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## WORKING PAPER 03

# Assessing Cities' Labour Market Efficiencies Using Mumbai Commuting Data

*Vasant Dhar, Harsh Vardhan Pachisia, Vaidehi Tandel, Kadambari Shah and Girish Gupta*

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# Abstract

Ease of mobility is crucial for cities' productivity. Better mobility allows better access to jobs and allows firms access to a larger pool of workers. As cities grow, congestion can rapidly erode productivity as well as impose heavy environmental costs. We use publicly-available Uber Movement data to measure congestion across 40 key routes connecting major Mumbai residential areas to the city's key business districts. We go on to quantify the economic and environmental costs of congestion. We provide actionable results for policymakers by identifying chokepoints, specific route segments which contribute to congestion. Left unaddressed, the situation will have damaging effects on the potential benefits of agglomeration and, ultimately, Mumbai's productivity.

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# Executive Summary

Mumbai's congestion is infamous. The megacity's roads are clogged every single day, leading to something far worse than simple inconvenience. It means the destruction of the city's ability to fulfil its most basic function of bringing people and organisations together. When cities function well, firms can optimise the costs of finding workers and of transporting goods and services to consumers. Workers, in turn, are able to find jobs matching their skillset and are more likely to switch. Ease of mobility is key in ensuring such markets function smoothly.

Mumbai had a population of more than 12 million when the country's last Census was conducted in 2011. The economic powerhouse is one of the densest cities in the world. Between 2011-12 and 2014-15, it accounted for around 17% of Maharashtra's GDP. In 2018-19, Mumbai tax, customs and excise collections formed nearly 30% of India's total tax revenue. Some 700,000 people enter the city every day.

We aimed to unearth the extent of Mumbai's congestion, quantify its economic and environmental costs and provide actionable results for policymakers by identifying chokepoints. Uber Movement data fed into our novel approach, showing that long commutes impose economic and environmental costs to the citizens of Mumbai; we developed a new methodology to quantify these costs.

The average commute on Mumbai's major routes is longer than an hour, more than double the averages of Singapore, Hong Kong and New York. We found that every petrol-fueled daily round trip commute between Borivali and Lower Parel costs more than INR 350 due to congestion. This implies that those living in Borivali are unlikely to seek jobs in Lower Parel, a demonstration of a fragmented labour market and the hampering of economic productivity.

To assist policymakers in eradicating congestion, we identified chokepoints that should be addressed through granular interventions depending on existing infrastructure and traffic conditions at these bottlenecks. Improving mobility on such routes will be a key factor in ensuring productivity that, in turn, will aid the economic growth of Mumbai.

This research can be further developed and used by academics as well as policymakers. Academics can apply a similar methodology to analyse other cities. Policymakers can use this research to address and remove chokepoints on major routes, leading to improved economic productivity. Lastly, a cross-collaboration can be undertaken between academics and policymakers through this research where academics design granular interventions to eradicate chokepoints which can then be implemented by policymakers.

# 1. Introduction

The ability to move easily and freely is key to quality of life in an urban environment. It also directly affects productivity and determines whether cities flourish or stagnate. "Cities are primarily large labour and consumer markets," wrote urbanist Alain Bertaud in *Order Without Design: How Markets Shape Cities.* "These markets work best when the possibility of contact between workers and firms increases." When such markets function well, firms can optimise the costs of finding workers and of transporting goods and services to consumers. Workers, in turn, are able to find jobs matching their skillset and are more likely to switch jobs. Ease of mobility is key in ensuring such markets function smoothly.

Bertaud (2018) adds that commuters are typically unwilling to travel more than one hour each way, becoming increasingly dissatisfied as trips lengthen. This, in turn, effectively constrains the size of the labour market. Prioritising mobility will increase the area accessible within that hour. Moreover, congestion has socio-economic and environmental impacts, such as additional fuel costs, increased air and noise pollution as well as health issues.

In India, private vehicle ownership has rapidly grown due to households' higher purchasing power, resulting in increased congestion. Public transport has effectively remained stagnant. The 2018 TomTom Traffic Index shows that Mumbai has the world's worst traffic jams, with drivers facing 65% longer travel times due to traffic.

Indian Institute of Human Settlements (2015), Padam & Singh (2004), NITI Aayog, et al. (2018) and others have discussed India's congestion and its impacts on quality of life, finding rife congestion and pollution. Empirical studies on large Indian cities have created mobility indices and measured congestion (Storeygard, et al., 2018), looked at the effects of congestion on quality of life in Kolkata (Bardhan, et al., 2011) and used secondary data along with travel survey data to estimate greenhouse gas emissions due to road transport in Mumbai's Metropolitan Region (Bharadwaj, et al., 2017).

This paper adds to the existing literature by providing a Travel Time Index and identifying chokepoints, i.e., segments with the lowest speeds, in Mumbai. Further, it estimates the economic and environmental costs of congestion. Through these contributions, we aim to highlight the extent of Mumbai's congestion problem and that improving ease of mobility is essential for ensuring productivity so that the economic growth of the city does not suffer.

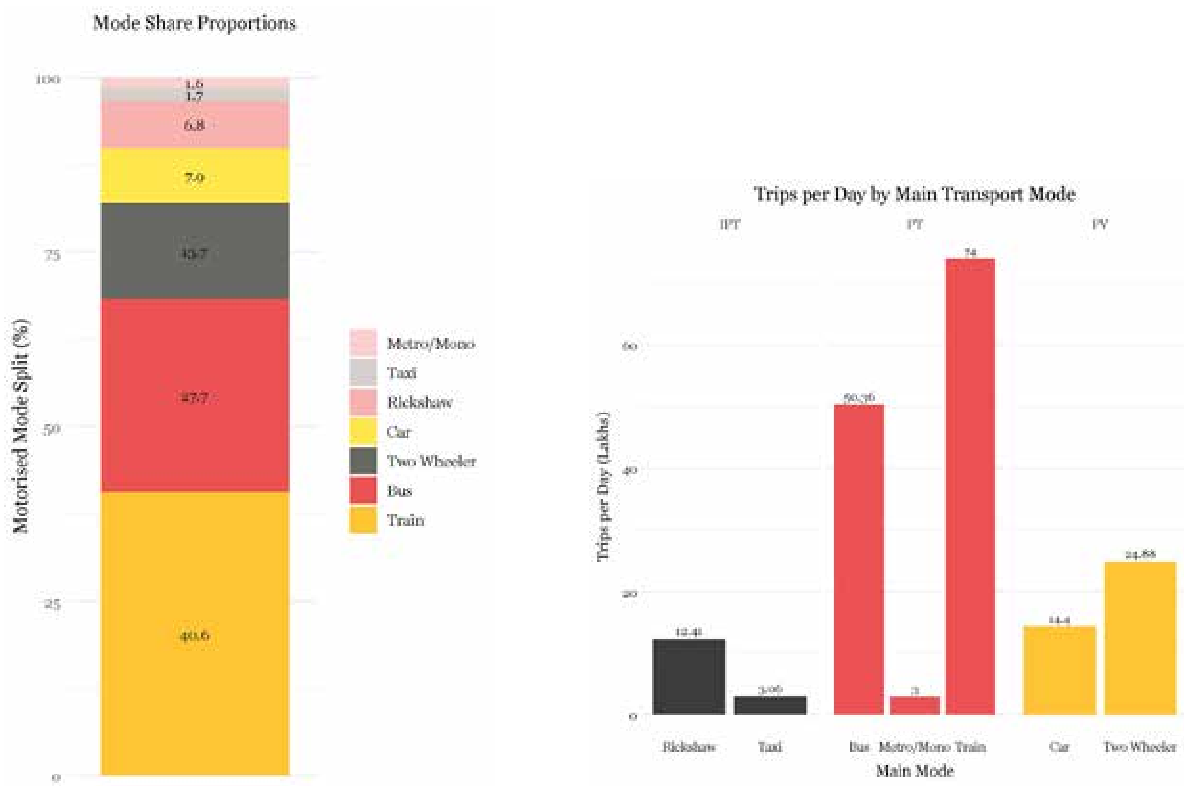
# 2. Background

Mumbai had a population of more than 12 million when the country's last Census was conducted in 2011. The economic powerhouse is one of the densest cities in the world. Between 2011-12 and 2014-15, Mumbai accounted for around 17% of Maharashtra's GDP. In 2018-19, Mumbai tax, customs and excise collections formed nearly 30% of India's total tax revenue (MCGM, 2016). Some 700,000 people enter the city every day (MCGM, 2016).

