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TREND OR FAD?

Deciphering the Enablers of Micromobility in the U.S.

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1. EXECUTIVE SUMMARY

Tiny vehicles have flooded the streets of American cities. Fans of micromobility praise its ability to provide convenient and quick rides, but most importantly, for its ability to make travel joyful. While others have questioned the safety and sustainability of micromobility. The issue of whether micromobility as-we-know-it is a glimpse into our mobility future or a short-lived fad has fostered heated debates. This report presents our analysis of the state of micromobility and speculation of its near-term future.

Enablers of Micromobility

We decipher the enablers of micromobility. The familiarity and acceptance of shared mobility is fostering the rapid adoption of microvehicle sharing. Millennials are prime candidates for shared mobility and micromobility as they depend on private vehicles much less unlike their preceding cohorts. Recent advancement in vehicle and communication technologies is enabling affordable microvehicles and dockless vehicle sharing platforms. Venture capital has fueled the rapid expansion of microvehicle sharing.

Micromobility Under a Microscope

We present findings of our analysis of micromobility usage patterns. E-scooter sharing is used for very short trips with 63 percent of trips being less than 1 mile long. Dockless e-bikesharing is used for longer trips with only 35 percent of trips being less than 1 mile long. Temporal distribution varies by mode. E-scooter riders are more likely to ride in the middle of the day and on weekends, suggesting social and recreational use. Dockless e-bikesharing exhibits morning and evening peaks, suggesting more utilitarian use including commuting. A significant portion of e-scooter sharing trips are for recreation. Early surveys suggest micromobility is replacing walking trips and generating new trips.

The Delight Factor

We draw from existing knowledge base on other travel modes to understand how microvehicles have delighted its users. Microvehicles offer a new mode of transportation that uniquely provides a combination of the most desired attributes of travel: freedom and control of driving, pleasantness of walking, excitement of cycling, and convenience of skateboarding.

Bumps on the Road

We highlight the key challenges in micromobility. The operational characteristics such as travel speed and operating width are in need of research to better inform the appropriate right-of-way of microvehicles. Limited studies shed light to road safety issues related to micromobility, but further investigation is required. The current designs of microvehicles have limitations regarding their use as they are largely sensitive to weather and do not offer cargo space or the ability to travel with multiple passengers. The less-than-ideal economics of microvehicle sharing stems from consumer-grade microvehicles and cost of charging and distributing.

Trend or Fad?

We speculate that micromobility is only at its beginning of the exponential innovation and growth curve. We believe that the demand for micromobility will not wind down. We anticipate significant improvement in microvehicle durability as well as innovation in microvehicle design and sharing models. The innovation trajectory will continue to pose challenges to regulators. The impact of micromobility on travel patterns and road safety are largely unknown and require significant investigation.

2. INTRODUCTION

The 2010s – the decade where innovation continuously challenges the mobility status quo. Micromobility, the newest challenger, resulted in American streets being flooded with tiny vehicles such as e-bikes and e-skateboards. Fans of such vehicles praise their ability to provide convenient and quick rides, but most importantly, for their ability to make travel joyful. Others have questioned their safety and sustainability. Now, almost two years since its emergence, the first micromobility wave has finally settled and the norm of urban mobility has been redefined. Will there be more waves to come?

The question of whether micromobility as-we-know-it is a glimpse into our mobility future or a short-lived fad has fostered heated debates. This report presents our analysis of the state of micromobility and speculation of its near-term future. First, we attempt to address some fundamental questions. What enabled the micromobility boom? What mobility gap does micromobility fill? Drawing from existing literature on other travel modes, we make inferences on how micromobility has managed to delight its users. We highlight some key challenges surrounding its safety and financial sustainability of micromobility. Finally, we share our speculations of the anticipated future of micromobility.

In this report, we adopt the vocabulary proposed by Chang [1]. Micromobility vehicle (hereafter microvehicle) refers to the class of tiny vehicles such as e-bikes and e-scooters. We exclude solely human-powered vehicles like pedal-only bikes. "Micromobility" refers to the travel mode category that uses microvehicles. Users of microvehicles are called "micromotorists." Shared e-scooters and e-bikes are collectively called "microvehicle sharing." Micromobility vocabulary is currently being standardized at SAE International[1].

3. ENABLERS OF MICROMOBILITY

In 2018, microvehicle sharing (e.g., e-scooter and e-bikesharing) facilitated 45 million trips [2]. It is fair to say that we have officially entered the micromobility era. In this section, we decipher the enablers of micromobility, which can be largely attributed to the shared mobility trend, Millennials' consumer demand, technological advancement, and venture capital.

3.1. The Shared Mobility Trend

Shared mobility is often characterized as disruptive, new, innovative, and emerging. As expected with any rapidly evolving systems (akin to micromobility at present), shared mobility has long suffered from open questions about how it should be defined and how it influences and changes established transportation systems. Uncovering answers to these questions may facilitate better understanding to what extent and of which elements of shared mobility are in fact disruptive, new, innovative, and emerging. These questions have been partially addressed through SAE J3163 , which explains that the shared mobility ecosystem encompasses traditional public transportation services and incumbent services such as car rentals and ridesharing (i.e., traditional carpooling) [3].

In this light, shared mobility is not new. Instead, a subset of public transportation has evolved into shared mobility [4]. The mechanisms that facilitate the access of mobility services (e.g., ridesourcing, microtransit) and shared fleets of vehicles (e.g., carsharing, e-scooter sharing) have been modernized and/or enhanced through the infusion of technology. Lyons [5] proposes

[1] At the time of writing, SAE J3194 and SAE JA3163 are in development. J3194 will provide a taxonomy and classification of microvehicles. JA3163 will provide a taxonomy of shared mobility for surface and air transport.

[2] SAE J3163 – Taxonomy and Definitions for Terms Related to Shared Mobility and Enabling Technologies was published by SAE International in 2017.

that in developed economies, mobility is transitioning from automobility or "motor age" into a new type of regime in which car ownership will seem increasingly less important and car use will seem increasingly banal. This is consistent with the general speculation (and limited empirical evidence) that private ownership of automobiles is likely to decline in favor of shared mobility.

What we may refer to as the first generation of modern shared mobility (e.g., ridesourcing and pedal bikesharing) has paved the way for microvehicle sharing. Many travelers were already accustomed to the concept of accessing and paying for shared mobility trips via smartphone. We could infer that this element played a critical role accelerating the adoption of microvehicle sharing. This is especially true for Millennials, who have been recognized as the greatest fans of shared mobility.

3.2. The Millennial Factor

Millennials (i.e., those born between 1982 and ~2000), are not only the largest living generation, but also, the largest cohort in history, surpassing the peaks reached by the Baby Boomers in the U.S. [6, 7]. Millennials are largely born and raised in an era of ubiquitous technology, making them the first generation of "digital natives" and often touted as the generation that will bring about transformative changes in the transportation sector [8, 9]. They have been exhibiting driver's licensure and travel patterns that are different from those of their predecessor cohorts [8, 9]. The differences are striking when compared to Baby Boomers and Generation X who have fostered a long and close relationship with their cars. Older Millennials are just beginning to enter their peak driving years – the period from roughly ages 35 to 55 [8]. These years are correlated to the peak period for workforce participation and key life milestones, such as marriage and parenthood, and by extension, the period during which people make the greatest use of the transportation system [8].

