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Tavoos Hassan Bhat
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

Farzaneh, Hooman
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

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Tavoos Hassan Bhat, Hooman Farzaneh
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka, Japan
*Corresponding author email: farzaneh.hooman.961@m.kyushu-u.ac.jp

Abstract: *Increasing the number of people who walk and bike to work is a significant step toward achieving the public health objective of increasing physical activity and decreasing urban air pollution. We examined the health and financial benefits of Delhi's policies encouraging walking and bicycling using the Health Economic Assessment Tool (HEAT). Encouraging active travel and public transit is excellent for the environment and public health since it increases physical activity, reduces air pollution, and emits less greenhouse gases. We assessed those 4080 premature deaths could be prevented annually because of changes in the quantity of walking and cycling and reduction in air pollution, and an annual decrease of CO2 by 722,630 tons in Delhi. The monetization of mortality and carbon emission reductions has an economic value of 955 M USD per year.*

Keywords: Non-motorized transportation, health impact assessment, exposure-response functions (ERF), reduced mortality risk (RMR), value of a statistical life (VSL)

1. INTRODUCTION

1.1 Background

Due to the continual rise of the urban population, private vehicle ownership, and congestion, urban transportation faces significant issues. Non-motorized transportation (NMT) is an important aspect of achieving urban mobility sustainability and is increasingly being favored by policymakers and environmentalists as a viable alternative to motorized transportation as transportation-related greenhouse-gas emissions are rising, with considerable growth expected in low- and middle-income nations.

Active travel (mainly walking and cycling) has gained popularity in the transportation and environmental sectors due to its advantages as low-emission and space-efficient means of transportation.

Non-motorized or active Transportation, which includes Walking and Bicycling, can provide both transportation (access to goods and activities) and recreation, while users may view a specific journey to serve both aims. Walking and cycling for transportation provide significant health benefits to users by increasing physical activity [1].

In addition, advantages include increased accessibility, more cost-effective travel, Congestion reduction, cost savings on roadway and parking infrastructure, energy conservation, reduced air, and noise pollution, and lower accident risks to other road users [2]. Furthermore, it is a low-cost mode of transportation for millions of low-income people especially in India.

Various strategies for modeling the health effects of active travel have been developed in recent years. These often weigh the advantages of physical exercise against the risks of injury and increased exposure to air pollution. According to recent studies, India has substantially higher percentages of physical inactivity, ranging from 38 to 70% [3]. In Delhi, just 30-34 percent of the population exercises moderately [4]. In India, 20% of the population is not physically active, while 37% is just moderately active, suggesting that 57 percent of the population does not meet the World Health Organization's recommended physical activity routine. As a result, a large section of India's population faces the risk of getting a variety of NCDs like Diabetes mellitus (DM), hypertension, coronary artery disease, and breast and colon cancer [5]. Through consistent physical exercise, these noncommunicable diseases (NCDs) can be lowered.

Other studies have indicated a 54.4% in activity level in the adult population. However, most Indians are sedentary, with only about 10% participating in leisure physical exercise. As a result, immediate actions must be taken to increase physical activity in India in order to combat the twin epidemics of diabetes and obesity [3].

In Delhi, 80 percent of trips are under 6 km, which is the perfect distance for walking and cycling. Private vehicles are used to travel these short distances in the lack of adequate public transportation and convenient walking and cycling facilities, which contributes to congestion [6]. These are the perfect trip lengths for bicycling and provide a highly effective way to switch to a transportation mode that emits no greenhouse gases [7]. Studies have indicated physical activity positively impacts coronary heart disease, stroke, diabetes, some types of cancer, musculoskeletal health, energy balance, and aspects of mental health (including anxiety and depression) [8].

Previous studies have quantified the health benefits of riding a bicycle instead of driving in urban settings [9][10]. These health advantages have primarily been attributed to increasing levels of physical activity [11]. Previous studies have also calculated the economic and health benefits of using public transportation, which is tied not just to increased physical activity, but also to a reduction in road traffic fatalities and crime [12].

