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ROAD TRANSPORT PERFORMANCE IN INDIA

Mert Kompil, Jingyu Gao, Yue Li, Abhinav Narayanan and **Jiaqi Su***

Abstract

Countries aim to develop and maintain efficient transport infrastructure to connect regions and make settlements accessible. Obviously, an area that is better connected and more accessible has higher potential to reach social and economic activities, and is more likely to participate in global value chains. This study measures road transport performance in India using a transport assessment framework recently implemented in European Union countries. It is the first time the framework is applied to an Asian country at a fine spatial granularity. The study finds that performance varies considerably across major Indian states. Mumbai and Delhi metropolitan areas are on par with European cities, but the majority of the subdistricts are far behind. It also shows that urban areas of some states underperform rural areas of other states, which differs from the pattern in Europe and contradicts conventional wisdom. Finally, the study also applies the framework to simulate the impact of the Gujarat Rural Roads project and the potential effects of connecting the planned Dholera (Gujarat) airport through different road investment projects.

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* Mert Kompil: Consultant, AIIB. Email: consultant.m.kompil@aiib.org (corresponding author 1)
Jingyu Gao: Economic Associate, AIIB. Email: jingyu.gao@aiib.org (corresponding author 2)
Yue Li: Senior Economist, AIIB. Email: yue.li@aiib.org
Abhinav Narayanan: Economist, AIIB. Email: abhinav.narayanan@aiib.org
Jiaqi Su: Economic Analyst. Email: jiaqi.su@aiib.org

1. Introduction

Asia is home to some of the most dynamic manufacturing hubs in the world. Economic growth in Asian economies has long been benefited from increasingly integrated regional and global trade. Even during the peak of the COVID-19 pandemic, trade in Asian economies remained robust. Much of this resilience comes from well-functioning transport networks that ensure timely delivery of goods and services. However, there are still considerable gaps in transport connectivity. Promoting connectivity within borders, across Asia and between Asia and the global economy, is thus a key strategic focus for AIIB. Since 2016, AIIB has been involved in 30 transport projects, including road, railway and metro infrastructure.[1] Given this context, it is important to understand the status of transport networks in Asian countries and to identify gaps in connectivity.

This study aims to measure road transport performance in India using a framework first developed and implemented in European Union member countries (Dijkstra et al., 2019; European Commission, 2022). This framework is highly suitable for measuring how a specific area is connected and accessible based on a transportation network. One of its key advantages is spatial granularity. By first using one-kilometer (km) X one-km grids/cells as the basic units of measurement, it can then be used to compare transport connectivity performance at different levels of spatial aggregations, from villages/towns up to provinces and to countries, thereby reducing any aggregation bias. It also captures the quality of connectivity, beyond measuring the length of roads built, but by essentially benchmarking performance based on the population (number of people) that can be reached with and without a road network.

The framework consists of three main elements: 1) proximity as the number of people within a 120 km radius that can be potentially reached; 2) accessibility as the number of people reached within a 90 minutes' drive by car using the current road transport network and 3) road transport performance as the ratio between accessibility and proximity, providing information on the quality of the current road transport network.

This study measures road transport connectivity from the fine spatial granularity described above and applies the concept to various spatial levels in India. Two main data sources are used, including gridded population and a comprehensive, detailed road network.

The study finds that the overall road transport performance of India is around 28 percent, with an average accessibility of 7.4 million people and average proximity of 26.9 million people. It indicates that, on average, 7.4 million people can be reached by road using the current transport network, whereas 26.9 million can potentially be reached if the benchmarking speed can be obtained. There are considerable variations geographically. The study shows that Mumbai and Delhi metropolitan areas are on par with European cities, but most of the subdistricts are far behind. Urban areas appear to outperform rural areas on average (35 percent versus 19 percent). However, it also shows that urban areas of some states

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[1] AIIB. Connectivity and Regional Cooperation. https://www.aiib.org/en/about-aiib/who-we-are/infrastructure-for-tomorrow/connectivity-and-regional-cooperation/index.html; AIIB. Project Summary. https://www.aiib.org/en/projects/summary/index.html (accessed in January 2023).

underperform rural areas of other states, which differs from the pattern in Europe and contradicts conventional wisdom.

This study also conducted two simulations applying the same framework. The first simulation evaluates how road infrastructure investments will affect the connectivity indicators for a proposed airport in Gujarat, India. The second simulation assesses the potential impact on accessibility of a completed project in Gujarat that constructed rural roads in selected small villages.

2. Data

2.1. Gridded Population

Geospatial data on population, and artificial and natural environment play an important role in regional research and policy making. Lately, many nonprofit organizations as well as the commercial companies have developed global, geo-referenced data with high spatial resolution (Lloyd et al., 2017). With improved technological capabilities, more studies use these data sources for spatial analysis and decision-making. This makes it crucial to evaluate and better understand quality, interoperability, validity and use of each population database. Recent scientific papers compared and evaluated different global gridded population data sources. Four of these papers are reviewed in Table 1, which at the same time can be seen as basis for a preliminary evaluation for the gridded population data for India and Asian countries, in general.