Since the late 1990s, automobility has been declining [10]. Decreases in automobility are not compensated by increases in the use of other travel, nor do decreased trip distances explain the downturn in automobility [10]. Many point to Millennials for this drop, who have even been dubbed as the "go-nowhere" generation [11]. So, why are Millennials driving and traveling less?

Millennials are often characterized as being asset-light. They have less money to spend and are putting off major purchases like houses, cars, and luxury goods or avoiding them entirely [9, 12]. In 2016, 36 percent of American adults under 35 owned a home, compared to about 50 percent for Generation X and Baby Boomers at the same age [13]. Vehicle ownership has been declining. In 2007, 73 percent of households headed by an adult younger than 25 owned or leased at least one vehicle, compared to 66 percent in 2011 [14]. Furthermore, driver's licensure among 20- to 24-year-olds declined from 87 to 79 percent from 1994 to 2016 [15, 16]. Socioeconomic differences of Millennials only explain part of the story. Several studies have found that Millennials drive less than previous generations of young Americans even when economic and other factors linked to vehicle ownership and driving are taken into account [8]. McDonald [10] found that Millennials' lifestyle shifts such as decreased employment and delayed household formation only explain 10 to 20 percent of declining automobility. Meanwhile, changing attitudes and preferences coupled with increased virtual connectivity (e.g., online shopping and social media) explain 35 to 50 percent of the decrease in driving [10]. Whether driven by preferences or need, urban Millennials have been increasingly embracing shared mobility. Furthermore, we could infer that lower vehicle and maintenance costs of microvehicles may attract Millennials to purchase their own microvehicles as an alternative to conventional motor vehicles.

The unique traits exhibited by Millennials pose a challenge for transportation planners who are grappling to understand how travel demand will evolve in the future, and the consequent implications for long-term transport infrastructure investment and policy formulation [9].

3.3. Technological Enablers

The first microvehicle, the Segway Personal Transporter (known as Human Transporter initially), arrived in 2001, but with its hefty form and even heftier price tag, it has remained niche for nearly two decades [17]. Recent vehicle-related technological advances have facilitated the development of lighter, smaller, and nimbler microvehicles with better range at affordable prices. In many cases, microvehicles blur the line between children's toys and vehicles primarily designed for utilitarian transport. In some cases, like kick scooters, the addition of the electric motor has transformed a children's toy into a microvehicle. In the case of bicycles, electrification has greatly improved its popularity [17]. The e-bikes in New York's City Bike system average 15 trips per day compared to 5 for pedal bikes during high ridership months [2].

Used in various combinations and capacities, rapidly advancing technologies are revolutionizing how travelers execute trips. Specifically, internet-of-things (IOT), global positioning systems (GPS), smartphone applications, cloud platform, and mobile payment technologies are transforming how travelers access transportation services and modes. Microvehicle sharing is exemplary of this revolution. Its main driver has been the rise of the dockless system, which allows users to park anywhere rather than at fixed docking stations. For microvehicle sharing operators, the dockless system allows deployment and scaling with lower capital costs and greater operational flexibility, as they do not have to build out fixed stations [17]. The ubiquity and affordability of these technologies are facilitating easy access and effective matching of supply and demand.

3.4. The Micro Gold Rush

Since the inception of Uber in 2010, shared mobility has been enjoying its position at the epicenter of venture capital investment. The most recent venture capital frenzy was e-scooter sharing with more than $1 billion of investment in Bird and Lime alone as demonstrated in Figure 1. Even when compared to ridesourcing giants, Uber and Lyft, microvehicle sharing companies have attracted enormous investment in very early stages of operation. Bird, arguably one of the largest e-scooter sharing operator in the U.S. has become the fastest shared mobility operator to reach unicorn status (i.e. $1 billion valuation) [18]. At the time of writing, e-scooter sharing in the U.S. is less than two years old and yet the e-scooter sharing operator giants, Bird and Lime, are valued north of $2 billion each [18, 19]. Early analysis of e-scooter sharing adoption of these services has shown growth at an unprecedented pace, mirroring the investment that they have attracted in venture capital. Research from July 2018 demonstrates that e-scooter sharing experienced an average adoption rate of 3.6 percent across major cities [20]. At the time of this research, e-scooter sharing has been available for less than 12 months (and less than 5 months in most markets). This adoption rate is unprecedented when compared to other shared travel modes, such as carsharing, which experienced a 2 to 3 percent adoption rate after 12 years since launch [20].

Recent analysis of trip data found that since the introduction of dockless microvehicle sharing, the total number of trips using shared bicycles and scooters more than doubled from 2017 to 2018 [2]. Bird reached 1 million rides within 7 months and 10 million rides within the first year [21]. Lime, which started as a dockless bikesharing company in June 2017, added e-bike and e-scooter sharing product lines in the first half of 2018. Lime reached 6 million (e-)bikesharing and e-scooter sharing rides within first 12 months of operations and 50 million rides after 22 months [22].

Consolidation of shared mobility operators is becoming more common. Bird acquired the moped sharing operator, Scoot, while Uber acquired the e-bikesharing operator, JUMP, and Lyft acquired the pedal bikesharing operator, Motivate [23]. Both Uber and Lyft have since added e-scooter sharing to their product lines. It is anticipated that more consolidations of shared mobility operators will take place, allowing shared mobility platforms to inch closer to Mobility-as-a-Service (MaaS).

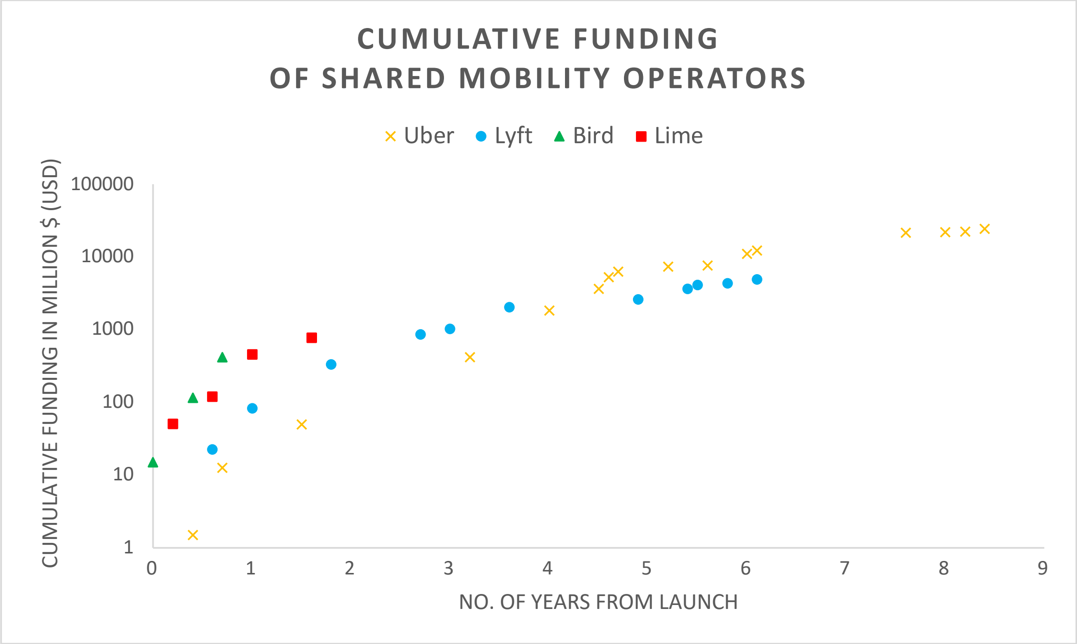

Figure 1. Cumulative Funding of Shared Mobility Unicorns Over Time[3]

4. MICROMOBILITY UNDER A MICROSCOPE

Almost two years in the micromobility craze, we begin to see patterns on how microvehicles are being used. In this section, we present findings of our analysis to provide a glimpse into how micromobility fits in the context of mobility ecosystem.