Major commercial and economic activities have clustered in various Central Business Districts (CBDs). The most important among these are in Nariman Point, Bandra Kurla Complex (BKC), Lower Parel, Andheri East and Malad (Appendix A).

The 2016 Comprehensive Mobility Plan (CMP) for Greater Mumbai is the city's most up-to-date report on travel patterns. The survey of 5,000 households found around 49% of motorised trips are made by road (bus, private vehicle or Intermediate Public Transport (IPT)) while the rest are by rail and metro. The IPT segment includes cycle and auto rickshaws as well as ridesharing applications such as Uber and Ola. The share of public transit as the main mode of travel declined from around 81% to 70% between 2005 and 2014 (Figure 1).

**Figure 1:** Daily Motorised Mode Split, 2014




*Source: Comprehensive Mobility Plan, 2016*

The city's existing road network has been unable to accommodate the growing number of private vehicles. As of 2015, there were around 2.3 million registered private vehicles (i.e., cars and two-wheelers), an increase from 800,000 in 2001. Additionally, over 200,000 IPT modes are now traversing the city.

The lack of adherence to traffic and parking laws has severely impacted traffic flow (CMP, 2016). Mumbai's public transit infrastructure is also inadequate in satisfying existing travel demand. The BrihanMumbai Electric Supply and Transport Undertaking (BEST), which runs the city's bus services, had a 3,337-strong fleet in 2015. London, with a population of 8.1 million, had a fleet of 8,600 in 2017 (Transport for London, 2017).

The primary mode of travel in Mumbai is walking, making up 46% of all trips (CMP, 2016). This could be attributed to a significant share of the population being too poor to afford transit, to a significant share of jobs and residences being poorly connected to the existing transit network or to a data anomaly—whereby the findings fail to separate commuting trips from trips to school, markets, etc.

# 3. Research Questions

Our study aims to highlight the extent of Mumbai's congestion problem and that improving ease of mobility is essential for ensuring productivity. We study commuting trips for Mumbai's five CBDs: Nariman Point, Lower Parel, BKC, Andheri East and Malad.

Commutes in the United States represented only 20% of weekday urban trips in 2013 (Polzin, 2013). Similar data is not available for India. Despite being a small fraction of all trips, commutes are extremely useful in measuring ease of mobility. The timing of such trips corresponds to peak hours when congestion is at its worst. Analysing commutes is useful because they can help calibrate transport infrastructure to meet peak travel demand.

**We focus on three research questions:**

1. How should congestion be measured along Mumbai's major routes?
2. What are the economic and environmental effects of congestion?
3. Can we identify chokepoints on these critical routes?

# 4. Data

### *Travel Time and Distance*

### Time

Uber releases limited data through Uber Movement, which provides average travel times between two zones for a given time period across a city.

The company records the position and time of its vehicles every four seconds. To ensure privacy, Uber assigns the position to one of 695 Traffic Analysis Zones (TAZs) and removes TAZ pairs that either do not carry a minimum number of trips or have unique riders. The minimum threshold is not published.

For Mumbai, such data is currently available for 12 quarters from 2016 to 2018. Uber also provides the TAZs' spatial boundaries and corresponding IDs.

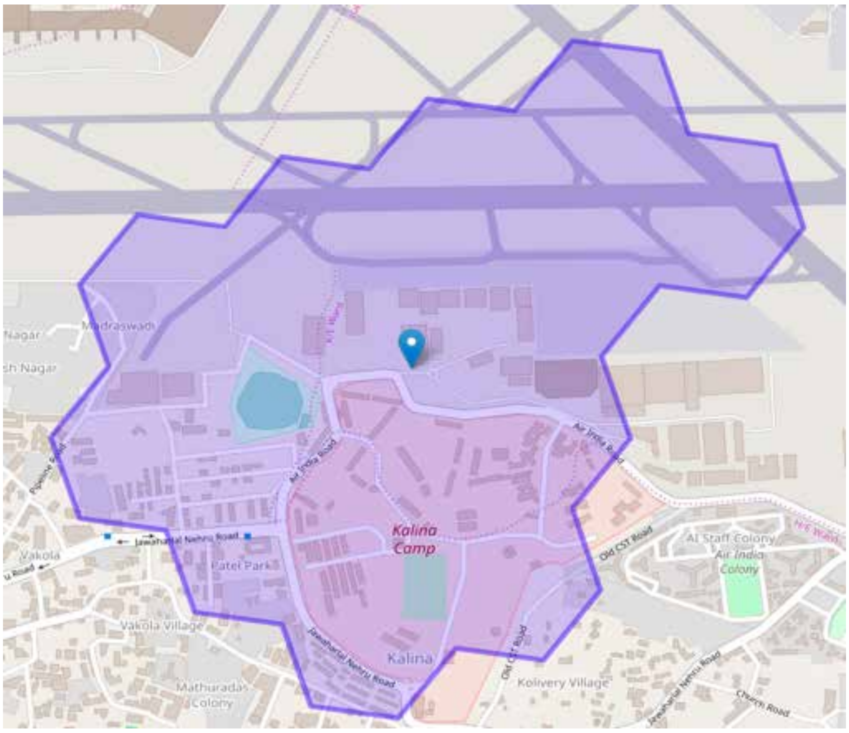
To analyse commutes, we first downloaded aggregate mean travel times for weekdays. We merged the datasets and created a unique identifier for each time period (Table 1).

**Table 1:** A 10-row snapshot of Uber Movement Dataset for Mumbai with time period identifiers

| SOURCEID | DSTID | HOD | MEAN_TRAVEL _TIME | STANDARD_DEVIATION_ TRAVEL_TIME | TIME_ PERIOD |
|---|---|---|---|---|---|
| 382 | 265 | 19 | 8184.53 | 1523.69 | 6 |
| 382 | 265 | 9 | 4342 | 761.02 | 10 |
| 382 | 403 | 19 | 6156.42 | 868.82 | 2 |
| 577 | 382 | 19 | 235.2 | 194.69 | 2 |
| 382 | 265 | 18 | 8561.85 | 1497.05 | 2 |
| 577 | 382 | 8 | 152.26 | 97.79 | 9 |
| 265 | 382 | 9 | 7296.48 | 1772.23 | 7 |
| 598 | 382 | 8 | 2491.08 | 528.65 | 8 |
| 598 | 382 | 19 | 2276.69 | 427.63 | 9 |
| 577 | 382 | 18 | 293.21 | 229.9 | 8 |

We calculated the centroid of each TAZ (Figure 2) and obtained the position of the source and destination TAZs. The maximum distance from a TAZ's centroid to its boundary ranges from 190 metres to 1.93 km, with an average of 960 metres.

**Figure 2:** A TAZ in Kalina, Mumbai, with its centroid. The maximum distance within this TAZ is 920 meters, i.e., the shaded area is less than one square km.




Our final dataset contained more than half a billion data points over 50 million rows. Each row contained the average time taken between two TAZs during a particular hour of a weekday for one quarter (Table 2).

