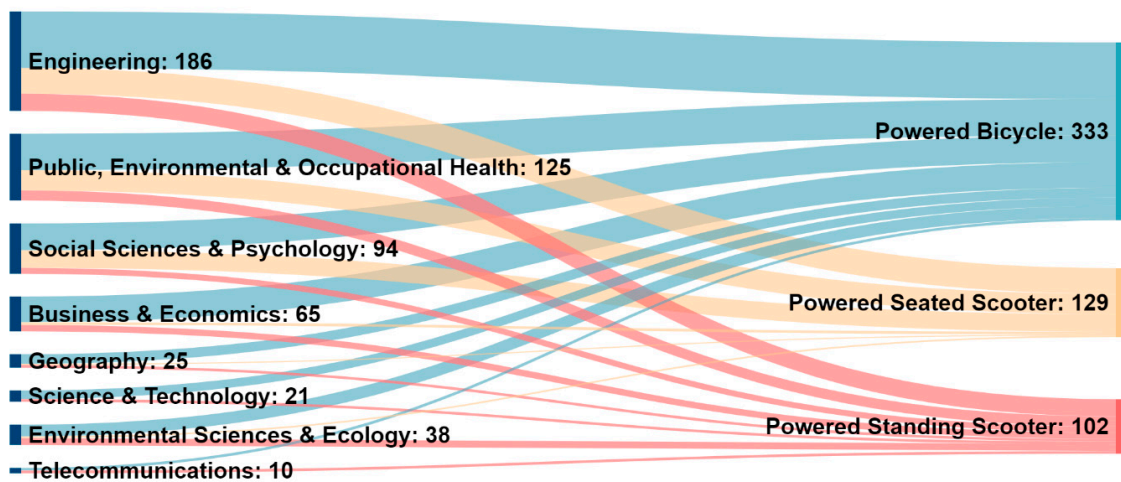


Figure 5. Research category by main mode.

### 3.3. Countries and Institutions

The search identified research originated from 50 countries and 526 organisations, based on the first author details attributed to each publication. Figure 6 provides a thematic representation of published articles by country with the top ten research organisations highlighted. The most published articles originated from organisations in the USA (22.6%), China (22.4%), the Netherlands (7.4%) and Australia (7.2%). Southeast University (6.2%), University of British Columbia (4.3%) and Monash University (3.8%) were the organisations attributed with the greatest number of published articles.

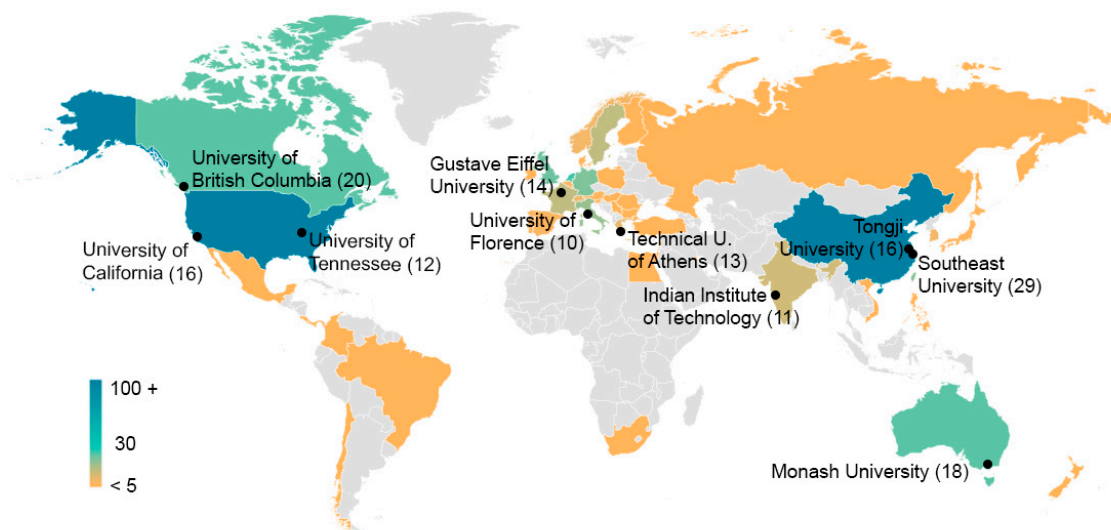


Figure 6. Publications by country and organisation.