4.1. Trip Distance

Fans praise micromobility for its ability to fill the last-mile gap, which has long been a critical problem in American cities. Micromobility has been touted as the perfect mode for short distance trips that are a tad too long to walk but awkwardly short to drive. Our early analyses of microvehicle sharing trips indicate that usage patterns differ by the vehicle type (i.e., e-scooter vs. e-bike vs. pedal bike) and operational models (i.e., docked vs. dockless). In Washington DC, travelers use dockless pedal bikesharing and e-scooter sharing for very short trips, with 70 to 73 percent of trips being less than 1 mile long as presented in Figure 2. This is a striking difference when compared to dockless e-bikesharing, for which only 35 percent of trips are less than 1 mile long. Unsurprisingly, the addition of the electric motor to shared bicycles has allowed travelers to achieve greater distances. In fact, around 90 percent of pedal bikesharing trips were less than 2 miles long, compared to 3 miles for dockless e-bikesharing in

[3] Figure 1 presents data collected from Crunchbase [23].

Washington DC. An analysis by NACTO [2] presents similar findings with average trip distances of e-scooters being significantly lower than dockless e-bikes at 1.2 and 1.6 miles, respectively. Oakland, CA observed similar trends with average trip distances of 1.2 and 2.3 miles for e-scooter sharing and station-based, pedal bikesharing, respectively [24].

Despite the fact that e-scooter riding may be less physically demanding than pedal and e-bikes, the vast majority of e-scooter trips are extremely short. Figure 3 presents the results of our analysis of e-scooter sharing trips in Austin, TX, Louisville, KT, Minneapolis, MN, and Washington DC. The vast majority of e-scooter trips were less than 1 mile long, accounting for average of 63 percent of total trips. Ninety-eight percent of e-scooter sharing trips across the four cities were less than 5 miles long. This finding supports the notion of microvehicles being viable alternatives for short trips of 5 miles or less, which account for 60 percent of trips in the U.S. and of which 76 percent are currently made by personal cars [25]. The observed trend of very short e-scooter trips could be partially explained by the high accessibility and visibility of e-scooters on sidewalks that may serve to encourage e-scooters as alternative to medium to long walking trips coupled with by-the-minute pricing.

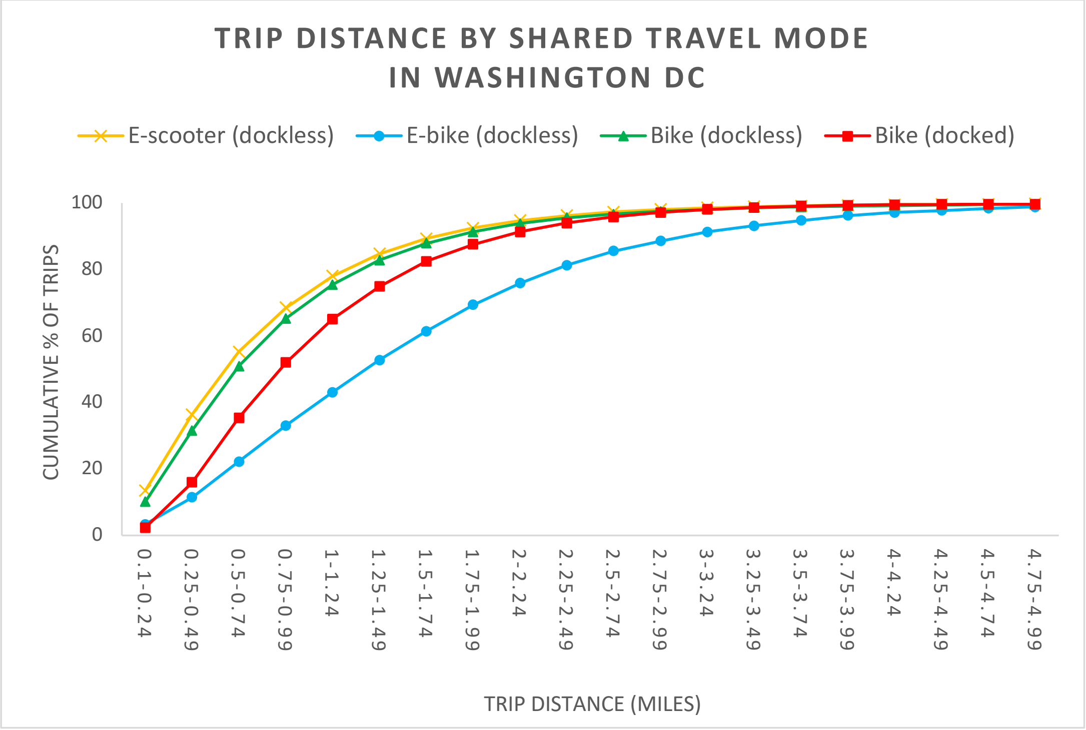

Figure 2. Distribution of Trips by Distance by Mode in Washington DC[4]

[4] Figures 2 and 6 present data provided by Populus. The values were derived from reverse-engineering of publicly available scooter and bikesharing vehicle location data in the form of General Bikeshare Feed Specification (GBFS) in Washington DC. For Figure 2, trips under 0.1 miles were removed from the calculation of cumulative percentage of trips.

