A Review on an Emerging New Mode of Transport: The Shared Dockless Electric Scooter

Narith SAUM [a]*, Mongkut PIANTANAKULCHAI [b]

[a,b] *School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, 12120, Thailand*
[a] *E-mail: saumnarith@gmail.com*
[b] *E-mail: mongkut@siit.tu.ac.th*

Abstract: In just few years, dockless shared electric scooters have gained their popularity and have been introduced to more than 90 cities around the globe. To date, there are limited number of academic studies related to this new mode of transportation. This paper reviews characteristics of dockless e-scooter, trip characteristics, market trend, impact on urban mobility, safety issue, regulation, and social perception. It is found that dockless e-scooter is the cost and time effective mode for short distance, 0.8 – 3.5 km. Majority of users feel satisfied with the trip and evaluate this mode in the positive view in dealing with congestion and emission. However, safety issue of e-scooter has raised the awareness of using or even adopting this mode. Adaptive regulation, technology innovation and commitment of all stakeholders could minimize the negative impacts from this new of transport mode.

Keywords: E-Scooter, Shared Micro-Mobility, Traffic Safety, First/Last-Mile Problem

1. INTRODUCTION

Urbanization, technology change and environmental issues lead to growing interest in active and shared service transportation. Shared mobility has proliferated in global cities not only as an innovative transportation mode enhancing urban mobility but also as a potential solution to address first- and last-mile connectivity with public transit (Shaheen and Chan, 2016). Sharing service mode includes bike-sharing, car-sharing, ride-sourcing, and more recently electric (e-) scooter-sharing (Smith and Schwieterman, 2018). While public transit is often constrained by fixed routes, driver availability, and vehicle scheduling, shared mobility provides a cost and time effective feeder. Moreover, it can extend the catchment area of public transportation by filling the gap of the existing transportation network. The concept of sharing service in transportation has the roots from economic models which based on peer-to-peer sharing or collaborative consumption of resources, particularly since 1990s. The factors that facilitate sharing among strangers include online social network platforms, and global positioning systems (GPS) enabled mobile technology.

In 2016, transportation produced around 25% of total emissions (around 8 $GtCO_2$) with the average annual growth of 2.7%, and 71% of these emissions were from road transport (IEA, 2018). To deal with emission issue from road transportation, tighter and tighter regulation on vehicle's emission has been implemented resulting in two emerging technologies: electrification and alternative fuel technology (such as low sulphur, hybrid vehicle, and hydrogen energy system). Higher social interest in sustainable environment resulting from climate changes in addition to supports and subsidies from government have

* Corresponding author.

provided business opportunity to private companies to adopt electrification in transportation field including bike, scooter, family car, truck, bus, and train.

Dockless e-scooter first appeared in Santa Monica, California, in September 2017, when a micro-mobility company, Bird Rides Inc., placed thousands of their scooters all around the city. These scooters were immediately popular with riders, presumably due to their ease of use, convenience, and low cost (Trivedi et al., 2019). Dockless e-scooter is time and cost effective for short distance trip, 0.8 – 3.5 km, with the operating speed up to 25 km/h. Besides these advantages, dockless e-scooter leaves some safety concerns such as battery explosion, accidents, and conflicts with the pedestrian. In the US, standing electric scooter injured 1545 people in 2018 (Hamilton, 2019). More seriously, an elderly pedestrian died after being hit by an e-scooter as she was out for a stroll in Barcelona, Spain (Badcock, 2018).

To date, there has been no comprehensive literature review of this new mode of transportation, dockless e-scooter (motorized or electric kick scooter). So, this paper targets to provide a better understanding and discussion about their characteristics and their impact on urban mobility in several aspects such as sharing service, safety, and policy regulations. This paper is organized into 8 parts. Firstly, the introduction is presented. Secondly, research method is explained. Thirdly, the characteristics of e-scooter are reviewed including type, power, speed, and emission. Fourthly, market trend and trip characteristics of dockless e-scooter is reviewed. Fifthly, accidents and safety issues related to this mode are discussed. Then, related regulations and the social perception on dockless e-scooter are reviewed in the 6th and 7th part respectively. Finally, discussion and conclusion about the issues and opportunity of this transportation mode are summarized.

2. METHODOLOGY

In the aim of providing a comprehensive review of shared dockless e-scooter's impact on urban mobility, data were collected from various sources. Previous reviewed studies were collected from 6 mains search engines including Google (https://www.google.com), Google Scholar (https://scholar.google.co.th), Sciencedirect (https://www.sciencedirect.com), Researchgate (https://www.researchgate.net), JSTAGE (https://www.jstage.jst.go.jp/browse), and IEEE Explore (https://ieeexplore.ieee.org/Xplore/home.jsp). Since not many studies about dockless e-scooter were formed, some reliable information from other online sources such as government websites, news, magazines, online-press, and online reports were collected additionally. Sixteen papers related to this mode including the evolution of motorized scooter, battery capacity, injury severity simulation, trip characteristics, and accidents were reviewed. Other data such as dockless scooter evolution, market trend, number of phone application installation, riding fee, and regulation are collected from online sources, especially Crunchbase (www.crunchbase.com), google play (https://play.google.com), and shared scooter operators' website and social media (Facebook, Instagram, and Twitter). Several important keywords are used such as dockless e-scooter, shared scooter, shared micro-mobility, and mobility personal vehicle. Some information written in other languages are translated to English by Google translate. The critical information available online are compared between several sources before reaching the conclusion, but we cite only the most popular and reliable source. The data were retrieved from online sources up to June 5, 2019.

3. CHARACTERISTICS OF E-SCOOTER

Scooter, derived from “scoot” means fast movement, represents entertainment product sliding on land, water, or ice, and also children’s toy skateboard car (Ming-tang and Manlai, 2008). Similar to other transportation modes, electrification is also adapted to scooter, called electric or e- scooter, as soon as 1991 by Honda in the aim of replacing gasoline-powered scooter rooted from 1902. Currently, the word “Scooter” is given to various transportation modes such as self-balance scooter, motorized scooter, motor scooter, and mobility scooter (Figure 1). Motorized scooter refers a powered stand-up scooter using a small utility gas or electric engine, while motor scooter is a type of motorcycle with a step-through frame and a platform for the rider’s feed, well-known modes are Vespa and Lambretta. Motor scooter is gaining widespread acceptance in China, Taiwan, and European countries, because of its low or zero emission (Kendall et al., 2017). In this case, countries in the Asia-Pacific region where motorcycle gains much popularity such as Taiwan, China, Vietnam, Indonesia, and Thailand, foresee promising demands for the electric motor scooter. Electric self-balance scooter also gains their popularity because of their low cost, lightweight, stylish look, and off-road capability. Standing e-scooter (Segway and motorized scooter) has emerged to high demand after the introduction of dockless sharing service in the last few years. Another mode, mobility e-scooter has improved the quality of life of the elderly by enabling them to access the social activities like shopping, errands or doctor visits (Eck et al., 2012). Lastly, motorized scooter gains its popularity since the 2000s for short distance trip in the compacted urban, then it was introduced to dockless services last few years.