### 3.4. Authors

Figure 7 shows a network representation of author collaboration. The knowledge map includes all authors with at least four publications and five citations, representing 44 of the 1178 authors identified in the WoS search. Each node in the figure represents one author and the size of the node indicates the number of citations attributed to that author. Links indicate the strength of collaboration between authors. The diagram shows that there are several co-authorship clusters investigating micromobility, represented through different colours; however, there is limited collaboration between these clusters, signifying that past collaboration in the field has been somewhat rare and localised.



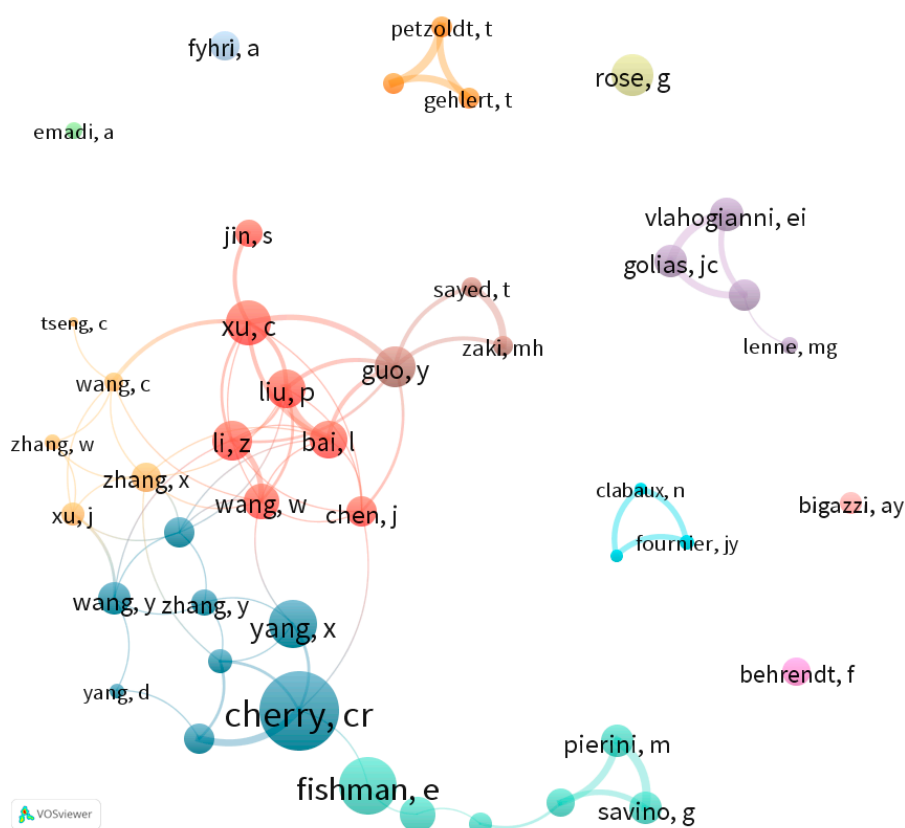


Figure 7. Network representation of co-authorship.

Table 2 provides a summary of the 10 most cited authors identified in the search, who also represent key nodes in Figure 7.

Professor Christopher Cherry (University of Tennessee) was the most prolific author, publishing 15 articles, which have received 714 citations from articles in the WoS core collection. Professor Cherry's most cited publication "Comparative environmental impacts of electric bikes in China", published in *Transportation Research Part F*, received 133 citations [31].

Dr Elliot Fishman (Institute of Sensible Transport) was the next most cited author, and authored the most cited manuscript which is discussed in the next section.

Professor Geoffrey Rose (Monash University) published seven articles, which received a combined 170 citations. Professor Rose's research focuses on electric bicycles and powered two-wheelers, with the most cited article considering the emerging issues and policy insights for electric bicycles both from an Australian and International perspective [26,32].

The following most cited authors consisted of a number of co-authors with connections to Southeast University in China. These authors collaborated on a range of articles, shown in red in Figure 7. Articles produced by these authors considered safety issues regarding electric bicycles at intersections [33] and red-light running behaviour [34], issues of electric bicycle registration in China [35] and how the built environment can influence electric bicycle users mode choice [36].

