Bicycle Superhighway: An Environmentally Sustainable Policy for Urban Transport

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Abstract

Concerns are growing across various parts of the world due to increased negative transport externalities derived from fast growth of population and rapid urbanization. This increases necessity for sustainable urban transport. Bicycle is a sustainable low-carbon transport mode. However, insufficient or unplanned infrastructure leads to decrease in the share of bicycle in many cities of developing nations. In order to increase the bicycle share and to provide safer, faster and more direct routes, a bicycle superhighway is proposed for urban areas. For maximum use of a new infrastructure, an algorithm is presented to identify the optimum number and locations of the connectors between proposed new infrastructure and existing network. The household income levels are incorporated into the decision making process of individual travellers for a better understanding of the modal shift. A real-world case study of Patna, India is chosen to show the application of the proposed superhighway. It is shown that for Patna, the bicycle share can escalate as high as 48% up from 32% by providing this kind of infrastructure. However, together with bicycles, allowing motorbikes on the superhighway limits the bicycle share to 44%. The increase in the bicycle share mainly comes in from motorbike, public transport and walk to bicycle mode switchers. Further, this study extends an emission modelling tool to estimate the time-dependent, vehicle-specific emissions under mixed traffic conditions. Allowing only bicyclists on the superhighway improves congested urban areas, reduces emissions, and increases accessibility. However, allowing motorbikes on the superhighway increases emissions significantly in the central part of the urban area, which is undesirable. This study elicits that a physically-segregated high-quality bicycle superhighway will not only attract current non-cyclist travellers and increase the share of bicycle mode but will also reduce the negative transport externalities significantly.

Keywords: Bicycle superhighway, cycleway, sustainable transport, externality, emissions, accessibility, mixed traffic, agent-based simulation

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1. Introduction

1.1. Urbanization

The share of urban population has increased to 54% in 2014 up from 30% in 1930 and it is expected to rise to 66% by 2050 (United Nations, 2014). This is accompanied by the increase in the number of mega-cities (large urban agglomerations with more than 10 million inhabitants), which will increase from 10 to 41 in the period from 1990 to 2030. The spatial distribution of growth in urban population is uneven (Cohen, 2006; United Nations, 2014). For instance, approximately 90% of the increase in urban population (between 2014 and 2050) is projected to be concentrated in Asia and Africa.

1.2. Motorization, negative effects and economic losses

Rapid urbanization is likely to increase the dependency on road transport and thus increase vehicle usages. Depending on possible government interventions for future policies, the total number of cars across the globe is expected to increase between 2.2 to 2.6 times from 2010 until 2050 (WEC, 2011). Faster urban spread and motorization in urban agglomerations is likely to increase the level of congestion, emissions, noise etc. which can endanger sustainable development. In congested traffic conditions, vehicle speed reduces significantly and causes losses in time and fuel. Exhaust emissions is one of the major source of air pollution releasing a variety of pollutants. Negative transport externalities such as congestion, emissions, accidents, noise etc. cause significant losses to the GDP (Gross Domestic Product) in terms of public health and economic growth (Gwilliam, 2002).

1.3. Transport policies

In decisions regarding transport policies, agencies decide a policy minimally based on the traffic patters, pressure on the supply, income levels of the households, modal share, objectives of the policy (e.g. generate revenues, abate transport externalities, etc.). An effective policy for a particular situation might not be effective in other situations because it is likely to differ with level of motorization, economic development, and urban form in each city. In real world, several urban transport policies are implemented to manage transport demand and/or supply based on different policy objectives.[1] There is sufficient evidence in the literature which shows that the positive gains from the real-world traffic restrain or pricing scheme are limited to the short term (Zhou et al., 2010; Cai and Xie, 2011; Beria, 2015; Percoco, 2014). In addition to this, a pricing scheme will be less effective if the share of potential toll payers (mainly car users in urban traffic) is very low.

In many cities of the developing nations, low income households are captive to non-motorized or to cheaper alternatives and a significant number of individual travellers cannot afford subsidised public transport (Badami and Haider, 2007; Tiwari et al., 2016). These persons are sometimes referred as the 'urban poor'. In cities with significant share of households with low income groups, policies are very sensitive to household income levels, e.g. for travellers with low income, costs would be more important than travel time or comfort, whereas travellers with high income would prefer to travel with faster and more comfortable mode. In such scenarios, a possible measure would be to reserve a lane for those travellers who can pay the toll Powell (2001); Bar-Gera (2012); Anderson and

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[1] Please refer to Ch. 3 of Agarwal (2017) for an overview of different types of policy measures with related past studies.

Geroliminis (2015). A high toll on the reserved lane can restrict further possible switches from non-car (or non-motorized) to car (or motorized) trips and produce a balance between different user preferences (travel time/cost). Toll values in such cases, mainly, depend on demand and supply. Such a policy would be effective in cases where the majority of urban roads have two or more lanes, which is, however, typically not the case in urban areas of many cities of developing nations, e.g. 36% of the total road length in Patna, India have a width of less than 5 m (TRIPP et al., 2009).

1.4. Sustainable urban transport

Concerns about the aforementioned issues related to fast growth of population and rapid urbanization are growing. Civic bodies are exploring sustainable low-carbon transport options and measures to increase the non-motorized transport (NMT) modes (e.g. bicycle, walk). Apart from its established health benefits (Mueller et al., 2017), it is quoted as one of the most sustainable forms of transport due to its reliability, affordability and low or zero negative transport externalities (Gatersleben and Appleton, 2007). Rastogi (2011) recognises major key issues and provide several guidelines in favour of sustainable transport, and significant importance is given to the promotion of walking and bicycle. Bicycle used to be a neglected field of study, but is gaining ground and becoming a more important transport mode. In order to increase the share of sustainable and low carbon transport modes, strong measures like a strengthening and integration of public transport and NMT infrastructure as well as improvements in fuel and vehicle technology are required. In absence of sufficient infrastructure for public transport (PT) and NMT, travellers, who can afford this, are shifting to private modes (e.g. car, motorbike). Interaction with motorized traffic increases the real and perceived danger, and discomfort for walking and bicycling which is likely to reduce the NMT share (Jacobsen et al., 2009). Similar reasons has led to decline in the share of walk and bicycle modes in many cities of India (Tiwari et al., 2016).

In the last few decades, emphasis of urban transport policies is set on the development of sustainable urban transport strategies such that the interests of future generations can be protected. According to Bugliarello (2006), for a city, the three important sustainable measures are: (a) to reduce the external footprint, (b) to make city more livable in terms of transportation, housing, water etc. and (c) to make the suburbs more sustainable. Similarly, Goldman and Gorham (2006) identify four directions, which outline the potential visions of sustainable transport while major importance is given to innovative practice on ground. One of the directions is to make cities more livable which concerns accessibility. With an example of Bogotá, the authors highlight the strict provision of pathways for non-motorized transport modes through urban centres. Following such visions, use of bicycle is promoted in different parts of the world via diverse policy initiatives to increase the share of bicycle (Martens, 2007; Su et al., 2010; Buehler et al., 2016; Pucher and Buehler, 2008). Cyclists[2] are sensitive to distance, turn frequency, slope, intersection control, traffic volume, traffic-mix, travel time, on-street parking, roadway speed limit, discontinuities (Broach et al., 2012; Sener et al., 2009; Verma et al., 2016; Menghini et al., 2009; Hood et al., 2011). The comfort perception of the cyclists is also affected by age, type of two-wheeled vehicles, width of bicycle lane, roadside land-use etc. (Bai

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[2] Terms 'bicycle' and 'cycle' are common ways of addressing two-wheeler non-motorized vehicle. In the context of developing nations, the latter is more common. In this study, both terms are used interchangeably unless otherwise stated. Thus, a cyclist refers to the bicycle rider.

et al., 2017). Several studies have shown that improvement of various bicycle facilities is likely to increase the bicycle ridership (Martens, 2007; Wardman et al., 2007), trip length (Tilahun et al., 2007) and safety (McClintock and Cleary, 1996). The provision of bicycle lanes adjacent to the lanes for the motorized traffic is a common way of bicycle facilities in many parts of the world. In a study, it is shown that a bicycle lane offsets the negative effects of adjacent motorized traffic. It does, however, not offer any additional attractiveness than a low traffic volume local street (Broach et al., 2012). In addition to this, the safety, comfort, convenience of riding a bicycle are top priority for potential users than captive riders (Jain et al., 2010). Safety, comfort, convenience of cyclists are likely to increase with a physically segregated infrastructure and this, in turn, can play a vital role in promotion of sustainable urban transport.