	Name Power range Speed range Running range	**Self Balance mono-wheels Scooter** 350 - 1800 W 10 - 45 km/h 15 - 90 km		Name Power range Speed range Running range	**Motor Scooter (Mini Size)** 250 - 2000 W 20 - 45 km/h 40 - 60 km
	Name Power range Speed range Running range	**Hoverboard or Self Balance two-wheels Scooter** 200 - 1000 W 12 - 15 km/h 15 - 25 km		Name Power range Speed range Running range	**Motorcycle or Motor Scooter (Large Size)** > 2000 W > 50 km/h 40 - 150 km
	Name Power range Speed range Running range	**Motorized Scooter or Electric Kick Scooter** 200 - 1300 W 20 - 60 km/h 10 - 120 km		Name Power range Speed range Running range	**3-Wheels Mobility Scooter** 180 - 1000 W 6 - 28 km/h 17 - 60 km
	Name Power range Speed range Running range	**Two wheel scooter with handle or Segway** 1000 - 4000 W 18 - 30 km/h 25 - 60 km		Name Power range Speed range Running range	**4-Wheels Mobility Scooter** 180 - 1200 W 6 - 28 km/h 17 - 60 km

Figure 1: Type of Electric Scooter (Power, Speed and Running Range per Charge)

Currently, three modes of scooter are introduced to shared service such as Segway, motor scooter, and motorized scooter. According to the scope of this paper, we focused on the motorized or electric kick scooter, since this mode is the new emerging mode and has a high adoption rate. Figure 2 shows only the import evolutions with a similar appearance to current motorized scooter serving in shared service. The early scooter was a grassroots from children’s toy by just a soap-box, few pieces of board, and a discarded pair of roller skates.

Then it became commercialized devices and introduced to kid's sport. During 1910s to 1920s, powered scooter was developed purposely for mini-skirt riders such as Autoped, ABC Skootomota, and Austro Motorette (Goner, 2018; Madcharge, 2018). Later, such scooter was modified to motor scooter popularly Japanese Rabbit and Italian Vespa (Ming-tang and Manlai, 2008). In 1974, Honda company introduced "Kick-n-Go", a scooter driven by a pedal on a lever, and this creative scooter was popular among children even it still required as much effort as the regular one. Before the popularity of bicycle, steel scooter with two small bicycle wheels (similar to BMX scoot) had been a useful vehicle for children, especially the favorite of dog scootering. In 1996, Wim Ouboter, the man behind micro-mobility system solving the first/last-mile problem where the distance is too short to drive and too far to walk, invented a very popular foldable aluminium scooter which was very light and convenient transporter. This model was sold to Razor and was introduced to people in Tokyo in 1999, then it became a fad around the world. One of the earliest and successful manufacturers of motorized scooter, Patmont Motor Werks with the brand of Go-Ped, started their business in 1985 and introduced the gasoline and electric scooter in 2001 and 2003 respectively (UrbanScooters).

Figure 2: Evolution of motorized or electric kick scooter

Powered engines of electric vehicles can be classified into 4 types: battery electric vehicles (BEVs), plug-in hybrid electric vehicle (PHEVs), hybrid electric vehicles (HEVs), and fuel-cell electric vehicles (FCEVs). HEVs have both gasoline engine and battery, but its battery energy comes from regenerative braking or gasoline engine, and it cannot be recharged from the power grid. A BEV runs entirely on a battery while PHEV is powered by both battery and the internal combustion engine. FCEVs is another type of electric vehicle powered by hydrogen and oxygen. It is considered as the best type of electric vehicles in term of environment because it produces only water emission, even though it is still in the development phase (Ogura and Kolhe, 2017). Currently, there are dozens of manufacturers of motorized scooter, while the top 5 brands are Razor, Segway-Ninebot, Xiaomi, Swagtron, and EcoReco. As shown in Figure 1, the current electric kick scooter has the power, speed, and charging range of 200 – 1300 W, 20 – 60 km/h, and 10 – 120 km respectively. Based on the device's detail on Alibaba website, the battery is mostly lithium battery, while some manufacturers use the battery from LG or Samsung. Moreover, these batteries have the charging time from 3 – 8 hours, while the recharging time is around 300 (some cases are more than 900) or the warranty of 1 – 2 years. The scooter's frame is mostly steel, aluminium alloy or carbon fiber. The price of motorized scooter depends on battery, type of frame, and brand, and has a range of $50 – $700.

Based on open source data of shared vehicle on Austin city from April 3, 2018, to May

30, 2019, there are around 2,864,989 scooter trips with total devices of 36,343, supposed all devices have a different ID. The number of trips per scooter is linearly distributed from 1 to 650, so we choose the highest amount to consider the life cycle of scooter. Most of 320 scooters with the total number of trips ranging from 400 – 650 have the start date on Sep 2018 and end date on May 2019. With this reason, we believe that the dockless scooter could have the life cycle of 8 months with the average total trips of 450, while some online articles choose 500 trips. In general, the cycle life of battery depends on temperature of battery, charging level, depth of discharge, rate of charge/discharge, storage, and usage. Typically, lithium-ion battery has the life cycle of 300 – 500 charge/discharge cycles, but the modern battery optimized performance could last more than 1000 cycles. In this case, Cadex laboratory had examined 11 types of Li-polymer batteries, and the result showed that the battery capacity reduces almost linearly with the number of cycles. At 250 cycles, the battery capacity will reduce around 20% (Cadex, 2019). Another example from an online blog, Kamps did a financial analysis of shared scooter, Bird, by creating three scenarios pessimistic case (300 trips/scooter), optimistic case (500/ trips/scooter), and Superscooter with swappable battery (1000 trips/scooter). From these scenarios, he got the gross margin of 10%, 40%, and 62% respectively (Haje, 2018). These two articles gave a very similar result of our analysis, so we can conclude that the shared electric scooter could have the life cycle of 8 months for around 450 trips.

Matt Chester, an energy analyst in Washington DC, wrote an article about the emission of dockless e-scooter (Matt, 2018). Based on three models of e-scooter in the market (Ecoreco S5, Ninebot and Swagtron), the CO_2 emission per kilometer from these three models are 5.6, 4.7, and 2.5 grams respectively (using DC electric grid emission rate of 0.622 gram per watt-hour). At the same distance, riding e-scooter account for only 1% to 2% of the CO_2 emissions from driving an average car in the US. In addition, he considered three scenarios of the emission from e-scooter taking into account transporting to and from recharging locations (20 caped by Bird, and competitive between charging contractor limit to fewer). Since there were no data of the distance of collecting e-scooter, 3.22 km, 8.1 km and 16.1 km were used in the analysis. For average 2.4 km per trip and 5 trips per e-scooter per day, the most-efficient case of recharging trips, e-scooter accounts for 2% of the emission of a car, whereas the medium-efficient case accounts for 8% of car emissions; and the least-efficient case accounts for 28% of the car emissions. Thus in the least-efficient case, if less than 28% of the scooter trips are replaced by car trips then e-scooter actually generate more total CO_2 emissions than the cars would.