Rounding out the top ten most cited authors was Professor Eleni Vlahogianni from the National Technical University of Athens. Professor Vlahogianni's articles focused on powered two-wheelers including investigating intelligent transport systems [37], assessing the factors that influence their manoeuvrability and overtaking [38,39], and investigating their safety [40,41].

**Table 2.** Most cited authors.

Author	Affiliation	Country	TP	TC	C/P
Christopher Cherry	University of Tennessee	USA	15	714	47.6
Elliot Fishman	Institute of Sensible Transport	Australia	4	349	87.3
Geoffrey Rose	Monash University	Australia	7	170	24.3
Yanyong Guo	University of British Columbia	Canada	9	164	18.2
Zhibin Li	Southeast University	China	8	157	19.6
Pan Liu	Southeast University	China	8	148	18.5
Chengcheng Xu	Southeast University	China	8	144	18.0
Lu Bai	University of Hong Kong	China	8	140	17.5
Wei Wang	Southeast University	China	7	124	17.7
Eleni Vlahogianni	National Technical University of Athens	Greece	6	98	16.3

TP = Total Publications, TC = Total Citations, C/P = Citations per publication.

### 3.5. Article Citation Analysis

Citation analysis identified the ten most highly cited articles within the identified publications (Table 3). Dr Elliot Fishman authored the most cited article identified in the search, which presents a literature review of bike-sharing. The manuscript is focused more generally on bike-share schemes, however, the authors highlight that e-bikes are increasingly being introduced into existing shared systems. Given the manuscript was published in 2016, the research foreshadows the proliferation of shared powered-microvehicles and highlights the potential for e-bikes to cater for longer trips and attract new users to shared schemes. The author identifies future directions including the integration with GPS, dockless systems and linking with public transportation. They also highlight the need for further research regarding key issues of mode choice, congestion, environmental issues and health.

Professor Christopher Cherry authored the two second most cited articles. Both articles investigated issues of electric bicycle use in China [17,31]. The first article investigated the environmental impacts of electric bicycles and found they emit lower levels of pollution compared to cars and motorcycles, but had comparable emissions to public transport, with emissions linked to the underlying power source used for charging [31]. The authors conclude that comparative analysis of the environmental performance of electric bikes should be considered when developing policy and that microvehicles should be encouraged when they displace car and motorcycle use.

The examination of use patterns identified that electric bicycle users tended to travel further distances than conventional bicycle users and that the mode was more often used as an alternative to public transportation, as opposed to human-powered modes [17]. The research highlighted the need for policy makers to understand why people choose to use electric bikes and in particular understand the modal shift that would occur in their absence [17].

Professor Cherry also co-authored two other highly cited articles; the first addressed shared bicycle and shared electric bicycle use in Beijing [42] and the second presented a case study regarding the rapid growth of electric bicycles in China, including discussion of technical, economic and political factors [43]. These manuscripts demonstrate how personal e-bikes offer an attractive alternative to public transportation, however caution against shared systems for providing first-and last-mile transport solutions [42]. Also highlighted are how policy can influence purchase choice and how learnings can be applied to other countries and modes of transport, which is a particularly pertinent issue given the rapid rise of e-scooters.

Table 3. Most cited articles.

Article Title	Author Full Names	Journal	Year	Citations
Bikeshare: A review of recent literature	Fishman, Elliot	TRANSPORT REVIEWS	2016	253
Comparative environmental impacts of electric bikes in China	Cherry, Christopher R.; Weinert, Jonathan X.; Xinmiao, Yang	TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT	2009	133
Use characteristics and mode choice behavior of electric bike users in China	Cherry, Christopher; Cervero, Robert	TRANSPORT POLICY	2007	123
The red-light running behavior of electric bike riders and cyclists at urban intersections in China: An observational study	Wu, Changxu; Yao, Lin; Zhang, Kan	ACCIDENT ANALYSIS AND PREVENTION	2012	103
Factors influencing the choice of shared bicycles and shared electric bikes in Beijing	Campbell, Andrew A.; Cherry, Christopher R.; Ryerson, Megan S.; Yang, Xinmiao	TRANSPORTATION RESEARCH PART C-EMERGING TECHNOLOGIES	2016	99
The transition to electric bikes in China: history and key reasons for rapid growth	Weinert, Jonathan; Ma, Chaktan; Cherry, Christopher	TRANSPORTATION	2007	95
Nonconventional on-board charger for electric vehicle propulsion batteries	Solero, L	IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY	2001	95
E-bikes and urban transportation: emerging issues and unresolved questions	Rose, Geoffrey	TRANSPORTATION	2012	83
The safety of electrically assisted bicycles compared to classic bicycles	Schepers, J. P.; Fishman, E.; den Hertog, P.; Wolt, K. Klein; Schwab, A. L.	ACCIDENT ANALYSIS AND PREVENTION	2014	80
Analysis of powered two-wheeler crashes in Italy by classification trees and rules discovery	Montella, Alfonso; Aria, Massimo; D'Ambrosio, Antonio; Mauriello, Filomena	ACCIDENT ANALYSIS AND PREVENTION	2012	73