1.5. Physical segregation of bicycle lane

Bai et al. (2017) show that physical segregation of bicycle lanes from motorized traffic and pedestrian lanes (footpath) significantly increase the comfort perception of cyclists. Given the scarcity of space in urban areas, it is possible that such bicycle lanes are somewhat longer and off-track. However, with the help of revealed preference surveys, it has shown that bicyclists adjust their routes to use off-street or off-track bicycle path (Krizek et al., 2007; Howard and Burns, 2001; Broach et al., 2012). Bicyclists are also willing to take the longer route to use such bicycle lanes (Standen et al., 2017). In another study, it is found that these detours could be as high as 67% higher than shortest distance (Krizek et al., 2007). An off-track bicycle facility is also likely to increase the bicycle ridership (Tilahun et al., 2007). This will encourage the captive users as well as currently non-cyclists. The female bicycle ridership is very low in many developing nations (Tiwari et al., 2008), which is likely to rise with an off-track cycleway (Standen et al., 2017). Therefore, based on the foregoing discussion, this study analyses the importance of a bicycle superhighway[3] for urban centres. The term ’superhighway’ is used to distinguish this infrastructure from (regular) bicycle lanes. The aim is to provide safer, faster, direct and comfortable routes for bicycle riders rather than providing an infrastructure to move out non-motorized modes from motorized traffic lanes to make motorized traffic faster.

1.6. Research gap

The benefits from the new cycleway or superhighway in an urban area are understudied, particularly, in (a) integrating income levels of the individual travellers into the decision making process, (b) quantifying the potential of increase in bicycle share, (c) decrease in congestion, emissions in the urban area and (d) increase in accessibilities. This study bridges these gaps with the help of a real-world case study. For this, a bicycle superhighway in the urban centre is proposed and the extent of the aforementioned benefits are quantified using an activity-based multi-agent transport simulation framework. For the application of bicycle superhighway, a case study of Patna, India is chosen. Further, this study also proposes an innovative approach to find the optimal number and locations of the connectors between new infrastructure and the existing network. To estimate the vehicle- and link-specific time-dependent emissions under mixed traffic conditions, an emission modelling tool (EMT; Kickhöfer et al., 2013) is extended. Moreover, using the

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[3] Please refer to http://denmark.dk/en/green-living/bicycle-culture/cycle-super-highway and http://lcc.org.uk/pages/cycle-superhighways for some practical examples.

case study, this work provides insights which are useful to encourage policy makers and law-enforcements.

The remainder of the paper is organized as follows. Sec. 2 prepares rationale for the bicycle superhighway and explains the proposed methodology for the connectors of bicycle superhighway. The multi-agent transport simulation framework for the present study is briefly presented in Sec. 3. Application of bicycle superhighway is exhibited in Sec. 4. This section also illustrates the simulation set up, income-dependent utility function and policy scenarios. The results and findings are analysed in Sec. 5. The impact of the policies on the congestion, emissions and accessibilities are visualized spatially in this section. Further, main findings of this study are summarised in Sec. 6.

2. Bicycle superhighway

London has a few cycle superhighways (TfL, accessed Sep. 2017) and an overall positive effect is observed (Law et al., 2014). In the context of developing economies such as India, the development of NMT is favourable because (i) a high share of travellers belongs to low or middle income households, (ii) the share of shorter trips is very high (Rahul and Verma, 2013). Thus, there is a vast scope to increase the share of bicycle mode as well as walk mode, provided, an efficient infrastructure is available. In the similar direction, this study recommends a bicycle superhighway for Panta, India and evaluates its impact in terms of modal share, congestion, emissions and accessibilities.

For Patna, the bicycle share is about 33% (TRIPP et al., 2009) which favours the need of a physically segregated infrastructure for bicycle modes. There are at least two major hurdles for laying a bicycle superhighway in the urban area:(i) Space requirement: This is a common problem before laying any kind of road infrastructure or widening of existing road infrastructure for a bicycle lane and/or footpath. The situation can becomes severe if required land is in built-up area. A bicycle superhighway is preferred on ground however, if space is limited in built up areas, superhighway can be overhead. (ii) Restriction on motorbike: Generally, a bicycle lane in India is about 2.5 m wide so that cycle-rickshaw[4] drivers can also use them Tiwari (2001). A major drawback of this is that due to wide bicycle lane and poor law enforcement, it is also used by motorbike riders. This is likely to reduce the attractiveness for bicycle riders. A similar situation can not be ruled out on the bicycle superhighways. These two issues are addressed later in Sec. 4.2.3 for the case study.

2.1. Cost-benefit comparison

Generally, the feasibility of a project or a new infrastructure is determined based on a cost-benefit analysis. However, it is beyond the scope of the present study. In order to show the importance of the use of bicycle superhighway, a brief comparison with motorized highway based on several attributes is presented in this section. In Tab. 1, it can be observed that more passengers can be transported in less space using a bicycle infrastructure which is also associated with lower investment costs compared to infrastructure for motorized traffic. In addition to this, the monetary benefits from reduction of congestion, air pollution, accident risk, vehicle operation cost etc. can amount to 250,000 Indian rupees per day if 1% of travellers switch their mode from motorized mode to non-motorized mode in Bangalore city (Rahul and Verma, 2013).

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[4] A cycle-rickshaw is generally a three-wheeler, non-motorized vehicle and used to move goods or passengers.

Table 1: Comparison of various parameters between motorized highway and high quality bicycle lane. Source Rastogi (2011).

	infrastructure for...	
Attribute	**motorized vehicle**	**bicycle**
space requirement per person $[m^2]$	120	9
passenger capacity $[/hour \cdot /m]$	100-400	1500
cost of construction (ratio) $[unit]$	20	1
material requirement $[kg/person]$	$1260 - 1440$	30

2.2. Bicycle superhighway connectors

Algorithm 1: Identification of connectors between existing network and bicycle superhighway.

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Input: Nodes of existing network $N_{e,n}$
Input: Node of proposed bicycle superhighway network $N_{b,m}$
for every node $N_{b,i}$ in set $N_{b,m}$ do
    $N_{e,i} \leftarrow$ get nearest node from $N_{e,n}$;
    $N_i \leftarrow$ connect $N_{b,i}$ to $N_{e,i}$ to get connector;
Output: Number of connectors ($N_c$) between bicycle superhighway and existing networks
Output: Combined network