**Table 2:** A 10-row snapshot of the Uber Movement Dataset for Mumbai with time period identifiers and source-destination pairs

| SOURCEID | DSTID | HOD | MEAN_ TRAVEL_ TIME | STANDARD_ DEVIATION_ TRAVEL_TIME | TIME_ PERIOD | LNG_O | LAT_O | LNG_D | LAT_D |
|---|---|---|---|---|---|---|---|---|---|
| 382 | 598 | 8 | 2137.63 | 230.26 | 11 | 72.82177573 | 18.92790968 | 72.89194254 | 19.04435159 |
| 265 | 382 | 19 | 5627.81 | 1233.62 | 10 | 72.86236799 | 19.22057712 | 72.82177573 | 18.92790968 |
| 382 | 577 | 19 | 351.65 | 286.22 | 2 | 72.82177573 | 18.92790968 | 72.82171334 | 18.93477731 |
| 577 | 382 | 9 | 219.08 | 118.87 | 7 | 72.82171334 | 18.93477731 | 72.82177573 | 18.92790968 |
| 265 | 382 | 9 | 7179.19 | 1467.64 | 8 | 72.86236799 | 19.22057712 | 72.82177573 | 18.92790968 |
| 403 | 382 | 8 | 4948.17 | 821.64 | 6 | 72.83397494 | 19.13399766 | 72.82177573 | 18.92790968 |
| 382 | 577 | 18 | 411.62 | 284.95 | 12 | 72.82177573 | 18.92790968 | 72.82171334 | 18.93477731 |
| 382 | 265 | 18 | 9132.93 | 1482.53 | 8 | 72.82177573 | 18.92790968 | 72.86236799 | 19.22057712 |
| 382 | 403 | 9 | 4462.51 | 656.45 | 7 | 72.82177573 | 18.92790968 | 72.83397494 | 19.13399766 |
| 403 | 382 | 19 | 5006.38 | 803.39 | 3 | 72.83397494 | 19.13399766 | 72.82177573 | 18.92790968 |

## Distance

To calculate on-road distances, we used the Open Street Routing Machine (OSRM) Route API which gives the fastest travel path between coordinates, i.e., our source-destination pairs.

**BOX 1:** Travel times between South (downtown) Mumbai and the city's international airport

Travel times between the city centre and airport play a key role in the productivity of a city (AOA, 2016). The 30 km trip to Mumbai's international airport can take over 1.5 hours from South Mumbai during peak evening traffic. For comparison, the 48 km trip between Shanghai city centre and its airport takes around 45 minutes at peak times (Google Maps).

While travel times from South Mumbai to the airport decreased 6% between 2016 and 2018, times in the opposite direction increased 9%. Seasonal variation is also evident: travel times rise between July and September, perhaps due to the monsoon. This is followed by a sharp decline in times for the remainder of the year, perhaps due to a string of public holidays (Figures 1.1 and 1.2.).

**Figure 1.1:** Travel times between South Mumbai and Mumbai's international airport.

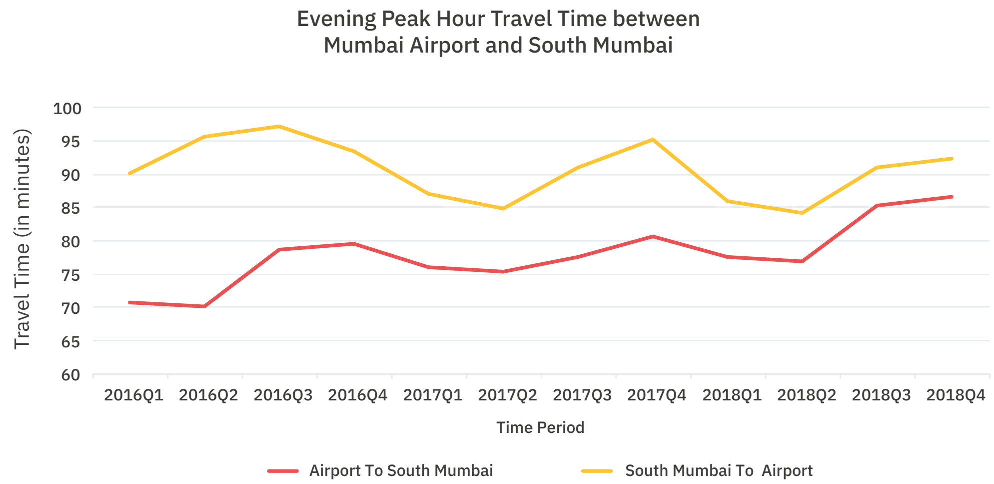
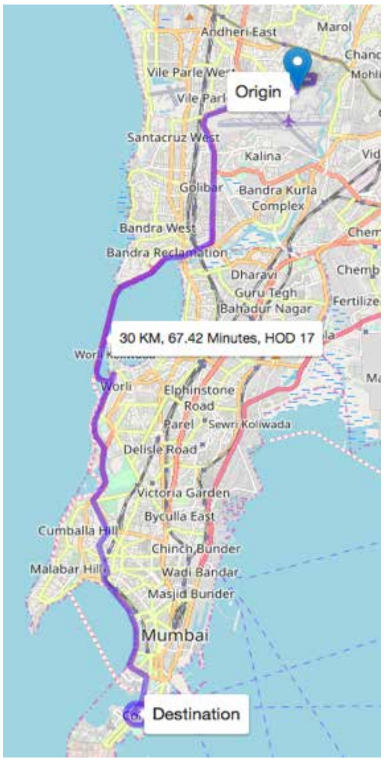



**Figure 1.2:** Route taken between Mumbai's international airport and South Mumbai.



### *Economic and Environmental Costs*

### Employment-Unemployment Surveys

India's National Statistical Office conducts large Employment-Unemployment Surveys, the latest of which took place in 2011-12. Table 3 shows the district-level schedule with the relevant columns for wages and time disposition of work during a week. We estimated average weekly wage earnings.

**Table 3:** Survey schedule for the Employment-Unemployment Survey (2011)

[5.3] time disposition during the week ended on ...........

| srl. no. as in col.1, bl. 4 | age (yrs.) as in col.5, bl. 4 | current day activity particulars | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | srl. no. of acti-vity | sta-tus (co-de) | for codes 11 to 72 in col. 4 | | intensity of activity (full-1.0, half-0.5) | | | | | | | total no. of days in each activity (0.0) | for codes 31, 41, 42, 51, 71, 72 in col.4, wage and salary earnings (received or receivable) for the work done during the week (Rs) | | | |
| | | | | industry division (2-digit NIC-2008 code) | for rural areas only, operation (code) | 7th day | 6th day | 5th day | 4th day | 3rd day | 2nd day | 1st day | | cash | kind | total | mode of payment (code) |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| total | | | | | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 7.0 | | | | |

*Source: National Statistical Office, 2011*

### Fuel Prices

Fuel prices were compiled via Petroleum Planning & Analysis Cell (PPAC) and Indian Oil. We took an average from all available Mumbai prices between 2016 and 2018.

To obtain the fuel consumed, we use Maruti Suzuki's Swift Dzire figures of 21.21 and 28.40 km per litre of petrol and diesel respectively (Certified estimates under Rule 115(G) of CMVR 1989). Since two-wheelers do not use diesel, we only use Hero's Super Splendor mileage of 60 km per litre of petrol.

Driving conditions would certainly alter fuel consumption, however, we believe our figures to be reasonable. We did not find similar data for compressed natural gas-powered vehicles.

We used the 2016 CMP for Greater Mumbai to calculate additional fuel costs. Since two-wheelers and cars respectively comprised on average 64% and 36% of private vehicles between 2010-2015, we used these weights to provide a more accurate picture of additional fuel costs.