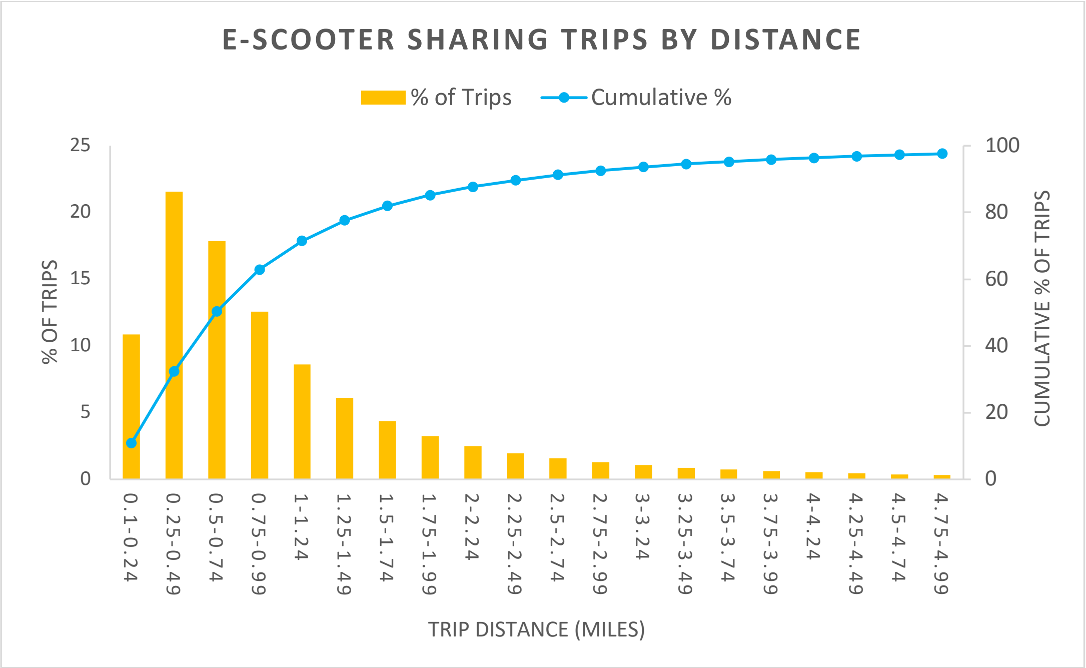

Figure 3. Distribution of E-Scooter Sharing Trips by Distance in Austin, Louisville, Minneapolis, and Washington DC[5]

4.2. Temporal Distribution

Our analysis of Austin, Louisville, and Portland mirror recent findings by NACTO [2] that e-scooters are used throughout the week but use is higher during weekends. As presented in Figure 4, 20 percent more daily trips occur on Friday through Sunday, compared to Monday through Thursday. Saturdays have the highest use of e-scooter sharing with 40 percent more use than Mondays, the weekday low. Figure 5 presents the average hourly profiles of e-scooter sharing trips in Austin, Louisville, Minneapolis, Portland, and Washington DC. The hourly profiles are significantly different between weekdays and weekends. E-scooter sharing usage does not exhibit two distinct weekday peaks unlike automobile commute patterns. On weekdays, e-scooter sharing exhibits a small peak at 8 a.m. followed by a prolonged afternoon peak between 12 to 5 p.m., during which 51 percent of weekday trips. On weekends, e-scooter sharing use builds a single smooth afternoon peak with about 72 percent of weekend trips occurring between 11 a.m. and 6 p.m. E-scooter sharing exhibits similar temporal patterns to casual bikesharing riders, who are more likely to ride in the middle of the day and on weekends, suggesting social, shopping, and other recreational use [2].

E-scooter sharing appears to be the anomaly in temporal distribution. Figure 6 presents the hourly distribution of (e-)bikesharing and e-scooter sharing trips on weekdays in Washington DC. Dockless e-bikesharing and Capital Bikeshare exhibit similar hourly profiles with two distinct morning and evening peaks at 8 a.m. and 5 p.m., suggesting usage for primarily utilitarian transport, specifically, commuting. Though to a lesser degree, dockless pedal bikesharing share the two peaks.

[5] Figures 3 and 5 presents the results of our analysis which combines (i) publicly-available, trip-level, e-scooter sharing data from Austin, TX, Louisville, KY, and Minneapolis, MN [26, 27, 28]; and (ii) values for Washington DC provided by Populus and derived from reverse-engineering of GBFS data. For Austin, data reflects city-wide trips between April 2018 and March 2019. For Louisville, data reflects city-wide trips from August 2018 to February 2019. For Minneapolis, data reflects city-wide trips from July 2018 to November 2018. Trips under 0.1 miles were removed from the calculation of cumulative percentage of trips in Figure 3.

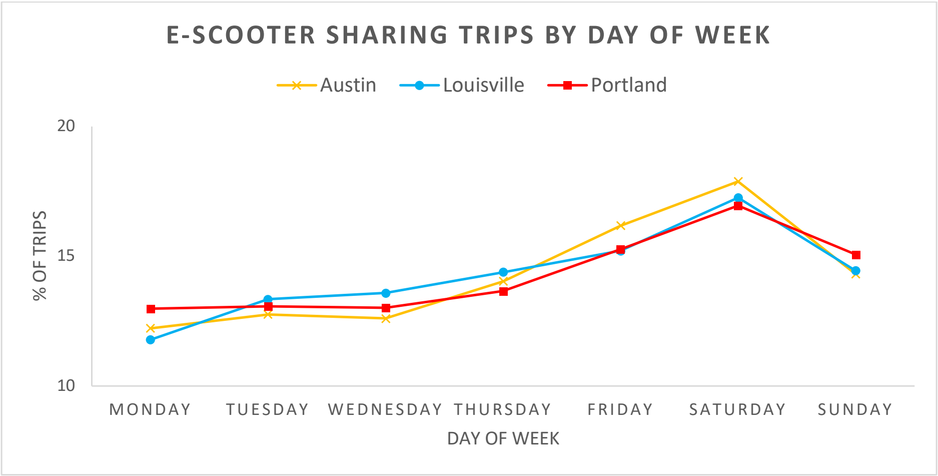

Figure 4. Distribution of E-Scooter Sharing Trips by Day of Week[6]

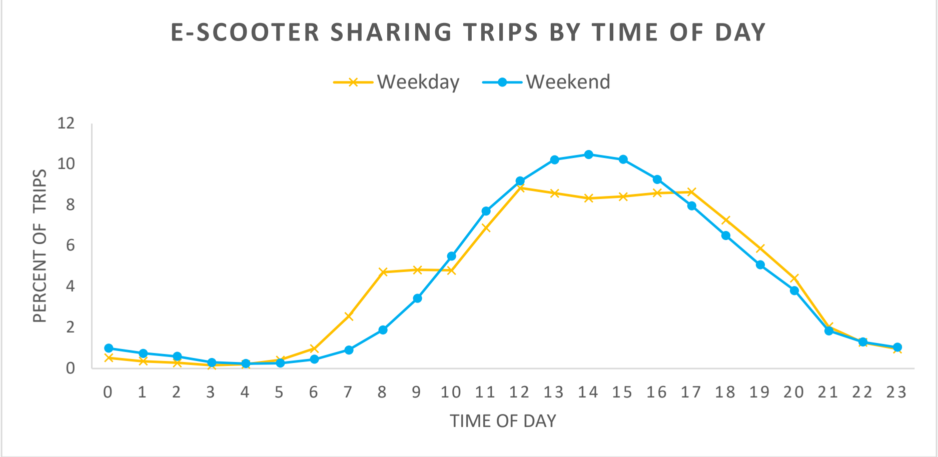

Figure 5. Distribution of E-Scooter Sharing Trips by Time of Day in Austin, Louisville, Minneapolis, Portland, and Washington DC[5]