Data: $N_c \leftarrow$ total number of connectors
Data: Combined network
Input: Termination criteria $T$
Input: $I_r \leftarrow$ iterations to let the agents react under all connectors
Input: $I_u \leftarrow$ iterations after which a connector is removed
for each iteration $I$ do
    for for each connector until, termination do
        if $I <= I_r$ then
            let the agent react ;
        else if $(I - I_r)\%I_u == 0$ then
            get the least used connector and remove it;
```

The success of a vehicle-specific highway depends on the benefits and usage of the superhighway. This, in turn, depends on the links which connect the existing network to the new highway. Too few connectors would not produce maximum throughput whereas too many connectors will increase the construction cost. Therefore, an efficient planning of the connectors is critical. This study proposes an algorithm (Algo. 1) to identify the optimum number and locations of bicycle superhighway connectors. (1) In the first step, the bicycle superhighway is connected with the existing network with all possible connectors. The resulting network is called as combined network. (2) In the next step, for initial I_r iterations, agents are allowed to react under given choice dimensions (e.g. change mode, route, time etc.). This parameter should be high enough so that further increase does not yield any significant increase in the bicycle share. (3) Thereupon, after every I_u iterations, the least used connector is identified and removed from the combined network. The parameter I_u will be smaller than I_r and large enough such that significant changes are not observed any further. (4) The process is continued until the termination criteria is reached. A termination criteria is decided based on the objective of the new highway, e.g. terminate as soon as bicycle share starts dropping, terminate after pre-decided number of connectors (N_c), terminate if the cost of connectors has reached a certain value, etc. Eventually, this algorithm returns a network with an optimum number and location of connectors based on the given objective for the superhighway. The proposed algorithm is applied in the context of bicycle superhighway, however, it is suitable for any other scenario and for any other travel simulator which allows individual travellers to interact, learn and adapt to the system.

3. Travel simulator

In this study, an activity-based, multi-agent transport simulation framework, MATSim (Horni et al., 2016) is chosen because (a) the underlying network algorithm is a queue model which controls agents at entry/exit of the link only (Gawron, 1998; Cetin et al., 2003). This makes it computationally fast and suitable for large-scale scenarios. (b) simulation of a sample size is possible (Agarwal et al., 2017a). (c) it is embedded into an iterative co-evolutionary algorithm in which agents interact, learn and adapt to the system and to the price levels (tolls) if any etc. This iterative cycle is shown in Fig. 1 and explained next.

The essential inputs for a simulation experiment are physical boundary conditions (i.e. network), daily plans of individual travellers. It is possible to set the scenario-specific parameters (e.g. utility parameters, choice dimensions, travel modes etc.) in the configuration of the simulation experiment. The iterative cycle consists of three parts: Mobsim, scoring and replanning.

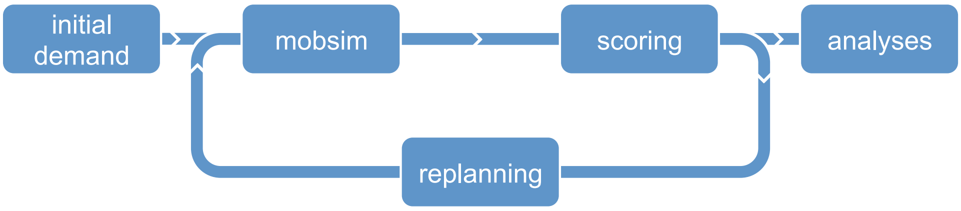

Figure 1: Iterative cycle of MATSim

(1) **Mobsim:** In this step, plans of all individual travellers are loaded onto the network simultaneously. Therefore, this step is known as plan execution or *mob*ility *sim*ulation (mobsim). For network loading algorithm, a time-step based queue model is used (Gawron, 1998; Cetin et al., 2003). The traffic dynamics of the queue model resemble Newell's simplified kinematic wave model (Agarwal et al., 2016, 2017a). The underlying queue model can simulate mixed traffic conditions for different link dynamics (Agarwal et al., 2015; Agarwal and Lämmel, 2016).

(2) **Scoring:** Simulated plans are evaluated using a utility (or scoring) function. Typically a plan's score (S_{plan}) consists of two parts i.e. $S_{plan} = \sum_{q=0}^{N-1} S_{act,q} + \sum_{q=0}^{N-1} S_{trav,mode(q)}$.

The former part aggregates the utilities for an agent while performing different activities (see Nagel et al., 2016, for further detailed explanation). The latter part is sum of utilities gained for travelling between different activities (see Sec. 4.2.2 and Eq. (2)).

(3) **Replanning:** In this step, agents react and adapt to the system depending on the available choice dimension. Replanning consists of two parts: plan innovation and plan selection. In the former, a new plan is created and then executed in the next iteration. The new plan is generated by modifying an existing plan according to given choice dimensions (e.g. route choice, mode choice, time choice etc.). In the plan selection step, agents select a plan from the generated choice set according to a probability distribution which converges to a multinomial logit model (Nagel and Flötteröd, 2012).

4. Application of bicycle superhighway to Patna, India

For the application of bicycle superhighway, a real-world case study of Patna, India is chosen. Patna is situated along River Ganga. It is one of the most populated cities in the eastern part of India. The population of Patna agglomeration area was 5.77 million in 2011 (Census, 2011). The study area includes 72 zones of the Patna Municipal Corporation (PMC). Initial scenario is taken from Agarwal et al. (2017b) and briefly explained next.

4.1. Scenario set up

The digital network of Patna is created using TransCAD (TransCAD, 2012) files. Three major arterials are Ashok Rajpath, the old bypass and the new bypass, which are spread in east-west direction. The travel demand of the region is categorized in two groups, urban and external travel demand.

The urban travel demand is synthesized directly from a trip diary survey (TRIPP et al., 2009, Patna Comprehensive Mobility Plan, (Patna, CMP)). A total of 13,278 plans are recorded which constitutes approximately a 1% sample of the full population. In order to obtain a 10% sample, each record is cloned by randomizing its origin, destination and departure time of the trip. Travel modes for urban trips are bicycle, car, motorbike, public transport (PT) and walk. The modal share for these modes is 33%, 2%, 14%, 22% and 29%, respectively (TRIPP et al., 2009).

