The Impact of Traffic Calming Measures on Cyclists' and E-Cyclists' Safety

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***Abstract*—Cycling is a sustainable transport mode, especially in urban areas for short distances. Electric bikes and electric scooters are increasingly emerging into traffic network in cities in Sweden due to advantages related to accessibility, environment, etc. However, they bring questions in terms of traffic risk and accidents. The road infrastructure must be adapted to accommodate the increasing share of these new types of bikes in traffic. The study will assess both bikes and e-bikes safety according to exposure, risk and consequences. The study will review relevant literature on Traffic Calming Measures (TCMs). It will develop a conceptual framework to determine the impact of different TCMs (horizontal and vertical) on traffic safety for both traditional and e-bikes safety. Accident data from the Swedish Traffic Accident Data Acquisition (STRADA) will be collected and analysed in order to identify roundabouts (as a chosen type of TCMs) with high accidents rates for cyclists in Norrkoping city in Sweden.**

***Index Terms*—traffic safety, traffic calming measures, cyclists, electrical bikes**

I. Introduction

Traffic accidents are a leading cause of health, social, and economic problems worldwide. There are more than 1.4 million people killed in road accidents every year, and more than 40 million were injured, according to the World Health Organisation (WHO) report in 2016. The majority of road deaths and injuries occur in developing countries [1]. Most of victims are young people and vulnerable road users such as pedestrians and cyclists.

Cycling is a sustainable transport mode, especially for short distances (5-10 kilometres) in urban areas. They can reduce air pollution, energy use and traffic congestion. Sweden has a long cycling tradition and is one of the highest-ranking countries when it comes to cycling usage. In Sweden, cycling represents 10% of all travelling modes [2]. According to the Swedish Traffic Accident Data Acquisition [3], 26 cyclists killed in traffic in Sweden (out of 253, the total number of traffic deaths). Sweden, as in many other countries, has a high under-reporting rate of bike accidents in comparison to other transport modes, mainly for minor and slight injuries. Cyclists have a higher traffic risk comparing to bus and car occupants in terms of distance and time travelled. Most accidents where cyclist is seriously injured occurred in urban areas, and generally in student cities than in other cities. In Sweden cyclist accidents are overrepresented due to weather conditions in winter mainly.

There are different factors that can elevate the cyclist traffic accident rates: trip length, weather, age, gender, speed, topography, infrastructure, road user behaviour, type of facilities, etc. Sweden is one of the leading countries within traffic safety. It has managed to reduce the number of cyclist fatalities during last decades. This is due to a successful planning and implementation of traffic safety policies, which have included a number of prevention and remedial measures in traffic engineering, enforcement, road user education, safe infrastructure, separated bikes lanes, increase usage of helmets, regular cycle paths inspection, traffic signals for cyclists, priority lanes, etc [4]. These measures correspond to so-called Vision Zero in Sweden "no one should be killed or seriously injured in the traffic".

Motorisation as well as unplanned urbanisation have led to lack of appropriate cyclists' facilities, with inadequate design and usage. In some developing countries cycling travel patterns are different since cyclist have a different position in traffic. Sometimes they must use the same roads as motor-driven vehicles and follow their rules, other times they must share paths and rules with pedestrians. The problem sometimes is variance of speed between road users or having too little space to combine both walk and cycling in the same path.

Some of the main problems for conventional bicycles in urban traffic include the difficulty to travel long distances, over hills and the possibility of arriving at a destination (such as work or school), sweaty or tired. Therefore, the interest in using electric bikes (e-bikes) has increased. Some other advantages include, but not limited to, higher speed, the ability of cyclists with limited physical capacity to use e-bikes. Also, the public are interested in zero emissions and less noise, which e-bikes provide. Reference [5] presented a comprehensive review of e-bikes development and practices worldwide.

Due to their advantages, the number of e-bikes and e-scooters is increasing rapidly in the market both in Sweden and other countries. Also, the e-bikes' design has developed rapidly last decade (e.g. less battery size, better battery efficiency and weight of the e-bike). In Sweden, up to 130,000 e-bikes were sold between August 2017 and August 2018, almost four times than year 2014 [6]. Furthermore, Sweden encourages the purchase of e-bikes by regulations and providing subsidies to people to purchase e-bikes in Sweden. Therefore, authorities are

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welcoming research studies on this topic of e-bikes usage and safety.