Table 1: Summary of Studies on Gridded Population - Data Comparison

Name and year	Purpose	Input data	Benchmark data and year	Study area	Unit of analysis	Outcomes	Other notes
Xu et al., 2021	Evaluating performance of gridded population data in China.	GPW4, GHS LandScan and WorldPop.	Statistical data from 2015	Southwest China	1 square kilometer (km^2); other adm. levels	GHS and WorldPop have had high accuracies.	Google Earth high-resolution images used for an additional comparison of gridded data.
Fries et al., 2021	Comparing population data accuracy for public health studies.	LandScan, WorldPop and HRSL	Census data from 2018	Equatorial Guinea	1 km^2	LandScan performs well in urban areas; HRSL is better in rural areas.	WorldPop is significantly underperforming in this area.
Archila Bustos et al., 2020	Evaluates five of the most-used global gridded population datasets in Sweden.	GPW, GHS-POP, GRUMP, LandScan and WorldPop	Historical data (1990 to 2015); 100-meter resol. from the statistical office.	Sweden	1 km^2	GHS-POP, LandScan and WorldPop were able to estimate the known population more accurately.	None of them performs best under all situations; the study provides a comprehensive comparison.
Galdo et al., 2019	Proposes methods to identify urban areas; compare population for identifying urban areas.	GHSL, LandScan and WorldPop	Census data from 2011	India	1 km^2; other adm. levels	WorldPop underestimates and GHSL overestimates urban pop. in India; least error with LandScan.	GHSL defined urban cores are very similar to the predicted 'urban areas' in the study.

Source: Author's own elaboration

Considering the studies summarized in Table 1, the GHSL (GHS-POP), WorldPop and LandScan population grids are able to estimate known populations and, hence, are suitable for transportation and accessibility analysis. None of the datasets are perfect under all circumstances (e.g., GHSL overestimates populated cells, but have higher accuracy together with the unpopulated areas; WorldPop is not very good at estimating unpopulated cells; it has, on the other hand, higher accuracy to estimate sparsely populated cells), but they satisfy a certain level accuracy in most cases. Apart from this, GHSL and WorldPop datasets are open and publicly available at desired fine spatial resolution and year; LandScan, on the other hand, is commercial and more difficult to achieve or acquire. Therefore, in the rest of the evaluation of population data sources, focus has been given to GHSL and WorldPop data sources (Table 2) while comparing them with census data in India.

Table 2: Description of Gridded Population Dataset for India

GHS-POP - Global Human Settlement Layer (GHSL) Population Data

- Product: GHS-POP, epoch: 2015, resolution: 1 km by 1km, coordinate system: Mollweide.
- Landing page: https://ghslsys.jrc.ec.europa.eu/ghs_pop2019.php
- Download link: https://cidportal.jrc.ec.europa.eu/ftp/jrc-opendata/GHSL/GHS_POP_MT_GLOBE_R2019A/GHS_POP_E2015_GLOBE_R2019A_54009_1K/V1-0/GHS_POP_E2015_GLOBE_R2019A_54009_1K_V1_0.zip
- Download Coverage: Global
- Reference document: https://ghslsys.jrc.ec.europa.eu/documents/GHSL_Data_Package_2019.pdf?t=1478q532234372

WorldPop population counts for India – constrained and UNDP adjusted[2]

- Product: WorldPop - India, epoch: 2020, resolution: 100 m by 100 m, coordinate system: WGS84.
- Landing page: https://www.worldpop.org/geodata/summary?id=49992
- Download link: https://data.worldpop.org/GIS/Population/Global_2000_2020_Constrained/2020/BSGM/IND/ind_ppp_2020_UNadj_constrained.tif
- Download Coverage: India (other countries also available for download)
- Reference document: https://hub.worldpop.org/geodata/summary?id=49992

Detailed results of gridded population data comparisons in India through descriptive statistics, correlation analysis and census-based analysis are given in Appendix A with tables and figures. The main findings from these comparisons are summarized as follows:

- Considering the populated cells, GHS-POP distributes population to a smaller number of cells. Hence, represented with the cells with higher population – concentrated.
- WorldPop, on the contrary, has a higher number of populated cells. Hence, represented with the cells with lesser population – dispersed.
- When aggregated to lower spatial resolutions, the two datasets converge into each other. The populated cells of the two datasets have a positive moderate correlation rate at 0,50. This rate goes up to 0,81 and 0,89 when the rasters are aggregated from one km^2 to five km^2 and 10 km^2, respectively.

