Quantifying Health & Economic Benefits of Bicycle Superhighway: Evidences from Patna

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Abstract

Active mode of transport is good for health as well as it is one of the most important mode of sustainable transport. In many previous studies/reports, a cost-benefit analysis for a new infrastructure is provided, however it rarely includes the benefits due to physical activity. The present study attempts to quantify the benefits from physical activities. A comparison is made between business as usual and bicycle superhighway (BSH) scenario. The protective benefits are calculated for different values of average cycling duration. For reference, cycling for 3h/week results in the relative risk of 0.72; in other words, cycling for 3h/week results in 28% lesser deaths from any cause than non-cyclists. The average cycling duration are estimated using the output of a multi-agent transport simulation model. This subsequently is used to determine the number of deaths prevented each year for both scenarios. With the help of a simulation model of Patna, India, it is shown that a substantial increase in the longer bicycle trips is observed. This results in saving of more than 750 deaths each year.

Keywords: Health economics, Cycling, Bicycle Superhighway, Physical Activity

1. Introduction

The users of bicycle can be categorized as primary and secondary. The former consists of the commuting trips, i.e., to work, education whereas the latter comprises of leisure, shop, sport or recreational trips. Typically, commuting bicycle trips are significantly higher than non-commuting (secondary) bicycle trips [21]. In India, the driving force to use the bicycle (and walk) for primary activities is household income and thus, called as captive users [24]. Though, the benefits of cycling to user (e.g., mobility, health, safety) and community (e.g., lesser transport negative externalities, livability, etc.) are well known [15], the modal share of the bicycle trips is seeing a decreasing trend [22, 18]. A few reasons for this are poor infrastructure, perceived danger, discomfort of cycling (and walking) close to the motorized vehicles, preference to motorized vehicle with an increase in income, social perception to cycling, etc., [14, 22].

A few past studies [16, 6, 3] have demonstrated various ways to increase the bicycle share which will assist in reduction of congestion, emission, improve accessibility, etc. However, a few studies have attempted to quantify the health economic benefits of cycling [10, 7, 11]. Götschi et al. [12] provides a review of past studies from the health perspective for cycling. The annual per capita direct or indirect cost savings of physical activities ranges between 195$ to 1175$ as stated by different study or agency [15]. WHO [25] developed an Health Economic Assessment Tool (HEAT) for non-motorized transport (NMT) modes. It estimates the economic value of reduced mortality as a result of higher active mobility (walking, cycling). It is an online tool for European context and to assist the policy makers.

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The active mobility also comes with negative effects i.e., exposure to air, noise pollution, risk of injuries, etc. Agarwal et al. [3] propose a bicycle superhighway (BSH) for Patna, India and exhibit the reduction in congestion levels, emissions as well as improvements in the accessibility. However, Agarwal and Kaddoura [2] demonstrate that the BSH in the middle of the urban area will increase the air pollution exposure. This is likely to create a dilemma and a greater confusion to the policy makers. Therefore, a comprehensive cost-benefit analysis of BSH is required which considers the investment costs, economic benefits of the BSH (e.g., lesser levels of congestion, emissions, reduction in fuel consumption, health benefits, etc.) and the drawbacks (e.g., exposure to air, noise pollution, elevated levels of risk of crash if not physically segregated infrastructure, etc.). Buekers et al. [7] show that the physical activities outweighed the other health impacts for the bicycle highways (BHs) in Antwerp-Mechelen and Leuven-Brussels. Similar results are obtained by Rojas-Rueda et al. [20] for Barcelona. In Netherlands, cycling prevents more than 6500 deaths each year which is equivalent to 3% of Dutch GDP (gross domestic product) [11].

Very limited studies attempt to quantify the economic benefits of active mobility. An extent of various cost and benefits of NMT and policies are illustrated in a study by Rastogi [19]. The author emphasizes the increase in the health, congestion, accident costs, etc. due to provision of mobility over accessibility. Buis [8] performs a cost-benefit analysis for a bicycle policy in Delhi (one of the four case studies) and shows that time and user costs savings are significantly higher than costs. However, health economic benefits are minor. Rahul and Verma [18] compute the economic benefits of reduction in congestion, emissions, accidents, etc., for a unit shift from motorized travel modes to NMT modes in Bangalore. TERI [23] estimates the health benefits of substituting short-distance MTWs and cars in India by bicycle trip, which comes out to 1.8 trillion (1.6% of annual GDP of India). It includes fuel savings, health benefits of physical activity, reduced air pollution and travel time savings. However, as per the author’s best knowledge, no study attempt to quantify the health benefits of cycling infrastructure at a city scale. The present study attempts to bridge this gap by quantifying the health benefits of a bicycle superhighway (BSH). A BSH in Patna, India is proposed by Agarwal et al. [3]. The scope of this work is limited to estimation of health benefits from BSH in terms of the reduction in mortality.