Traffic calming is a set of physical measures used in cities to slow down traffic, reduce traffic volume, divert traffic to alternate routes, modify driver's perception and behaviour. As a result, TCMs improve safety for pedestrians and cyclists as well as improving the environment for residents. However, TCMs may increase noise, air pollution, congestion, vehicle delay, energy consumption and "rough ride" for drivers, passengers and cyclists. In earlier studies by the author [7], [8], different TCMs showed various delay time impact of travel of cars. Finding the best choice of TCMs is a challenge for traffic engineers and planners, which depend on the local conditions of traffic and infrastructure (e.g. type of road: local, collector or arterial, traffic flow, funding, etc).

There are mainly two types of TCMs 1) horizontal measures such as chicane, chokers, curb extension, centre island narrowing, roundabouts, mini roundabout, etc.; and 2) vertical measures such as speed hump, speed bump, speed table, speed cushion, raised intersection, rumble strips, etc. Alert road marking and 3d illusional painting are other superficial measures, which have impact to reduce noticeably the speed of vehicles.

The overall objective of the study is to assess infrastructure in terms of Traffic Calming Measures (TCMs) on cyclists and e-cyclists' safety. The study develops two matrixes to determine 1) the exposure, risk and consequences for both types of bikes, and 2) the impact of different TCMs on traffic risk for both bikes and e-bikes usage and safety.

II. Methodology and Data

The methods applied in order to reach the study goals are:

- Theoretical review of existing knowledge regarding cyclist and e-cyclists' safety at international level and national level.
- National Swedish handbooks e.g. TRAST (traffic for an attractive city) [9] and VGU (roads and streets implantation guide) [10].
- STRADA (Swedish Traffic Accident Data Acquisition) includes police and hospital accident data for fatal and non-fatal accidents involving cyclists [3].
- Models as VISUM-Safety in order to identify which location at roundabouts will be the most hazardous for cyclists. Based on a Master thesis work [11], supervised by the author.

III. Theoretical Background

Cycling safety depends on the road infrastructure such as bike routes, painted bike lanes, TCMs, signs, etc. Speed brings higher risks and severity in traffic for cyclists. Speed in streets with a higher exposure of cyclists, must stay under 30km/h in order for cyclists to survive under a traffic accident. To reach speed limits, TCMs are good countermeasures to be implemented in urban roads. A Swedish infrastructural solution is given by separating cyclists from all traffic with motorised vehicles as possible [12].

By improving infrastructure includes design and maintenance, an increasing share of cyclists in traffic can be achieved. To ensure the quality of bikes' infrastructure network, there must be coherence, consistency, connectivity of lanes along with homogenous speeds need to be ensured. It is necessary to identify deficiencies in the existing cycling networks in a city include: the missing links, locations with limitations in accessibility, locations with high traffic accident risk, route layout with markings and signs, visibility of all cyclists at intersections and roundabouts.

Compared to traditional intersections, roundabouts as one type of TCMs, can reduce severity through the reduction of severe conflicts points (mainly crossings potential conflicts). Therefore, pre-accidents studies such as The Swedish Traffic Conflict Technique, Traffic Risk Assessment, Naturalistic Cycling, etc. are increasingly applied over short time of observations. In previous studies [13], [14], we applied pre-accident observational techniques for accident assessment and prediction.

Different countries have various designs for roundabouts, they are categorised mainly into [15]:

- Mixed traffic roundabout where cyclists share the same entry lane, exit lane, and lanes with motor vehicles
- Cycle lanes within the roundabout (adjacent cycle lane) with a bike lane marking.
- Separated cycle lanes alongside with pedestrian paths outside roundabout.
- Grade separated (multi-level) cycle paths e.g. bridges or underpass the roundabout as tunnels.

Separated cycle paths at roundabouts are seen as the best solution in Sweden [16]. In terms of geometric design for roundabouts, [17] recommended tangential design for roundabouts in Sweden in order to keep speed and capacity of vehicles. However, this design can reduce safety for cyclists at/around the roundabouts.

Despite the large increase of e-bikes/e-scooters, few studies have been made to quantify the benefits of that new transportation mode in terms of road accidents. Previous few studies addressed aspects related to the development of technologies, modal shift, energy saving and human interaction with the environmental. Previous studies showed that when conventional bicycling is increasing, it may be because people reduce their travel by public transport or walking. However, according to a recent study [18], the increase of e-cycling has appeared to reduce the usage of cars.

E-bikes require safe, comfortable and attractive infrastructure that can provide longer cycle routes (distance) and longer travel time, wider cycle paths, integration with the public transport system, reduced need for lifting the bike (because electric bicycles are heavier), public charging spots, etc. Moreover, the determination of the optimal sites for e-bikes' charging stations in a city needs careful planning to promote the use of e-bikes. This can be a complicated problem that can involve multiple criteria include operational benefit, effects on environment/safety/accessibility, and harmonisation between electrical vehicle charging stations and urban infrastructure development.