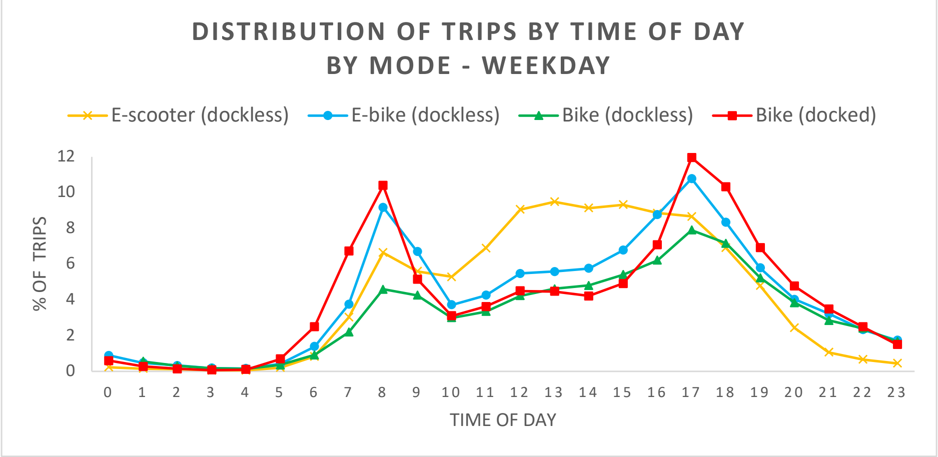

Figure 6. Distribution of Trips by Time of Day by Mode in Washington DC on Weekdays[4]

[6] Figure 4 presents the results of our analysis which combines (i) publicly-available, trip-level, e-scooter sharing data from Austin, TX and Louisville, KY [26, 28]; and (ii) values reported by Portland [29]. For Austin, data reflects city-wide trips between April 2018 and March 2019. For Louisville, data reflects city-wide trips from August 2018 to February 2019. For Portland, data reflects city-wide trips from July 2018 to November 2018.

4.3. Trip Purpose

Micromobility is used for both utilitarian and recreational purposes. In Austin, 35 percent of respondents ranked work and school commutes as their most frequent purpose for using dockless e-scooters and (e-)bikes [30]. In Portland, 20 percent of respondents ranked work and school commutes as the top purpose of e-scooter sharing trips [31]. In a survey conducted in San Francisco, Lime [32] found that the primary trip purpose for 55 percent of their e-scooter riders was work and school commutes.

The "fun factor" of micromobility is undeniable. In Portland, 28 percent of respondents ranked "for fun/recreation" as the most frequent trip purpose for which e-scooter sharing was used [31]. Almost all (96 percent) of Austinites included recreation among their trip purposes using dockless mobility [30]. These findings demonstrate that a significant number of joy rides are generated by the fun or delight elements that microvehicles offer. These findings also challenge the traditional travel demand modeling paradigm which is based on the working assumptions of travelers' desire to reduce travel time, cost, and distance.

4.4. Mode Shift

The enormous popularity of micromobility begs the question, where did all these micromotorists come from? Is micromobility filling a travel demand that was previously unmet? Or, is micromobility substituting private vehicle trips? Early survey results demonstrate that e-scooter sharing is largely replacing walking and cycling. In an online survey conducted by Denver Public Works in January 2019, 57 percent of respondents stated that e-scooter sharing trips replaced walking (43 percent) and biking (14 percent) trips [33]. In Portland, 46 percent of respondents stated that they would have either walked (37 percent) or cycled (9 percent) if a shared e-scooter had not been available for their last trip [31]. A survey conducted by Lime of e-scooter riders in San Francisco asked what mode(s) of transportation the respondent would have taken if a Lime e-scooter was not available for their most recent Lime trip. Sixty-one percent of the respondents chose walking as one of the modes, while 12 and 7 percent (also) chose station-based bikesharing and personal bike. These findings raise questions of the implications of mode shift away from active transport to micromobility, including those related to physical activity and other health and environmental concerns.

E-scooter sharing is replacing personal car and ridesourcing (i.e., Uber and Lyft) trips. Thinking of their last e-scooter trip, 34 percent of Portlanders reported that they would have either driven a personal car (19 percent) or hailed a taxi, Uber or Lyft (15 percent) had a shared e-scooter not been available [31]. In Denver, 32 percent of respondents stated that e-scooter sharing replaced a trip using ridesourcing services and private vehicles [33]. In a survey of Lime riders in San Francisco, if Lime e-scooter was unavailable for their most recent trip, 51 percent of respondents would have considered Uber, Lyft or taxi; 9 percent would have considered driving their personal vehicle; and 3.9 percent would have considered carsharing [32]. A study by Uber on early JUMP adopters found that during morning and evening commute times when congestion is at its worst, Uber trips declined by 15 percent and were replaced by Jump e-bikesharing trips [34].

E-scooter sharing is generating new trips. In Portland, 8 percent of respondents stated that they would not have made the trip if an e-scooter had not been available [31]. Meanwhile, 7 percent of Lime e-scooter users chose "I wouldn't have made the trip" as one of the responses to the question of what mode of transportation the respondent would have taken if a Lime e-scooter was unavailable for their most recent trip [32]. Further investigation is needed to better understand whether microvehicle sharing, specifically, e-scooter sharing is improving mobility and accessibility, or generating new trips due to their recreational nature, or perhaps a combination of both.

5. THE DELIGHT FACTOR

Conventional wisdom divides public transit riders into choice and captive users [35]. Choice riders are those who have access to a personal car yet choose to take transit while captive riders are those who do not have the luxury of other mode alternatives. If we apply this dichotomy to micromobility, we speculate that most micromotorists are choice riders. So why are they choosing micromobility? Micromotorists applaud microvehicles for their ability to provide fun and convenient trips. What aspects of micromobility are delighting its users? Plenty of studies have found that more people dislike their commute trips than like them and often found boring and burdensome [36, 37]. Traditional travel demand modeling based on the working assumptions of the desire to reduce travel time, cost, and distance. Micromobility may be an anomaly to this. Micromotorists appear to be so delighted that new trips are generated for recreation. To the best of our knowledge, no study of micromotorist satisfaction exists. In this section, we review a series of literature on traveler enjoyment as well as reported (un)attractive attributes across travel modes to draw potential parallels to micromobility to infer and speculate on why and how microvehicles have delighted their users.

Pedestrians and cyclists are consistently found to be more satisfied than motorists and public transit riders. A study in Montreal, Canada showed that cyclists were significantly more satisfied than other mode users followed by walkers [38]. In Surrey, United Kingdom, Gatersleben and Uzzell [37] found that driving was not pleasurable and potentially too arousing (i.e., stressful), whereas public transit was not pleasurable and may not be arousing enough (i.e., boring). Walking and cycling were found to be pleasurable and cycling was found to be more arousing (i.e., exciting) than walking [37]. Using data from the 2007-2008 French National Travel Survey, Mokhtarian, Papon [39] investigated which type of trips were found to be pleasant and tiring. The authors found that only trips by motorcycle and bicycle were more often seen as the most pleasant while trips made as car driver were the least pleasant. The authors also found that walking was the least mentally tiring (i.e., most comfortable) travel mode, followed by car passenger, bicycle, public transit, motorcycle and car driver. We can infer that micromotorists may share similar positive sentiments as pedestrians, cyclists, and motorcyclists. Furthermore, these values may be influenced by where micromotorists are permitted to ride, the quality of the infrastructure, and where they actually ride the microvehicles. For example, Austinites reported higher levels of comfort for traveling in bike lanes compared to sidewalks (especially those on a busy road) and car lanes.