2. Methods

2.1. Physical activity benefits from reduced mortality

The health benefits of cycling and walking are given in terms of reduced mortality and morbidity. Similar to [25], in absence of sufficient data, the present study also estimates benefits related to mortality only which makes the benefits underestimated. The relative risk of cycling is 0.72 for cycling more than 3h/week. In other words, a person cycling for 3h/week is 28% less likely to die from any cause than non-cyclist [25]. The generalized form can be written as Equation (1) and shown in Figure 1(a). Protective benefits are defined as the probability of preventing deaths and \( t_{\text{actual}} \) is the average cycling duration per week. As recommended by [25], protective benefits are capped at 50%.

\[
\text{Protective Benefits} = 1 - 0.72^{t_{\text{actual}}}
\]  

2.2. Data assumptions

For the present study, data assumptions are as follows. (1) **Mortality rate**, typically, is different for different age group which can be used. However, the age of the travelers (see Section 3) is not available in the model. Therefore, the mortality rate for Patna is taken as 5.0 per 1000 inhabitants [9]. (2) **Value of statistical life (VSL)** is varying over various studies, a value of ₹15.0 million is assumed as VSL in India for year 2006 [17].
2.3. MATSim

In the present study, a multi-agent transport simulation framework [MATSim, 13] is used. The inputs to MATSim are a representation of the road network and daily travel plans of the sample population. MATSim constitutes a three step iterative cycle. These are: (a) Mobility simulation (mobsim): Daily travel plans of individual travelers are executed on the road network using a queue model. A mixed traffic implementation of queue model is used for the present study [5]. (b) Scoring: Executed plans are evaluated using a utility (scoring) function which incorporates the utility of performing an activity and (dis)utility of traveling. (c) Replanning: Post-scoring, to react and adapt to the system, agents are allowed to replan as per the defined innovative strategies (e.g., time choice, route choice, mode choice, etc.). The iterative cycle continues to a convergence stage where the simulation aborts. In approximately, 20% (configurable) of the last iterations, only plan selection is allowed so that unrealistic plans can be filtered out.

2.4. Calculation of health benefits

As shown in Table 1, two scenario, business as usual (BAU) and bicycle superhighway (BSH), are considered. The travel duration in the simulation model represents a typical work-day. To calculate the weekly cycling duration, following steps are taken. (1) From the simulation output, average duration of cycling is calculated for each income category. (2) The average cycling duration (typical work day) is multiplied by number of working days (i.e., 5) assuming five work/ education days in a week. The same approach is used for other trip purposes due to lower income levels (i.e., significant captive users). (3) The protective benefits are calculated using Equation (1) for the average duration of cycling. (4) Number of persons for each income category are counted, scaled up to represent 100% (traveling) population. To exclude the persons who stays at home, the trip production rate of 0.79 [1] was used. Therefore, the number of persons are multiplied by 1.27 to represent the whole population of Patna. (5) The total prevented lives are calculated for each income category by multiplying protective benefit for each category with number of persons and mortality rate (5%). (6) Total prevented lives are monetized using the VSL.

3. Case study: Patna, India

To emphasize the importance of the new bicycle infrastructure, a case study of Patna is used. A simulation model for Patna was developed, calibrated and validated by Agarwal et al. [4]. The scoring functions of individual travelers integrate the monthly income in it and therefore the choices are affected by it. The same income categories are used for the analysis purposes.

The scenario comprises of urban travelers, commuters and through traffic. The former is synthesized using a household travel diary survey and the latter two using the cordon counts and origin-destination (OD) matrix. In the business-as-usual (BAU) scenario, the modal share for urban travelers is 32.3%, 2.7%, 14.7%, 21.7% and 28.6% for bicycle, car, motorbike, PT and walk travel modes. Bicycle, car, motorbike transport modes are simulated on the network whereas PT and walk modes are simulated based on the beeline distance and average speed factor for PT and average speed for walk. A bicycle superhighway is proposed (see Figure 1(b)) which increases the share of bicycles from 32.3% to 48.7% [3]. A comparison of modal share for urban travelers is shown in Table 1. The analysis is performed only for urban travelers.
Table 1: Model share reference study, post calibration and for scenario BSH [3].

<table>
<thead>
<tr>
<th>scenario</th>
<th>travel mode</th>
<th>bicycle</th>
<th>car</th>
<th>motorbike</th>
<th>PT</th>
<th>walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>reference study</td>
<td>33.0</td>
<td>2.0</td>
<td>14.0</td>
<td>22.0</td>
<td>29.0</td>
</tr>
<tr>
<td>BAU</td>
<td>post-calibration</td>
<td>32.3</td>
<td>2.7</td>
<td>14.7</td>
<td>21.7</td>
<td>28.4</td>
</tr>
<tr>
<td>BSH</td>
<td>policy</td>
<td>48.7</td>
<td>2.1</td>
<td>11.2</td>
<td>12.9</td>
<td>25.1</td>
</tr>
</tbody>
</table>

4. Results

Cycling duration. Figure 2 shows the number of persons for different income categories and cycling duration bins. The number of persons for higher cycling duration bins are very few and therefore ignored from the Figure 2. A significant rise in number of cyclists for each income category can be observed in the BSH scenario which is a result of better bicycle infrastructure [also see 3]. Interestingly, the increase in longer bicycle trips is observed for higher income groups also which is contrary to the belief of bicycle being a travel mode for lower income households.

