Safety Challenges and Solutions in Bike-Sharing Systems

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***Abstract*—Bike-Sharing Systems (BSS) is a new mode of transportation that allows users to rent bicycles and use them across the city for short trips. It has spread to all of the continents in the world due to its convenient nature and benefits. In contrast to other methods of public transportation, this service allows users to travel directly to their desired location, solving the first/last mile problem—when users' public transportation does not take them within one-fourth of a mile from their final destination. This allows users to get closer to their final destination than taking the subway alone, encouraging the use of public transportation. BSS also increases physical exercise, reduces carbon emissions, and is a flexible mode of transportation. These benefits have led to the growth of BSS. With this growth, several problems have emerged. These include re-balancing of underflow and overflow stations, predicting demand for each station, station placement, and, most importantly, safety. Re-balancing, predicting station demand, and station placement have been widely studied; however, safety has not been widely studied. This paper discusses the four leading safety concerns and provides new possible solutions and improvements to current solutions.**

***Index Terms*—Safety, Bike-Sharing Systems, Helmet Usage, Bike Lanes**

I. Introduction

Bike-Sharing Systems (BSS) allows users to rent bicycles and return them to docs across the city (Fig. 1). This mode of transportation has grown drastically and had positively affects the health of communities by increasing physical activity levels and decreasing carbon emissions. However, it has potential adverse effects on users due to the risk of accidents. In Europe, a study was performed in 2018 to determine the risk/reward relationship of BSS. It determined that 5.17 annual deaths were avoided due to users switching from car to bicycle transportation and that 73.25 annual deaths could be avoided if all BSS trips replaced car trips [1]. This shows that cycling is beneficial despite the potential risks. However, the risks should still be minimized.

Data from the United States Department of Transportation shows that cyclist fatalities have steadily increased from 2009 to 2018 (Fig. 2). There are similar trends among cyclists in the Slovak Republic. Between 2015 and 2019, the total number of accidents increased from 327 per year to 338. Cyclists accidents in Slovak have increased in all categories —fatalities, heavily injured, minor injuries, and the total number of accidents [2]. In Europe, cyclist accidents have plateaued, decreasing only 0.4% each year for the past 20 years [3]. Cyclist accidents plateauing is an excellent step in the right direction, but there is still substantial work to decrease the total number of accidents. Governments and researchers should look towards Europe's safety measures as inspiration to help decrease their accidents. Safety research is essential to decrease the number and intensity of cyclist accidents globally. Safety research should also be geared towards bicycle motor vehicle interactions since the majority of cyclist deaths come from motor vehicle accidents [4]. These trends provide sufficient evidence to support the study of BSS safety. The primary safety issues that need to be addressed include:

Fig. 1: Bicycle Dock in Philadelphia, USA

- **Low helmet usage**: Helmets drastically reduce the risk of injury, but the vast majority of BSS users do not use helmets.
- **Insufficient bike lanes**: Bike lanes have been proven to increase safety, but there are not enough protected bicycle lanes in cities.
- **Insufficient adequate cyclist merging lanes**: Having physical dividers, separate turn signals, and green paint separating cyclists and motorists has been proven to increase safety, but still, there are not enough effective merging lanes in cities.
- **Low visibility of cyclists**: Increasing visibility features have been proven to increase safety, but the majority of cyclists and bicycles do not have adequate lights and visibility features.
- **Reckless and inexperienced cycling**: Inexperienced and reckless riders have shown to be more likely to get into

This research was supported in part by NSF REU site grant CNS 1757533.

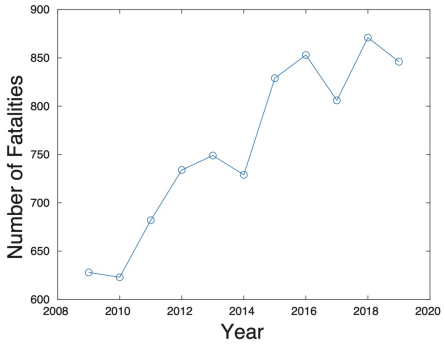

Fig. 2: Cyclist fatalities in the US from 2009 to 2018 [5]

accidents, but there have been few initiatives to decrease inexperienced and reckless riders.