The popularity of driving privately owned vehicles has been predominantly explained by instrumental factors such as its speed, flexibility, convenience, freedom, and control [40]. In terms of speed, the top speed of microvehicles may reach up to 30 mph, depending on vehicle type. In practice, travel speeds may be much lower. Arellano and Fang [41] found that e-scooters travel 9.5 and 12.3 mph on sidewalks and streets, respectively. Nevertheless, the observed average e-scooter speeds are three to four times faster than pedestrians, and are similar to manual bicycles, inline skates, and skateboards [41-44]. In their study, Gatersleben and Uzzell [37] found that the same proportion (14 percent) of cyclists and

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[7] Uber defines “early JUMP adopters” as riders who averaged at least one Uber or JUMP trip per week before and after their first JUMP ride and have taken more than one JUMP ride in their lifetime.

motorists responded that the most pleasant part of their commute was flexibility. A study on skateboarders commuting to university campus by Fang and Handy [42] found that participants liked that skateboarding blends the positive attributes of cycling and walking, such as higher travel speeds like bicycles and pedestrian-like flexibility, as skateboards are easy to carry and do not need to be parked and locked up [42]. We could infer that the speed benefits offered by skateboards and bikes are amplified with electrification (i.e., e-skateboards). Furthermore, most microvehicle sharing services leverage dockless technology which enables true door-to-door mobility option without the needs to carry the vehicle, park, or lock the microvehicles. It is important to note that some cities are moving towards (if not already) designated parking spaces for microvehicle sharing [45], which may transition microvehicle sharing from door-to-door to more curb-to-curb.

Many previous studies suggest that perceived freedom and control significantly influence mode choice [37, 46]. Stradling, Meadows [46] showed that almost all (90 percent) of their respondents felt that driving private vehicles provides freedom and control. Whereas, Gatersleben and Uzzell [37] found that a significant source of stress for drivers was in fact the lack of control (e.g., getting stuck in traffic). For non-drivers, perceived control was not an important source of stress [37]. We could speculate that micromotorists enjoy the ability to be in control of their schedules and routes while avoiding congestion.

Manual forms of the microvehicles under study are often used for recreation (i.e., skateboards, bicycles, and kick scooters). In 2014, a survey of 16,193 American adults found that 57 percent of American cyclists only cycle for recreation [66]. Ninety-four percent of skateboarders agreed that skateboarding is a fun way to travel [42]. Thus, it is unsurprising that many micromotorists find their trips fun, resulting in significant recreational rides. New e-scooter riders often share that they reminisce riding kick scooters in their childhood. In their study of skateboarders in Davis, California, which enjoys a flat terrain, Fang and Handy [42] found that skateboarders found that not having to travel uphill is convenient, although flat terrain can make skateboarding less fun. Through electrification, microvehicles have the advantage of removing the burden of traveling uphill.

Microvehicles offer a new mode of transportation that uniquely offers a combination the most desired attributes of travel: freedom and control of driving, pleasantness of walking, excitement of cycling, and convenience of skateboarding.

6. BUMPS ON THE ROAD

The first wave of micromobility tsunami has settled. It has delighted many and confused some. We speculate that we are in the very beginning of the exponential innovation and growth curve of micromobility. As we brace ourselves for the next micromobility wave, we highlight the key issues around right-of-way, barriers to microvehicle use, and financial sustainability of microvehicle sharing.

6.1. Whose Sidewalk and Bike Lane?

One of the more contentious issues over micromobility pertains to their physical compatibility with other road users [41] and existing infrastructure. Microvehicles have been a target of media for their nuisance and/or speculated threat to safety to other road users, especially pedestrians. Evidence suggests that e-scooter riders may receive negative feedback wherever they ride. Pedestrians might argue that e-scooter riders are a nuisance and/or a threat to their safety, while some reports shed light to cyclists' discontent in sharing their facilities with slower e-scooter riders. Drivers have also expressed frustration and safety concerns regarding the slower travel speeds and lower acceleration of e-scooters coupled with dangerous behaviors of select riders such as splitting lanes.

At the time of writing, there is a lack of consensus on the right-of-way of microvehicles (i.e., where they should be operated) across state and local regulations in the U.S. In Washington DC, e-scooters fall under the city's regulations on personal mobility devices [47]. In the city's central business district, riders must operate e-scooters in bike lanes and car lanes as they must follow the same rules as bikes; sidewalk riding is only permitted outside the central business district [47]. Whereas in Denver, sidewalk riding is permitted for e-scooters on streets where the speed limit is greater than 30 mph, but, riders may only travel up to 6 mph to ensure safety of pedestrians on sidewalks [33]. In California, e-scooter users must ride in car lanes unless there is a bicycle lane, in which case they must ride there. There is a pressing need for clarification on what is a safe speed for various types of microvehicles and their right-of-way.

Though limited, few studies shed light on the preferences of micromotorists regarding operational domain. Early survey results from Portland and Austin found that micromotorists strongly prefer riding on bike lanes. In Portland, 64 percent of respondents stated that they "always" ride e-scooters on bike lanes or do so "most of the time," compared to 3 and 30 percent in sidewalks and car lanes [31]. In a question regarding their preferences, 66 percent of Portlanders chose bike lanes as their first choice [31]. This mirrors sentiments of Austinites on e-scooters and (e-)bikes who have responded average of 4.11 and 3.64 for protected bike lanes and painted bike lanes, respectively, on a scale of 1 (very uncomfortable) to 5 (very comfortable) [30]. However, in cases where bike lanes are not available, where are micromotorists supposed to go? Most local regulations point to car lanes. However, micromotorists have expressed their discomfort riding in car lanes for safety reasons. Austinites for example, felt the most uncomfortable riding e-scooters and (e-)bikes in car lanes and the least number of Portlanders chose the car lanes as their first choice for riding e-scooters [30, 31]. A key question facing cities is what their responsibilities are in creating new infrastructure that could enable the safe growth of micromobility.

Other safety discussions around micromobility revolve around sidewalks. We focus on e-scooters for this discussion. Whether e-scooters are appropriate for sidewalk use may largely depend on their operational characteristics (e.g., travel speed and operating width) compared to pedestrians, as well as the built environment of a city. Some cities have developed guidelines for e-scooters to be used on sidewalks, particularly in areas with wide streets for car traffic, higher car traffic speeds, and limited bike infrastructure. However, other denser cities with high pedestrian traffic are likely to adopt guidelines to ensure that specific speed restrictions are adhered to when operating alongside pedestrians or require that they only operate in on-street bike lanes along those corridors.

The average operating widths range from 3 to 3.6 ft for manual kick scooter riders, Segway Human Transporter riders, manual bicyclists, and manual skateboarders; inline skates required larger average operating widths of 4.3 ft [44]. No similar data is currently available on microvehicles. One consideration is that some e-scooter riders may exhibit "carving" behavior or travel in an S-shaped pattern instead of a straight line. We could infer that electrification and improved suspension of scooters may make it easier for riders to carve compared to manual kick scooters, potentially resulting in larger operating widths. One study found that only 13 percent of observed e-scooter riders exhibited carving behavior [41]. Even without taking carving into consideration, two e-scooter riders in parallel would fill up the entire effective width of a sidewalk.