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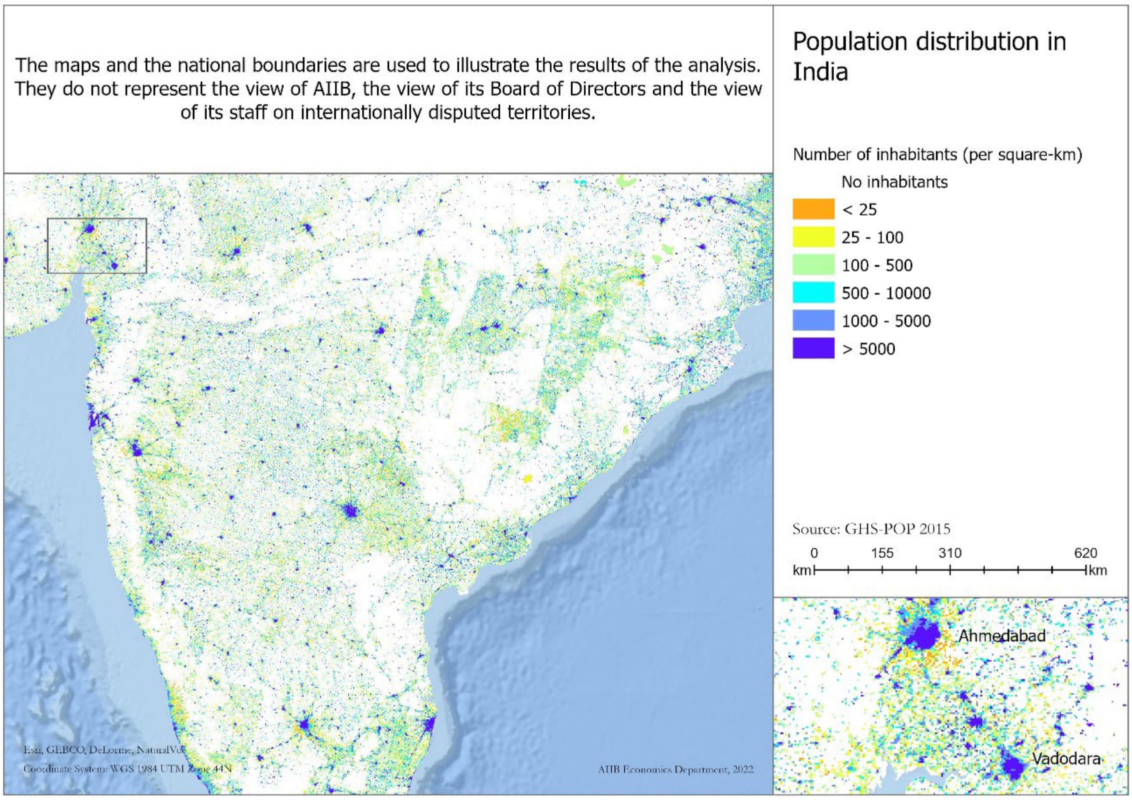
[2] The WorldPop population grid has been aggregated to one square kilometer (km^2) and snapped to GHSL one km^2 population grid for comparability and consistency.

- According to a comparison at district level (in 588 districts), both population datasets are highly correlated (90 percent) with the census-based population in India. Apart from this, the two datasets are almost identical at district-level aggregation with over 99 percent correlation between each other.

In conclusion, population distribution and human activities, together with transport infrastructure and means, are the most important variables for transport and accessibility modeling. Therefore, it is crucial to evaluate beforehand the quality, interoperability and usability of available gridded population data. This study focused on the two population datasets in India – GHS-POP 2015 and WorldPop 2020 – and applied some comparative analyses. The results indicate that both datasets are able to estimate known population distributions successfully and can be used for transport policy analysis and/or accessibility modeling.

It is more likely that resulting accessibility indicators from these datasets will be highly correlated especially at the regional level because the two datasets converge into each other when they are aggregated from one km^2 to five km^2 or 10 km^2. However, using a population grid at lower spatial resolution would be problematic in terms of spatial modeling, including accessibility: 1) existing heterogonous/detailed spatial information is generalized, which, at the end, causes losing information, and 2) for small administrative areas and for border areas, aggregation of values might be biased because of possible misplacement and misrepresentation during aggregation of values. On the other hand, the higher the spatial resolution, the more computation time is needed. At this stage, although GHS-POP data is available at 250 square meters (m^2) and WorldPop is available at 100 m^2 grids, it is more suitable to compute accessibility indicators at one km^2 – for a good balance of accuracy and computation time. Another important issue is related to the number of cells in population rasters – GHS-POP has a more concentrated population structure with a smaller total number of populated cells. This creates less computational difficulty for cell-based accessibility or road transport performance calculations, particularly in large countries like India. Because of this, GHS-POP 2015 has been selected and used as the population grid in this study as shown in Figure 1.