Tackling these safety issues will decrease cyclist accidents and improve the overall safety of cyclists. Increasing helmet usage will decrease the severity of accidents that occur. Increasing bike lanes will make cities more cyclist friendly, safer, and increase the feeling of safety amongst cyclists. Increasing effective merging lanes would ease the transition from cyclist lane to intersection and help decrease the amount of accidents. Increasing the visibility of cyclists would allow cars to become more aware of cyclists and decrease the overall amount of accidents. Decreasing reckless and inexperienced cycling would decrease the overall amount of accidents. These five categories are extremely important in increasing cyclist safety.

II. Helmet Usage

Head injuries make up three-fourths of cyclist fatalities, one-third of emergency room visits, and two-thirds of hospitalizations [6]. Therefore, reducing the risk of head injuries is critical for increasing the safety of BSS. Helmets have been shown to help decrease the severity of head, brain, and severe brain injury by 63-88% [6]. It has been predicted, in the United States, that 151,400 out of 181,150 nonfatal cyclist-related head injuries could be prevented if all cyclists wore helmets [7]. For this reason, laws have been passed around the world requiring cyclists to wear helmets.

To date, 26 countries from all continents have passed laws requiring helmets. In the United States, there is no federal law requiring helmet usage. State and local laws determine helmet usage instead. 21 states and 202 local laws currently enforce helmet usage in the US [8]. When helmet laws were introduced in Australia, the percentage of cyclists wearing helmets increased in Victoria from 31% to 75% and in New South Wales from 26% to 85%. In addition to the increased percentage of cyclists wearing helmets, the proportion of cyclists' head injuries from motorist-related accidents treated or admitted to the hospital decreased by 13%. Head injuries in pedestrians also declined at a similar rate after the helmet law, so the helmet law may not be the only cause in the reduction of head injuries [7]. Although these laws proved effective

Helmet Usage in Various Cities

City Name	BSS Usage(%)	Private Usage (%)	Helmet Law
London	16	46	n
Seattle	20	91	y
Montreal	12	51	y
NYC	11		y

TABLE I: Helmet usage for BSS users and private cyclists in cities [9]

in certain aspects, they are harmful because they discourage cycling. One study showed helmet laws decreased the overall amount of cyclists by 36-44% per year [7]. This supports the idea that helmet laws are not the ideal solution to increase helmet usage.

Despite the existence of laws, studies have shown that in some cities helmet usage of BSS users is extremely low, especially compared to private riders (Table I). This data shows that BSS users are far less likely to wear helmets than private riders and that current laws enforcing helmet usage in these cities do not have a substantial impact. Further supporting that creating and enforcing new laws is not the ideal solution. Instead, efforts should focus on promoting helmet usage, especially for BSS users.

Since 2007, some BSS Companies, like NYC Citi Bike, have attempted to increase helmet usage by giving away 150,000 helmets. They also have helmet self-fit events to correctly size helmets on users [10]. However, Helmet usage in NYC is still low, so this initiative is not notably effective. There needs to be increased helmet usage, especially among BSS users, and the government and BSS Companies should be responsible for creating new incentives and new ways to make helmets more convenient to use.

III. Bike Lanes

Having a sufficient number of bike lanes is essential for the safety of cyclists. There are three distinct types of bike lanes—protected bike lane (Fig. 3), standard bike lane (Fig. 4), and shared bike lane (Fig. 5). These three types all provide safety and comfort to cyclists but at differing levels. Protected bike lanes have shown the greatest amount of comfort out of all types of bicycle lanes. One study showed 45% of cyclists felt "very safe" on protected bike lanes, compared to around 30% and around 10% for standard and shared bike lanes [11]. This increased feeling of comfort encourages riding and leads to increased safety.

One study showed that within one year of implementing protected bike lanes, ridership increased by 21-171%. This increase of ridership comes from cyclists that changed their route to use the bike lane, new riders, and riders that would have chosen a different mode of transportation had there not been the bike lane[12]. Having more cyclists in a city has been proven to increase the safety of cyclists, so this increase, caused by bike lanes, is a positive step at increasing safety.

There has also been tremendous community support for constructing bicycle lanes, with 75% of residents interviewed greatly support more implementation for bike lanes [12]. 96% of cyclists and 79% of residents stated cyclist safety increased

Fig. 3: Protected Bike Lane in San Francisco, CA [13]

Fig. 4: Bike Lane in New Jersey [14]

Fig. 5: Shared Bicycle lane in Fairfax County, VA [15]

after installing protected bike lanes [16]. Protected bike lanes also result in a 28% lower risk of injury and a substantially lower crash rate [17]. This data implies that all bike lanes are not equal, and implementing adequate bike lanes, specifically protected bike lanes, is a critical part of city planning.