4. DOCKLESS E-SCOOTER MARKET TREND, AND THEIR CHARACTERISTICS

The rise of micro-mobility companies has been well documented over in last few years with companies like Ofo and Mobike in China, and Citi Bike and Jump Bike the US providing the consumers with convenient options for first-mile/last-mile transport. In 2018, this micro-mobility trend was re-energized with the emergence of the shared dockless e-scooter, pioneered by Lime and Bird in the US. The adoption rate of e-scooter across major cities in the US reached 3.6% in less than a year, compared to shared bike 13% in 8 years and shared car in 18 years (Populus, 2018b). The data from Lime showed that one million and six millions e-scooter rides were reached in the first 7 months and 14 months respectively (Adeyemi, 2019). Growing adoption of e-scooter sharing services in countries such as USA, France, Germany, Spain, Singapore, Thailand, has spurred the e-scooter demands. Companies like Bird, Lime, Spin, Jump, Razors, and Neuron, offering such sharing services are procuring electric scooter mainly from prominent manufacturers.

Figure 3 shows the month and year of the first deployment shared scooter across the countries and operators. Founded in 2014, Samocat's founders created the smart payment platform for station-based kick scooter sharing in the aim of solving the last-mile problem in smart cities, as well as inside university campuses or other large-scale workplaces. Samocat won several local and international prizes for this creative idea and started trialing their rental kick scooter in Russia in August 2015, before reaching European countries shortly after. However, this startup company did not gain much social interest due to the inconvenient of station-based mode and kicking fatigue. After few months of trial run in Singapore, Telepod launched their first dockless e-scooter sharing in August 2016. However, this startup business still gained less popularity due to the strict regulation, limited allowable area, high fare, vandalism, and thief. A year later, two other operators, Neuron and Popscoot, joined this business. Only until September 2017, a giant dockless e-scooter operator, Bird, got the permission to deploy their scooters in California, then dockless scooter gained its popularity and invaded to other cities. Several months after the success of Bird, another giant dockless e-scooter provider, Lime, started deploying their scooters, followed by Spin, Skip, BlueDuk, and Goat covering many states of US.

Beside Us, Bird and Lime along with the local operators, Troty Grin and Voi, had expanded the dockless e-scooter to some European counties (firstly France and Spain), Brazil and Mexico. After one year of the great success of shared e-scooter, many more countries started to accept the impact of this mode on urban mobility and began the trial run. Seeing the growth opportunity, several unicorn companies like Lyft, Grab and Bolt-Taxify joined the dockless scooter era. With the high interest in Asian countries, Neuron Mobility expanded their business beyond Singapore to Thailand in October 2018, to Malaysia in early 2019, and to Australia few months later. In South Korea, Kickgoing scooter firstly deployed their e-scooters in September 2018, while four more operators (Gbility, GogoSsingcity, Ryde, and elecle) are allowed to start deployment during few early months of 2019. At the end of May 2019, there are about 60 dockless e-scooter providers who already deployed their e-scooters in 35 counties covering more than 150 cities and 40 universities.

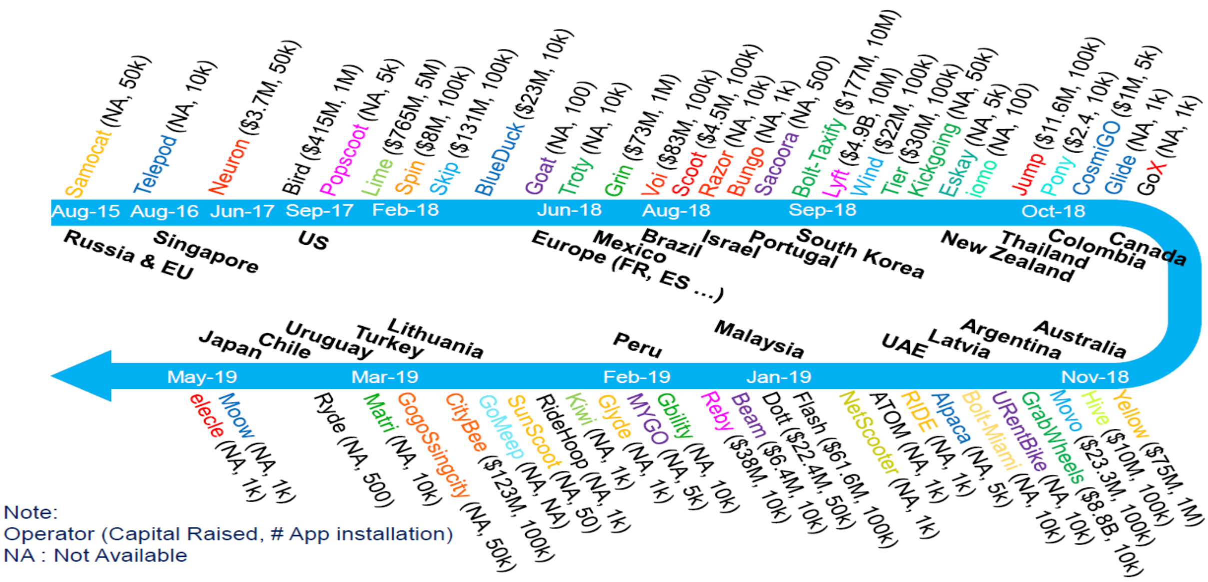

Figure 3: Deployment month and year of shared scooter by countries and operators with the capital raised and number of phone app installations (Source: operator's Facebook & Instagram, Crunchbase website, and Google play store)

Scooter sharing service provides a feasible solution to the “First Mile/Last Mile” problem or the distance that feels strenuous to walk but too short to drive (Allem and Majmundar, 2019). In this service, customers can use e-scooter by downloading mobile applications to their smartphones, then pick up the nearest available e-scooter via global positioning system. After completing their ride, customers can leave their e-scooter anywhere outside restricted zones, as indicated on the mobile phone. Smith and Schwieterman (2018) examined the potential of travel time, cost and trip convenience of sharing service e-scooter to fill the mobility needs in Chicago. The analysis shows that e-scooter could be a dominant mode for short trip in range of 0.8 – 3.5 km, at speed up to 25 km/h. For this distance, e-scooter could provide more than 2 minutes of time-saving on 61% of routes being alternative to driving. In parking-constrained environments, the introduction of e-scooter could increase the number of trips in which non-auto options are competitive with driving from 47% to 75%. The cost of using is about $1.1 per trip plus $0.83 per km, making them cost-effective for this short trip range. E-scooter would make about 16% more jobs reachable within 30 minutes compared to the number of employment opportunities currently accessible by public transit and walking alone (Smith and Schwieterman, 2018).

