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Modelling the effect on injuries and fatalities when changing mode of transport from car to bicycle

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ABSTRACT

Background: Several studies have estimated the health effects of active commuting, where a transport mode shift from car to bicycle reduces risk of mortality and morbidity. Previous studies mainly assess the negative aspects of bicycling by referring to fatalities or police reported injuries. However, most bicycle crashes are not reported by the police and therefore hospital reported data would cover a much higher rate of injuries from bicycle crashes. The aim of the present study was to estimate the effect on injuries and fatalities from traffic crashes when shifting mode of transport from car to bicycle by using hospital reported data.
Methods: This present study models the change in number of injuries and fatalities due to a transport mode change using a given flow change from car to bicycle and current injury and fatality risk per distance for bicyclists and car occupants.
Results: show that bicyclists have a much higher injury risk (29 times) and fatality risk (10 times) than car occupants. In a scenario where car occupants in Stockholm living close to their work place shifts transport mode to bicycling, injuries, fatalities and health loss expressed in Disability-Adjusted Life Years (DALY) were estimated to increase. The vast majority of the estimated DALY increase was caused by severe injuries and fatalities and it tends to fluctuate so that the number of severe crashes may exceed the estimation with a large margin.
Conclusion: Although the estimated increase of traffic crashes and DALY, a transport mode shift is seen as a way towards a more sustainable society. Thus, this present study highlights the need of strategic preventive measures in order to minimize the negative impacts from increased bicycling.

1. Introduction

The popularity of bicycling in urban areas has increased and in recent years more attention has been paid by stakeholders to create a safer road environment for bicyclists. Especially in big cities, bicycling is an important complement to reduce vehicle congestion and greenhouse gas emissions. Transportation bicycling also provides an opportunity for individuals to incorporate physical activity into daily life. Previous studies have shown that bicycling as a health enhancing physical activity can reduce the risk of mortality and morbidity (Matthews et al., 2007; Oja et al., 2011). A meta-analysis identified that bicycling reduces the risk of all-cause mortality by 10 percent (Kelly et al., 2014) and a Danish cohort study identified that bicycling to work reduces the risk of all-cause mortality by 28 percent (Andersen et al., 2000). Several studies have highlighted the positive health impacts of bicycling as active commuting, showing benefits in reducing risk for various cardio vascular diseases (Hu et al., 2007; Hamer and Chida, 2008). Furthermore, studies have shown that the health benefits of moving from cars to bicycles outweigh the cost of injury from road chrashes (Lindsay et al., 2011; Rabl and DE Nazelle, 2012).

On the other hand, bicyclists and other vulnerable road users have higher risk of being injured or fatally injured compared to car occupants. The number of bicyclists killed per passenger-kilometer has been reported to be nine times higher than for car occupants (Björketun and Nilson, 2006). According to hospital reported crashes and injuries, bicyclists account for a higher proportion than any other road user in Sweden. In 2014, bicyclists and car occupants

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represented 45% and 33% of all hospital reported injured, respectively (STA, 2015). The injury consequences of bicycle crashes are primarily correlated to non-fatal injuries (de Hartog et al., 2010) and they statistically represent around 6% of all road fatalities in Sweden (STA, 2015). In total almost 80% of all bicycle crashes in Sweden are single crashes (Rizzi et al., 2013), which is similar to results based on hospital data from other countries (Schepers et al., 2014).

Several studies have tried to estimate the total health effect of active commuting, claiming that the health benefits of bicycling outweigh the risks in terms of increased injuries and fatalities related to bicycle crashes (Holm et al., 2012; de Hartog et al., 2010). However, in previous studies the assessments of the negative aspects of bicycling mainly refers to fatalities or police reported injuries. Since only around 7% of bicycle crashes in Sweden are police reported, the negative impact may not be adequately described using police reported data (Rizzi et al., 2013). Hospital data cover a much larger share of bicyclist injuries and are therefore more suitable when analysing bicyclist crashes and injuries.

The aim of the present study was to estimate the effect on injuries and fatalities due to traffic crashes when shifting mode of transport from car to bicycle.

2. Method and materials

In this study, the health effect on injuries and fatalities due to a change in transport mode from car to bicycle was modelled by estimating the change in bicycle and car crashes, based on a scenario where car occupants in Stockholm change mode of transport to bicycle given that they can reach their work place within 30 min by bicycle. Given this scenario, a flow change from car to bicycle was estimated to 135 million km per year (111,487 new bicyclists) by Schantz (2015). At a national level, this corresponds to an increase of bicycle traffic volume by 5.9% and a decrease of car traffic volume by 0.2%.