Bike lanes decrease traffic congestion, promote cycling in cities, and increase biker visibility [18]. Since the majority of cyclists accidents occur from drivers' inability to see cyclists, this increased visibility and awareness of cyclists is critical [3]. There is also increasing evidence stating that having higher cyclist rates increases overall road safety. One study done in California, from 1997 to 2007, showed lower fatality rates, among all road users, in bike-oriented cities—cities that encourage cycling and have sufficient infrastructure [19]. Having ample bike lanes and cyclist-oriented cities increases overall safety and should be implemented more widely.

Although adding bike lanes would dramatically increase

Fig. 6: Cyclist Turn Signal [20]

safety, doing so would be difficult because there are high costs and limited urban development budgets. The construction of bike lanes is also tricky due to spatial constraints in cities. To cope with bike lane shortages, the NYC Citi Bike app plans routes based on bike lanes [10]. This allows cyclists to feel more comfortable and is a step in the right direction for bike lanes, but it is only a bandage on the problem. Cities should make constructing bike lanes a higher priority because of the strong connection between bike lanes and safety.

IV. Turning Lanes

Bike lanes, especially protected bike lanes, are a great tool to increase safety. However, at intersections, a new problem arises because bike lanes need to merge or interact with motorist traffic unless movements are signalized. Unsurprisingly, a majority of cyclist motor vehicle accidents occur at intersections. Crashes and injuries for protected cyclist lanes increase at least 10% at intersections [17]. To combat this traffic signals separating cyclist and motor vehicle movements have been added at some intersections and a combination of paint and barrier lines has been placed to separate motor vehicle and cyclist spaces. These new additions to bike lanes are still being developed and are not widespread yet.

There currently are several ways to ease the merge of cyclist lanes to car traffic—striped lines, paint, physical barriers, or a combination of these. The most effective way to ease the merging of cyclist lanes and car traffic is to use green paint and have a physical barrier of either flex posts, planters, or curbs. These were shown to increase biker comfort levels over a striped line [16]. Another way to ease merging is to have a bike box (Fig. 7). This addition to turning lanes dedicates space to cyclists to create greater separation and increase comfort levels. These methods help distinguish which areas are for cyclists and cars, creating increased comfort levels and safety.

Turn signals separating cyclist and motor vehicles have also shown to be notably effective (Fig. 6). It is the most effective method of increase cyclist comfort and predictability of cyclists. 92% of cyclists felt safer with this method, and 53% of motor vehicle resident owners stated the predictability of cyclists and motorists increased. It also is noted that 77-93% of cyclists and 84-92% of motorists followed the turn signals [16]. Because motorists and cyclists followed the signals,

Fig. 7: Bike Box [21]

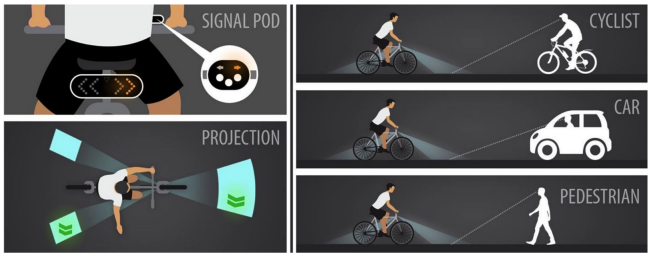

Fig. 8: Bike Gesture Initiative [22]

cyclists' intentions were more apparent, and cyclists felt safer than without turn signals, it can be assumed that adding turn signals separating movements of cyclists and motorists is a very effective method of increasing cyclist safety.

Another initiative to solve this safety problem is the Gesture Bike. This system displays cyclists' turn signals and a map for navigation on the ground for cars, pedestrians, and other cyclists to see. These signals can either be activated by cyclists' arm movements, which is the traditional way to signal a turn or through buttons (Fig. 8). This program intends to increase the visibility of cyclists' intentions past the traditional arm signals. This increases visibility and makes cyclists' intentions clearer, easing the merging of cyclist and motor vehicle lanes. This program is still being developed and testing different display types to determine if buttons or hand gestures are the easiest to use, least distracting, and most visible.

A combination of physical methods to ease the merging of cyclist lanes and motorist traffic and turn signals separating cyclist and motor vehicles, at high traffic intersections, would significantly improve cyclist safety. This research area is critical due to its potential to have a significant impact on cyclist safety.