From Table 1, we can see that for the fee of a 30 minutes trip, users in Europe pay the highest fee of $6.27, while those in Israel, US, and Mexico need to pay $5.6, $5.5 and $5.2 respectively. Users in ASEAN countries pay the lowest fee for a 30 minutes e-scooter trip ranging from $3 – $3.52. The fee of Lime E-scooter and E-Bike is the same, but this rate is slightly higher than the shared bike, Jump-Bike ($2 for 30 minutes) and Ford Gobike ($3 for 30 minutes). Dockless e-scooter has the maximum speed in the range of 23 - 48 km/h and their charging range are 24 - 60 km. Since the fee is calculated based on minute-use, so e-scooter with higher speed will be preferable (Smith and Schwieterman, 2018). For instance, the time and cost saving for a 3.5 km trip with the average speed of 10 km/h and 15 km/h are 7 minutes or $1 accordingly.

Table 1: Standard fee of dockless e-scooter in each region (various online sources)

Region (e-scooter Provider)	Standard Fee		USD Equivalent	
	Unlock Fee	Riding Fee	Unlock Fee	Riding Fee
US (Bird)	$1	0.15 $/min	$1.00	0.15 $/min
Europe (Lime)	€1	0.15 €/min	$1.14	0.171 $/min
Mexico (Lime)	MEX $10	MEX 3 $/min	$0.52	0.156 $/min
Israel (Bird)	NIS 5	0.5 NIS/min	$1.40	0.140 $/min
Singapore (Neuron)	SGD $1	SGD 0.12 $/min	$0.74	0.089 $/min
Thailand (Neuron)	20 ฿	3 ฿/min	$0.64	0.096 $/min
Malaysia (Neuron)	RM 3	0.3 RM/min	$0.75	0.075 $/min

Bird reported that it provided 170,000 rides per weeks in the weeks of May 2018, with around 10,500 active scooters during that period (Hawkins, 2018). On average, an active e-scooter could make around 5 trips per day, and generate around $3.65 per ride. Meanwhile, Bird’s cost includes $1.72 per ride on charging costs, and another $0.51 per ride on maintenance, excluding credit card fee, permit fees, insurance, customer support, and other costs. So in May, Bird was pulling in about $602,500 in weekly revenue, offset by $86,700 in maintenance costs. That means Bird was eking out $0.70 in profit per ride, or a 19% gross profit margin. Tech innovation would help reducing unit costs and increase its life. The most important tech innovation could be battery life, interchangeable rechargeable battery, sturdier e-scooter with better materials, efficient construction and larger wheels which will increase e-scooter life by a factor of 2 or more (Adeyemi, 2019).

General guideline (CityofAustin, 2018) for using dockless e-scooter is the following:

- One scooter one person: don't use e-scooter with additional passenger (no hop-on).
- Pedestrians first: always yield to people walking on sidewalks.
- Park courteously: Park in a secure, upright position in a designated area, at least 1 meter of clearance for sidewalk, and never park on private property or blocking wheelchair ramp, business entrances, fire hydrant.
- Ride respectfully and safely: wear helmet whenever possible, never drink and ride, always obey traffic law, and do not take dockless e-scooter to unauthorized areas.
- Know what you're sharing: users have to access to dockless mobility service without having to share Personally Identifiable Information and can opt into data sharing only after getting clear information about what data will be shared.
- Fix or report: if you see fallen or improperly parked e-scooter, please help out by righting them or report the issue to authority/customer service center.

The Austin City Council authorized the dockless mobility, including e-scooter and bike, since May 5, 2018 (CityofAustin, 2019). Table 2 shows that the trend of dockless mobility in Austin has significant growth since introduction, while 95% of them are e-scooter. Austin has been licensed to several dockless mobility service operators such as Bird (4000 scooters), Jump (150 scooters, 1500 bikes), Lime (4500 scooters), Lyft (1000 scooters), OjO (100 scooters), Razor (500 scooters), Skip (500 scooters), Spin (500 scooters), VeoRide (350 bikes), and Wind Mobility (200 scooters). However, the number of active dockless devices are less than that registered devices, while some operators have not yet deployed their devices (CityofAustin, 2018). The data show that e-scooter gain more popularity compare to bikes, i.e. average daily trip production of e-scooter is around two, while that of shared-bikes is only one. The average trip length and time spent by e-scooter was 1.8 km and 14 minutes respectively. On the other hand, shared bikes are used for the longer trip which are around 3.23 km, and 22 minutes trips. The average speed of dockless bike is 9.2 km/h, and e-scooter is 8.1 km/h.

Table 2: Trip characteristics of e-scooter & bike/e-bike in Austin, Texas (CityofAustin, 2019)

Austin/Texas	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18
Dockless e-scooters									
Number of Scooters	871	271	907	1,165	2,471	4,518	5,167	8,705	8,675
Number of Trips	51,157	8,659	67,647	112,321	279,889	301,501	341,787	330,374	297,516
Total Distance (km)	101,041	23,538	136,863	204,043	476,450	457,391	520,295	524,585	478,952
Average Distance (km)	1.98	2.72	2.03	1.82	1.71	1.51	1.53	1.59	1.61
Average Time (min)	14.46	20.12	14.43	12.85	12.56	11.40	11.91	12.01	12.26
Average Speed (km/h)	8.22	8.11	8.44	8.50	8.17	7.95	7.71	7.94	7.88
Dockless bikes and e-bikes									
Number of Bikes/E-Bikes	2	NA	NA	170	445	380	369	429	407
Number of Trips	9	NA	NA	6,884	10,186	11,328	17,271	20,787	4,374
Total Distance (km)	24	NA	NA	24,692	35,562	38,505	56,398	55,789	12,854
Average Distance (km)	2.72	NA	NA	3.59	3.49	3.40	3.27	2.69	2.95
Average Time (min)	31.19	NA	NA	23.40	21.70	22.22	20.13	16.62	18.86
Average Speed (km/h)	5.23	NA	NA	9.21	9.65	9.18	9.75	9.71	9.38

NA: Not Available

This trip pattern is likely caused by fee policy. For instance, shared bike (Jump) will charge at the rate of $2 for the first 30 minutes, plus 0.07 $/minute, while e-scooter is charged at the rate of $1 for unlock plus 0.15 $/minute. In this case, e-scooter is popular for short trip, but dockless bike is more time and cost effective for longer trip (Smith and Schwieterman, 2018). The trip purposes of dockless e-scooter are joy riding 34%, running errand 23%, commuting 19%, visiting someone 13%, and work break/lunch 9% (Toll, 2018). Majority of people reportedly used the e-scooter on both sidewalks and streets. The report found that 18% of riders said they only rode on the sidewalk, while 29% reported only riding on the street. But the result from Lime shows that there were only 8 % who mostly rode on sidewalk, while the majority of them (65%) rode mostly on street (Lime, 2019). When each individual was asked to pick two main reasons of riding on sidewalk, the answers are: sidewalk feels safer (81%), sidewalk offers a smoother ride (42%), sidewalk is more convenient (20%), I don't think about whether I ride on the street or sidewalk (11%) and I don't know where to ride (7%). However, a protected bike lane has significantly increased the likelihood of switching to the street.