Travel speeds of e-scooters depend on where they ride. Arellano and Fang [41] examined a limited sample of observations (n=115) for speed of e-scooter users riding on car lanes, sidewalks, and pedestrian-cyclist, mixed-use paths in downtown San Jose, CA. E-scooter riders traveled slower on sidewalks compared to car lanes at 9.5 mph versus 12.3 mph, respectively. Though e-scooters travel much slower on sidewalks than the maximum vehicle motor speed of 15 mph [48, 49], they are traveling three times faster than pedestrians (with the assumption of average walking speed of 3 mph). The speed of 9.5 mph of e-scooter riders is similar to the average free-flow speeds of manual kick scooters (7.5 mph), manual skateboards (8 mph), and inline skates (10 mph). These speeds are similar to the average speed of the Segway Human Transporter (9 mph) which are permitted to travel on sidewalks in most states [44].

It is challenging to determine whether e-scooters are appropriate for sidewalks given our limited understanding of the operating characteristics. We review the guidelines by the American Association of State Highway and Transportation Officials (AASHTO) which caution against bicyclists riding on sidewalks. AASHTO states two main reasons: (i) "[t]here is significantly higher incidence of bicyclist-motor vehicle crashes with bicyclists riding on the sidewalk than with bicyclists operating in the roadway;" and (ii) "sidewalks are typically designed for pedestrian speeds and maneuverability and are not appropriate for higher speed bicycle use." Furthermore, "walkers, joggers, skateboarders, and inline skaters can, and often do, change their speed and direction almost instantaneously, leaving bicyclists insufficient reaction time to avoid collisions" [50]. Whether e-scooters would be more similar to cyclists or skateboarders and inline skaters is yet to be determined. Furthermore, would the addition of an electric motor for skateboards or inline skates result in significantly different operating characteristics? These open questions highlight the pressing need for research to better understand the operating characteristics of microvehicles to better inform regulation.

6.2. How Safe is Safe Enough?

Safety has been at the center of discussions related to micromobility. E-scooters present a unique case for road safety as its operating guidelines and domains largely remain vague. Furthermore, other road users are often unfamiliar with microvehicles, especially e-scooters, and their position in priority hierarchy of road user types. At the time of writing, only two studies have examined injuries related to e-scooters: (i) Trivedi, Liu, et al. [51] conducted a review of medical records of 249 patients presenting injuries associated with e-scooters at two urban emergency departments in Southern California from September 2017 to August 2018; and (ii) researchers at Austin Public Health and the Center for Disease Control and Prevention [52] identified 192 patients who sustained injuries associated with e-scooters in Austin. In Southern California, 92 percent of identified patients were riders and 99 percent in Austin [51, 52]. In Southern California, researchers found that the most common mechanisms of injury for e-scooter rider patients were fall (80 percent), followed by collision with an object (11 percent) and being hit by a moving vehicle or object (9 percent) [51]. Of the non-rider patients in Southern California, 52 percent were hit by an e-scooter and 24 percent tripped over a parked e-scooter [51]. In Southern California, 5 percent of e-scooter rider patients had physician-documented intoxication while in Austin, 29 percent of riders consumed alcohol in the 12 hours preceding their injuries [51, 52]. More than one-third of injured Austinites reported that excessive e-scooter speed contributed to their injury. Meanwhile, 19 percent of patients believed the e-scooter malfunctioned (e.g., brakes, wheels, etc.) [52].

Early data indicate very low levels of helmet use by e-scooter riders. In San Jose, Arellano and Fang [41] found that only 3.7 percent of observed e-scooter riders were wearing helmets. In their study of injuries in Southern California, Trivedi, Liu [51] found that only 4.4 percent of e-scooter rider patients were documented as wearing a helmet. In Austin, less than 1 percent of injured e-scooter rider patients were wearing a helmet [52]. Given the lack of helmet use explains the high rates of head injuries observed in Austin and Southern California at 40 to 48 percent of patients [51, 52].

6.3. Limitations of Microvehicle 1.0

Understanding and addressing the barriers to current forms of micromobility is critical in understanding where micromobility fits in the context of the entire mobility ecosystem as well as informing the next generation of microvehicles. Two main usage barriers specific to microvehicles include (i) sensitivity to weather conditions; and (ii) lack of cargo space. Weather can influence nearly every aspect of travel, from a traveler's decision to make a trip to what mode to use [53]. Popular microvehicles (e.g., e-scooter, e-skateboards) are similar to bikes in regard to the rider being fully exposed without a protective shell, unlike conventional motorized vehicles. Thus, we review existing literature on the impact of weather on cycling and bikesharing for insight. A study of two Dutch cities found that 80 percent of daily fluctuations can be attributed to weather conditions and that recreational cycling is much more sensitive to weather than utilitarian cycling [46]. A study of Montreal, Canada found that temperature has a direct positive effect on ridership, whereas the effect of humidity is negative [53]. The combination of heat and humidity produces an additional reduction of cycling flows [53]. Cycling does not do as well in cities with more days with freezing temperatures and precipitation [54]. In a study by Uber, they found that on a day with abnormally heavy rainfall in San Francisco, JUMP e-bikesharing trips declined by 78 percent while Uber trips saw a 40 percent increase [34].

A study investigating the reasons why people use their cars for short journeys (5 miles or less) over alternative modes in Great Britain found that carrying heavy goods is the most common main reason (19 percent) [55]. The need to give a ride to other people was found to be a significant generator of short car trips, including "giving a lift to a family member or friend" (17 percent) and "taking an elderly or ill person" (3 percent) [55]. For car trips of less than 1 mile, 22 percent of reported carrying heavy goods was the main reason for using a car [55].

Though niche, there are few vehicle options that address sensitivity to weather, provide cargo space, and accommodate more than one rider. Few microvehicle models are equipped with shells to protect the rider from precipitation. Velomobiles such as the Organic Transit's ELF and VeloMetro's Veemo are low-speed electric tricycles with shells designed within the parameters of the 3-classes of e-bikes. Velomobiles and cargo bikes are examples of microvehicles that offer small cargo space. We could anticipate seeing more multi-passenger microvehicles are starting to appear in the form of mopeds and tandem e-bikes. Industry experts have clearly indicated that we are only scratching the surface with what is possible in terms of microvehicle shape, size, and capability [56]. We can bet on a spectrum of new designs to emerge in the near future that will address the current barriers to microvehicle use.

6.4. Unit Economics Is Everything

The year, 2018, has been dubbed as the year of the e-scooters. In the U.S., 38.5 million e-scooter sharing trips and 6.5 million e-bikesharing trips in 2018 [2]. The micromobility boom can be largely attributed to microvehicle sharing. Private ownership of microvehicles seems to be growing, but it still remains niche in the U.S. The future of micromobility is highly dependent on the success of the microvehicle sharing operators.