V. Cyclist Visibility

90% of cyclist fatalities occur from collisions with motor vehicles [4]. Increasing the visibility of cyclists is a major way to improve safety. Bright front lights, rear reflectors, and reflective vests are effective ways to increase visibility. Despite the importance, case studies have shown that cyclists do not have adequate visibility features. It showed that at night 25% of cyclists had front lights, 50% had rear reflectors, and 12% had a reflective vest [22].

It is crucial to have these features when biking at night due to decreased light and visibility. A case study has shown that cycling at night is up to 5 times more dangerous than cycling during the day [22]. This implies that research and initiatives should focus on increasing visibility, especially at night.

A current initiative to solve this is Bike Swarm, which an MIT research lab developed. They added a removable cover of white LED lights to the bike frame that pulsate in unison to create a unified presence when a cyclist is within 5 meters of another cyclist. This is meant to increase the visibility of cyclists and mimic swarms of insects, like crickets and fireflies, who flash their lights in unison [23]. This innovation, if widely adopted, would help increase the visibility of bikers to cars.

Cyclists being unable to see cars and potentially dangerous situations is another safety hazard. One system developed by Pin-Cheng Lai, et. al, uses ultrasonic sensors to detect tailgating cars to eliminate blind spots [24]. If implemented, this would allow cyclists to be more aware of potentially dangerous situations. It would decrease cyclist motor vehicle accidents and would improve overall safety.

These initiatives show great potential, but they need to be implemented throughout BSS to create an impact. There currently are visibility features, such as lights and reflectors on BSS, but they could improve. BSS companies should improve the design of their bikes by implementing more lights similar to bike swarm. These additions, well costly, would substantially increase biker visibility and safety.

VI. Reckless and Inexperienced Cyclists

Reckless and inexperienced riders are another safety concern. Reckless riding includes dangerous activities such as biking at high speeds, fast accelerations, and weaving through lanes. These behaviors increase the chance of a bicycle accident. One study showed that young and older cyclists had the highest injury risk in relation to exposure in Finland. It was determined that their cognitive resources available were the causal factor, not age [25]. This implies that inexperienced riders are at a high risk of getting in an accident. To try and decrease inexperienced riders, several BSS companies are currently teaching classes on safety and how to ride a bike. The BSS company Indego, in Philadelphia, provides several classes to teach users how to ride a bike in urban areas [26]. These virtual and in-person courses are free and offer instruction and practice in urban cycling in multiple languages. This program can decrease accidents related to inexperienced riders.

Some BSS companies, such as Indego and NYC Citi Bike, also offer safe riding guides on their website that outline safe practices and laws related to urban biking [10][26]. More cities across the globe should take the initiative and implement free-riding guides on their websites to teach cyclists safe riding habits to help decrease accidents.

VII. Future Research

This section discusses future research to improve cyclist safety. It provides new ideas and builds upon previous ideas. Future research should be directed to these initiatives to maximize cyclist safety.

- **Helmet convenience:** To make helmet usage more convenient, helmets could be provided with the BSS service. Currently, BSS users have to bring a helmet to use during their ride. This is a massive inconvenience because users would have to carry their helmets with them around their day. If wearing a helmet was more convenient, more users would wear helmets and helmet usage would rise.
- **Helmet usage:** Helmet usage could also be improved by using the helmet as a key to unlock and lock a bicycle, forcing helmets to be worn in order to ride a BSS. There has already been research on how to do this with motorcycles, namely smart E-bike developed by Durga K Prasad Gudavalli et al. This innovation has a safety engine system and a security lock system that only unlocks and starts the motorcycle when the rider is wearing a helmet [27]. This innovation would ensure that riders wear helmets. This could be applied to BSS, except the helmet would be used to unlock the bicycle. This would significantly increase the percentage of cyclists wearing helmets, but it could discourage cyclists from using BSS because they would be forced to put on a helmet and some users might be uncomfortable with sharing helmets.
- **Bike lanes:** Bike lanes have already been proven to be incredibly effective; they now need to be implemented throughout every city. Governments need to take the initiative to integrate adequate bike lanes in their city planning and make cities more cyclist-friendly.
- **Turning lanes:** Bike lane merging methods at intersections, like green paint to distinguish biker areas and physical barriers, also have been proved very effective. These methods should be implemented throughout cities across the globe. City governments need to integrate these methods to ease cyclists merging lanes with motorist traffic at all intersections with high cyclist traffic. This would significantly improve cyclist safety and reduce accidents.
- **Cyclist visibility:** Research needs to be done on which initiatives provide the most visibility and on new initiatives to increase visibility. This would include adding more features, such as lights or reflective pieces to bicycles and encouraging cyclists to wear bright or reflective clothing so that they are easily seen.
- **Reckless and inexperienced riding:** Looking into the car industry for inspiration, Onestar by Allstate and similar car insurance services are optional programs that track reckless driving. These programs measure acceleration speeds, braking, cornering, speed, phone use, and time of day. This initiative was put into place because risky driving correlates with collisions and risky behavior preceded 50% of collisions [25]. Users receive discounts based on their safe driving habits. This data is either gathered from in-vehicle data recorders or smartphones. This program promotes safe driving and could be applied to other modes of transportation, such as cycling.