### Environmental Costs

Transport accounted for over 20% of 2014 global carbon dioxide emissions (World Bank Indicators).

To calculate the amount of additional carbon dioxide released due to congestion, we used two existing estimates: Gilani (2012) calculated the weight of carbon dioxide emitted per litre of petrol and diesel. He estimated that, in India, 2.66 kg and 2.30 kg of carbon dioxide is discharged per litre of petrol and diesel, respectively. To put monetary values to carbon dioxide emissions, we used Ricke, et al.'s (2018) estimate that, in India, a tonne of carbon dioxide emitted is worth $86. We employed the same weights mentioned in the previous section to capture the environmental costs of traffic.

# 5. Methodology

***Estimating Times, Distances and Speeds***

To assess commuting patterns between our five CBDs, we selected four major residential areas in the city's north (Borivali), south (Marine Drive), east (Chembur) and west (Andheri West) regions. We chose these areas based on Municipal Corporation of Greater Mumbai (MCGM) land use plans (Figures 3a and 3b).

**Figure 3a:** Five CBDs of Mumbai


**Figure 3b:** Four Residential Areas


We analysed travel times from each residential area to each CBD in morning peak-hour traffic (between 8:00 and 10:00) and each CBD to each residential area in evening peak-hour traffic (between 18:00 and 20:00). For each of these trips, we calculated (Appendix B):

1. Travel times for residential area-to-CBD and CBD-to-residential area trips.

2. Distances between residential area-to-CBD and CBD-to-residential area.

3. Speeds by combining the above.

We also calculate the Travel Time Index (TTI) for individual routes. TTI is a ratio between how long a trip would take in peak hour traffic versus in free-flow hours (i.e., between 1:00 and 5:00). A TTI of one would indicate that peak traffic was freely flowing, whereas a TTI of three would indicate traffic flowing at three times slower than in free flow. The average TTI for Mumbai is 2.21; a 30-minute trip with no traffic takes 66 minutes at peak times.

TTI is usually measured as the ratio between peak-hour speed and the government speed limit (Lyman et al, 2008). Given weak implementation of speed limits across India, travel time in free-flow conditions is preferred. We calculated route-level TTIs on such a basis (Appendix C) for analysing 40 selected routes. These routes include: a) 20 morning commutes from four residential areas to five CBDs, and b) 20 evening commutes from five CBDs to four residential areas.

***Quantifying economic and environmental costs***

### Opportunity Cost of Congestion

The opportunity cost is the cost incurred by spending additional time commuting which could have instead been used for work or leisure. To define costs, we use average wage rates, estimated via the Employment-

Unemployment Survey data. We assumed a nine-hour workday and a seven-day work week, as the survey asked respondents to report weekly wage earnings with those constraints. The cost of leisure is assumed to be half this wage cost, supported by theoretical work that shows that value of leisure must be less than the wage rate (Johnson, 1985). Additionally, Small (2012) suggests that value of commute time is typically estimated to be around half the wage rate.

The average hourly wage cost for Mumbai is INR 50, very likely to be an underestimate for the purpose of this study as those driving will be earning above average. For those belonging to lower income groups, the preferred mode of travel is usually on foot, bicycle or train. Hence, our estimate is conservative.

We assume people choose between work and leisure with equal probability so the opportunity cost of congestion is:

*Opportunity cost of congestion = Additional hours in commute ** 
*((probability of working * wage cost) + (probability of leisure * (wage cost/2)))*

### Additional Fuel Cost

We calculated the costs of additional petrol (cars and two-wheelers) and diesel (cars only) consumed due to bottlenecks.

We multiplied distance and fuel consumption to get the volume of fuel consumed in free flow. We then multiplied the volume of fuel consumed per route and route-level TTI to obtain the volume of fuel consumed during peak hours.

The additional volume of fuel consumed per route owing to congestion is the difference between the volume of fuel consumed during peak hours and that consumed in free flow. To arrive at the additional fuel cost per route, we multiplied the additional volume of fuel consumed by the cost of fuel per litre.

The above steps were performed separately to calculate additional fuel costs per route for both two-wheelers (petrol only) and cars (petrol and diesel). Finally, we used the weights of 0.64 and 0.36 respectively to arrive at the total additional petrol costs per route in INR.

### Environmental and Monetary Costs of Emissions

We calculated the costs of carbon dioxide emissions due to congestion in environmental terms (i.e., the amount of carbon dioxide emitted by traffic) and in monetary terms (i.e., assigning monetary values to the amount of carbon dioxide emissions):

The first steps in calculating the additional amount of fuel consumed remain the same as those mentioned in estimating costs of additional fuel consumed.

Using the numbers for the additional volume of fuel consumed, we computed the additional carbon dioxide emitted by multiplying the additional volume of fuel consumed and carbon dioxide emissions (Gilani, 2012).

Higher carbon dioxide emissions have several harmful effects, such as exacerbating air pollution and increasing the likelihood of health problems.

To quantify these emissions in economic terms, we multiplied the additional carbon dioxide emitted with the cost of emissions to estimate the cost of additional fuel emissions. Ricke, et al., (2018) estimated that carbon dioxide per kilogram in Indian cities costs the economy USD 0.086.

The above steps were performed separately to calculate the monetary cost of additional fuel emissions for both two-wheelers (only petrol) and cars (petrol and diesel). Finally, we use the weights cited earlier to arrive at the total cost of additional petrol emissions in INR terms (using the exchange rate of USD 1 to INR 70).

Hence, we calculated the economic and environmental costs of emissions on the selected routes for petrol and diesel. Such costs for petrol-run vehicles are mentioned in the findings section, the costs for diesel-powered vehicles can be found in Appendix D.

### Identifying chokepoints on selected routes

After estimating congestion and its associated costs, we wanted to identify specific chokepoints. We created a quartile distribution of the route distances and from that split the routes into segments (Table 4).

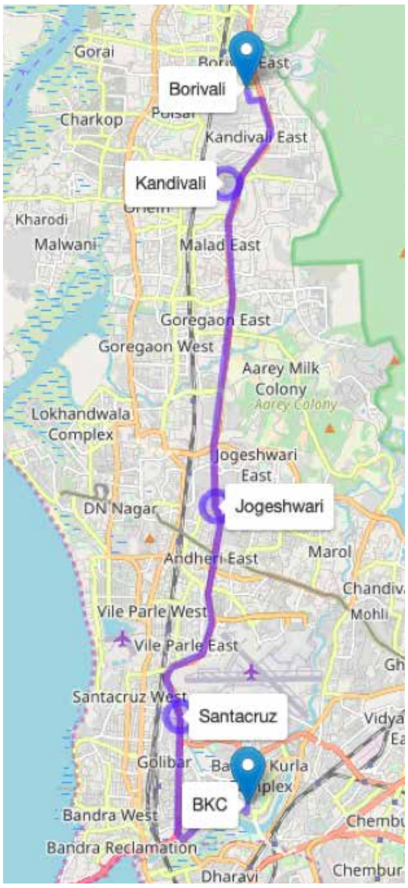
**Table 4:** Quartile distribution of the route distances and break up of routes into segments

| | LOWER BOUND (KM) | UPPER BOUND (KM) | NUMBER OF SEGMENTS PER ROUTE |
|---|---|---|---|
| Q1 | 5.13 | 11.36 | 2 |
| Q2 | 11.36 | 17.81 | 3 |
| Q3 | 17.81 | 23.56 | 4 |
| Q4 | 23.56 | 33.53 | 5 |

This is best illustrated by example: The 21.67 km trip from BKC to Borivali places it in the third quartile and hence, it was split into four segments. These four segments were delineated by three waypoints (in addition to the origin and destination) (Figure 4).