Still in its infancy, the microvehicle sharing industry is experiencing growing pains [56]. Many industry analysts have questioned the economics of e-scooter sharing [57, 58]. Hawkins [57] explains that it all comes down to the unit economics – how much revenue each individual e-scooter brings in for the operator. The more trips and miles a single e-scooter can cover, the better chance for the operator to recoup the cost of each vehicle, then, start making profit [59]. An analysis by ARK suggests that e-scooter sharing operators are generating $2.43 in revenue per mile, but their costs are roughly $2.55 per mile [58]. The main costs for e-scooter sharing operators include e-scooter hardware, charging and relocation, maintenance, and credit card fees [58]. Higher utilization rates and improved durability of e-scooters are anticipated to significantly improve the currently less-than-optimal unit economics.

The initial microvehicle sharing wave (2017 to 2018) was largely powered by fleets of consumer-grade hardware that were never designed for intensive use. The majority of e-scooter companies purchased e-scooters from Xiaomi and Ninebot-Segway, the latter made 1.5 million e-scooters in 2018 [57]. Shared e-scooters have not only experienced widespread theft and vandalism, but also damage from being left outdoors and being transported for charging and relocation. Analysis by Quartz of publicly available trip-level, e-scooter sharing data of Louisville, KY determined that the average lifespan of a Bird e-scooter was 28.8 days[8] with an average of 3.49 rides per vehicle per day. The Quartz analysis found that Bird only recoups $67 on the cost of the average e-scooter thus losing $293 per e-scooter in Louisville [59].

The e-scooter sharing version 1.0 vehicles had insufficient range and did not offer battery swapping capability. This resulted in labor- and cost-intensive charging needs and significant out-of-service time. Not all but many microvehicle sharing operators continue to rely on the gig economy to collect e-scooters later in the day, charge them overnight, and redistribute them the following morning. The Information [60]reported that as of May 2018, Bird made an average of $3.65 per ride in revenue while spending $1.72 per ride to pay people to retrieve, charge, and relocate the e-scooters. In the case of both e-bikesharing and e-scooter sharing, to make revenue, microvehicles must be located where demand is and with sufficient battery capacity. Missing one of these two marks results in little or no utilization. Some operators are opting to simply flood the market with microvehicles rather than bear the full cost associated with constantly redistributing assets to make sure a microvehicle is nearby when a rider wants one [56].

E-scooter sharing operators have since invested resources and staff for research and development of vehicle design. Some have partnered with manufacturers to design more robust e-scooters with higher durability, greater range, and swappable batteries. There are industry conversations regarding charging interoperability that could facilitate the deployment of microvehicle charging docks, which would not only help with the charging issue, but also, the issues of sidewalk clutter from (improperly) parked microvehicles as well as theft. It is anticipated that many of the issues raised will be addressed in the near future.

[8] Bird has since disputed the results of the e-scooter lifespan analysis stating that Bird e-scooters may have been operated in other cities prior to being used in Louisville, KT.

The current influx of venture capital is fueling the rapid growth of the microvehicle sharing operators while subsidizing riders, and is reminiscent of the ridesourcing industry, where after several years, the two ridesourcing giants in the U.S. are still far from turning in profit.

7. TREND OR FAD?

In previous sections, we presented our understanding of the enablers of micromobility, followed by our observations of the usage patterns and challenges of the first wave of micromobility. The question of whether micromobility is a trend or a short-lived fad still remains.

The initial phases of curiosity and hype triggered by the sudden emergence of microvehicles has come and gone. Yet, the demand for micromobility does not appear to be winding down anytime soon. Some may argue that current Millennial travel patterns will not persist as they are a result of delayed major life milestones and lingering effects of the economic recession [9, 61]. Recent research has demonstrated that as Millennials age into their 30s, they are exhibiting behaviors that increasingly mimic the activity-time use patterns of prior generations. Millennials are "catching up" with older cohorts, characterized by increasing rates of driver's licensure coupled with increasing number of trips by car-as-driver [9, 62]. Would this mean a downturn in Millennials' demand of micromobility in favor of automobility? We do not think so. Where Millennials will live will greatly determine their travel behavior. In search of city-like amenities (e.g., high density, mixed-use buildings, excellent public transportation) without the compromise of affordability, Millennials will seek "urban burbs" [63]. We speculate that micromobility could serve much of the trips within the urban burbs. Also, we cannot forget about Generation Z who are entering adulthood in an era of micromobility.

Micromobility as-we-know-it will continue to rapidly evolve. Innovation is in the works and fueled by large wallets. We can expect to see a slew of new microvehicle designs in the near future. The new designs will tailor to a variety of traveler needs. We have already begun to see bodied microvehicles for protection from weather, lighter and smaller microvehicles that can easily fit in the traveler's backpack, sit-down e-scooters for travelers who prefer to sit. In fact, we speculate that the current synonymity of micromobility to e-scooters to fade.

The less-than-ideal unit economics of microvehicle sharing can be largely attributed to the durability of microvehicles and charging costs. We are already beginning to see the introduction of second-generation e-scooter models that are specifically built for shared, commercial use. Bird has begun phasing out its consumer-grade scooters in favor of their custom-built e-scooters, Bird One [64]. With larger batteries, greater range, and anti-theft upgrades, the Bird One e-scooters are predicted to last in the fleet for a whole year. The mega microvehicle manufacturer, Segway-Ninebot, has revealed Shared Scooter Model Max [65]. Greater range of microvehicles will significantly reduce the out-of-service time and charging costs. The current model of charging depends on a network of chargers that pick-up, charge, and drop-off the microvehicles. We anticipate that the deployment of curb-side charging stations will alleviate the significant costs associated with charging, theft, and vandalism as well as curbspace management.

The beginning of the micromobility era was fueled by microvehicle sharing that provided travelers with on-demand access for single trips. As microvehicles continue to delight more micromotorists, we anticipate an increase in private ownership and subscription plans for microvehicles. With increasing familiarity of microvehicles, we speculate increased private ownership of microvehicles. Microvehicle sharing operators have begun piloting subscription plans including JUMP+ through which users are given their own e-bike to use for the month. Such subscription plans offer micromotorists with the guarantee of an available microvehicle without the burden of ownership, such as maintenance and theft. Furthermore, as we inch closer to true MaaS platforms, we anticipate that travelers will be offered a growing pool of multimodal subscription models.

The continuous evolution of micromobility will pose a challenge for regulators. At present, most of the evolving regulation focuses on the right-of-way of e-scooters and permitting process of microvehicle sharing. As micromobility grows in popularity and more out-of-the-box microvehicle designs and sharing models roll out, we can anticipate the continuation of the sandbox approach to regulation.

The year 2018 marked the first wave of micromobility. Are there more and larger micromobility waves is in the queue? We certainly think so. Afterall, a tsunami is a series of waves.

8. AUTHOR CONTRIBUTION

AC conceived and designed the work. AC collected the data. AC analyzed the data and interpreted the results. AC prepared the draft manuscript. LMM, RC, and LS reviewed the findings of the work and provided guidance for revision of the manuscript. AC drafted the final version of the manuscript. All authors reviewed the results and approved the final version of the manuscript. The material presented in this report was developed to serve and will serve as a chapter of AC's PhD dissertation in the Department of Civil Engineering and Applied Mechanics at McGill University.

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9. DISCLAIMER

The views and opinions expressed in this publication are those of the authors and do not necessarily represent those of SAE International.

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