Figure 1: Population Distribution in India, Based on GHS-POP 2015



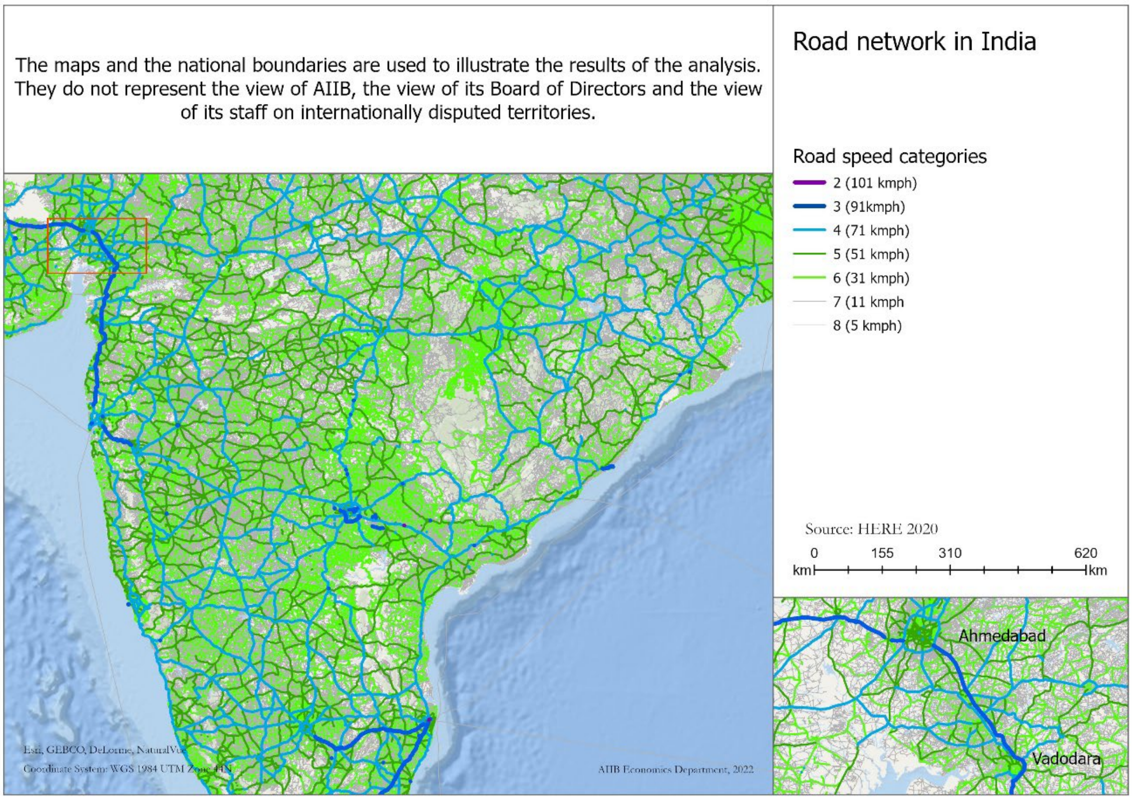
Source: Author's own elaboration

2.2. Road Transportation Network

Computing road transport performance indicators requires a connected and navigable road network data that is suitable for calculating service areas via route calculations and shortest-path algorithms. The level of geographical coverage is the first prerequisite of a good road network data – e.g., all streets, roads and intersections, even the new ones, are included in the dataset. The higher the accuracy of its coverage, the better the road network data for geospatial analysis. A second important element of a navigable road network data comes from its features for road links, such as road hierarchy, elevation, restrictions, directions, turns, signs, speed category and speed. These road link features convert a set of spatially referenced polylines into a connected and navigable road network, and enables modelers to estimate real-life travel patterns of vehicles and passengers on streets via reliable measurements of travel routes, distance, time, etc.

In the case of India, a commercial navigable road network data from HERE Technologies (HERE) has been acquired and technically evaluated for the year 2020. The results of this evaluation indicate that the coverage of the road links, together with their corresponding features and information, have high quality standards and suitable for transport and accessibility related modeling and geospatial analysis in India.[3] The road network data from HERE has been built using ArcGIS Pro Network Analyst (Figure 2). Travel times on each road link have been calculated based on the lower boundary values of the speed category information already provided in the dataset, e.g., 91 kilometers per hour (kph) for speed category 3 and 71 kph for speed category 4 road links. Details on the technical evaluation for HERE road network data in India is given in Appendix B, along with other explanations, assumptions and parameter choices of the network-building process.

Figure 2: Road Network in India, Based on HERE Technologies 2020 Data



The maps and the national boundaries are used to illustrate the results of the analysis. They do not represent the view of AIIB, the view of its Board of Directors and the view of its staff on internationally disputed territories.

Source: Author's own elaboration

According to the Ministry of Road Transport and Highways (2021, p.7), India has the second-largest road network in the world, with about 6,216,000 km in 2020-2021. This comprises national highways and expressways (136,440 km), state highways and major district roads (176 818) and finally other district roads and village roads (5,902,539 km). This is approximately similar to HERE road network data in 2020 at 6,063,523 km in 2020. As shown in Table 3, about 85 percent of the roads in India are under speed category 7, or with lower speed and usually residential and rural characteristics. Roads with speed above 50 kph and where the majority of passenger and vehicle traffic occurs constitute only a small portion, around 3.6 percent, of all road infrastructure.