**Figure 4a:** Direct Route


**Figure 4b:** Route with Segments




We applied the same methodology to 38 of the 40 routes. Two routes—the short 1.37 km trip from Marine Drive to Nariman Point and the long 38.58 km trip from Nariman Point to Borivali—were excluded since they were outliers in terms of distance. The first is short and so was analysed as one segment; the second was broken into six segments with five intermediate TAZs.

After determining the number of segments and waypoints for each route, we identified and assigned the closest TAZ to each waypoint. We were able to assign source, intermediate and destination TAZs for each route. Based on these, we calculated times, distances and speeds for each segment of every route. Ultimately, we were able to create a quartile distribution of speeds of all segments on the 40 routes (Table 5). We have marked chokepoints in red and darker red.

**Table 5:** Quartile distribution of speeds of all segments on the 40 analysed routes

| | LOWER BOUND (IN KM/HR) | UPPER BOUND (IN KM/HR) |
|---|---|---|
| COMMUTING SPEED RANGES (IN KM/HR) | 30.14 | 81.40 |
| | 21.62 | 30.14 |
| | 15.36 | 21.62 |
| | 8.01 | 15.36 |

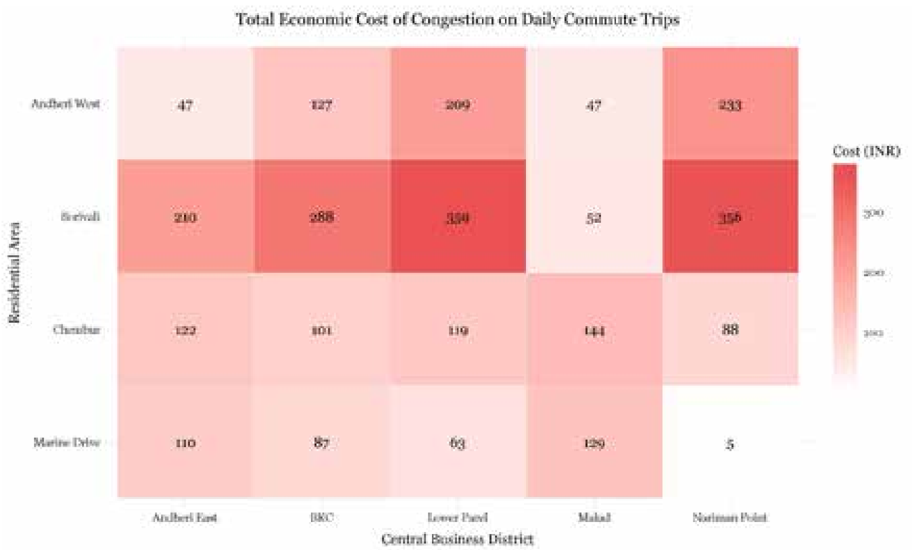
Mumbai's major routes are extremely slow relative to those in Hong Kong, for example, where average speeds range from 20 km/hr to just under 40 km/hr (Hong Kong Transport Department, 2016). Mumbai's moderate traffic is Hong Kong's chokepoint.

# 6. Findings

The routes studied are all heavily congested, the costs of which are extremely high (Figure 5).

For example, each petrol-fueled daily round trip commute between Borivali and Lower Parel costs, on average, over INR 350 due to congestion. This implies that those living in Borivali are unlikely to seek jobs in Lower Parel.

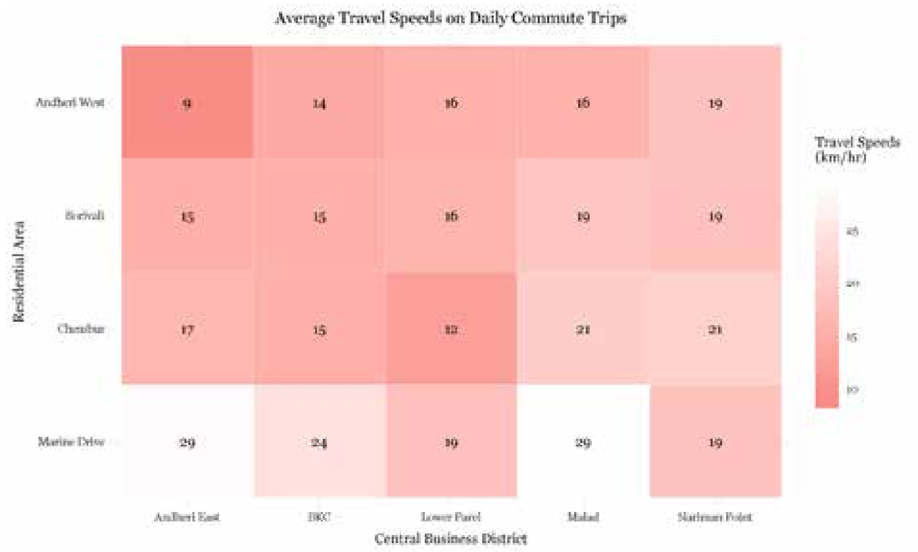
**Figure 5:** Total Economic Cost of Congestion (for petrol-fueled vehicles)




*Congestion on major routes*

The average travel time for a commute on Mumbai's major routes is more than 60 minutes; the average car trip time in Singapore, Hong Kong and New York is less than half that (Bertaud, 2018). To measure the impact of congestion, we identified six major patterns from average travel speeds for commute trips (Figure 6).

**Figure 6:** Average travel speeds on daily commute trips




The highest average commute speeds across CBDs are less than 30 km/hr. Travelling north-south is much faster than travelling east-west. A worker travels at double the speed when starting from Marine Drive as compared to Chembur when travelling to BKC in the morning. If their place of work is Andheri East, the evening commute for Marine Drive residents is 8 km/hr faster when compared to residents of Chembur.

Commutes from residential areas in South Mumbai to any CBD are significantly faster since the commuter is likely going against heavy traffic. Assuming a 30-minute free-flow trip, a commuter wastes only 12 minutes in morning peak-hour traffic when travelling between Marine Drive and Malad whereas the same commuter would waste 51 minutes travelling from Borivali to Malad.

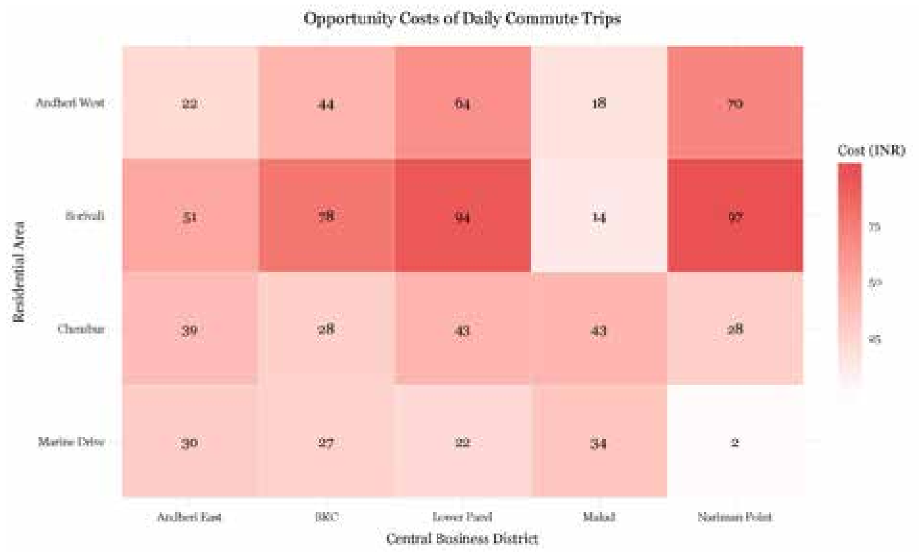
People working in Lower Parel face low speeds irrespective of residential area, a pattern that implies possible chokepoints when entering or exiting Lower Parel. This is identified given that an evening commute, on average, takes 54 minutes longer due to congestion if a person works at Lower Parel.