Professor Geoff Rose's article addressed similar questions regarding emerging issues associated with e-bike usage, while presenting a conceptual model for investigating emerging vehicle types [26]. The article also highlights aspects for e-bike use regarding mobility, environmental impacts, health, safety and policy, which reflect broader issues associated with powered micromobility. Rose identifies the need for a transportation profession to develop performance based standards and a deeper understanding of emerging modes of transport.

The remaining articles dealt with issues of technology, behaviour and safety. When considering technology, Solero [11] presented research investigating on-board charger arrangement for installation on electric scooters. Wu [44] conducted an observational study of red-light running behaviour of e-bike and conventional bicycle riders. The study did not find a statistically significant difference in red-light

running behaviour of e-bike riders versus conventional bike riders and the authors concluded that red-light running is a common behaviour amongst both road user groups.

The final two most cited articles addressed issues of road safety. Schepers [45] investigated emergency department treated bicycle and e-bike users in the Netherlands to compare crash risks of the two road user groups. The findings highlighted an increased risk of injury for e-bike users, however, noted that the severity of crashes was equal with bicycle users. Montella [46] investigated powered two-wheeler crashes in Italy using data mining techniques and identified combinations of road, environment and driver attributes that contributed to crash severity while proposing a range of engineering countermeasures and policy initiatives to reduce PTW injuries including safety barriers for run-off road crashes, perceptual countermeasures to calm traffic and improved road alignment.

Figure 8 shows the citation trend for the above identified articles over time. Fishman's review on bike-sharing systems was published in early 2016 and rapidly advanced to be the most cited article in the field. A similar fast, though much lower citation increase rate can be observed for Campbell et al.'s article. The graph also shows that older articles (i.e., published before 2010) only became recognised after the research field had further emerged, demonstrating the recent growth and interest in the field of research.

