Development of a new zone-based cycling safety metric to determine the crash risk associated with work trips

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1 INTRODUCTION

Cycling is a healthy, green, and low-cost mode of transport and numerous policies and initiatives are employed for promoting cycling in the Netherlands. Despite various individual and societal advantages of prevalent bicycle use, the increasing number of fatal and severe injury crashes involving cyclists has raised concerns over safety of cyclists. In this regard, past studies have investigated effective environmental and traffic factors on cycling safety. In evaluating the relationships between cycling safety and probable effective factors, accounting for a reliable risk measure is critical.

Exposure and the number of incidences are two important factors in crash risk measurement. Unlike vehicular crash analysis, a common limitation in analyzing cycling crash risk is the availability of extensive bicycle counts as the exposure variable [1]. In the past studies, bicycle counts, bicycle trips, and bicycle-kilometer-traveled are some proxies used as exposure variable (e.g., [1-3]). In this regard, Ding, Sze [1] revealed that application of trip-based exposure variable (expressed in bicycle-kilometer-traveled) resulted in outperformance of cycling safety models. Moreover, new machine learning methods used for prediction of number of crashes [4, 5] have enhanced crash risk estimations. Despite the new ideas developed in cycling safety analysis, past studies have failed to address how cyclists as "travelers" are exposed to traffic crashes along their trips from an origin to a desired destination. Thus, this paper suggests a methodological approach to introduce a trip-based risk index to estimate crash risk associated with specific trip purposes at specific locations. We applied this approach to estimate a trip-based index for crash risk indicating the cost associated with work trips by bicycle in the municipality of Utrecht. This city is known as the best-bicycle-city in the world in 2022 with a 51% cyclists population. This study is focused on postcode-level 5 (PC5) zones in Utrecht and a 5 km buffer area. Various databases including road and cycling network, zonal socioeconomic and demographic chacrteristics, crash data, and Dutch national travel behavior data were used in the analysis.

2 METHODOLOGICAL APPROACH

This paper uses a 4-steps modeling approach coupled with a route choice model and safety model to develop a trip-based crash risk index estimating the potential crash risk associated with work trips between different origins and destinations. The mothodology consists of five main steps as follows.

1) Configuration of OD trip distribution matrix: First, the PC5 zones were assigned as origins and destinations based on landuse and demographic characteristics of the zones. The trip distribution matrix was then generated based on the density of population and number of jobs in the zones.

2) Route choice set generation: We generated choice sets for the OD pairs by minimization of six different impedance factors including *(actual) travel distance*, *travel time*, *number of crossings*, and *perceived* *travel distances.* We considered the perceived travel distances based on three scenarios in which the road types of mixed traffic, suggested cycling road and separated cycling lanes/paths were differently weighted.

3) Assignment of trips on generated routes: The probability of choosing each route among others in the generated route choice set was calculated based on a path-size route choice model for cyclists. This model was developed by Ton, Cats [6] in the municipality of Amsterdam. Then, Eq. 1 was used to calculate share of potential work trips between ODs made by bicycle on each route (W^r); where, T_{ij} is the potential number of work trips between zones i and j; and P^r is the probability of selection of route r between the O_i and Dj. We also took the share of bicycle use in making trips to/from work into account. According to data from Travel Survey in the Netherlands, this share was about 21.85% in the Province of Utrecht.

$$W_{ij}^r = T_{ij} \times P_{ij}^r \times 21.85\% \tag{1}$$

4) Safety modeling: In this study we included two types of sever and slight injury crashes in the analysis. We used the national crash data in the Netherlands to develop a safety model indicating the relationships between traffic, road network, and other environmental characteristics on crash frequency. To alleviate the problem of extenssive number of zeros in the crash data a resampling method [7] was also applied. Then the number of crashes were predicted based on this model developed by a machine learning method (XGBoost).