The external travel demand is further classified as through traffic and commuter traffic. Through traffic simply pass through Patna and at most make one trip per day. Commuters are the individuals who commute between Patna and nearby areas of Patna. These travellers make at most two trips a day. Travel modes for external demand are bicycle, car, motorbike and truck. Patna CMP provides classified hourly counts for 7 outer cordon stations in both directions. This alone is insufficient to generate the daily plans. Thus, daily plans for external demand are created by extending Cadyts (Flötteröd, 2009) for mixed traffic (see Agarwal et al., 2017b; Agarwal, 2017, for more details about the calibration process).

4.2. Simulation preparation

4.2.1. Travel modes

For the simulation, the combined travel demand (urban and external) is used. Bicycle, car, motorbike and truck modes are physically simulated on network (called as main or congested modes) whereas PT and walk modes are teleported between origin and destination. The flow and storage capacities of a link are observed for congested mode (see

Agarwal, 2017, for more detail). The maximum free speed and passenger car equivalents (PCE)[5] for different congested modes and teleportation speed for teleported modes are shown in Tab. 2.

Table 2: Modal attributes for Patna scenario.

	maximum free speed				**teleportation speed**	
	bicycle	**car**	**motorbike**	**truck**	**PT**	**walk**
Speed (km/h)	15	60	60	30	20	5
PCE	0.15	1	0.15	3	–	–

4.2.2. Utility function

Variations in household incomes are likely to affect travel behaviour of individual travellers. Therefore, the effect of household income is included in the scoring function (Agarwal et al., 2017b). The mode-specific utility function is shown in Eq. (2).[6] C_m is alternative specific constant for mode m, t_{trav} is travel time between two activities, d_{trav} is travelled distance between two activities, $\beta_{d,m}$ is marginal utility of distance for mode m, $\beta_{trav,m}$ is marginal utility of travelling for mode m, $\gamma_{d,m}$ is monetary distance rate for mode m, $\bar{y}$ is median income of all individuals and y_j is household income of individual j. The utility parameters are shown in Tab. 3. For PT, a distance based cost is used (see Eq. (1); Kumar et al., 2004).

$$\text{PT trip costs [USD]} = \begin{cases} 0.045, & \text{if } d \leq 4\ km \\ 0.045 + (d-4)\cdot 0.0047, & \text{if } d > 4\ km \end{cases} \tag{1}$$

Table 3: Utility parameters (Agarwal et al., 2017b)

travel mode	**bicycle**	**car**	**motorbike**	**PT**	**walk**
monetary distance rate (γ_d)	–	$-3.7\cdot 10^{-5}$	$-1.6\cdot 10^{-5}$	Eq. (1)	–
marginal utility of travelling (β_{trav}) [util/h]	−0.12	−0.0	−0.12	−0.40	−0.12
alternative specific constant (C) [util]	0.0	−0.6	−0.58	−0.545	0.0
marginal utility of distance (β_d) [util/m]	$-1.1\cdot 10^{-4}$	–	–	–	$-1.2\cdot 10^{-4}$
marginal utility of performing (β_{dur}) [util/h]	0.19				

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[5] Please note that PCE is used only to note down the consumption of flow and storage capacity of a link in the queue model (Agarwal et al., 2017a, 2015). It is not used to convert heterogeneous traffic flow into a homogeneous traffic flow. Each vehicle is considered individually with its own attributes.

[6] For truck, a different behavioural model is required which is out of scope for the present study. However, the congestion effect of the commercial vehicles is included in the simulation and default utility parameters are used for them.

$$\begin{aligned}
S_{trav,bicycle} &= C_{bicycle} + \beta_{trav,bicycle} \cdot t_{trav} + \beta_{d,bicycle} \cdot d_{trav} \\
S_{trav,car} &= C_{car} + \beta_{trav,car} \cdot t_{trav} + \frac{\bar{y}}{y_j} \cdot (\gamma_{d,car} \cdot d_{trav}) \\
S_{trav,mb} &= C_{mb} + \beta_{trav,mb} \cdot t_{trav} + \frac{\bar{y}}{y_j} \cdot (\gamma_{d,mb} \cdot d_{trav}) \\
S_{trav,PT} &= C_{PT} + \beta_{trav,PT} \cdot t_{trav} + \frac{\bar{y}}{y_j} \cdot (\gamma_{d,PT} \cdot d_{trav}) \\
S_{trav,walk} &= C_{walk} + \beta_{trav,walk} \cdot t_{trav} + \beta_{d,walk} \cdot d_{trav}
\end{aligned} \tag{2}$$

4.2.3. Policy scenarios under consideration

It is proposed to lay the bicycle superhighway along the railway line because

1. it is more likely that there is enough space available on both side of the railway line,
2. the railway runs from the east to the west of the city and
3. it is parallel to the one of the major arterial (see Fig. 2).

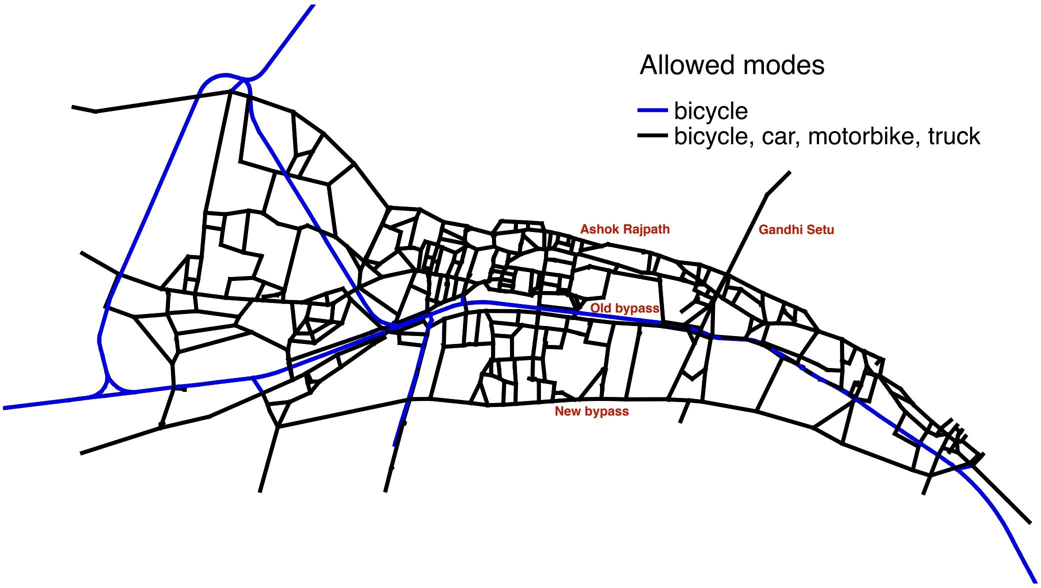

Figure 2: Patna network with bicycle superhighway.

Since, it is a physically segregated bicycle superhighway (rather than a bicycle lane parallel to arterials), motorbikes can be restricted by law enforcement. However, a what-if case is considered in which bicycle superhighway is used by bicycle and motorbike simultaneously. The initial calibrated scenario is taken from Agarwal et al. (2017b) and named as base case in this study. The output of the base case is used as input for all scenarios under consideration. The first scenario is business as usual which is used to compare the output of two policies. Overall following three scenarios are considered for Patna.

1. **BAU:** Business as usual
2. **BSH-b:** Bicycle superhighway used by bicycle mode only
3. **BSH-mb:** Bicycle superhighway used by motorbike and bicycle modes.

4.2.4. Policy set up

Connectors to bicycle superhighway A bicycle superhighway is created parallel to the railway track within Patna as shown in Fig. 2. The optimum number and locations of entry/exit to the bicycle superhighway are decided based on an optimization approach (see Algo. 1). For each link of the bicycle superhighway, it is assumed that bicycles are about two times faster than on the regular network and the effort to ride a bicycle is reduced to half.[7] As described in Sec. 2, the objective of the identification of the connectors could be constrained by cost of construction or on other factors. However, in this study, the objective is to find the minimum number of connectors which returns the maximum share of bicycle. The algorithm filters out the less desirable location of the connectors.

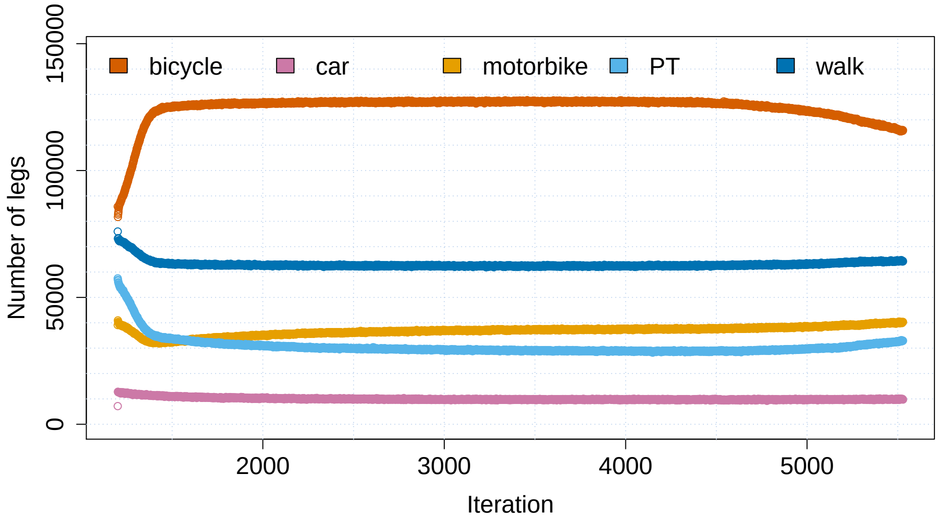

Figure 3: Modal share of urban travellers during identification of bicycle superhighway connectors.

In Algo. 1, initially, the agents are allowed to react in the presence of the all connectors for 100 iterations ($= I_r$). The mode choice is allowed for urban travellers until the terminal therefore, in the first step, agents react to the new bicycle superhighway and switch to bicycle mode. Afterwards, the least used (by cyclists) link is removed after every 10 iterations ($= I_u$) until termination.