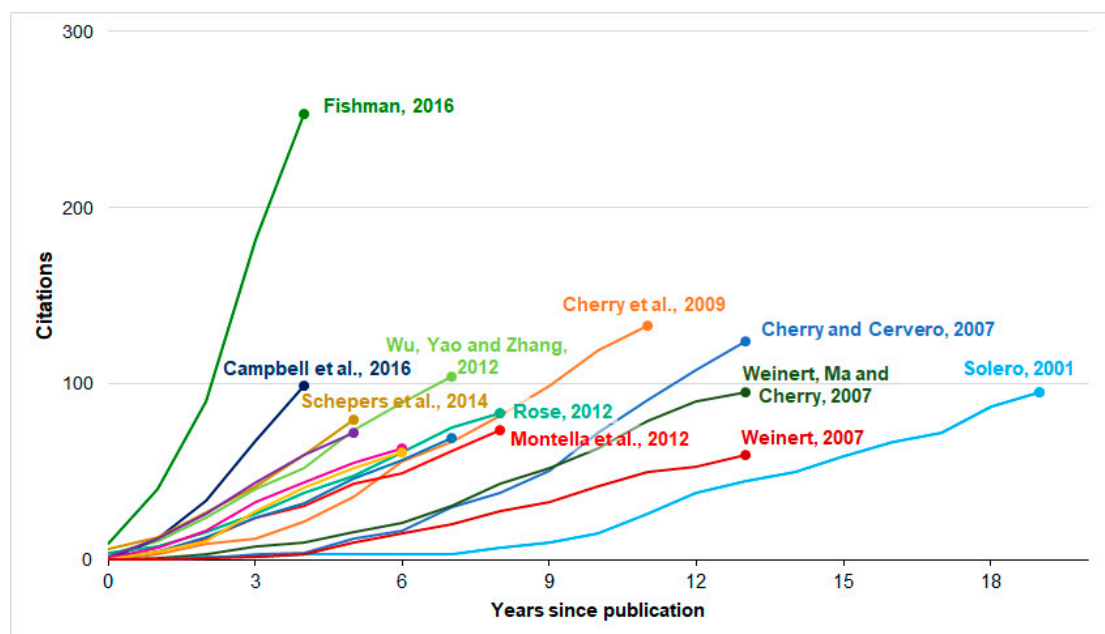


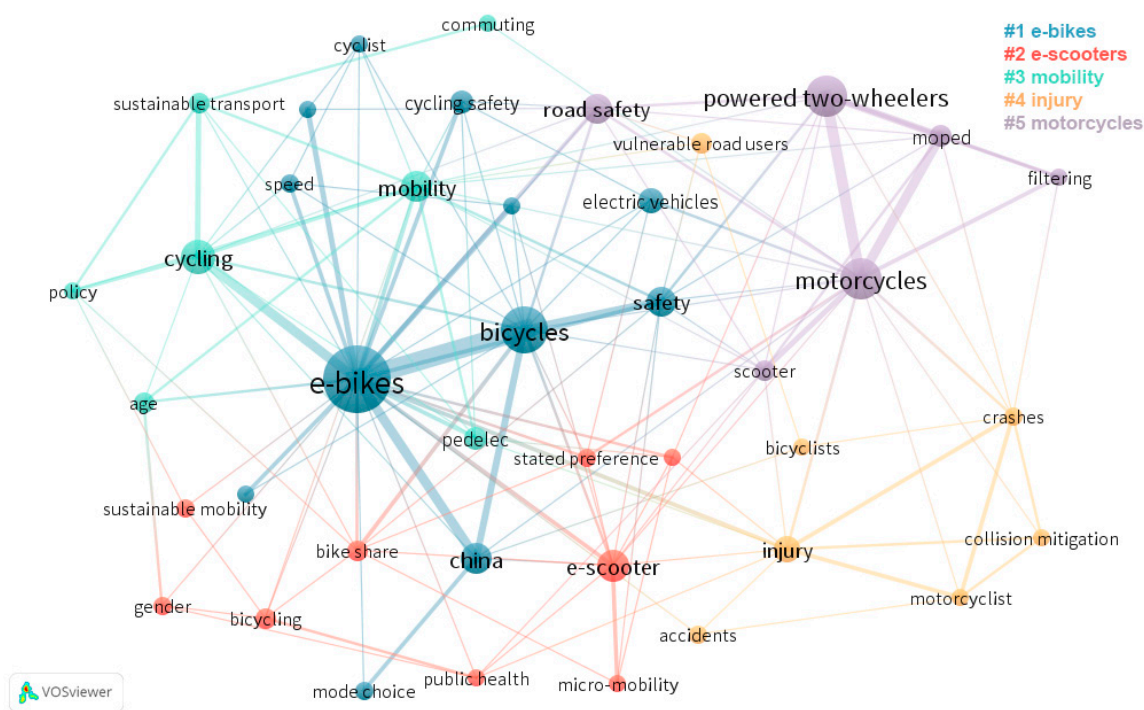
Figure 8. Most cited articles.

### 3.6. Keywords

Finally, analysis of article keywords was undertaken. Keyword analysis was limited to publications from 2012 and onwards, as publications prior to this date are often missing keyword records, in particular the WoS generated keyword plus. The analysis considered both author keywords, the plain language words selected by the authors to describe their research, and the WoS Keyword plus, keywords that frequently appear in article references and are determined using an algorithm developed by Clarivate Analytics. Table 4 provides a summary of the top ten keywords identified using each approach, while Figure 9 provides a cluster analysis of the author keywords. Individual modes of transport were the most common author keywords, with e-bikes, bicycles, motorcycles, powered two-wheelers and e-scooters all appearing in the top ten. Beyond the modes of transport, author keywords identified issues including mobility and safety. Similar keywords were found from the analysis of keywords plus, with a particular focus on safety-related keywords including impacts, accidents and crashes.