5. SAFETY ISSUES OF DOCKLESS E-SCOOTER

While electric scooter could reduce emissions, automobile congestion in the local area, this powered two-wheeler drivers are extremely vulnerable to road risks (Allem and Majmundar, 2019). Based on 324 posts on Bird's official Instagram account, there were only 6.17% containing persons wearing protective gear, while 6.79% had protective gear somewhere in the post. More seriously, the toll of news reports about e-scooter related accidents have raised the awareness of e-scooter usage (Badcock, 2018; Blumert, 2018; Hamilton, 2019). Other safety issues of e-scooter are battery explosion (Weissman, 2018), malfunction/handlebar defect/split in half during riding, brake failure, (McGeeLerer, 2019). For instance, Lime had recalled for a scooter model after reported crack and break apart while riding (Liptak, 2018). Furthermore, due to e-scooter's small size wheels and lightweight (lack of stability), street conditions can be a potential hazard as well such as potholes, speed bump, curb ramp, and uphill/downhill streets.

Xu et al. (2016) used MADYMO to simulate and compare the severity level (Head Injury Criterion, HIC) of pedestrians, cyclists, and mono-wheel and Segway riders, during the accident with automobile. The study investigated the impact of several parameters such as scooter's speed (0 - 14.4 km/h), crash angles, automobile speed (36 - 86.4 km/h), and contact positions. Vehicle's speed in the most critical factor. In this case, Segway is more vulnerable than cycling and mono-wheel, but safer than walking. The vulnerable index is not sensitive to the Segway's speed. Rear-end crash will leave the most severed head injury, while head-on collision has the lowest HIC due to the impact of handlebar. The mass of Segway has a positive impact on head-injury severity but, it may not enhance the safety performance that much (Xu et al., 2016).

A Lithium-Ion battery is commonly used to power e-scooter due to its high energy and power density, rapid charging, high load capacity, lightweight, low self-discharge and longer life cycle (Ogura and Kolhe, 2017). However, due to the volatile nature of the lithium electrolyte, the battery may go into the thermal runaway which frequently led to the explosion (Fawcet et al., 2018). In this case, Lime recalled for 2,000 e-scooters back from rental fleets after manufacturing defects that could lead to battery explosion (Dellinger, 2018). E-scooter chargers are regular people who make money by collecting e-scooters for charging and distributing to the designated location. The chargers could collect e-scooters from 9 pm to redistributes them before 7 am, and they could earn from $5 to $20 each e-scooter. However, this policy seems to be unsafe, because these chargers do not have sufficient safety equipment like auto extinguisher, charging in the house, and overload plug-in. There was an accident in St. Paul where 8 e-scooters caught fire during charging at night (Gotterfried, 2019). The cause of this accident is supposed to be an overload of the detached garage's electrical system.

In Southern California, US, 249 e-scooter related patients from 2 urban emergency departments were collected to analyze the injury characteristics and the common use practice in order to experience adoption of dockless e-scooter (Trivedi et al., 2019). This data was collected from September 2017 to August 2018, where 228 of them were riders and 21 of those were nonrider pedestrians. The average age of these patients is 34 years old, and 58% of them are male. The common incidents are fall (80%), collision with object (11%), and hit by moving vehicle (9%). The accidents happened mostly from 3 pm – 11 pm (57%), 7 am – 3 pm (26%), and 11 pm – 7 am (17%). Moreover, three unsafe practices were reported like no helmet use (95%), tandem riding (8%), and failure to comply with traffic laws (9%). The report also found that around 11% of the patients were less than 18 years old, even the rental agreement is required to be at least 18. Especially, riding on sidewalk is prohibited but 26% riders still ride there. Even wearing helmet is required by law in California, only 4.4% of riders reported wearing helmet. Therefore, head injuries are the most common cases accounting for 40%, while fractures/cuts and sprains/bruises are 32 and 28% respectively, see the two bottom chart in Figure 4. Among 149 patients, 30% of them had to stay in hospital for more than 4 hours, while 2 of them were sent to the intensive care units.