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[3] OpenStreetMap (OSM) also provides a free network data suitable for routing and navigation. It is a good option where commercial data is not available. It works fine in most of the cases for transport analysis; however, its coverage might be limited and could be missing links and information, particularly in rural areas. After an initial check and evaluation, and considering its detailed geographical coverage and road link features, the option of a commercial dataset has been evaluated as a more proper option for this study.

Table 3: Descriptive Statistics on Road Network Data in India, HERE Technologies 2020

Speed Category	Number of road links	Total Length (km)	Share of total length (%)	Free-flow speed assigned (lower boundary value)
1	-	-	-	130
2	84	9.4	0.0	101
3	30 232	4 701	0.1	91
4	619 891	84 316	1.4	71
5	987 601	124 334	2.1	51
6	3 107 540	517 530	8.5	31
7	29 473 157	5 185 651	85.5	11
8	764 262	146 979	2.4	5
Total	34 982 767	6 063 523	100.0	-

Source: Author's own elaboration

3. Methodology

Accessibility is an indicator of two main components – the effectiveness of transport systems and the spatial distribution of activities or places. Accessibility of a place could be high either because of its size and density of activities, or because of its well-connected and developed transportation system. To distinguish between these two components, the European Commission (EC) and the International Transport Forum have developed a methodological framework based on three elements – proximity, accessibility and road transport performance indicators (Dijkstra et al., 2019; EC, 2022).

Proximity refers to the number of people within a 120 km radius (buffer), e.g., number of nearby people that can be reached "potentially or ideally." Accessibility refers to the number of people that can be reached within 90 minutes by car, or the number of people that can be 'actually' reached with a road transport network measured via service areas. Finally, road transport performance refers to the ratio between accessibility and proximity measured for a specific area (e.g., the ratio between the service area and the buffer shown for a populated cell in Figure 3). It is a kind of measurement that provides information on the quality (e.g., density, connectivity and average speed) of the transport network, while comparing real-life conditions of a specific area with its potential.

$$\text{Proximity}_\text{i} = \text{Number of people living within a 120 km radius}$$

$$\text{Accesibility}_\text{i} = \text{Number of people that can be reached within 90 minutes drive time}$$

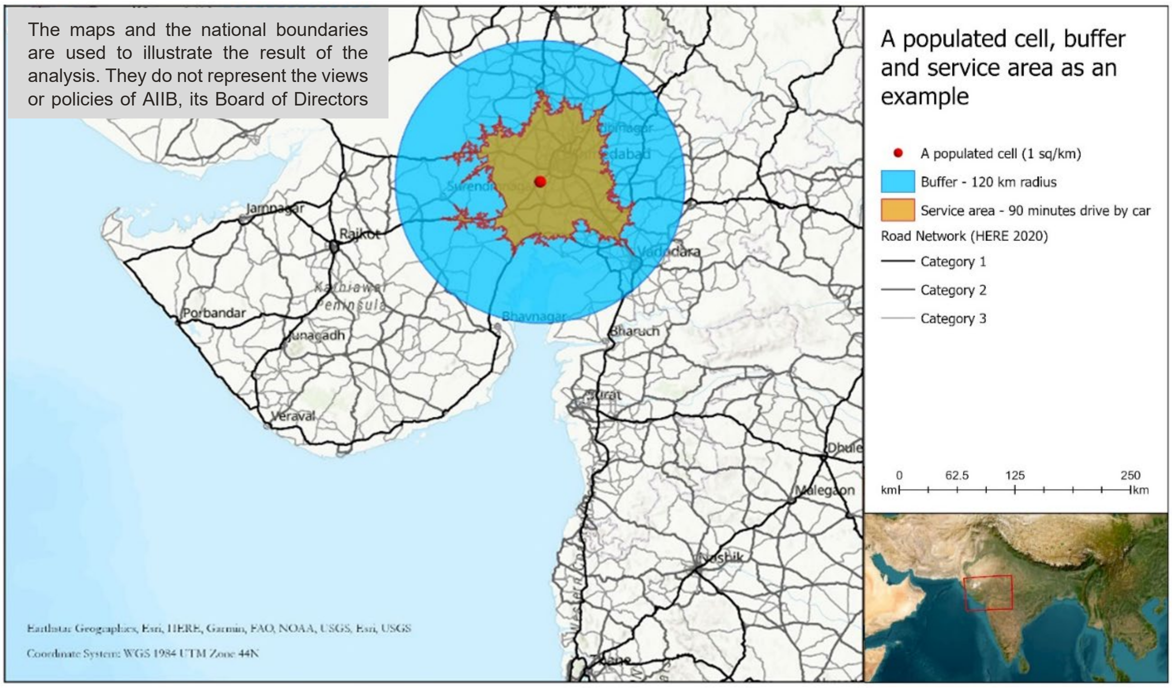
$$\text{Road Transport Performance}_\text{i} = \left(\frac{\text{Accesibility}_\text{i}}{\text{Proximity}_\text{i}} * 100\right), \text{i refers to the population grid cell i}$$

This framework is highly suitable to measuring how connected and accessible a specific area is based on population distribution and existing transportation network or infrastructure. Instead of the number of people that are accessible, it is possible to use other indicators such as the number of commercial activities or number of jobs. It is also possible to measure the performance of rail transport (by train) similar to road transport (by car).