**Table 4.** Summary of author keywords and keywords plus.

Rank	Author Keywords	<i>n</i>	Keywords Plus	<i>n</i>
1	E-Bikes	86	Behaviour	55
2	Bicycles	44	Safety	51
3	Motorcycles	30	Bicycles	49
4	Powered two-wheelers	28	China	44
5	E-scooter	21	Cyclist	38
6	China	18	E-bikes	32
7	Cycling	18	Vehicles	28
8	Mobility	15	Impacts	26
9	Safety	15	Accidents	26
10	Road safety	14	Crashes	21



**Figure 9.** Author keyword clusters.

Author keywords with at least four occurrences were clustered with VOSviewer. From these 44 keywords, five thematic clusters emerged. Figure 9 shows that these clusters are mainly built around a central keyword, which were therefore selected as the cluster names.

- Cluster 1—E-bikes: The largest cluster encompasses 12 keywords centred around electric bicycles. Strongly linked keywords are related to cyclist safety, speed and mode choice.
- Cluster 2—E-scooters: The second cluster contains keywords such as e-scooter, bike share and micromobility, thus represents the colloquial understanding of micromobility.
- Cluster 3—Mobility: The third cluster is mainly comprised of keywords related to the cycling activity, its users and benefits.
- Cluster 4—Injury: The fourth cluster focuses on road safety and injury aspects of micromobility.







and trips being made using microvehicles [3], which is being driven by the recent trend towards public powered micromobility schemes.

The renewed interest in powered micromobility can be somewhat attributed to the new wave of fourth generation vehicles available in bike-sharing and e-scooter sharing schemes [4,5]. The schemes that use powered and power-assisted vehicles also include technologies such as dockless share systems, demand-responsive pricing and integrated mobile phone applications [4]. These enhancements over conventional share bike schemes are demonstrated to attract greater usage than previous docked systems and dockless human-powered shared bicycle schemes [4]. So much so, that a number of shared micromobility operators have transitioned their fleet of vehicles away from human powered microvehicles towards e-bikes and e-scooters [3]. There is also growth in the number of privately purchased microvehicles, often referred to as personal mobility devices, with proponents identifying benefits in terms of cost saving, and prolonging mobility options for older road users [18,42,47]. Other factors driving powered micromobility use include pro-environmental and technophile attitudes, particularly amongst early adopters [28].

Our research demonstrated that the growth in publications is occurring alongside growth in citations, particularly amongst a core set of articles within the field. These seminal research works cover topics including user behaviours, mode choice and safety. Interestingly the most cited research does not capture the issues surrounding e-scooters, despite their recent popularity as a transport mode. The review also highlighted that outside of the core articles citations are sparse, highlighting that while the growth in micromobility mode share and usage is occurring rapidly, the field of research is still in its infancy and there is a considerable lag between the uptake of powered micromobility vehicles and the scientific research investigating the field. This may highlight why issues surrounding newer modes of micromobility are yet to be explored and more broadly researched within the academic literature.

The citation analysis highlights that there is limited collaboration within the field with much of the research to date involving collaborations at an institutional or geographic level; similarly, it may provide indication of citation bias between collaborators. Notwithstanding, this is somewhat expected given the broad range of issues being investigated including safety, psychology, health, technology, planning and policy. Nevertheless, this finding points to a pertinent opportunity for greater collaboration, particularly when considering the differing levels of maturity of micromobility research and usage in different countries, an issue that was also noted in previous reviews by Rose [26]. For example, some of the most highly cited research from China addresses issues of technical, economic and political factors of e-bike usage from 2007 [43]. The analysis also highlighted researchers at Chinese institutions, particularly Southeast University, have undertaken considerable research addressing electric bicycles, which are an established mode of transport in China [48]. These learnings can be applied to other jurisdictions where power-micromobility remains a relatively new phenomenon.

The review also demonstrated that many European nations have extensive experience with various forms of powered-micromobility particularly powered two-wheelers and electric bicycles, with research identified in numerous European countries including the Netherlands, Italy and Sweden [49–51]. Furthermore, conceptual models for investigating emerging vehicles have been developed and could be applied to better understand new and emerging forms of powered microvehicles [26] and investigate specific issues in new jurisdictions. The substantial body of research from Europe and China also highlights a potential limitation of this review as the analysis only considered research articles published in English, which may exclude pertinent powered micromobility research published in other languages.