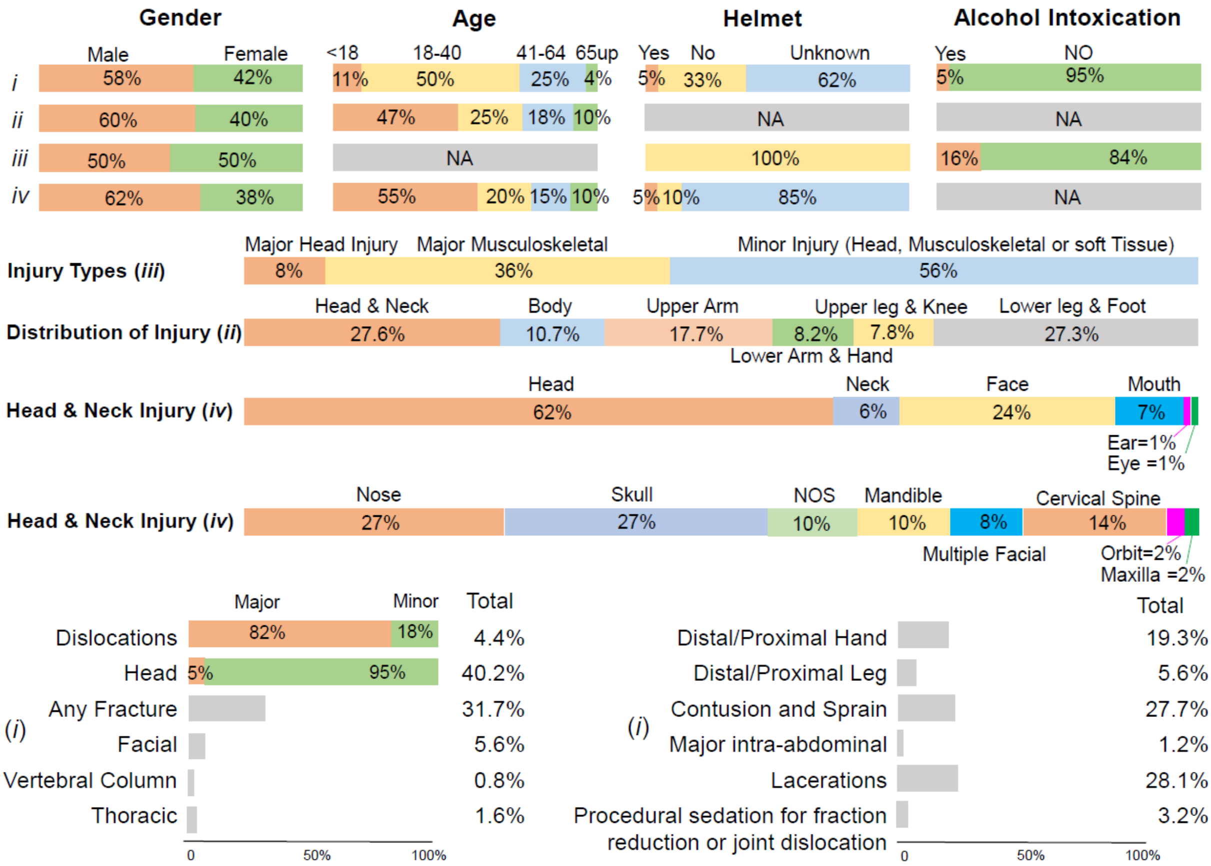

Figure 4: Summary the injury characteristics of e- scooter related accidents (Source: *i*: Trivedi et al., 2019, *ii*: Aizpuru et al., 2019, *iii*: Badeau et al., 2019, *iv*: Bresler et al., 2019

Similarly, Badeau et al., (2019) use the electronic medical record from two emergency departments in Utah, US to quantify and characterize the injuries of dockless e-scooter. In this study, they got 8 data from June 15 – November 15, 2017, and 50 from June 15 – November 15, 2018. From the data in 2018, they classified the injury into three types major head injury (8%), major musculoskeletal (36%), and minor injury (56%) (Badeau et al., 2019). Moreover, a research team from California and New York used the motorized scooter-related injuries from National Electric Injury Surveillance System (NEISS) of US to construct the anatomic distribution of e-scooter injuries (Aizpuru et al., 2019). Around 32,400 injuries were collected from 2013 to 2017, while the number of injuries increased by 77% between 2016 and 2017. The anatomic distribution of injuries shows that the distribution of injuries was 27.6% on neck and head, 10.7% on body, 17.7% on upper arm, 8.2% on lower arm & hand, 7.8% on upper leg & knee, and 27.3% on lower leg & foot (see Figure 4). On the other hand, Bresler et al., (2019) also used the motorized scooter-related injuries from NEISS to study the craniofacial injuries. From 2008 to 2017, they got 990 cases, where 62%, 24%, 7%, 6%, 1%, and 1% had happened on head, face, mouth, neck, air, and eye respectively. In the other ways, these injuries could be classified to be nose (27%), skull (27%), cervical spine (14%), mandible (10%), NOS (10%), orbit (UL2272), and maxilla (2%) (Bresler et al., 2019).

In case of South Korea, the number of accident related to personal electric vehicle (motorized scooter, self-balance scooter, and Segway) increased rapidly from 117 cases in 2017 to 225 cases in 2018 (JoongAng, 2019). The number of collisions with pedestrian increased 85%, while the collisions with car increased by 143%. Moreover, the first death of a pedestrian from the collision with motorized scooter raised strong social concern about the presence of dockless e-scooter which were just deployed in September 2018. The current causes of e-scooter-related accident are road damage (55%), electric scooter (25%), and other vehicles (20%) (Gov.KR.24, 2019).

6. REGULATIONS FOR ELECTRIC SCOOTER

Through the literature review, the regulations for dockless e-scooter are different from country to country or even city to city, and time to time as well. This is because some regions are just piloting this mode to assess the impact and social perception. Some common regulations are age, speed, helmet, riding lane, and parking. For shared-service providers, they have to register their devices, assure that the devices are compliant with the law, response for abandoned/damaged/improper park scooters, and educate users. Moreover, the service providers have to assure the privacy of customers and provide the financial bond (in case of failing to response the violated e-scooter which are done by authority), commercial general liability insurance, business license, and clean-hand certificate. The penalties can be fined, jailed or device seized.

In the US, the regulations for e-scooter vary from states to states, and the local authority might be able to add more regulations as well. Based on California Legislative Information (CLI), electric scooter is subject to vehicle code VC §21225, Article 5: Operation of Motorized Scooter [21220 - 21235]. In general, e-scooter does not require registration, license plate, financial responsibility or insurance, but the local authority could enforce these regulations too. The electric scooter has to comply with some criteria like emission, lighting, brake, red/yellow reflector, and width. All e-scooters shall have helmet (especially users under 18 years old, but not lower than age of 16), possess any driving license or instruction permit, ride scooter alone, and keep at least one hand upon the handlebars. Motorized scooter is not allowed on sidewalk, but they can ride on trail, bike lane or public road at speed up to 25 km/h (therefore e-scooter is not allowed on highway with speed limit of 25 km/h or more). Users should not leave e-scooter lying on its side on any sidewalk, or park it in any position that obstructs pedestrian traffic.

After gaining its popularity during the first phase of piloting the dockless scooter in District of Columbia from September 2017 (DC.Government, 2018), district department of transportation (DDOT) had introduced a long-term program in January 2019 for one year period to assess the shared-service providers' commitment in solving the safety issue and sustainable mobility. Under this permit, each operator could deploy their e-scooters up to 600 (minimum 100) and could increase the fleet more if they have good performance. In this case, permit holders have to limit the speed of their e-scooters to 16 km/h or less and offer cash payment option and the ability to locate or unlock scooters without smartphone. Electric scooter also has to comply with personal mobility devices requirement (18 DCMR 1201), and electrical system standard (UL 2271 or 2272). In addition, the operators have to submit the operational plan including hours/days of operation, methods of educating users about safety and proper parking, procedures of assuring that the scooter is safe, well-maintenance and available in each ward, and plan of responding during special events or complaints. Furthermore, all operators shall submit the monthly reports containing aggregated users data, vehicle data, trip data, safety report, parking report, member surveying report, and maintenance report. If the operators want to increase the fleet, DDOT will evaluate based on trip characteristics, responsibility to violation, adaptive vehicle operations, vehicle idle time, parking infrastructure, and proper parking incentive.