A road transport performance value that is 100 or more than 100, means that the performance of this area is high; if it is close to zero, this means that the performance of this area is low, i.e., its potentially accessible (nearby) destinations cannot be accessed with a proper transport infrastructure. This concept is part of a set of counter-based accessibility measurements (Curtis and Scheurer, 2010), and at the same time carries thematic similarity with an accessibility indicator called "network efficiency" (López et al., 2008), which compares a situation measured with an ideal travel impedance versus a real one and tries to model transport infrastructure performance based on the ratio between them.

It is worth mentioning that good accessibility is a positive outcome of integrated land use and transportation systems. Proximity and connectivity are the two main components of accessibility. Accessibility is usually high where proximity of destinations and transport network connectivity occurs at the same time. This concept does not provide information only on the proximity of destinations and accessibility of an area, it also informs on the transport connectivity. Connectivity here can be seen as a prerequisite for being accessible, and good connectivity as having higher accessibility. "Non-connected" people or non-reachable destinations (with a transportation network) are not considered in the road transport performance indicator. On the contrary, areas that are well connected with a dense high-speed network, e.g., areas close to a city, are more likely to achieve beyond their potential within the determined time thresholds.

Figure 3: An Illustration of the Computation of Proximity and Accessibility



The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors

Source: Author's own elaboration

This study applies the proposed framework for the first time to an Asian country at a fine spatial granularity and makes comparative analyses for India aggregated per region and per degree of urbanization (as demonstrated in the next section). Overall, the main limitation of this framework may come from 1) arbitrary choice of travel time thresholds; 2) its assumption of all activities/destinations as being equally important; 3) not considering congested roads or infrastructure and 4) being single-mode specific or not multimodal, at least for this specific implementation.

Apart from this, some important quality aspects of a transport system such as pricing, comfort and safety are not considered with this concept, where accessibility and connectivity are given higher priority to measure. On the other hand, there are some certain strengths of this framework: 1) easy to compute and communicate, which does not require a transport model; 2) does not require a sophisticated dataset where main inputs are usually available publicly at global scale – a population grid and a road network; 3) it produces results at fine spatial resolution which can be then aggregated any spatial level, hence, not biased by non-homogenous settlement size.

4. Road Transport Performance in India

The described methodology to measure connectivity and accessibility was applied in India based on the GHSL population data in 2015 and HERE road network data in 2020 at one km^2 spatial resolution. Each one-km grid cell representing a populated area has become a unit of analysis in computing the proximity, accessibility and road transport performance indicators. There are more than 800,000 populated cells in India, which yields the same number of measurements to get the results for each indicator. Results on India-wide proximity measurements are presented in Figure 4, where the north and northeast India (e.g., Delhi, Uttar Pradesh, Bihar, West Bengal) has the highest proximity values (40 million to 75 million people on average) with highly populated, dense cities and regions. High proximity values in these regions also suggest high potential for transport accessibility in these areas in India. On the other hand, not surprisingly, low proximity values are concentrated in remote and mountainous states, such as Chattisgarh, northwest Rajasthan and other smaller states in northeast India. For these states, low proximity values suggest that even if the local transport network would perform well, the maximum number of people accessible in those places would be limited, due to geographical conditions or simply scarce population distribution.

The results for the accessibility indicator are presented in Figure 5. Overall, geographical distribution of accessibility indicator appears to be significantly different from the proximity indicator. Higher accessibility values suggest more people can be reached within 90 minutes' drive by car through the transport network from the origin population grid. In India, as expected, areas with high accessibility are more concentrated in metropolitan areas such as Delhi, Kolkata and Mumbai, where its value reaches more than 40 million people on average.

The distribution of accessibility in India is not entirely associated with the population distribution, but also with transportation infrastructure quality and connectivity. For example, Uttar Pradesh's accessibility is only about 10 million people, whereas the state has the biggest population in India (217 million) and ranks third in terms of population density. The gap between population distribution and accessibility values reveals that the transport efficiency in Utter Pradesh might be lower than other states. In contrast, Gujarat has an average accessibility of 7 million people, the third highest among all states in India, but it has a moderate population density compared to other states. Comparatively, transport efficiency in Gujarat appears to be better than in Uttar Pradesh.