The variation in modal share over iterations is shown in Fig. 3. From this, it can be observed that, initially, in the presence of all possible connectors, the bicycle share (orange color) increases steeply, reaches its maximum value and remains constant until 4500 iterations. After 4500 iterations, the share of bicycle starts decreasing. Therefore, the connectors at iteration 4500 are taken as the optimum number of connectors. The resulting network is chosen for the two policy measures (BSH-b and BSH-mb).

Replanning strategies of policy scenarios All three scenarios (see Sec. 4.2.3) are run for 200 iterations. For the BAU scenario, the existing network is used whereas for other two scenarios, the network with bicycle superhighway and their connectors are used. For re-planning, plans innovation is used until 80% of the iterations. In each iteration, 10% of urban travellers are allowed to change their mode and 15% are allowed to change their

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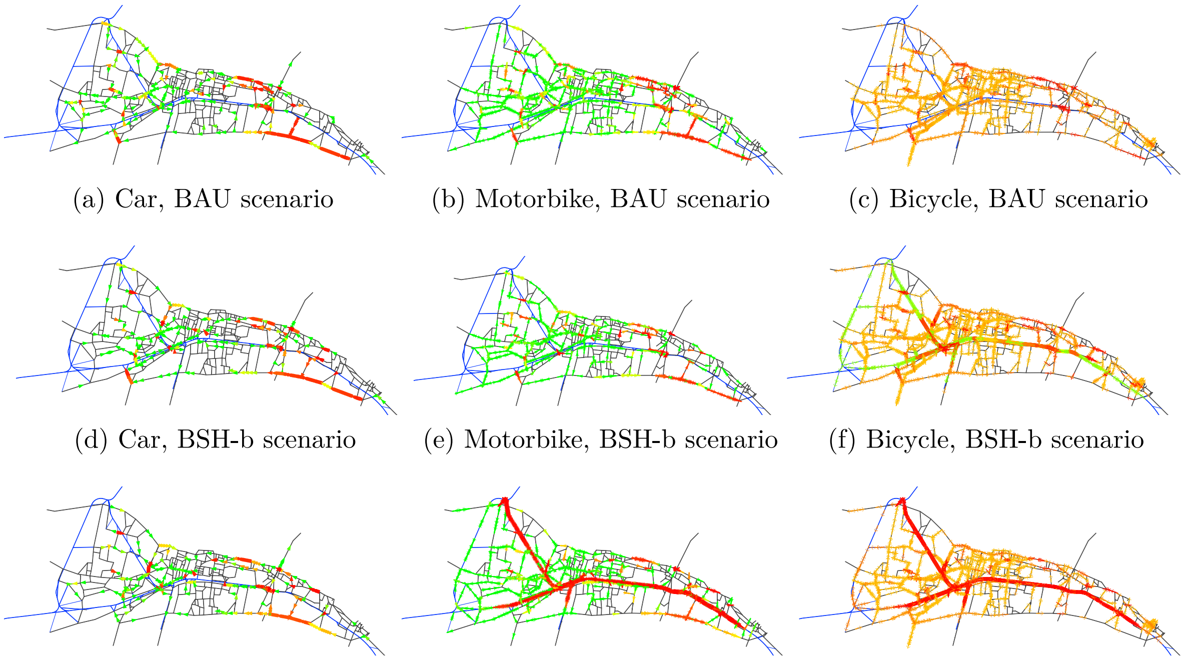
[7] Technically, this is achieved by giving each link of the bicycle superhighway only half of its true length.

route. For all external trips, only reroute is allowed for 15% of the agents. Rest of the agents until innovation and all the agents afterwards, select a plan from their generated choice sets.

5. Results

This section presents and compares the results of the three scenarios. Firstly, in order to show the impact of the bicycle superhighway, the congestion patterns of the three scenarios are presented in Sec. 5.1. This is followed by a comparison of the modal split for all three scenarios in Sec. 5.2 and an detailed analysis of the mode switcher and retainer in Sec. 5.3. The effect of the bicycle superhighway on the emissions and accessibility is spatially visualised in Secs. 5.4 and 5.5 respectively. The results of the two policy scenarios (BSH-b and BSH-mb) are compared with the BAU scenario. The results are based on the analysis of urban travellers, while external demand has been added to the model for inclusion of congestion effects from external demand.

5.1. Congestion patterns



(a) Car, BAU scenario (b) Motorbike, BAU scenario (c) Bicycle, BAU scenario

(d) Car, BSH-b scenario (e) Motorbike, BSH-b scenario (f) Bicycle, BSH-b scenario

(g) Car, BSH-mb scenario (h) Motorbike, BSH-mb scenario (i) Bicycle, BSH-mb scenario

Figure 4: Comparison of the congestion patterns at 08:00:00 for three scenarios.

Fig. 4 shows a comparison of the congestion patterns[8] from three scenarios for car, motorbike and bicycle traffic at 08:00:00. The left column (Figs. 4a, 4d and 4g) shows the congestion patterns for car. A capacity relief on the new bypass and Ashok Rajpath can be observed in the BSH-b and BSH-mb scenarios. The traffic patterns on remaining streets for the car traffic remain largely the same in the three scenarios because the share of the car does not change much (approximately 2%; Tab. 4). The middle column

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[8] These congestion patters are generated using the visualization tool VIA (see http://www.via.senozon.com).

(Figs. 4b, 4e and 4h) shows the congestion patterns for motorbike. In the former two, the queues on several streets near Gandhi Setu and other parts of Patna have been reduced or fully dissolved, whereas long queues appear in the latter (BSH-mb) scenario, which is an effect of allowing motorbikes on the bicycle superhighway. The right column (Figs. 4c, 4f and 4i) shows the congestion patterns for bicycle traffic. In the BSH-b scenario, a few small bicycle queues appear on a few links of the bicycle superhighway, while the length of the queues on other streets of the network has decreased. The queues become longer in the BSH-mb scenario in which both motorbikes and bicycles travel on the bicycle superhighway. Overall, a capacity relief effect on the southern arterial (going east to west; new bypass) and other streets can be observed (also see Sec. 5.3.2).

5.2. Modal split

Table 4: Modal splits for urban travellers (in %) for various policy scenarios.

mode	**reference study**	**base case**	**BAU**	**BSH-b**	**BSH-mb**
bicycle	33.0	32.3	32.5	48.7	44.0
car	2.0	2.7	2.5	2.1	1.9
motorbike	14.0	14.7	15.3	11.2	18.5
PT	22.0	21.7	21.2	12.9	10.3
walk	29.0	28.6	28.6	25.1	25.3

Tab. 4 shows the modal splits for various scenarios. In the business-as-usual scenario (BAU), the modal split is about the same as the base case scenario and the reference study. The effect of the bicycle superhighway is clearly visible in the BSH-b and BSH-mb scenarios. In the BSH-b scenario, approximately half of the urban trips are made by the bicycle mode. The increase in the bicycle share comes mainly from PT trips and partly from motorbike and walk trips (also see Tab. 5b). This is plausible since a significant number of households belongs to the low income group. On the other hand, in the BSH-mb scenario, the superhighway is an attractive option for motorbike riders as well, which increases the share of the motorbike to more than 18% and reduces share of the bicycle to 44%. This is significantly higher than the modal share in BAU scenario, but, at the same time, less than the modal share in the BSH-b scenario. A more detailed analysis for mode switchers and retainers is given in the next section.

5.3. Mode switcher analysis

5.3.1. Change in number of trips

Tab. 5a shows the number of trips of mode switchers (e.g. car to bicycle, motorbike to car, etc.) and mode retainers (the diagonal values in the matrix; e.g. car to car, bicycle to bicycle, etc.) for the BAU scenario. Clearly, as expected, for the BAU scenario, most of the agents retain their modes.

Tab. 5b and Tab. 5c show the change in the number of trips of mode switchers/retainers with respect to the BAU scenario for BSH-b and BSH-mb policy scenarios respectively. In the BSH-b scenario, with respect to BAU, the increase in the bicycle share is mainly contributed from motorbike, PT and walk to bicycle mode switchers (11712, 20330 and 9058 trips respectively). The contributions from motorbike, PT and walk to bicycle mode switchers have significantly decreased in BSH-mb scenario (7166, 13560 and 8594 trips

Table 5: Analysis for number of trips of mode switcher/retainer.

(a) Absolute number of trips for BAU Scenario

		last iteration (it.1400)					
		bicycle	**car**	**motorbike**	**PT**	**walk**	**total**
first iteration (it.1200)	**bicycle**	82408	56	430	774	2140	85808
	car	48	4772	1712	622	2	7156
	motorbike	526	1056	36186	1308	16	39092
	PT	1084	702	2296	53408	28	57518
	walk	2176	4	18	22	73766	75986