In Singapore, e-scooter or other personal mobility device is subject to regulations by Active Mobility Act by Land Transport Authority (LTA). The devices (included e-scooter) have to meet the criteria of maximum width (70 cm), weight (20 kg), and speed (25 km/h) which came to effective since May 1, 2018 (Tan, 2019). However, e-scooter is not required to wear helmet, but they cannot ride on traffic lanes. E-scooter is allowed to be ridden on shared path (bike lane) and sidewalk by the maximum speed of 25 km/h and 10 km/h respectively. All electric personal devices must be registered, by the owner of age at least 16, at the fee of $20 before July 2019. In addition, these electric devices have to comply with the UL2227 fire safety standard which will be effective by January 1, 2021. Several tests in this standard are overcharge, short circuit, overdischarge, temperature, imbalance charging, dielectric voltage withstand, leakage current, grounding continuity and isolation resistance (UL2272). Failure to comply with these regulations, users will be fined up to $5,000, and/or jailed for 3 months, and the devices will be seized and later forfeited. The penalties will be double for repeated offenders. LTA also require shared service providers to apply for sandbox license (before February 11, 2019) and full license for their e-scooter, unless they cannot deploy them in public area. Sandbox license operators could have a small fleet size, but they can increase their fleet after awarded the full license. To be granted for the full license, some criteria will be considered such as devices criteria, fire safety standard, ability to manage indiscriminating parking and maintain fleet, availability of parking space, and contravention record. The penalties will be up to $100,000 for each instance of non-compliance, reducing their fleet size, suspending or canceling the license. On January 14, 2019, LTA also implemented QR parking code system that will guide users to park at properly designated parking, while the additional charge of $5 will go to users who fail to do so.

In Europe, electric scooter is classified as the personal light electric vehicle (PLEV). However, the rules and regulations for this mode are unclear and it seems to be unfavorable due to its safety concern. In Spain, e-scooter is limited to at most 20 km/h speed, 25 kg self-weight, 1-meter length, 0.6-meter width, and one user for each scooter (AjuntamentdeBarcelona, 2019). Reflective elements, light, and insurance are recommended.

E-scooter is not allowed on sidewalk and roads, but they can be ridden on bicycle lanes, single-lane streets and footpath in the park (at least 1.5-meter width) at the maximum speed of 10 km/h. All users must be at least 16 years old and required to wear helmet all the time. These electric devices could be parked only at authorized parking places, and it is forbidden to tie them to trees, traffic lights, benches, and other furniture, and to park them on sidewalk that might block the pedestrian flow. The users will be fined for £100, £200, and £500 for minor, serious and very serious infringements respectively. In case of economic activities (mainly tourism activities using Segway), every group up to 6 people must be accompanied by a guide to tell them about authorized routes, and riding condition.

Table 3: The regulations for motorized scooter by countries

	US	Singapore	Spain	South Korea	Japan	Brazil	Australia
Scooter Width (cm)	No	70	60	NA	NA	No	70
Scooter Length (cm)	No	120	100	NA	NA	No	125
Scooter Height (cm)	No	NA	210	NA	NA	No	135
Scooter Weight (kg)	No	20	25	NA	NA	No	60
Max. Power (watts)	No	NA	NA	NA	600	No	200
UL 2271/2272	Yes	Yes	Yes	NA	NA	No	Yes
License Plate	No	Yes	Yes	NA	Yes	No	NA
Min. Age	16	16	16	16	16	No	18
Driving License	Yes	Yes	No	Yes	Yes	No	No
Max. Speed (km/h)	25	25 : road 15 : sidewalk	30: bike lane 10: others	25	25	20	15
Sidewalk	No	Yes	No	No	No	No	Yes
Road	Yes (R-40)	No	Yes (R-30)	Yes	Yes	Yes (R-40)	No
Cycling/Shared Paths	Yes	Yes	Yes	No	NA	Yes	No
Helment	Yes	No	Yes	Yes	Yes	Yes	Yes

NA: Not information available
R-30/R-40: Road with maximum speed of 30 or 40 km/h

South Korea firstly deployed dockless e-scooter in September 2018, while Japan just started the trial run in April 2019. However, these two countries don’t have a specific regulation for this new mode and consider this motorized scooter as mini-motorcycle or moped (Jtbc, 2018; Mooby, 2019). In this case, e-scooter is allowed only on the public road and require to have helmet, driving license and license plate (see Table 3). Contrary, Australia doesn’t require any licenses but allows to ride on only sidewalk with proper helmet (Aus.Gov). After several months of deployment, Brazil government decided to regulate the dockless e-scooter with helmet mandatory, speed limit and the ban on sidewalk (CityHall.SaoPaulo, 2019). On the other hand, there is no specific regulation for this mode in Thailand, while people could ride it on both sidewalk and public road in a safe and responsible manner.

Stricter and stricter regulations are also because of limited ability of service providers in responding to the violations and educating users to use e-scooter appropriately. In late 2018, Madrid authority ordered Lime, Wind, and Voi to remove their dockless e-scooter from the city, but they can redeploy only if they could fulfill some conditions such as phone app adjustment (GeoFence) to prevent using in unauthorized area, and better education commuting to assure the proper and safe usage (James, 2018). Similarly, the University of Arizona banned dockless e-scooter just based on the experience from Arizona State University (Mikayla, 2018). ASU banned dockless e-scooter because of safety concerns and unacceptable parking, but this mode will be deployed again if the service providers could solve these raising concerns. In Singapore, several dockless service providers (Neuron, Beam

& Telepod) have been charged in court for providing dockless service in public area without the license (Zhaki, 2018). Another serious case, UAE decided to ban dockless e-scooter just several months after deployment due to safety concern and irresponsible riders (Duncan, 2019). However, personal motorized scooter still ridable, but dockless e-scooter could come back after new regulation.

7. SOCIAL PERCEPTION ON DOCKLESS E-SCOOTER

As mentioned above, e-scooter fulfills a unique niche of the transportation ecosystem by providing a flexible link to transportation network. After the introduction in many cities around the world, this mode has left both positive and negative point of view. From mid-May to mid-July 2018, Populus, expert team on shared mobility service, conducted a survey from 7,000 people to understand the public perception on e-scooter in the US. The study found that a majority of people (70%) view electric scooter positively, including expanding transportation options, car-free lifestyle, convenient for short trips, and complementing public transit. Different from station-based shared bike which mainly been used by men by a factor of 2 to 3, dockless e-scooter, with the supports from authority, would make progress on closing the active transportation gender gap and improve safety for everyone (Populus, 2018b). The reason why women appear to be more open to e-scooter could be safer perception on small size e-scooter and riding on sidewalk, ease of standing on scooter with skirt, and distance sensitive. The results show that the higher income people have less positive view on dockless e-scooter. This might be because they concern more about safety while this mode improves the accessibility and vehicle equitability to low-income communities. In this case, we found that some states of US enforce the shared vehicle operators to distribute the dockless vehicles proportionally to the low and high-income communities. The attitude of people across the cities are relatively the same, except San Francisco ranks the lowest (it is maybe an unusual outlier). Moreover, this team also compared the equitable availability of vehicles between dockless vehicles (e-scooter and shared bike) and the Capital Bikeshare system in Washington D.C. city (Populus, 2018a). The result showed that the network distance to dockless vehicles is shorter than for station-based system, despite its much larger fleet.