Air pollution is also a significant public health issue in Delhi. Numerous epidemiological studies have linked poor air quality to various harmful health effects, emphasizing the major role that air pollution plays in the burden of disease in the general population, ranging from subclinical effects to early death [16]. The majority of Indian megacities, including Delhi, have greater levels of air pollution than the government recommends. [17][18]. A large portion of Delhi's population is exposed to high amounts of harmful pollutants and $PM_{2.5}$ emissions from Delhi are expected to cause 54,000 premature deaths[19].

Current conditions will increase $PM_{2.5}$-related mortality by 39.32% in 2025 and 100% by 2040[20].
Walking and cycling for transportation, supplemented by public transportation, represents a promising strategy to not only address problems of urban traffic congestion, pollution, and climate change, but also to provide significant health benefits.

1.2. Active transportation and non-motorized transport policies in Delhi

There are significant advantages of programs that promote increased amounts of physical exercise, particularly cycling and walking [13].
NMT accounted for 37 percent of commuter journeys, 26.3 percent walking, and only 10.7 percent cycling, whereas motor vehicle commuter trips accounted for 63 percent in Delhi [14].
NMT policy focused on improving and expanding the transportation network to handle the growing number of vehicles on the roadways and reduce air pollution, including the shift to non-motorized transportation.
In recent years, there has been a surge of interest in improving and boosting non-motorized transport in Delhi. NMT policy focuses on boosting NMT in Indian cities by examining the difficulties experienced in attempting to invest in pedestrian and cycling infrastructure across the country [15].

1.3 Research contribution

This study aims to develop various scenarios to replace private vehicles with walking and bicycle transport modes and quantify the impact of physical activity due to transportation mode shift on public health, as well as quantify the health impact on the general population from reduced air pollution as a result of this modal change. To this aim, scenarios are built in this study to quantify the health and economic implications of enhancing nonmotorized transportation share, energy consumption, and comparable PM and CO_2 emissions for 2030. In addition, the population and travel demand are taken into account, as well as predictions about technological growth and penetration rates. The study's main objective is to raise attention to the urgent need to improve non-motorized/active transportation and public transportation infrastructure in Indian cities, especially Delhi, through quantifying the health co-benefits of the NMT policies in this city.

2. Methodological approach

The health economic assessment tool (HEAT) was used in this study to quantify the health and economic benefits of NMT in Delhi. HEAT is an online tool that calculates the value of mortality reduction from regular cycling or walking. It uses a comparative risk assessment methodology to evaluate the effects of active transportation on carbon emissions and human health. It combines methodological approaches for economic valuations of transportation interventions and cost-benefit analyses. HEAT analyzes the advantages and dangers brought on by varying exposure levels and how these changes in a particular population over a certain time are quantified by health impact estimates [21]. The tool uses systematic assessments of economic evaluations of modes of transportation as well as reviews of the epidemiological literature to determine risk estimates for the health effects of walking and cycling [13]. HEAT also enables consideration of the mortality impacts of exposure to air pollution and car accidents while commuting by foot or bicycle. It assesses the health benefits of regular cycling and/or walking (and the related carbon emissions). Calculations of health effects are intended to quantify the advantages and disadvantages of a particular amount of a particular type of exposure or a change therein in a particular population over a specified length of time [21]. The methodological approach used in this study is shown in Figure 1.