(b) The change in the number of trips for BSH-b scenario with respect to BAU

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	+1092	−28	−228	−484	−352
	car	+990	−804	+10	−194	−2
	motorbike	+11712	−348	−10674	−682	−8
	PT	+20330	+210	+74	−20618	+4
	walk	+9058	−2	−10	0	−9046

(c) The change in the number of trips for BSH-mb scenario with respect to BAU

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	+942	−26	−204	−522	−190
	car	+542	−1734	+1538	−344	−2
	motorbike	+7166	−432	−5806	−920	−8
	PT	+13560	+554	+12892	−27014	+8
	walk	+8594	−4	+64	−2	−8652

respectively). This is an effect of allowing motorbikes on the bicycle superhighway. In addition to this, for BSH-mb scenario,

- a significant number of PT trips is shifted to the motorbike mode (12892 trips) and
- the number of motorbike retainers is approximately 5000 higher than the number of motorbike retainers in the BSH-b scenario.

The driving forces behind this are discussed in the next section.

5.3.2. Change in the average speed

Tab. 6 shows the changes in average route speed and in average beeline speed for mode switcher/retainer. The changes are computed with respect to the first iteration (it.1200) of each policy measure which is same for all scenarios. The route speed is the ratio of

Table 6: The changes in average speeds (in km/h) for mode switcher/retainer with respect to first iteration (it.1200).

(a) The changes in average route speed for BSH-b scenario

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	+1.09	+13.92	+17.07	+9.66	−5.42
	car	−7.28	+3.20	+6.92	+6.37	–
	motorbike	−12.73	+2.90	+4.28	+3.56	−26.59
	PT	−9.22	−1.91	+3.01	0.00	−15.01
	walk	+6.82	+30.04	+19.75	+15.02	0.0

(b) The changes in average beeline speed for BSH-b scenario

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	+0.37	+9.47	+11.47	+5.50	−3.22
	car	−4.88	+2.49	+4.82	+2.94	–
	motorbike	−9.31	+2.33	+3.03	+1.24	−15.20
	PT	−5.39	+0.29	+2.49	0.00	−10.16
	walk	+2.90	+16.09	+10.74	+9.78	0.0

(c) The changes in average route speed for BSH-mb scenario

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	−2.34	+7.26	+14.07	9.74	−5.83
	car	−16.12	+4.82	−3.18	+6.66	–
	motorbike	−21.87	+2.70	−3.95	+1.51	−25.21
	PT	−13.24	−1.67	−8.40	0.00	−15.01
	walk	+2.90	–	+14.56	+15.01	0.0

(d) The changes in average beeline speed for BSH-mb scenario

		last iteration (it.1400)				
		bicycle	**car**	**motorbike**	**PT**	**walk**
first iteration (it.1200)	**bicycle**	−1.76	+4.35	+8.72	+5.49	−3.42
	car	−10.35	+3.82	−2.54	+2.86	–
	motorbike	−15.21	+2.22	−3.76	−0.50	−14.73
	PT	−8.48	+0.79	−5.16	0.00	−9.43
	walk	+0.90	–	+6.12	+10.51	0.0

the route distance (along travelled links)[9] to the travel time in the simulation whereas the beeline speed is the ratio of the direct distance between the activity locations (beeline distance) to the travel time.[10]

Tab. 6a and Tab. 6b show the changes in the average route speed and average beeline speed for BSH-b scenario and Tab. 6c and Tab. 6d show the changes in the average route and beeline speeds for BSH-mb scenario. In BSH-b scenario, for bicycle retainers, the average route speed *in*creases by $+1.09\ km/h$ and the average beeline speed increases by $+0.37\ km/h$. This indicates that bicycles are faster and also travel longer distances. Since a significant number of bicycle trips are using the bicycle superhighway, a capacity relief on the network also increases the average route speeds of car and motorbike retainers ($+3.20$ and $+4.28\ km/h$). This also translates in higher beeline speeds ($+2.49$ and $+3.03\ km/h$), i.e. reduced origin-to-destination travel times.

The average route speeds for car and motorbike to bicycle mode switchers *de*crease by -7.28 and $-12.73\ km/h$ respectively whereas the average beeline speeds *de*crease by -4.88 and $-9.31\ km/h$ respectively. This indicates that switching from car/motorbike to bicycle makes the travel speed considerably slower, while the direct origin-to-destination speed and thus the travel time does not suffer as much.

In the BSH-mb scenario, due to congestion on the bicycle super highway, the average route and beeline speed for bicycle retainers *de*creases by $-2.34\ km/h$ and $-1.76\ km/h$ respectively i.e. the bicycle retainers move more slowly, but somewhat compensate by more direct routes. Similar to the BSH-b scenario, the average route speed *de*creases for car/motorbike to bicycle mode switchers. In contrast to the BSH-b scenario, the average route speeds for car to motorbike switchers and motorbike retainers *de*crease significantly and yet they are better off by travelling shorter distances.

From this mode switcher/retainer analysis, it can be summarized that the share of bicycle increases significantly. However, this gain is reduced in case motorbike riders are allowed on the bicycle superhighway as well. Further, a capacity relief effect is also observed. In the next section, the emissions externalities for all scenarios are estimated, which will emphasize the importance of the bicycle superhighway towards sustainable transport.

5.4. Emissions calculation

5.4.1. Estimation approach

In order to assess the impact of the policy scenarios, the emissions are estimated as a post-processing step. An emission modelling tool (EMT) for homogeneous traffic was developed by Hülsmann et al. (2011) and, further improved, extended and integrated to a simulation framework (MATSim, Sec. 3) by Kickhöfer et al. (2013). Total emissions are comprises of cold and warm emissions. The former depends on parking duration, distance travelled and vehicle characteristics; the latter depends on engine type, road type, speed of the vehicles. Together with the static vehicle characteristics (e.g. vehicle type, age, cubic capacity, fuel type etc.) and dynamic attributes from simulation (e.g. last engine start time, travelled distance, traffic state, vehicle type etc.), cold and warm emissions

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[9] As mentioned before in Sec. 4.2.4, to make the bicycle twice as faster as on the normal network, the length of the links of bicycle superhighway is halved. For the analysis of the average route speed, the actual link length of the bicycle superhighway is taken while making the speed of the bicycle double on these links.

[10] In general, if the activity locations does not change, the positive change in average beeline speed denotes the lesser travel time for the same beeline distance and vice versa.

are estimated. Further, in order to estimate time-dependent, vehicle- and link-specific emissions from motorbikes and other vehicle types, the EMT is extended to heterogeneous traffic conditions. Thereafter, the emissions[11] are calculated for all three scenarios.