Commuters travelling to and from Nariman Point experience the fastest speeds. While morning commuters still have to travel around 40 minutes between Chembur and Nariman Point, they do so at almost 25 km/hr which is a relatively high. Trips starting and ending in the residential hubs of Borivali and Andheri West appear to be the most severe bottlenecks. Addressing traffic patterns in and around these areas could alleviate congestion and improve the commutes for workers who live in these areas.

### Economic costs

The longest additional time spent commuting is for those working in Lower Parel. They suffer rides of almost 1.5 hours, leading to the highest opportunity cost, INR 55. On the other hand, people employed in Malad incur the lowest opportunity costs of being stuck in traffic at INR 27. Despite enjoying the highest speeds (Figure 6), people working in Nariman Point incur high opportunity costs since they still face long travel times. As a result, residents of North (Borivali) and West (Andheri West) Mumbai may not look for jobs in Nariman Point leading to labour market fragmentation, ultimately affecting Mumbai's productivity (Figure 7).

**Figure 7:** Opportunity costs of daily commute trips

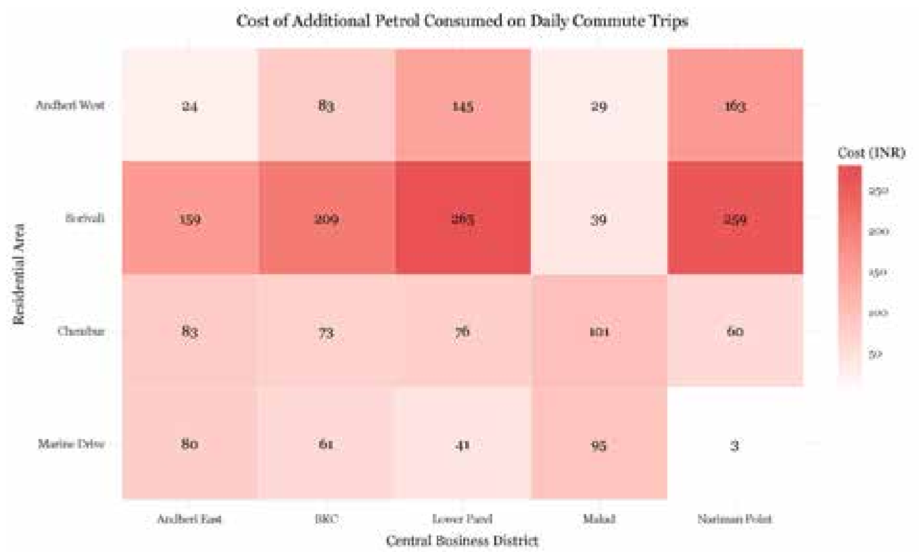



Congestion also leads to increased fuel costs. Due to Mumbai's congested roads, a person commuting between Lower Parel to Borivali for work could end up spending an additional INR 1,325 per week on fuel.

Next, while the costs associated with working in Malad are lower than those for other CBDs, residents of Chembur face relatively higher additional costs. Despite being 22 km from Malad, approximately 10 km less than between Marine Drive and Malad, the additional petrol costs are either the same or higher.

Also, residents of Marine Drive who work in Malad spend a lot more fuel on the way home than when they go to the office. As the distance and route remain the same, the amount of congestion plays a significant role in the additional fuel costs incurred (Figure 8).

**Figure 8:** Cost of additional petrol consumed on daily commute trips

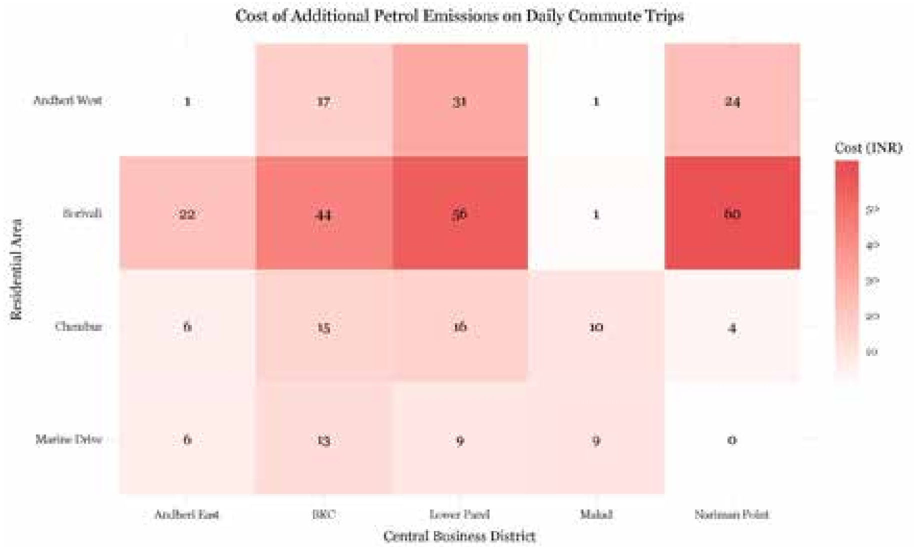



### Environmental costs

It could be assumed that longer distances translate into higher environmental costs. While such a pattern is seen for commute trips to and from Nariman Point and Lower Parel, it does not hold in BKC and Andheri East.

For example, the 23 km trip from Borivali to BKC is approximately the same distance as Marine Drive to BKC, but the two routes have significantly differing environmental costs. Despite similar distances, the congestion contributes significantly to higher carbon dioxide emissions. Commutes to and from Andheri East show similar trends with the 14 km trip between Borivali and Andheri East costing INR 22 in comparison to the cost of the 27 km commute trip between Marine Drive and Andheri East being just INR 6 (Figure 9).

**Figure 9:** Cost of additional petrol emissions on daily commute trips




### Chokepoints

While speeds of each segment across all analysed routes are outlined in Appendix E, we conducted an in-depth assessment of three routes to show how such analysis could be useful to policymakers.

### BKC to Borivali (21.67 km)

When compared to commute speeds to other residential areas from BKC (Figure 6), BKC to Borivali is particularly slow. Its average TTI is 3.51, illustrating that a 30-minute free-flow commute takes over 105 minutes in evening peak-hour traffic. We broke this route up into four segments with intermediate TAZs in Santacruz, Jogeshwari and Kandivali (Figure 10).

**Figure 10a:** Direct Route

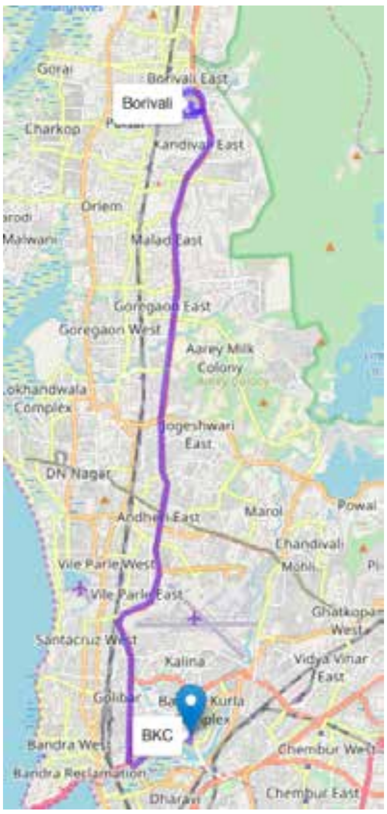



**Figure 10b:** Route with segments

By analysing speeds for each segment between 2016 to 2018 (Table 6), we see that while getting out of BKC has marginally improved over the years, speeds between Jogeshwari and Kandivali remain extremely low at around 11 km/hr. While this chokepoint is possibly a result of the congestion faced during evening peak-hour traffic on the Western Express highway, the more concerning new chokepoint is between Kandivali and Borivali. This bottleneck did not exist in 2016 with average speeds then close to 40 km/hr. However, by 2018, the speed dropped to 23 km/hr. Such a chokepoint should be prioritised and addressed before it worsens even further.