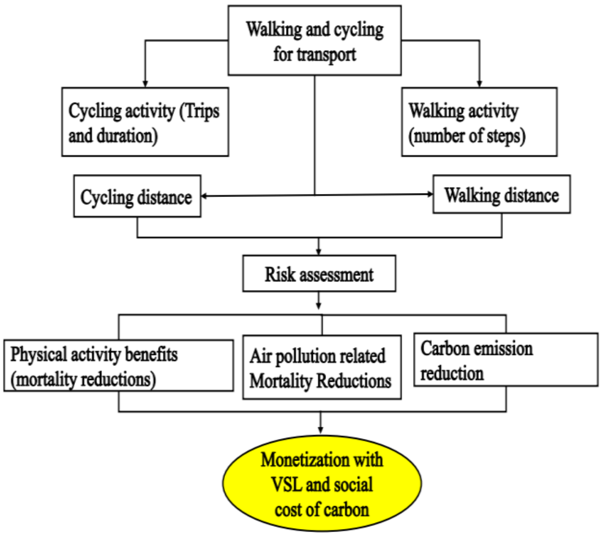

Fig. 1. The methodological approach used in this study

Walking and cycling are examples of active travel, which mixes transportation with physical exercise and serve as alternatives to motorized vehicles. The levels of physical activity from frequent walking or cycling between the two cases are used to quantify the difference in active travel. The health outcome used in this study is the difference in premature mortality between two cases: a reference case (Baseline case) and a comparison case (by comparing the variance in active travel).
The literature-based relative risk is adjusted to the local levels of cycling or walking, and the environmental impact is dictated by the travel demand, which is determined by the population size and transportation infrastructure.
The following scenarios were investigated in the current study:

- The model shifted from personal car and motorcycle to non-motorized transport
- Calculate the potential health advantages of switching from driving to NMT

The primary outcome measure was all-cause mortality and change in morbidities because of different scenario assessments:

a) Determine the health advantages of increasing cycling and walking in any city.

b) Evaluate how air pollution and traffic accidents impact these outcomes in addition to evaluating the economic worth of the health benefits connected to increases in cycling and/or walking.
c) Evaluate the impacts of road injuries and air pollution have on those who become more active
d) Predict how these individuals would be affected by their increased exposure to air pollution and the danger of accidents.
e) Calculate the reductions in carbon emissions brought on by any decrease in motorized transportation that results from an increase in cycling (and/or walking).

Input values used for quantifying the health impacts are indicated in Table 1. The health outcome of interest is calculated as the difference in premature mortality between two cases: a reference case (also known as the baseline case) and a comparison case. This risk assessment method compares two scenarios (also known as the counterfactual case). The levels of physical activity from frequent walking or cycling between the two cases are used to quantify the difference in active travel. Exposure-response functions (ERF) are used to quantify effects from epidemiological studies. The degree of the connection between an exposure (in the case of HEAT: the quantity of walking or cycling) and a health result is measured by exposure-response functions (ERF) (in HEAT: mortality from any cause, i.e., all-cause mortality). The exposure difference between the reference and comparative cases is estimated to quantify the health risk impacts. These impacts are characterized as relative risks, which contrast the risk among those who are exposed (walk or bike frequently) to the risk among those who are not exposed for things like the danger of dying too soon (who do not walk or cycle or walk or cycle less).
Equation 1 is used to calculate reduced mortality risk (RMR) from walking and cycling:

$$RMR = (1 - \mathrm{RR}) \times \left(\frac{\text{Local volume of active mode}}{\text{Reference volume of active mode}}\right) \tag{1}$$

The air pollution risk (APR) can be estimated by using the following formula:

$$APR = (1 - \mathrm{RR}) \times \left(\frac{\text{AP exposure of active mode users}}{\text{Reference AP exposure}}\right) \tag{2}$$

The crash Mortality risk (CMR) when cycling is calculated as follows:

$$CMR = \left(\frac{\text{Countrywide fatal crashes}}{\text{Countrywide volume of active mode}}\right) \times \text{Local volume of active mode} \tag{3}$$

A mean value of relative risk mortality for walking: 0.89 and cycling: 0.90 is used from the epidemiological studies.
In the case of air pollution, $PM_{2.5}$-related mortality relative risk of 1.07 per 10 μg/m3 increase in $PM_{2.5}$ is used in the model.