Figure 4: Proximity Indicator in India

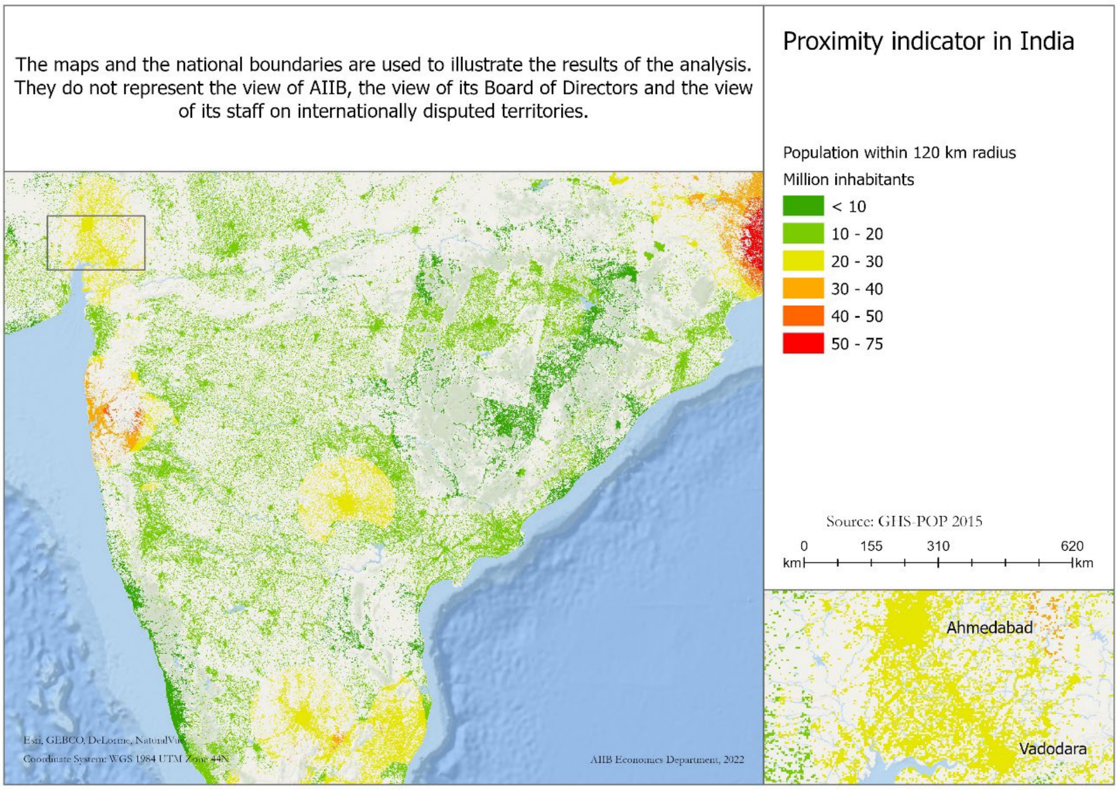


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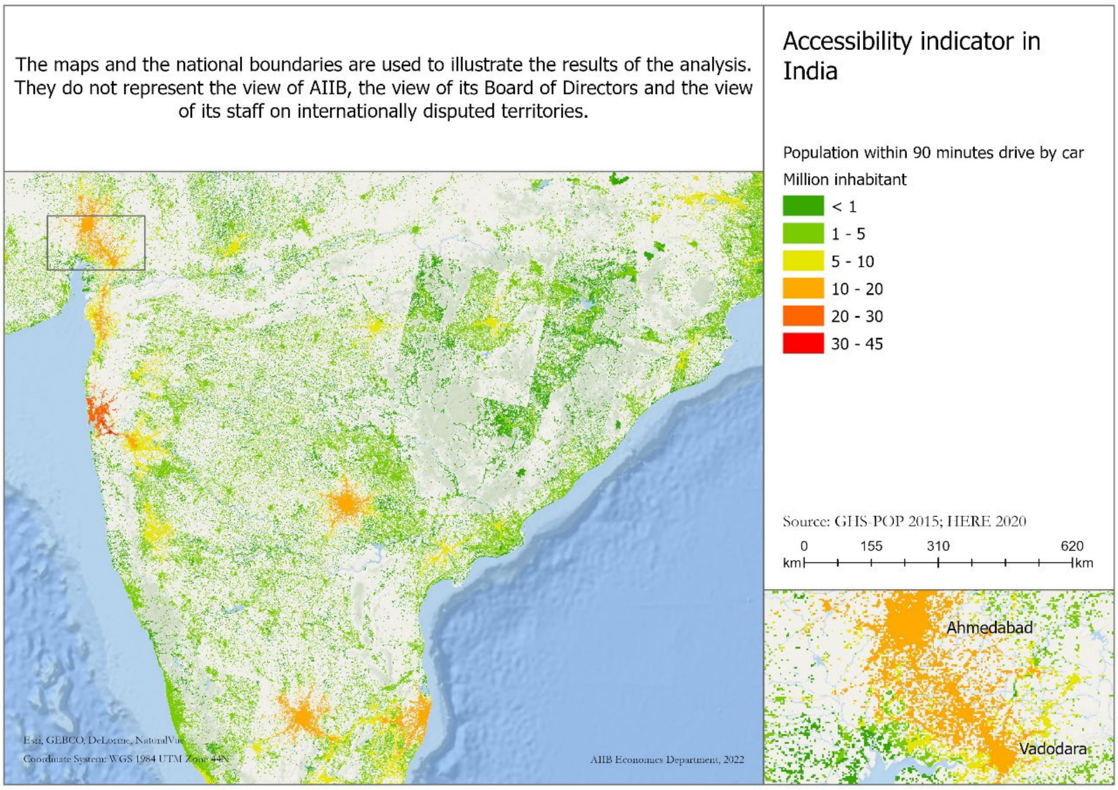
Figure 5: Accessibility Indicator in India