2.1. Modelling approach

Denote the number of bicyclists and car occupants being injured or killed as a random variate of $X_{i,j}$, where $i \in \{bicycle, car\}$ and $j \in \{injured, killed\}$. Also, let the health loss for each individual be a random variate of $Y_{i,j}$. Then, the aggregated health effect on a population, e.g. injured bicyclists, is as a random variable $Z_{i,j}$ defined as

$$Z_{i,j} = \sum_{k=1}^{X_{i,j}} Y_{i,j,k} \tag{1}$$

The variable $X_{i,j}$ was modelled as a random Poisson variable with expected value equal to the injury or fatality rate multiplied with the traffic flow change. The injury and fatality rates for bicyclists and car occupants were given in risk per distance and estimated using data from STRADA (Swedish Traffic Accident Data Acquisition; Swedish Transport Agency, 2016). STRADA contains information on crashes and injuries occurring in the Swedish road transport system as reported by the police, and medical data injuries as reported by emergency care hospitals. Traffic mileage data using the Swedish national travel survey RVU (Transport Analysis, 2014). Mileage, injury and fatality data were collected from year 2014. Suicide was not included in the data. In order to make the data represent active commuting to work, crash data involving bicyclists aged 18–65 years were used. The characteristics of the crashes for this group were similar to crashes occurring on work time hours. Furthermore, the total national traffic mileage from the RVU was used. The risk per distance at a national level was almost identical to the risk per distance in Stockholm. The national risk was preferred over the city-specific risk for two reasons. Firstly, the sample from national data was larger and hence, more stable results was yielded. Secondly, the city-specific risk might be biased since bicyclists that are involved in crashes outside Stockholm may still visit a hospital in Stockholm, resulting in upward biased risks.

The health loss expressed in terms of Disability-Adjusted Life Years (DALY) from a crash was modelled by the random variable $Y_{i,j}$. The distribution of $Y_{i,j}$ was constructed using empirical data of the health loss from bicycle or car crashes (Appendix A). Injury and fatality data for the empirical distributions were collected from the years 2010–2014. Again, suicide was excluded and only individuals aged 18–65 were included.

DALY is a measure that combines disability and mortality expressed as years of life lost due to premature death (YLL) and years lived with disability (YLD) (Eq. (2)). The YLL is the expected life years lost for a fatally injured individual (Eq. (3)). The life years lost due to an injury are equal to the duration of the injury multiplied with a disability weight relating to the specific injury (Eq. (4)) (Salomon et al., 2013). The health effect associated with a change of transport mode from car to bicycle was modelled as the DALY increase due to an increase of bicyclists and a DALY decrease because of less car occupants (Eq. (5)). Note that injury rate, fatality rate and the characteristics of health loss are based on the present situation. This implies that the model assumes that the distribution of age, gender and other factors that might influence the risk or the severity of crashes are somewhat constant in time.

$$DALY = YLD + YLL \tag{2}$$

$$YLL = E\,[life\ \ expectancy] - age \tag{3}$$

$$YLD = disability\ \ weigth * duration \tag{4}$$

$$\Delta DALY = YLD_{bicycle} + YLL_{bicycle} - (YLD_{car} + YLL_{car}) \tag{5}$$

The distribution of the random variable $Y_{i,j}$ was constructed using empirical YLD and YLL of bicycle and car crashes. AIS coded injuries from STRADA were translated into the injury types used in the Burden of Disease study (Salomon et al., 2013) by the metric used in Tainio et al. (2014) (Table B1). This transformation had to be done in order to compute the YLD and YLL caused by the crashes. In the case of multi trauma, only the injury with the highest YLD was used. Injuries with a lifelong duration were computed as the difference between the expected life time and the age of the individual. The life expectancy table used was collected from Statistics Sweden (SCB) (Table B2).

A distribution of the DALY change due to a transport mode change was obtained using the Monte Carlo technique and independent random samples of $X_{i,j}$ and $Y_{i,j}$ were obtained using the inverse method (Appendix A). An estimate and confidence interval (CI) of the DALY change were obtained using the percentiles of its distribution. For each simulation run, 1000 samples of the DALY change were simulated. In order to reduce the influence of random variation, each assessment was averaged over 50 simulation runs. This procedure was repeated to ensure convergence.

3. Results

The number of injured bicyclists and car occupants per million km were estimated to 5.2 and 0.2, respectively. The fatality rates were estimated to $14.3 * 10^{-3}$ fatalities per million km driven for bicyclists and $1.4 * 10^{-3}$ fatalities per million km driven for car occupants. The injury rate was 29 times higher for bicyclists than for car occupants and the fatality rate was 10 times higher for bicyclists than for car occupants.

The average YLD of a bicycle and car injury were 0.19 and 0.28 years, respectively. That is, the average life time lost due to an injury was 69 days for bicyclists and 104 days for car occupants.