In many cities worldwide, there have been launching the idea of e-bikes/e-scooters sharing. The idea is to have lots of e-bikes placed in the city, where the people can hire one of them by Mobile application. This will replace shorted trips made by cars or public transport. Similarly, during 2019, Linköping municipality in Sweden has chosen to invest in equipping the city with the opportunity of borrowing e-bikes [19].

As e-bikes start having a stronger presence on roads, the infrastructure demand needs to be investigated. Many cities in Sweden and worldwide are increasingly assessing policies, legislations and infrastructure facilities to accommodate such type of transport mode for the purpose of environment, traffic safety, mobility and accessibility.

IV. Results and Discussion

The number of serious traffic crashes for e-bikes is expected to rise because of higher risk and consequences due to speeding (include average speed and variance of speed with others regular cyclists, pedestrians and cars). Further, there will be a higher risk due to more older users for e-bikes, and misjudgement of the speed by other road users. E-bikes run much further in distance and time (higher exposure in traffic). With the increasing number of people choosing the e-bicycles and e-scooters and as a substitute for the car, a higher exposure for this type of modes will be resulted in traffic. Table I shows the expected increase of exposure, risk and consequences of e-bikes use in traffic in comparison to traditional bikes.

TABLE I. Exposure, Risk and Consequences in Traffic for Cyclists and E-cyclists

	Exposure in traffic (time and distance travelled)	Risk (speed)	Risk (variance of speed)	Consequences (severity)
Traditional bikes	Moderate	High	Moderate	High
Electrical bikes	Moderately increased	Higher risk	Higher risk	Severely increased

Table II summaries the impact of main TCMs on bikes and e-bikes traffic risk and accidents, based on the theoretical part discussed in section III. The criteria used in this assessment are higher speed, higher variance of speed, higher weight for e-bikes and larger proportion of elderly people will use e-bikes. The results in this table need to be further investigated according to field observations in future studies. Table II concludes that rumble strips, curb extensions, vertical TCMs, and roundabouts have higher traffic risk of accidents especially for bicyclists/e-bicyclists who are enforced to share the same street with other vehicles if TCMs are not designed properly. Another conclusion from the table is that the height of vertical TCMs e.g. humps should be implemented carefully on the streets where e-bikes are frequently used with a higher travel speed.

TABLE II. Expected Impact of TCMs on Cyclists' and E-cyclists' Traffic Risk

TCMs	Type	Impact on Safety
Chicane	Horizontal	Possible limitation for manoeuvring. It may force vehicles and cyclists/e-cyclists to share a narrow space.
Chokers	Horizontal	May force cyclists/e-cyclists to merge with vehicles.
Center Island Narrowing	Horizontal	May force cyclists/e-cyclists to merge with vehicles. The design should facilitate space that permit access by cyclists/e-cyclists.
Curb extension	Horizontal	Create uncomfortable space share for cyclists/e-cyclists in traffic.
Roundabout	Horizontal	Require cyclists/e-cyclists to adjust to a smaller number of crossing spaces. It reduces the number of conflict points with vehicles.
Mini roundabout/ circle	Horizontal	Cause cyclists/e-cyclists/vehicle conflicts at intersections due to narrowed travel lanes.
Speed bump	Vertical	Cause a "rough ride" for cyclists/e-cyclists, which can cause accidents.
Speed hump	Vertical	Easy for cyclists/e-cyclists to cross if designed appropriately. The height of hump should be used carefully where e-bikes are frequent or rapid. Approach a hump with a higher speed may cause serious injury. It is also possible any slow/sudden stop may cause loss of control and falling down.
Speed table	Vertical	Relatively easy for cyclists/e-cyclists to cross.
Speed cushion	Vertical	Can be avoided by cyclists/e-cyclists.
Raised Intersection	Vertical	Easy for cyclists/e-cyclists to cross if designed smoothly, appropriately and not slippery.
Rumble Strips	Others	May impact severely cyclists/e-cyclists accidents, due to loss of control and steering difficulties.
Alert Road Marking	Others	It requires high maintenance. It may not be effective in reducing vehicle/cyclists/e-cyclists speeds.
3D illusional painting	Others	Future studies are required in this direction.