Analysis of search terms using the six types of microvehicles specified by SAE highlight the evolution of research. Historically a high proportion of research was addressing powered seated scooters including powered two-wheelers. Throughout the study period, the annual number of publications addressing seated scooters remained relatively constant. However, analysis of search terms demonstrated a clear shift towards research investigating powered bicycles. This appears to correspond with the uptake of both shared bicycle schemes [52] and the increased availability of powered electric bicycles and pedelecs in Europe [53], coupled with research on powered bicycles

from China (for example Cherry [17]). E-scooters represented one of the 10 most utilised keywords by authors. We envisage there will be continued growth in this area of micromobility research in the near future corresponding with the proliferation of shared micromobility schemes.

The search terms also demonstrate the niche areas of powered micromobility. This is an issue previously highlighted by SAE in their technical report [14]. In their research, SAE speculates that micromobility demand will continue to grow, driven by innovation in microvehicle design and sharing models [14]. However, while some modes have established a transportation market, it is likely that other modes, such as powered skates and self-balancing boards, are more likely to remain in the realms of novelty vehicles, and rather than representing a mode of transportation are more likely to be used as toys and forms of recreation. Notwithstanding, these modes still require investigation as there are potential issues regarding safety and the appropriateness where to operate these different modes.

Analysis of the publishing journals demonstrated that there is a range of different research frontiers for powered micromobility research. Accident Analysis and Prevention and Traffic Injury Prevention published 57 and 34 articles respectively, combined representing 28.6% of total publications identified in the search. Unsurprisingly, many of these studies focused on crash and injury epidemiology with research investigating electric bicycles and powered two-wheelers and comparisons with conventional bicycles [45,52,54]. Studies also addressed sub-groups of road users including stratification by age and gender [34,54,55] with research presented from numerous countries including Slovenia, Italy, France, Norway and China [34,46,54,56,57]. Other issues identified in these journals were the use of protective equipment [58], and the speeding and red-light running behaviours of road users [34]. However, the analysis identified a lack of road safety and injury research for new modes such as e-scooters and this represents an important research frontier that warrants investigation.

The issue of safety is crucial and perceptions of the safety of a mode can be a barrier to participation, as can the requirement for safety equipment, particularly when using shared micromobility systems [59]. Addressing safety issues associated with powered micromobility will help define where in the road-reserve microvehicles can operate and determine their regulatory requirements. Clearly, there is considerable research still required to understand the safety implications of these modes. This includes investigation of hospital data, injury outcomes and linkage to trip characteristics and exposure data. The issue of exposure data is particularly interesting for powered micromobility as there have been difficulties obtaining this information for microvehicles [60]. This barrier can be somewhat overcome with powered-microvehicles, particularly those used in shared schemes as they are typically equipped with technology to monitor trip characteristics [13].

This represents a new frontier for research and makes big data collection a possibility for microvehicles, something that has previously been difficult to achieve with human powered microvehicles. Linking microvehicles into MaaS further facilitates the collection of data on linking trips, which represents an opportunity to understand how microvehicles connect and integrate within the broader transport system, for example providing improved first- and last-mile connections for public transport users [15,61]. MaaS may also leverage increased usage of shared micromobility. In this context, Guidon [5] highlights that pay per use may be favoured over subscription based shared micromobility systems. Data from these systems can inform policy and planning as they provide insight into travel behaviour across the service area [4] and can provide valuable information about infrastructure requirements for these new vehicles.

Other research frontiers were issues addressing the transport policy implications of micromobility, including estimating the impacts of micromobility on travel behaviour [62] and understanding factors that encourage adoption of these modes [63], including a more convenient and supportive mode of transport that requires less physical exertion. These issues are explored in the published literature, however, findings to date are drawn from isolated studies and there is yet to be consensus regarding policy issues.

Key research from the fields of transport psychology addressed factors associated with the intention to purchase and register microvehicles as well as perceptions towards using microvehicles

and the patterns of use and behaviour of micromobility users [25,35]. These studies found broad factors, including age, gender, education, income and car ownership, to influence user decisions.