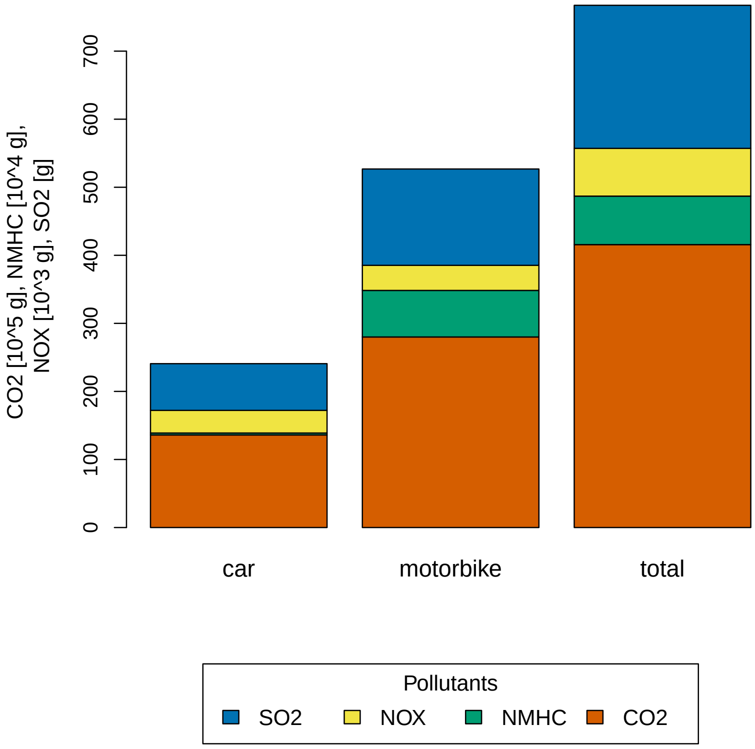

Figure 5: Absolute emissions for Patna BAU scenario.

5.4.2. Absolute emissions for BAU

Fig. 5 shows the emissions from car and motorbike for thee BAU scenario. Although emissions per km are higher for car than for motorbike (e.g. 200, 83 gCO_2/km for car and motorbike respectively), the emissions from motorbikes are significantly higher than the emissions from car due to the higher modal share of the motorbike. An important observation is that the NMHC from motorbike is approximately 95% of the total NMHC because in contrast to other pollutants, motorbikes produce significantly higher NMHC emissions than cars.[12] The estimated emissions from car and motorbike (e.g. 0.49, 0.11 gNO_x/km) are in line with the literature Goel and Guttikunda (2015).

5.4.3. Changes in emissions for policy measures

The % change in emissions for the two policy measures (BSH-b and BSH-mb) are shown in Fig. 6. The values are relative to the business as usual (BAU) scenario. For the

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[11] For the Patna scenario, Handbook Emission Factors for Road Transport (HBEFA; http://www.hbefa.net) version 3.2 is used. For motorbikes, it does not provide (a) the cold start emissions and (b) PM emissions. Thus, PM emissions are not shown in the analysis.

[12] The NMHC emissions from 2-stroke motorcycles are significantly higher than 4-stroke motorcycles Tsai et al. (2000). Therefore, it is likely that in the Indian context, the motorbike emissions estimated in this study are underestimated.

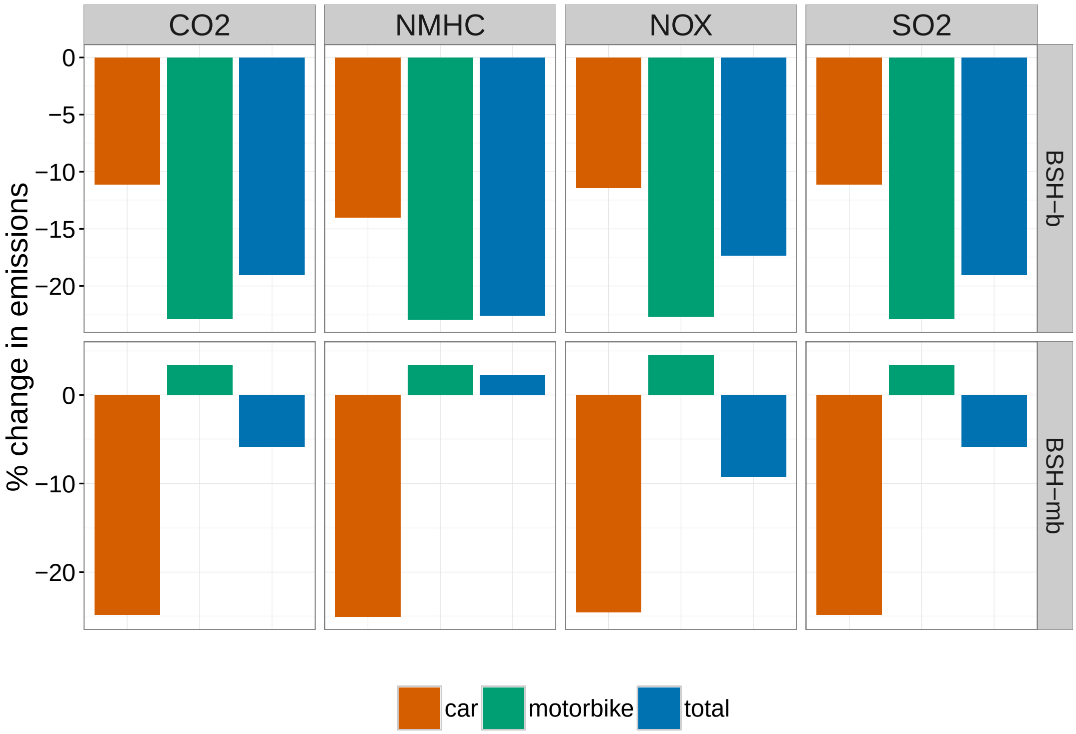

Figure 6: Change in emissions (in %) for the BSH-b and BSH-mb scenarios with respect to BAU scenario.

BSH-b scenario, all emissions are *de*creased significantly. This is a positive effect of higher bicycle share and lower motorized traffic (see Tab. 4). Further, in BSH-mb scenario, a significant reduction in emissions for car mode is observed. However, the increase in the share of motorbike yields an *in*crease in the emissions for motorbike. Interestingly, overall, total emissions is still lesser than the BAU scenario except NMHC. The share of NMHC emissions from motorbike is approximately 95% in the BAU scenario and an increase in the share of motorbike for BSH-mb scenario increases the total NMHC emissions.

To summarize this, the BSH-b policy measure reduced the emissions driven by significant higher share of bicycle and lower share of motorized vehicles. In the BSH-mb scenario, the increase in the share of motorbike increases the emissions from motorbike but the overall emissions decreases with an exception for NMHC emissions.

5.4.4. Spatial distribution

Fig. 7 shows the spatial distribution of NO_2 emissions.[13] Fig. 7a shows the absolute emissions (in g) for BAU scenario. The emissions on all major streets, “Gandhi Setu” are high. Figs. 7b and 7c show the change in NO_2 emissions with respect to BAU scenario for BSH-b and BSH-mb policy measures respectively. An increase in emissions is indicated by red hexagons, a decrease in emissions is indicated by green hexagons and white hexagons denotes very minor change in NO_2 emissions. From the spatial distribution plots, it can

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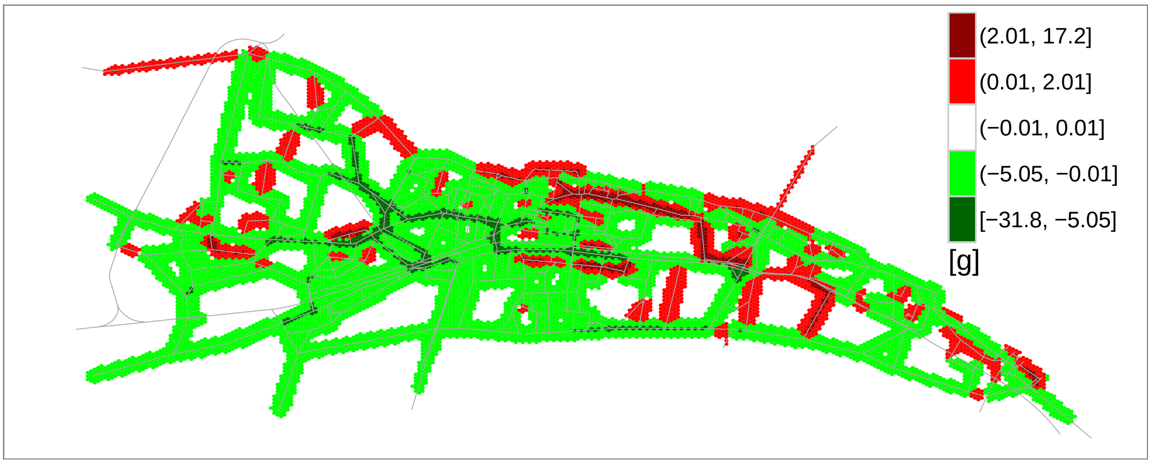
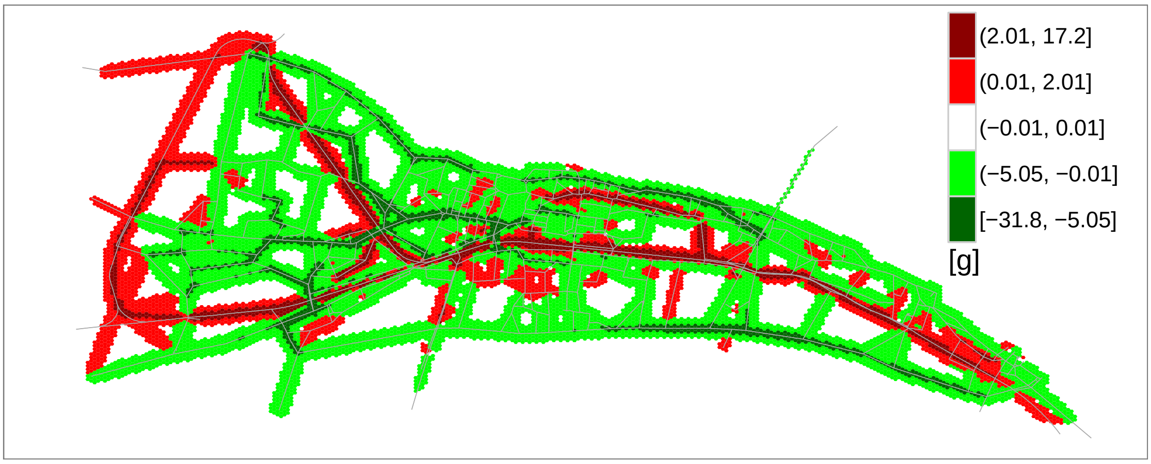
[13] Similar to a previous study (Agarwal and Kickhöfer, 2016), for illustration purposes, the emission plot only shows NO_2. For the visual presentation, a Gaussian distance weighting function is used to smooth emissions. Uniform hexagonal cells of size 100 m are used for this purpose. The smoothing radius is assumed to be 100 m. In contrast to Kickhöfer (2014) which assumes the emissions at the centre of the link, the emissions are linearly distributed on the link. For more information on the exact visualization procedure, please refer to Appendix A in Agarwal (2017).

(a) Absolute emissions for BAU scenario.



(b) Change in emissions for BSH-b scenario.



(c) Change in emissions for BSH-mb scenario.

Figure 7: Absolute NO_2 emissions (in g) for BAU scenario and change in emissions (in g) for BSH-b and BSH-mb policy measures. The values are scaled to full population.

be observed that emissions on most of the portion of major streets decreases. This is an effect of decrease in the share of motorized vehicles. The decrease in NO_2 emissions on major arterials is more significant in the BSH-mb scenario due to capacity relief effect (dark green hexagons). In BSH-mb scenario, a significant increase in the emissions on the bicycle superhighway can be observed. This is the result of allowing motorbikes on the bicycle superhighway. Thus, BSH-b policy measure reduces emissions significantly (approximately 18%; see Fig. 6) mainly from the inner city. In contrast to this, BSH-mb policy reduces total emissions by only about 5% (see Fig. 6), and mainly increases the emissions in the inner city. The latter is undesirable which directs to impose a strict policy measure to reserve superhighway exclusively for bicycle only.

5.5. Accessibilities

5.5.1. Computation approach

Quantitative computations of accessibilities can be used as a comprehensive and efficient planning instrument and are seen as a potential alternative or supplement to traditional planning tools (Ziemke et al., 2017). In contrast to typical infrastructure assessment instruments, which are mostly based on travel alone (like measuring and monetizing changes in travel times, highway levels of service, or delays), accessibilities focus more strongly on the actual needs of individuals and households.

The quantitative accessibility value of a given location is determined both by the patterns of land use and by the characteristics of the transport system. Thus, measures of accessibility usually consist of two components, a *land-use* (or *activity*) component and a *transport* component: The land-use component reflects the spatial distribution of opportunities and is characterized by both the amount and the location of different types of activities. The transport component reflects the ease of the travel between locations. Accessibilities, i.e. the interplay of land use and transport, determine how well needs of individuals for certain services can be fulfilled. The accessibility A_i of a location i computed as

$$A_i = \frac{1}{\mu} ln \sum_j e^{-\mu C_{ij}} \ , \tag{3}$$