Norrköping city is located in southern east part of Sweden with approx. 120,000 inhabitants. According to STRADA database (2013-2015), there were 625 traffic cyclists' accidents occurred with 3 fatal accidents, 21 severe accidents, and 457 minor injuries in Norrköping [20]. In Fig. 1, a heatmap is used to visualises traffic cyclists' accidents at roundabouts in Norrköping city between 2010 and 2017 by applying VISUM-Safety software. The heatmap analysis shows that most accidents involved with cyclists were occurred at intersections and roundabouts in Norrköping city. The threshold value of accident counts is 4 with a radius of location is 50 meters. Red colour refers to intersections/roundabouts with more or equal to 4 accidents; yellow colour refers to intersections/roundabouts with accidents are less than 4; while green colour refers to locations with less than 2 accidents.

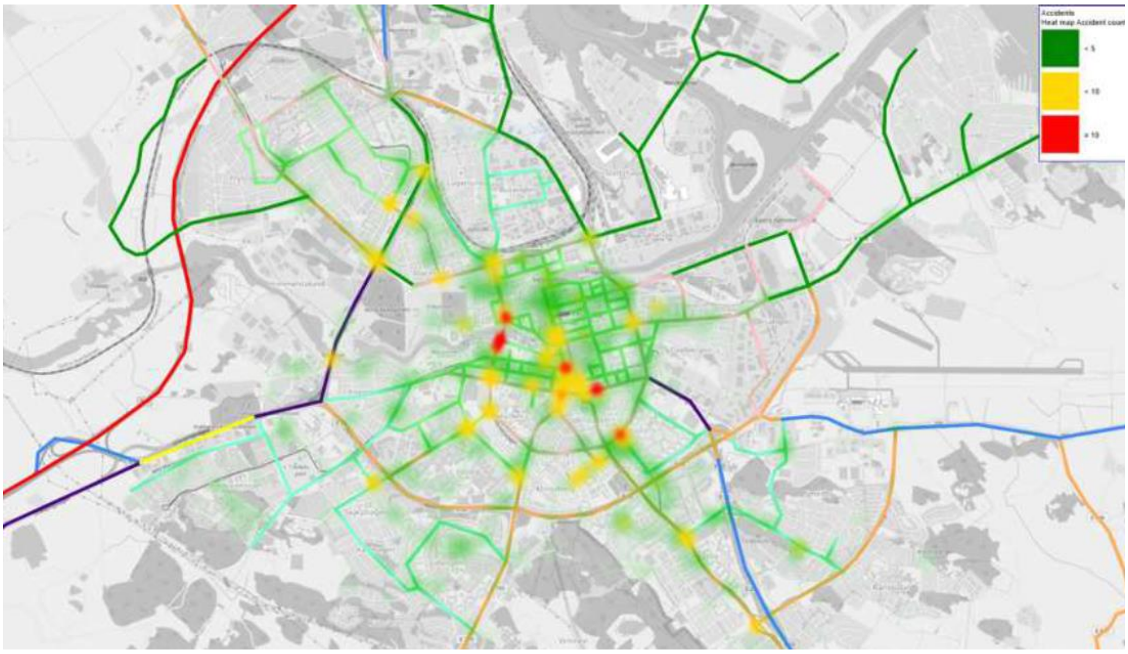

Figure 1. Heatmap for cyclists traffic accidents in Norrkoping city (2010-2017)

V. Recommendation and Conclusions

This study emphasised the importance to overcome the challenge of collecting historical accidents data for cyclists in terms of unreliability and under-reporting in national accidents counts. Data collected for both traffic police and hospitals must be integrated and reported.

Our conclusion in this study is that e-bikes can increase road accidents due to higher exposure, risk and consequences due e.g. speeding, variance of speed, conflicts with other transport modes and higher use by elderly people. It is necessary to ensure the quality of the infrastructure to accommodate this type of bikes. It is necessary to set up new national policy, targets and priorities for e-bikes usage include: speed limits, longer bike routes, charging sites and helmets legislation.

Conventional methods for travel survey collection for cyclists and e-cyclists risk and accidents have been based on interviews or computer-assisted by means of statistical modelling or simulation. However, these methods rely on respondent's survey or historical accidents data over a long period of time (5-8 years) for making a significant analysis. As a result, this study recommends applying pre-accidents observations at short time of period for future studies. The suggested methods are 1) the Swedish conflict technique, which identify the conflicts points (involving bikes/e-bikes); and 2) naturalistic cycling method in order to study the behaviour (e.g. manoeuvres, speed and travel time) of cyclists/e-cyclists and their interaction with real traffic infrastructure.

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Conflict of Interest

The author declares no conflict of interest.

Author Contributions

GA conducted the research and approved the final version.

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