Similarly, usage patterns were investigated utilising spatial analysis of micromobility [64], where spatial variables such as built environment factors [65] were investigated as a measure to predict demand. The influence of microvehicles on the built environment and land use planning were also raised with the need for favourable policy that supports microvehicles [66]. Researchers also highlighted the differing usage of microvehicles, for example as private transport [53], as a link to public transport services [42] and as delivery vehicles [67], albeit research regarding logistics and micromobility were scarce and represents an important under-researched area.

Other issues included how to reallocate space in urban environments to accommodate these microvehicles within the transportation network [68]. Several articles also explored the similarities and differences between human-and powered microvehicles from various perspectives including usage, trip characteristics or from a public health perspective [44,69–71].

In the years to come, there are likely to be many challenges and opportunities for shared micromobility schemes, particularly as cities begin to recover from COVID-19. Preliminary research from New York already demonstrates that micromobility schemes can be more resilient than public transport [72], and it is likely that powered micromobility will continue to play a larger role in urban transportation.

While the review has identified a range of research frontiers there are clearly a range of unanswered questions and topics that warrant further investigation. At the forefront, and as evidenced by the research to date, are issues of safety and how to incorporate these emerging vehicles into the transportation system. The research also points towards issues of usage and further work is required to understand the roles of these modes in providing transport alternatives, whether that is as an alternative to private, public or active modes. There is also a need to understand the trip types being undertaken using micromobility either for personal transport, commuting or as delivery vehicles. The augmentation of Big Data will help to answer many of these questions that have traditionally been difficult to address for other human powered microvehicles. These findings can inform land use planning policy and legislation and assist in addressing key issues related to congestion, mode choice, the environment and public health.

### *Limitations*

The manuscript provides an overview of peer-reviewed powered-micromobility research utilising scientometric techniques. These methods are being increasingly utilised as a preliminary means for investigating a field of research due to their ability to rapidly synthesise bibliographic data [7]. However, there are limitations associated with this data driven approach to literature review. At the onset of this research, it is noted that there are limitations with the search string utilised to extract data from the WoS. There is likely a great deal of valuable research in non-academic and non-peer-reviewed publications, as demonstrated by technical reports published by the ITF and NACTO on micromobility. This represents a potential limitation in the research, as clearly there are differences in the timelines for publication in academic and non-academic literature. Similarly, a previously noted limitation was restricting the search term to English language manuscripts. This was a necessary requirement for the analysis but again may significantly reduce the dataset from which conclusions can be drawn. The research also identified some ambiguity within the SAE micromobility typology, particularly regarding the use of terminology around scooters and powered-two wheelers, with articles using the terms interchangeably to refer to e-scooters, mopeds and motorcycles. Adoption of common terminology, through typologies such as SAEs, may help to reduce such overlapping terminology in future research.

While it is beyond the scope of this research to provide recommendations for improved scientometric techniques, previous research has noted various limitations associated with scientometric reviews due to the mathematical approaches utilised [73]. For example, the approaches suffer from a

temporal bias when assessing citations. There are also potential issues associated with citation bias and self-citation bias that can distort the findings of scientometric analysis.

It is noted that scientometrics is a useful preliminary method for exploring a field of research and that further review using systematic approaches are warranted to augment the findings of this study. Furthermore, there are issues with the currency of data and recognition that this is a retrospective form of analysis, as such there is a need for future reviews of the field of powered micromobility as it continues to grow and evolve.

## 5. Conclusions

Powered-micromobility represents an emerging field of transportation research that encompasses both new modes of transport, such as e-scooters, and established modes, such as powered two-wheelers, that have been extensively studied. The research to-date highlights many potential benefits of using micromobility. This review shows that there are still many unknowns that need to be addressed within the academic research and highlights how learnings from more established powered microvehicle modes should be applied to emerging vehicle types. The review demonstrates that the use of standard taxonomies, such as that developed by SAE, are beneficial in developing a common language amongst practitioners, with previous research using terms such as scooter used interchangeably to describe multiple modes of transport. The findings suggest that the focus to date lies on road safety, particularly amongst e-bikes, seated and standing scooters. While broader issues regarding usage and legislation have also been considered, this has generally been focused on specific markets or countries.

The research suggests that the field will continue to grow, spurred by the popularity of shared e-scooter schemes and that greater collaboration in the field is desirable to broaden the dissemination of findings.

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