The value of a statistical life (VSL) of USD 219 000 per premature death in India was used based on the formula below.

$$VSLi = VSLO_{2005,\ USD} \times (GDPC_{2005}/\ GDPO_{2005})^{IES} \times (1+\%\Delta CPIC_{2005\text{–}2017}) \times (1+\%\Delta GDP_{2005\text{–}2017})^{IET} \tag{4}$$

Where:
$V_{SL}O_{2005,\ USD}$: base value for OECD average V_{SL} of US$ 3.013 million
$GDPC_{2005}$: real gross domestic product (GDP) per capita of US$ at purchasing power parity in 2005 of the respective country
$GDP_{OECD\text{-}2005}$: OECD average real GDP per capita of US$ at purchasing power parity in 2005

Table 1. Default values used for the quantification of the health impacts [23]

Parameter description	Default value	Unit
Default carbon value by country and year (value for India in 2023)	78	USD2014 /tCO2
Default carbon value by country and year (value for India in 2030)	93	USD2014 /tCO2
Average occupancy rate for cars all purposes	2	persons
Default proportion shifted from car to bike	30	%
Default proportion shifted from pt to bike	50	%
Default proportion shifted from walk to bike	20	%
Default proportion shifted from bike to walk	20	%
Default proportion shifted from car to walk	20	%
Default proportion shifted from pt to walk	60	%
Average cycling speed	14	km/h
Average walking speed	5.3	km/h
Relative risk for mortality and bike (physical activity only, excluding air pollution effect)	0.9	ratio
Relative risk of air pollution (PM2.5) and mortality	1.08	ratio
Relative risk for mortality and walk (physical activity only, excluding air pollution effect)	0.88	ratio
Average number of trips per day using all likely modes	3	trips (all-modes)/ person *day
Average distance per walking trip	1.3	km/trip
Average distance per bicycle trip	4.1	km/trip
Average length of walking steps	72	cm
Population of Delhi	18,345,784	Persons

IET: income elasticity of VSL, by country income level: Low income and middle income = 1.2, High income = 0.8

IET: income elasticity applied to GDP growth

$1 + \%\Delta CPI_{2005–2017}$: change in the consumer price index in the respective country between 2005 and 2017, for inflation adjustment

$1 + \%\Delta GDP_{2005–2017}$: change in real GDP per capita in the respective country between 2005 and 2017, for income adjustment

3. RESULTS AND DISCUSSION

A scenario was built for Delhi (2022), and it was compared to a projection for 2030. The increased active transport scenario involved significantly more cycling and walking and less use of cars and two-wheelers in Delhi. As per the business as usual scenario, the current total active travel time per capita per day is 20 minutes, in which walking contributes 12 minutes and cycling 8 minutes [24][25].

A new scenario was developed for 2030 with an increase in active travel from an average of 20 minutes (12 minutes walking and 8 minutes for cycling) to 40 minutes per capita (24 minutes walking and 16 minutes for cycling). The population assessed ranged from 20-64 years in both cases, so in total, 60 percent of the population in Delhi within the age was considered in the study. $PM_{2.5}$ 143 ug/m^3 for Delhi was used in the study, and a discount rate of 5% was used for calculating the economic impacts.

Due to the increase in active transportation in Delhi, every year, 4080 premature deaths can be avoided. In addition, carbon emissions are decreased by 722630 tons. A decrease in mortalities and carbon emissions corresponds to an economic value of USD 955 M USD per year using a 219 000 USD value of statistical life (VSL).

Table 2. Co-benefits of cycling and walking in Delhi.

Co-Benefits	Cycling	Walking
Air pollution related avoided mortalities (cases)	2666	1525
Air pollution related mortalities Economic benefits (M USD)	584	333.9
Carbon reductions (Thousand tons)	426	296
Carbon reduction Economic benefits (M USD)	36.3	25.3
Physical activity related mortalities avoided (cases)	3471	515
Physical activity economic benefits (M USD)	760	1130
Crash risk related mortalities (cases)	225	128
Crash risk related mortalities economic cost (M USD)	49.3	28

We further observed that physical activity related mortalities avoided cases are higher than the avoided cases of air pollution related mortalities. Cycling was observed to have higher impact on reducing the mortalities than the walking. Carbon reductions due to cycling was 426 (Thousand tons) and 296 (Thousand tons) due to walking.