  To implement a similar program for BSS, reckless riding and an incentive would need to be defined. Reckless riding could be defined with similar characteristics of reckless driving, such as accelerating speeds, braking, phone use, speed, and weaving through lanes. These could be measured with sensors on the bike, like an accelerometer and Gyroscope sensor, or by a phone. Free or discounted rides could be used as an incentive in this program. If this program was implemented, users would be more likely to ride safely.

  There are a few challenges with this proposal. BSS is a very inexpensive service and car insurance is a large payment, so the incentive for BSS users to ride safely would be small. Due to the small size of the incentive, BSS users may choose to continue to ride recklessly. There are also some privacy issues with tracking reckless riding because riders would need to consent to have their riding tracked. These challenges would need to be considered if this research was done.

VIII. Bigger Picture

BSS has two main categories, dockless and dock-based. The majority of safety issues are consistent for both of these categories. Safety issues appear the same for dockless and docked stations, but dockless stations have additional safety concerns. Bicycle placement in streets or hazardous areas would need to be addressed for dockless BSS. All other safety concerns for dockless and docked BSS would be consistent. Overall, safety improvements in either docked or dockless BSS would positively impact overall BSS safety and are welcomed.

There currently are many other types of transportation—electric bicycles, scooters—and there are more types being developed. These methods are passive modes of transportation that are used when there is a demand for them and stay motionless when there are no users [28]. These methods of transportation are very similar to BSS and safety measures can be applied to them. Riders of electric bicycles and scooters both use helmets, bicycle lanes, need visibility features, and contain reckless and inexperienced riders. So, safety in BSS is essential due to the impact it can make in other areas.

A reduction in motor vehicle and bike accidents would greatly benefit both forms of transportation. Motor-vehicle cyclist accidents decrease with increased cyclists and pedestrians on the road, so having more cyclist-friendly cities would decrease the overall amount of motor vehicle cyclist accidents, improving cyclist and motor vehicle safety [25].

BSS can improve the safety and health of the general public in other ways. Carbon dioxide and air quality have been

a significant issue to the public's health. Along with BSS decreasing the global carbon footprint, one study has shown that it can help detect poor air quality with sensors. The data collected by the sensors is displayed on smartphones through a Firebase website and Google Maps using balloons to represent data points of air quality[24]. This feature would allow riders to be more informed on air quality in certain areas and plan bike routes in areas with better air qualities. If implemented widely, this feature would improve the general public's health by making people more aware of air quality in areas and allowing them to avoid low air quality areas. This research could promote other methods of using sensors to track data to be used to help the general public.

IX. Conclusion

BSS is an extremely valuable mode of transportation that has several benefits and potential risks. These risks should be minimized by making cyclist safety a priority. Research in cyclist safety would significantly improve overall safety of cyclists and motorists, but efforts above will take time and funding to happen. Cyclist accident rates are high, and more initiatives need to happen. Safety should be a priority of BSS companies and governments. They should also make more significant efforts to take actions that expand BSS to help improve public health and actions that increase safety. Governments should also push for more efforts similar to the sensors that detect air quality to be widespread. This would increase the general public's health and inform users to make the safest choices. Solutions to increase safety include increasing helmet usage, creating more bike lanes, creating more efficient merging lanes, increasing biker visibility, encouraging safe riding, and educating riders on urban cycling. Research in these areas would significantly improve cyclist safety and could be applied to other transportation methods. Progress in transportation safety will need substantial effort from governmental, private, and academic institutions.

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