**Table 6:** BKC to Borivali Travel Speeds (by Segments)

| SEGMENT | DISTANCE (KM) | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| BKC TO SANTACRUZ | 4.5 | 9.08 | 10.01 | 11.87 |
| SANTACRUZ TO JOGESHWARI | 4.9 | 14.65 | 11.17 | 12.52 |
| JOGESHWARI TO KANDIVALI | 8.5 | 12.81 | 11.38 | 10.40 |
| KANDIVALI TO BORIVALI | 4.6 | 39.15 | 23.70 | 26.31 |

### Chembur to Lower Parel (11.73 km)

When compared to commute speeds to Lower Parel from other residential areas (Figure 6), Chembur to Lower Parel is particularly slow. Its average TTI is 2.44, meaning a 30-minute free-flow commute takes over 73 minutes in peak morning traffic. Following the steps outlined above, we broke up this route into three segments with intermediate TAZs in Sion and Dadar (Figure 11).

**Figure 11a:** Direct Route

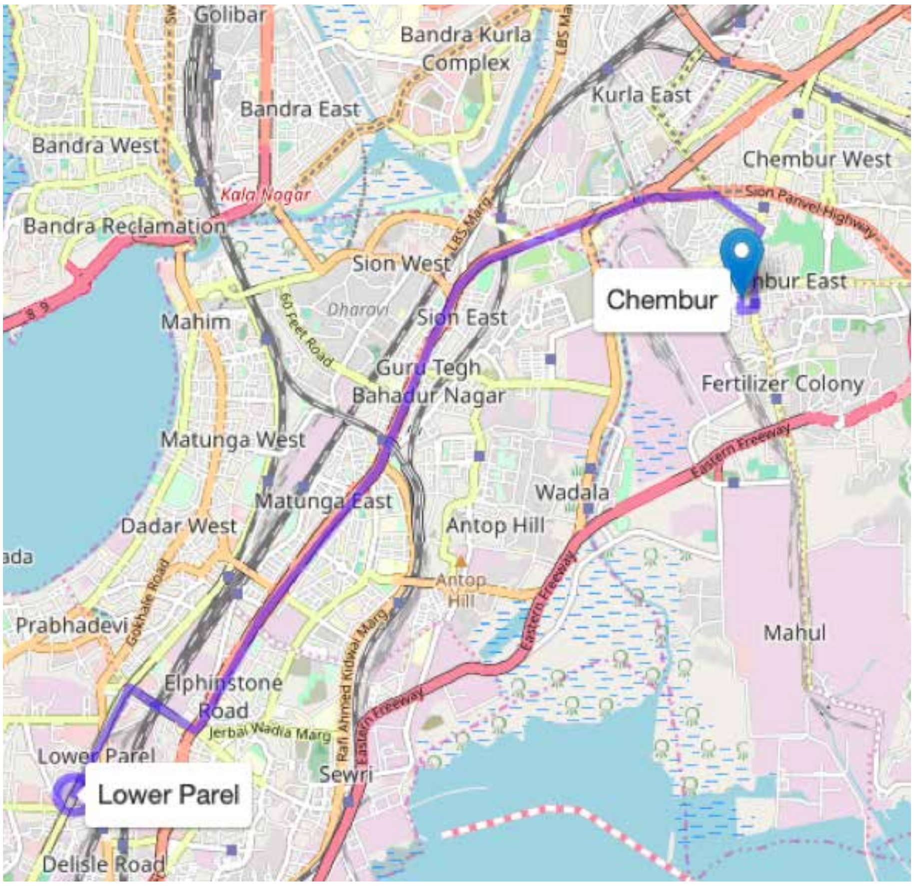
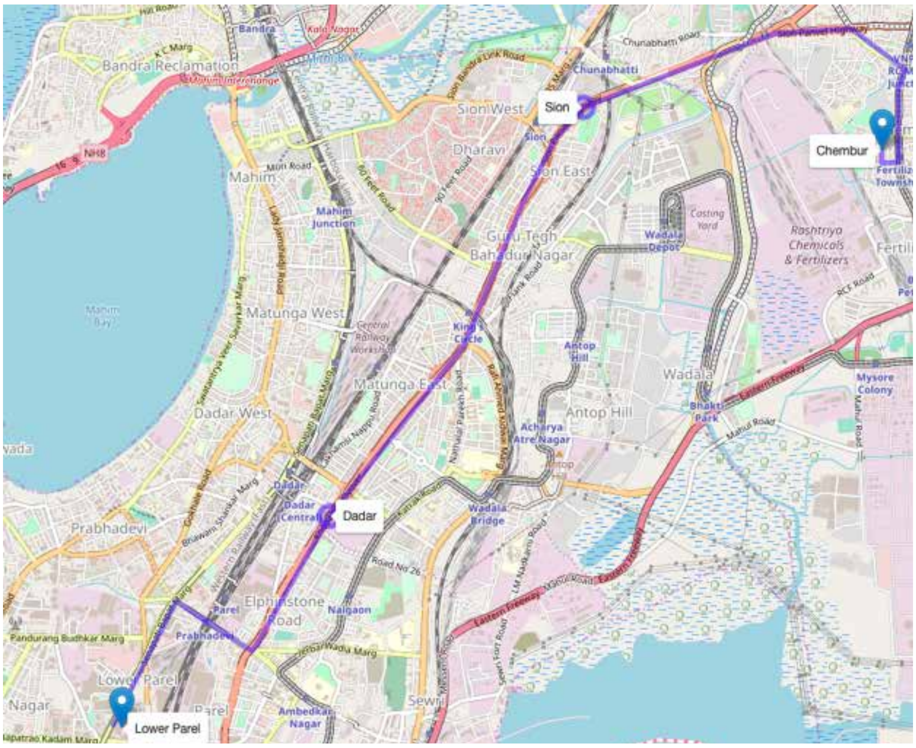


**Figure 11b:** Route with segments




Next, we calculated times and distances between each TAZ to determine speeds for each segment (Table 7). By analysing segment speeds between 2016 and 2018, we saw that entering Lower Parel in morning traffic was extremely slow. This is shown by speeds between Dadar and Lower Parel being close to 10 km/hr in 2018, possibly the result of having only one major entry point into the CBD. This bottleneck should be addressed before it worsens.

**Table 7:** Chembur to Lower Parel Travel Speeds (by Segments)

| SEGMENT | DISTANCE (KM) | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Chembur to Sion | 5.3 | 16.75 | 16.37 | 15.12 |
| Sion to Dadar | 5.2 | 20.84 | 21.77 | 21.70 |
| Dadar to Lower Parel | 2.6 | 12.00 | 10.30 | 10.10 |

### Nariman Point to Andheri West (31.33 km)

When compared to commute speeds from Nariman Point to other residential areas (Figure 6), Nariman Point to Andheri West is particularly slow. Its average TTI is 2.43, showing a 30-minute free-flow commute takes over 73 minutes in traffic. We divided this route into five segments with intermediate TAZs in Haji Ali, Koliwada, Bandra Reclamation and Andheri East (Figure 12).

Figure 12a: Direct Route


**Figure 12b:** Route with segments


We calculated times and distances between each TAZ on the route to determine speeds for each segment (Table 8). By analysing segment speeds between 2016 to 2018, we observed that the South Mumbai segments of Nariman Point to Haji Ali and Haji Ali to Koliwada suffer high congestion. Further, a major uptick in speed is shown in the Koliwada to Bandra Reclamation segment (possibly due to the Bandra-Worli Sealink).