5) Trip-based crash risk analysis on routes and in zones: In the last step, an index for trip-based crash risk assessment on the routes was developed that includes share of work trips made on the routes, number and cost of crashes of each type, as well as total exposure on routes (Eq. 2). The total exposure on route was estimated for 4 hours (during peak-hour traffic), during the working days in 4 years. The crash cost for severe injury crashes was considered equal to 1 million Euro (value of the Statistical Severe Injury (SSVI) in the Netherlands [8]) and the cost of slight injury crashes was considered equal to 5,000 Euro [9]. Finally, total value of crash risk costs for all potentail trips originating from each zone was calculated based on the summation of crash risk costs on the routes originated from each zone to all possible destinations.

$$Potential\ Crash\ risk\ Cost_{ij}^r = W_{ij}^r \times \frac{\sum_{t=1}^{T} (No.\ Crash_{ij}^t \times Crash\ Cost^t)}{Total\ exposure_{ij}} \tag{2}$$

3 RESULTS AND CONCLUSIONS

The insights gained from this study may be of assistance estimation of an index for crash risk imposed to travelers by accounting for route, mode, purpose, and time of the travel. Figure 1 depicts the histogram of such crash risk associated with work trips by bicycle on the routes. Figure 2 illustrates an example of generated cycling routes between zones 3438L and 3513A representing the results of estimated crash risk cost per year associated with work trips by bicycle between these zones. The routes are shown in different colors from red (the riskiest route) to dark green (the safest route). As this Figure shows, the route with smallest number of crossings which was the most probable route to be chosen by the cyclists. Whilst, the route with shortest distance found to be the safest route among others. This result could be due to small exposure value on this route.

Figure 3 shows the estimated injury crash risk cost associated with work trips in the PC5 zones. This figure shows that zones located in the center and Eastern areas of the city were safer. This result can be related to slower motor vehicle traffic because of traffic congestions during the peak hours in these areas. Additionally, presence of high density of jobs and short distance between the locations in the city center zones results in more attraction of more bicycle trips in these areas leads to presence of a large number of bicycles on roads in these zones. A result of that would be drivers pay more attention to cyclists, specifically on the mixed traffic roads and suggested cycling lanes. In contrast, the zones located in the Northwest and Northeast were less safe compared with other areas. This result can be explained by the high population density of the active population, as well as the high density of residential areas resulting in increased production of the work trips.

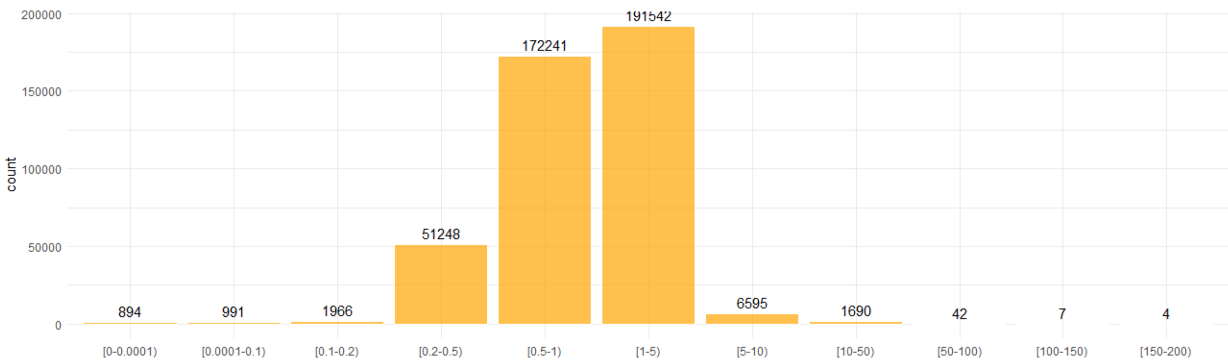

Figure 1 trip-based crash risk costs on routes

Figure 2 Alternative routes created between PC5 zones: 3438L – 3513A

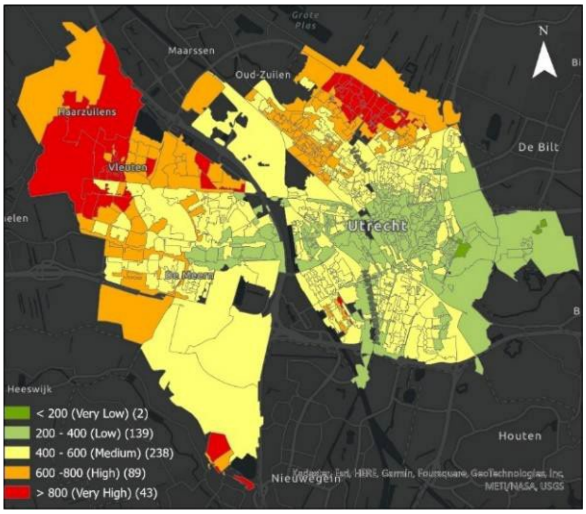

Figure 3 Total yearly average potential cost of crash risks associated with work trips by bicycle (€ per Origin)

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