where j is opportunities somewhere in the study area and C_{ij} is the generalized costs of travelling from i to j. This is an econometric accessibility measure (sometimes also referred to as utility-based measure) (Ziemke et al., 2017). Its value equals as the sum over the utilities of all opportunities reachable from that location including the costs of overcoming the distance.[14]

5.5.2. Changes in accessibilities for policy measures

To evaluate the effects of the proposed bicycle superhighways, accessibilities to education facilities are computed.[15] Education facilities are chosen because such facilities are relevant for almost all socio-economic groups of the population.

Fig. 8 shows the accessibilities of education facilities by bicycle in the BAU and BSH-b scenarios as well as corresponding accessibility changes between these two scenarios. Since accessibilities are computed based on free-flow speeds on the network, accessibilities are under this assumption the same for the BSH-b and BSH-mb scenarios. In reality, they may differ because travel times on the network change based on congestion in the network, which is different for the BSH-b and BSH-mb scenarios.

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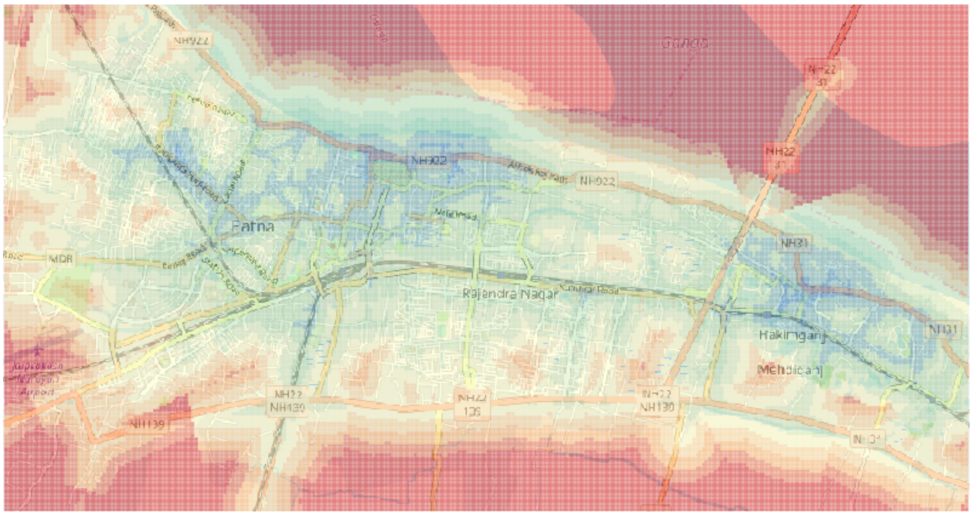
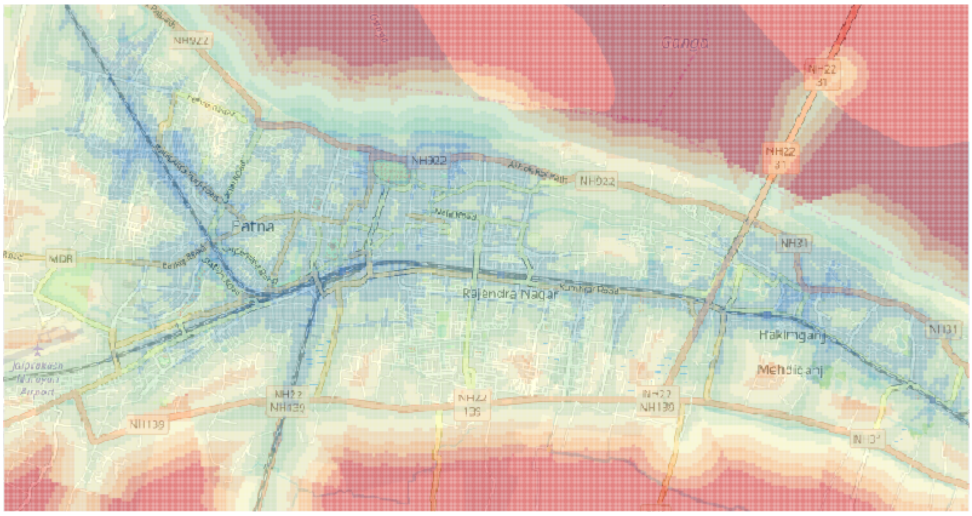
[14] Please refer to Ziemke et al. (2017) for a mathematical justification of Eq. (3) (also known as the *logsum* term) and for technicalities of the computation of accessibilities within the MATSim transport simulation framework.

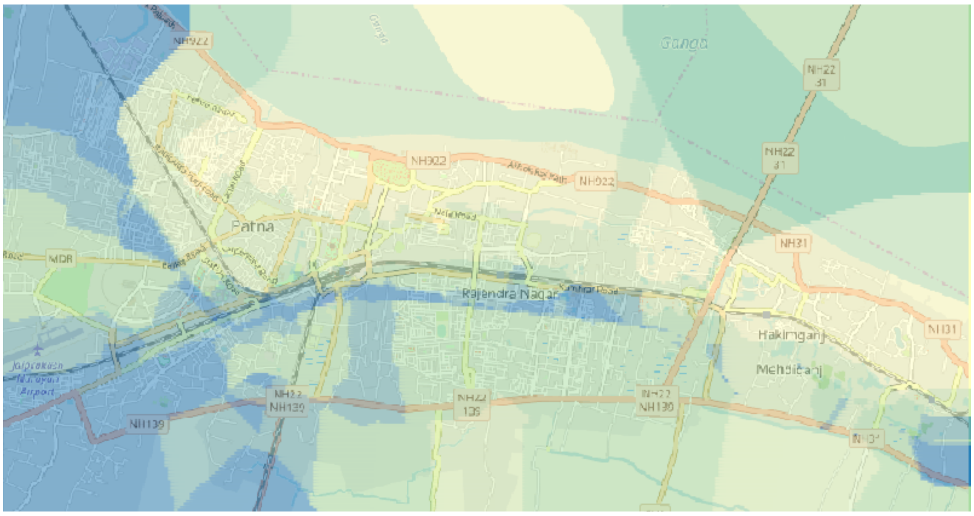
[15] The location of educational facilities for Patna is extracted from Google places using a web based API.



(a) Accessibilities of education facilites in BAU scenario.



(b) Accessibilities of education facilites in BSH-b scenario.



(c) Accessibility changes of education facilites in BSH-b scenario with respect to BAU.

Figure 8: Accessibilities of education facilities by bicycle in BAU and BSH-b scenarios and accessibility change in BSH-b scenario with respect to BAU (red colours denote low accessibilities, while blue colours denote high accessibilities (or an accessibility increase). Background map: ©OpenStreetMap contributors (http://www.openstreetmap.org).

Fig. 8a depicts the accessibilities to education faculties by when travelling by bicycle for the BAU scenario. It can be seen that accessibilities are highest near central and eastern part of Ashok Rajpath (depicted in blue colours).

Fig. 8b shows accessibilities to education facilities for the BSH-b scenario and Fig. 8c shows the change in accessibilities of education facilities for the BSH-b scenario with respect to the BAU scenario. It can be seen that accessibilities to education facilities for bicyclists has improved significantly. Areas of low education accessibility (red-coloured areas) have become discernibly fewer, while much more areas are associated with good education accessibility (areas depicted in blue). Importantly, not only areas in close vicinity to the proposed bicycle superhighway are positively affected, highlighting the positive city-wide impact of the bicycle superhighway. Similar to the educational facilities, the accessibilities for other facilities are also likely to increase which highlights the importance of the bicycle superhighway.

6. Conclusion

Bicycle is an environmentally sustainable transport mode which can be used as the main transport mode as well as the feeder to mass public transit systems. However, in many parts of the world, it is becoming unattractive due to insufficient and/or unplanned infrastructure. In this direction, this study proposed a physically-segregated bicycle superhighway in an urban agglomeration particularly, if the share of non-motorized transport modes is very high. In order to find the optimum number and locations of the connectors between superhighway and existing network, an efficient approach was proposed. Household income of individual traveller plays an vital role in the decision making process notably in the developing economies where many users are captive to cheaper alternatives. Therefore, the income levels were incorporated in the utility function.

To evaluate the impact of the bicycle superhighway, a case study of Patna, India was considered. The application of bicycle superhighway to Patna illustrated huge potential to increase in the bicycle ridership. Allowing only cyclists on the bicycle superhighway increased the bicycle share as much as 48%. However, allowing motorbikes also on it, narrowed the increase in bicycle share to 44%. A detailed mode-switcher analysis showed that captive users (walk, public transport) as well as other motorized transport mode (e.g. motorbike) users switched to bicycle mode. Further, a marginal mode-switch from car to bicycle was observed. This essentially featured the increased attractiveness for bicycle travel mode from low-middle income households.

This study has extended an emission modelling tool to estimate the vehicle- and time-dependent emissions under mixed traffic conditions. Total emissions decreased significantly if only bicycles are allowed on superhighway and, marginally if both bicycles and motorbikes are allowed on it. However, a spatial analysis exhibited that a bicycle superhighway reduces emissions significantly as long as motorbikes are restricted on it. This emphasized the requirements of strong law enforcements or other measures to restrict the usage of superhighway for bicycle and cycle-rickshaws only. A computation of accessibilities as a policy-assessment tool that is oriented on the actual needs of individuals, showed positive effects of the proposed bicycle superhighway on the accessibility of education facilities. Interestingly, it could be observed that large areas of the city, in particular also areas that are not located in the direct vicinity of the new infrastructure, are positively affected.

This study made an attempt to show the potential of increase in the bicycle share which is important for a low carbon urban transport. Such insights are useful for agencies to make decisions regarding transport policies. However, along with provision of infrastructure, to increase the share of bicycle, significant efforts are required to change the negative or neutral perception of the travellers (Gatersleben and Appleton, 2007). For instance, a mandatory program in schools to promote the bicycle usages because children have higher positive perception about cycling than adults (Verma et al., 2016). Similarly, introduction of voluntary programs to train the adults, seniors, new residents, etc. is likely to accumulate more cyclists (Buehler et al., 2016; Pucher and Buehler, 2008).

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