Table 2: Average cycling duration and number of lives saved for BAU and BSH scenario. Number of persons are scaled to full population.

<table>
<thead>
<tr>
<th>Income category (₹)</th>
<th>Number of persons</th>
<th>Avg. cycling duration (min/ day)</th>
<th>Lives saved (/ year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BAU</td>
<td>BSH</td>
<td>BAU</td>
</tr>
<tr>
<td>500</td>
<td>28,861</td>
<td>49.2</td>
<td>52.8</td>
</tr>
<tr>
<td>750</td>
<td>53,165</td>
<td>42.9</td>
<td>47.5</td>
</tr>
<tr>
<td>2,000</td>
<td>453,291</td>
<td>29.1</td>
<td>44.2</td>
</tr>
<tr>
<td>4,000</td>
<td>426,203</td>
<td>26.6</td>
<td>43.0</td>
</tr>
<tr>
<td>6,250</td>
<td>281,646</td>
<td>25.0</td>
<td>38.1</td>
</tr>
<tr>
<td>20,000</td>
<td>437,595</td>
<td>25.6</td>
<td>36.4</td>
</tr>
<tr>
<td>total</td>
<td>1,680,759</td>
<td>27.7</td>
<td>41.1</td>
</tr>
</tbody>
</table>

Deaths prevented. Table 2 shows a comparison of the two scenarios in terms of average cycling duration and number of lives saved per year. Firstly, an increase in the average cycling duration is observed for all income categories and it is substantial for higher income categories. Secondly, an average cycling duration of 27.7 min/day is likely to save about 1870 lives per year. Thirdly, for the whole population, the average cycling duration has increased by 48% in BSH scenario. Moreover, with the introduction of the bicycle superhighway, additional 755 lives per year can be saved. In Netherlands, the average cycling duration of 74 min/week, prevents 524 deaths/million persons [11].
same number of Patna is 1640 deaths prevented/ million person (for BSH scenario) due to higher average cycling duration.

**Monetized benefits.** The benefits to the bicycle superhighway can be monetized using the value of statistical life. Assuming a construction period of 2 years (from 2008), the VSL in 2010 (discounting factor using consumer price index = 218.06 / 201.6) is ₹16.2 million. Thus, the monetized benefits turns out to ₹12.25 billion of saving by preventing 755 deaths annually.

![Figure 3: Number of lives saved for different values of bicycle riding comfort index](image)

**Bicycle riding comfort (BCR) index.** As defined in [3], different BCR indices are used to demonstrate the sensitivity of the BSH (see Figure 3). It can be observed that there is only marginal increase in the lives saved with respect to BAU for values up to 1.5. However, a sharp increase in the number of lives are observed for BCR greater than 1.5. This emphasizes that the significant benefits can be achieved if a bicycle facility is very comfortable in terms of physical segregation from motorized traffic, continuity, smooth surface, free from obstructions, etc.

5. Conclusions and Discussion

The quantification of the health benefits from physical activity is important to policy makers and transport planners. This study estimated the economic benefits of physical activity by the introduction of a bicycle superhighway (BSH). For this, a case study of Patna is used for which a BSH was proposed [3]. Two scenarios, namely, business as usual (BAU) and BSH are presented. An increase in the cyclists for all income groups was observed. A substantial increase in the longer bicycle trip was also found which has become critical in the evaluation of the health benefits. It was shown that with the introduction of bicycle superhighway, more than 750 lives can be saved per year which accounts for about ₹12.25 billion. Clearly, these numbers are inspiring to the policy makers as well as to the individuals and therefore can be used to motivate the road-users. It is likely that in the post-COVID-19 scenario, more persons will shift to bicycle to maintain the social distancing and avoid the crowding in the public transport. This will further elevate the benefits of a bicycle superhighway.

Though the present study show the great potential for a bicycle superhighway by monetizing the health benefits of increased physical activity, following are the limitations which should be looked up on before adapting the results and can be addressed in the subsequent studies. (1) The average cycling duration in the present study includes the time for which the cyclists remain stationary in the queue which brings down the average speed. The relative risk of 0.72 for cycling 3 h/week is applicable to estimated speed of 14 km/h [25]. (2) In absence of the data, same mortality rate is assumed for all age-groups. (3) The relative risk and protective benefits (Equation (1)) approach is applicable primarily for the age between 20 – 60 years. However, in absence of the data, all persons from the simulation model are used. (4) The value of life per year will vary for different age group.

In addition to the above, the benefits obtained in the present study are underestimated due to exclusion of benefits from morbidity, benefits of walking and exclusion of commuters and through traffic. Therefore, future studies can include a comprehensive cost-benefit analysis of BSH, which includes the costs due to exposure to air pollution [2], noise, risk of injuries, crashes and benefits from reduction in mortality, morbidity, health benefits from walk, congestion relief, reduction in fuel consumption, etc.