Moreover, Qualtrics conducted the survey over 500 adults across the US as 176 of them experienced using e-scooter, about their perception on dockless e-scooter (Toll, 2018). The results showed that 55% of them believed that this mode was a lasting innovation, while that amount was even higher among those experienced e-scooter at 72%. Moreover, the majority of commuters showed their preference on e-scooter over shared-bikes, with 70% claiming that scooter was more useful and 75% agreeing that scooter was more fun to ride. 19% of respondents claim that they spent more money on the scooter, but they are still interested in using them. Several aspects of satisfaction level of using dockless scooter were evaluated such as trip satisfaction (88%), ease of parking (82%), satisfaction with scooter availability (85%), ease of sign-up (85%), and cost satisfaction (81%). On the other hand, 13% of those experiencing using e-scooter will not use them again since they found that e-scooter is either unsafe or inconvenient. Toward the environmental impact, 66% of adults felt that the e-scooter has positive impact on the environment. Furthermore, 75% agreed that air pollution could be positively impacted by more e-scooter usage. However, only 17% believed that dockless scooter could cope with congestion issues.

In South Korea, the National People's Right Commission conducted the analysis on 1292 complaints from 2016 to 2017 to examine the social perception on electric scooter usage

(Gov.KR.24, 2019). There were 5 types of complaint such as improper riding (39%), poor maintenance (22%), legal compliance (22%), income tax (12%), and accident (5%). Related to e-scooter regulations, there were 4 main illegal practices including riding on bike lane and shared lane (48%), riding in public park 27%, riding on sidewalk (19%), and young riders (5%). On the other hand, Korea Consumer Agency surveyed 200 e-scooter users (Kim, 2019). The results show that 92% of respondents never wear any protective gear (especially helmet), while 27% of those don't even have it, and 23% experienced scooter accident. Even though most of them (95%) felt dangerous without helmet, and 75% were agreed for this enforcement. Even it's mandatory, around 70% of them agreed of riding on bike lane or off-road places such as park, and university campus. 44% of these riders suggest for permission of riding on bike lane. In addition, 42% of e-scooter users did not know that this mode required a driving license.

8. CONCLUSION

Adopting electrification is currently one of the best option to deal with emission from road transportation, even though the source of electricity grid still mainly depends on emission sources, coal, and natural gas. Shared micro-mobility, especially e-scooter and e-bike, have played an important role in dealing with urban transportation issues including congestion, mobility, emission, and parking constraint. These shared services basically try to solve the problem of first-mile and last-mile in the compacted urban area. In this case, dockless e-scooter has the highest growth rates and have been adopted in many cities around the world especially, the US, France, Spain, Germany, Mexico, Singapore, Thailand, and Malaysia. Lime and Bird are the two mains shared scooter operators with the market value up to billion USD, while others dozen companies have engaged to this business as well such as Spin, Skip, Jump, Razor, Wind, PopScoot, Neuron, Bolt, Kickgoing, Yellow, MyGo, Kiwi, CityBee.

Shared scooter has gained its popularity because of its' cost and time effective for short distance range of 0.8 km – 3.5 km. Other attractive factors are the ease of finding/parking, less regulation, flexible routes, and fun experience. Customers could use dockless e-scooter by just downloading the application to their smartphone, then that application will show the location of the nearby e-scooter which customers can use and return after the trip. The trip fee is different between region to region, which basically includes the unlock fee ($0.52 – $1.40), and the riding fee (0.075 – 0.17 $/minute). As mentioned above, dockless e-scooter has really impacted on urban mobility, and increase the vehicle equitability. Moreover, the majority of users (88%) feel satisfied with the trip, and more than 70% evaluated this mode in the positive view on both congestion and environmental impact. If we compare the emission per mile, we can see that an e-scooter produces just 2% of CO_2 emission of an automobile.

Toward the increasing of interest in dockless e-scooter, there are also some issues raising such as safety issue, conflict with pedestrians, littering on sidewalk, and thief. The toll of e-scooter related accident has raised the social awareness of scooter usage or expansion of introduction dockless scooter in some cities, especially in Europe. These accidents are caused by several factors such as unsafe riding behaviors, battery explosion, scooter defects, and poor road infrastructure. Moreover, service providers also have limited ability to respond the violations and to educate users to use e-scooter appropriately. As result, stricter and stricter rules and regulations are implemented. These regulations are limited speed, riding lane/area, parking infrastructure, helmet, phone application improvement, payment method, and device criteria (weight, size, and fire safety standard).

A lesson-learned from South Korea, it seems that the authority reacts slowly and law enforcement is unclear, while there are many complaints regarding e-scooter usage or even high growth of conflicts with pedestrians. On the other hand, Brazil's authority quickly responds to social complaints by timely enforcing stricter regulations on dockless e-scooter. In case of UAE, the decision of banning dockless e-scooters appear to be very strict. While in Japan, law enforcement is very strict to both operators and riders, but there are still some operators who still have the will to gain the opportunity. However, these strict regulations will result in a high fee and low popularity. In some countries that the regulations are not clear such as Thailand, it is recommended to establish some basic regulations including helmet, riding lane, age, and speed limit.

Since there are various regulations on dockless e-scooter (i.e. e-scooter is allowed on sidewalk in Singapore, but in the US and Europe), so future researches should assess the effectiveness of these regulations. Moreover, the fee of dockless e-scooter is charged based on using time, so the users will try to minimize the trip duration as much as possible by speeding, riding on the opposite direction, and risky behavior at intersections. In this case, future studies should compare the risk behavior of shared/personal e-scooter and bike/e-bike in order to choose best charging fee policy ($1 + 0.15 $/minute, or $5.5 or less for 30 minutes). As we knew that, dockless e-scooter gain their popularity because of cost/time effective for short distance trip, ease of use/parking, and lease regulations, but the current enforced regulations are likely to against all those factors. Thus, future studies about the willingness to use dockless e-scooter should be assessed against all those regulations. The findings from these researches will assist the policymakers to choose optimal regulations that will keep this transportation mode in trend and operate at minimum social impacts.

In sum, we can see that there are both pros and cons that policy-makers have to balance. In case of US, lesson learned from the introduction phase of dockless e-scooter has raised some social reactions, especially safety issue, which led to another phase of piloting with stricter regulations before long-term permit. Besides regulation, operators themselves should also invest more in better safety instruction including promotion, campaign or incentive. Scooter battery should also improve to be safer, higher capacity and shorter charging time. Moreover, the frame, brake, bell, light and reflective materials must be more reliable. The social impacts and safety will be improved by some promising technology innovations including self-balance/self-folding/self-centering scooter, auto-relocation, smart lock, solar power integration, GeoFence, comprehensive vehicle tracking, and driver override system. Therefore, dockless scooter still stays in trends, while negative impacts could be minimized by commitments from all stakeholders as authority, operators, and users.

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