The results are further divided in Table 2 related to the contributions from cycling and walking separately and corresponding economic impacts and reductions in carbon emissions.

The results revealed that due to the increase in active transportation per capita, 12 minutes for walking and 8 minutes for cycling per day in Delhi, 4080 premature deaths can be avoided every year. In addition, carbon emissions are decreased by 722,630 tons. The findings suggest that each scenario has the potential to save significant amounts of CO_2 emissions and have public health benefits, which encourages the development of the infrastructure needed in Delhi for non-motorized transportation. We also observed that physical activity related to NMT has more impact on mortalities and related economic benefits.

The study's findings show that large population-level adjustments in travel habit might have significant health consequences.

We observed in this study that shifting to a more physically active and less car-based transportation system could provide significant benefits for population health by increasing physical activity and lowering air pollution while also lowering greenhouse gas emissions. The overall number of premature deaths was lowered with the NMT scenario due to decreases in the rate of mortality induced by air pollution. Significant reductions in premature deaths were also seen for the enhanced active travel scenarios because of increased physical activity.

4. CONCLUSION

Walking and cycling may be essential daily sources of transportation if our communities are designed to accommodate them. Lower average travel speeds, as well as a preference for local accessibility over long-distance transportation, make walking and cycling more appealing. These modifications would have a good impact on emissions, as well as major health advantages, mostly from increased physical activity.

The combination of reduced reliance on motorized transport and significant increases in active travel, along with proactive adoption of low-emission technologies, yields the best results in terms of climate change mitigation and public health.

Cycling has declined sharply as a form of transportation in Indian cities over the previous few decades. This can be due to both the danger of traffic accidents and the absence of bike facilities. When it comes to raising the percentage of bicycle ownership among potential users, safe cycling infrastructure may be quite important.

Urban regions must have a transportation system that is economical, functional, and environmentally friendly. in addition to the reduction in mortalities and decrease in carbon emissions, active transportation, which are quantified in this study, other indirect advantages of active transport include fuel savings, travel time savings, energy security, and reduced inequality. active transportation reduces traffic congestion, air pollution, and noise pollution, improving people's health and lowering fuel and energy consumption. Since Indian cities, including Delhi, have comparatively low commuting distances as 60% of journey lengths are less than 5 km. These are the optimal journey durations for active transportation. Interventions to reduce vehicle usage and enhance cycling and public transportation use in Delhi can yield considerable health and environmental benefits as well as a result in lower greenhouse gas emissions.

Non-motorized transportation is a cheap, sustainable, and environmentally friendly mode of transportation that currently needs national level intervention to be successfully promoted. Increasing investment in cycling and walking infrastructure in urban areas might encourage people to switch over to NMT.

To emphasize the advantages of bike-sharing, communities should also establish bicycle sharing networks at various sites within their jurisdictions.

To attain the health benefits as described above, effective policies that increase the distances walked and cycled while decreasing the usage of motor vehicles are required. Policies that encourage individuals to walk and bike are intended to improve the safety of active transportation.

Creating secure urban settings for mass active mobility would need prioritizing pedestrian and cycling demands over those of vehicles. Policymakers should shift funding away from highways for vehicles and toward infrastructure for walkers and bikes.

Therefore, policy measures should be taken to offer extensive safe walking and cycling infrastructure in Delhi, which may help enhance active transportation. Policies that encourage active travel and minimize the usage of motor vehicles should be encouraged.

We find that the net health benefits of NMT are significant. Increased physical activity levels are expected to improve health more than offset the negative impacts of road accidents and air pollution exposure. As a result, we urge the promotion of NMT in Delhi because of the significant health and economic benefits.

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