Evening peak-hour traffic on the Western Express Highway causes relatively high rates of congestion (as seen in the Bandra Reclamation to Andheri East segment). However, the final segment (Andheri East to Andheri West) is particularly concerning. Despite the relatively small distance (of just 3.3 km), commuters face speeds of under 10 km/hr. A possible reason for such low speeds is that commuters must exit the Western Express highway, a major arterial road, and travel through secondary road networks.

**Table 8:** Travel Speeds (by Segments)

| SEGMENT | DISTANCE (KM) | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Nariman Point to Haji Ali | 9.4 | 14.39 | 15.12 | 13.5 |
| Haji Ali to Koliwada | 1.8 | 11.92 | 11.68 | 11.09 |
| Koliwada to Bandra Reclamation | 5.45 | 37.30 | 41.63 | 42.03 |
| Bandra Reclamation to Andheri East | 11.5 | 17.69 | 17.20 | 21.64 |
| Andheri East to Andheri West | 3.3 | 8.56 | 8.63 | 9.35 |

Ultimately, we found Mumbai's major routes to be massively congested and calculated high economic and environmental costs as a result of such congestion. Further, through an in-depth assessment of three particular routes, we showed how our methodology can be used to identify chokepoints across a city.

# 7. Policy Recommendations

We have identified major chokepoints and believe these should be a focus for policymakers. However, we have not attributed causes to these chokepoints; that forms the basis of our first policy recommendation. To effectively eradicate bottlenecks, we recommend that policymakers deploy granular interventions for each chokepoint. This would require on-the-ground research to attribute cause (such as road quality, poor traffic management, timing of signals, change in lane widths, unique topography, etc). By removing these critical bottlenecks, policymakers would improve the productivity of Mumbai.

Our findings could also be used by policymakers during the rollout of the 8.91 billion INR Intelligent Traffic Management System (ITMS) (Indian Express, 2019). In particular, this research should be used to identify the most congested routes (or segments of a route) where the system's assets would have the largest impact. Hence, we recommend policymakers conduct pilots of the ITMS at the identified chokepoints.

Given that increasing the road network in the short term is difficult, we suggest policymakers implement congestion pricing around Mumbai's CBDs. Successful implementation of such a policy can reduce congestion and improve traffic flows as seen in Singapore (Menon, 2017) and London (Litman, 2005).

Improvements in roads alone will not, in the long-term, result in easing congestion since private vehicles as a means of transport will continue to grow in number. More importantly, the large portion of residents that primarily walk to work will continue to suffer poor labour matching since the catchment area of firms where their diverse skills would best be utilized would remain small.

To allow workers easy access to the city's CBDs and a larger labour market, policymakers need to massively invest in affordable public transport options.

We recommend that policymakers look at successful implementations of such infrastructure investments in other cities across developing countries. They should conduct a comparative study of such cities to understand factors that resulted in successful implementation. Such an exercise would be extremely useful in designing large scale public transit networks across Mumbai.

Ultimately, we recommend rapidly improving public transit as it is perhaps the best long-term solution for lowering costs of congestion, easing mobility and in turn, improving the economic productivity of Mumbai.

# 8. Conclusion

By analysing selected routes between four residential areas and five CBDs, we showed that long commutes impose various economic and environmental costs to the citizens of Mumbai. Using data from Uber Movement and other sources, we developed a new methodology to quantify the economic as well as environmental costs imposed on Mumbai citizens.

Given that these routes are most commonly used to reach the CBDs, we can assume they are critical in ensuring the economic viability and productivity of Mumbai. Our analysis finds that these routes themselves are massively congested. Therefore, we infer that congestion and lack of ease of mobility in Mumbai is fragmenting the city's labour market and hampering overall economic productivity.

The estimated opportunity cost along the selected routes ranges between INR 27 and 55 and the average opportunity cost is estimated to be INR 42 per person. In other words, this is the average cost of time spent in traffic due to congestion. As mean wages rise, this figure increases.

Further, given the amount of additional carbon dioxide emitted, congestion could be causing health problems across the city.

To assist policymakers in eradicating such congestion, we identified specific chokepoints on these critical routes that should be addressed through granular interventions depending on existing infrastructure and traffic conditions at these bottlenecks. Improving mobility on such routes will be a key factor in ensuring productivity that, in turn, will aid the economic growth of Mumbai.

One limitation of this study is that due to the diverse causes of chokepoints such as narrow road widths, driving behaviour, poor infrastructure (such as malfunctioning traffic signals), etc., we cannot identify the precise factors that may be behind the chokepoints. Doing that would require further on-the-ground research. A second limitation is that the time period analysed (2016-2018) coincides with the period of construction of a new metro system in Mumbai; this could have led to travel times being skewed upwards. Third, all data collected and analysed was reported in terms of averages, from which further averages were calculated that could have possibly affected our findings. Fourth, this study does not analyse train journeys which are used by a large proportion of citizens to commute. Other modes of public transport such as buses and rickshaws are indirectly included to a certain extent. However, we do not estimate the additional time costs of waiting and access for such modes of on-road public transport. Lastly, we only calculate the economic costs faced by workers, not firms. Hence, the total economic productivity lost by the city would be higher.

This research can be further developed and used by academics as well as policymakers. Academics can apply a similar methodology to analyse other cities. Policymakers can use this research to address and remove chokepoints on major routes leading to improved economic productivity. Lastly, a cross-collaboration can be undertaken between academics and policymakers through this research where academics design granular interventions to eradicate chokepoints which can then be implemented by policymakers.

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# Appendices

The Appendices of this paper are online. They can be accessed at:
https://github.com/hvpachisia/Urban-Mobility

The names of each Appendix are outlined below:

**Appendix A:** Importance and historical evolution of Mumbai's Central Business Districts

**Appendix B:** Commutes between residential areas and CBDs

**Appendix C:** Route-level TTIs

**Appendix D:** Additional Fuel, Emissions

**Appendix E:** Speeds for each segment across all analysed routes

**Appendix F:** Final Scripts

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## About the Authors

Dr. Vasant Dhar is Visiting Senior Fellow at IDFC Institute. He is Professor at Stern School of Business and the Center for Data Science at New York University. His work addresses the following question: when should we trust autonomous machine learning-based AI systems with decisions? The major problem areas of his research and practice include finance, healthcare, education, business, sports, and transportation.

Harsh Vardhan Pachisia is Associate at IDFC Institute. His research focuses on projects related to urban governance, data empowerment and privacy. Prior to joining IDFC Institute, he worked as an Economics Teaching Fellow at the NYU Stern School of Business. Harsh has also been a Research Assistant to several NYU professors analysing topics such as 'Shadow Banking around the World' and 'Social Media Entrepreneurship'.

Dr. Vaidehi Tandel is Junior Fellow at IDFC Institute. Her research interests lie in the areas of new institutional economics, urban economics, urban planning and land governance, and political economy. She has worked on projects commissioned by the Lincoln Institute of Land Policy, World Bank, Ministry of Urban Development, Government of India, and Municipal Corporation of Greater Mumbai.

Kadambari Shah is Senior Associate at IDFC Institute. Her research focuses on ease of doing business in India, special governance zones, and urban governance. At St. Xavier's College, Mumbai, she was on the editorial board of several scholarly journals and has presented research papers on development issues ranging from the middle-income trap to the role of race and gender in electoral politics.

Girish Gupta is Head of Data Science at IDFC Institute. Previously, he was a foreign correspondent based in Venezuela where he produced ground-breaking investigations, covered daily clashes and reported on an unprecedented economic, social and humanitarian crisis. He wrote widely-used web and mobile apps to provide live and historic data on the country's economy. He later expanded the software into a global platform, Data Drum. He also worked across Latin America and the Middle East.

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