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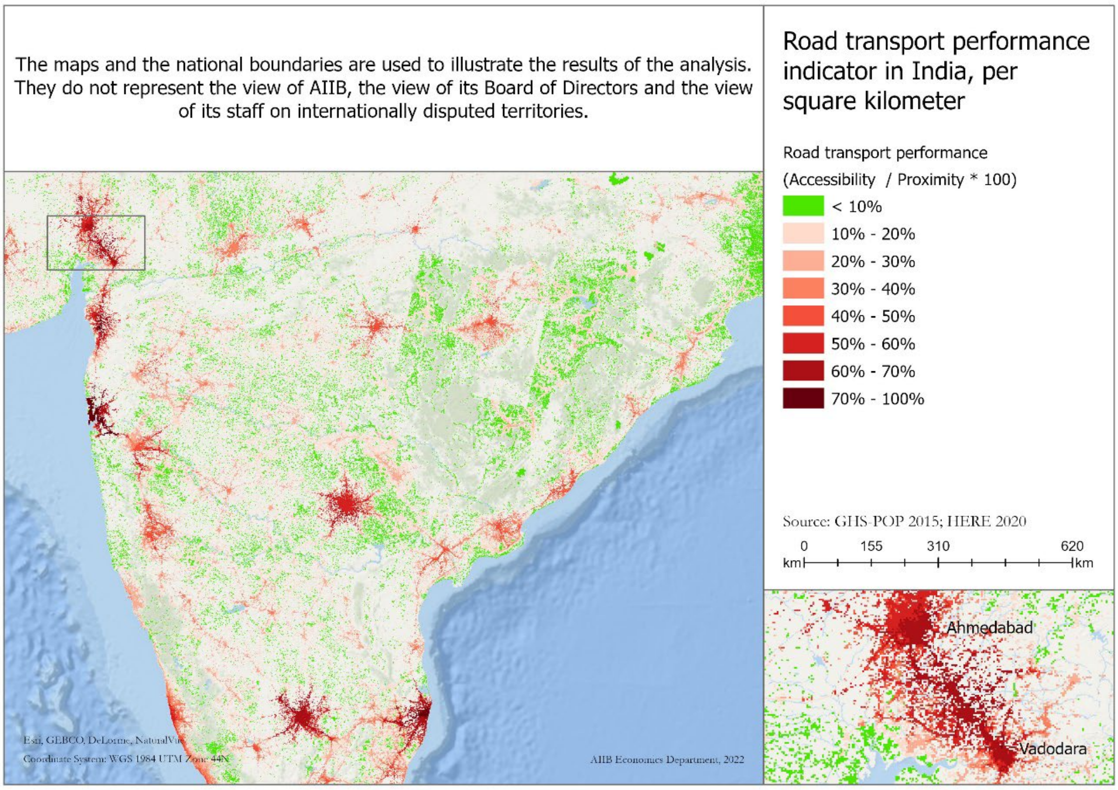
Source: Author's own elaboration

The ratio of accessibility over proximity yields the road transport performance indicator for India, as illustrated in Figure 6. Places with the highest road transport performance are mainly the well-known metropolitan areas – New Delhi, Ahmedabad, Surat, Mumbai, Bengaluru, Hyderabad and Chennai – where the transport infrastructure and connectivity are developed the most in India. These are also relatively more developed urban areas with a dense road network. The population- weighted road transport performance indicator value for entire India is 27%. As indicated in Table 4, Delhi, Maharastra, Gujarat, Haryana and Karnataka are the best-performing states in terms of road transport performance indicator with a value of above 37%. On the other hand, Odisha, Assam, Jharkhand, Madyha Pradesh have the lowest road transport performance with values ranging from 13 percent to 19 percent. When the same indicator is aggregated per administrative level 3, which in some countries is equal to municipalities or districts, Mumbai city center and Mumbai suburban areas have the highest road transport performance in India with around an average indicator value of 80 percent and above (Figures 7 and 8). With this value, road transport performance in Mumbai is equal to the European average (urban and rural combined) indicated in a recent study by the European Commission (EC, 2022, pp. 117).

The north and northeast parts of India, where there is a huge potential in terms of highly populated and dense areas, do not have good road transport performance as expected. This is a sign of relatively inadequate or less-developed transport infrastructure in these areas. Apart from this, sparsely populated and rural areas usually have lower road transport performance compared to urban areas. A sparsely populated area usually requires more road infrastructure to provide access to certain number of places or destinations. Areas where such requirement cannot be provided because of high economical costs have usually lower road transport performance in India.

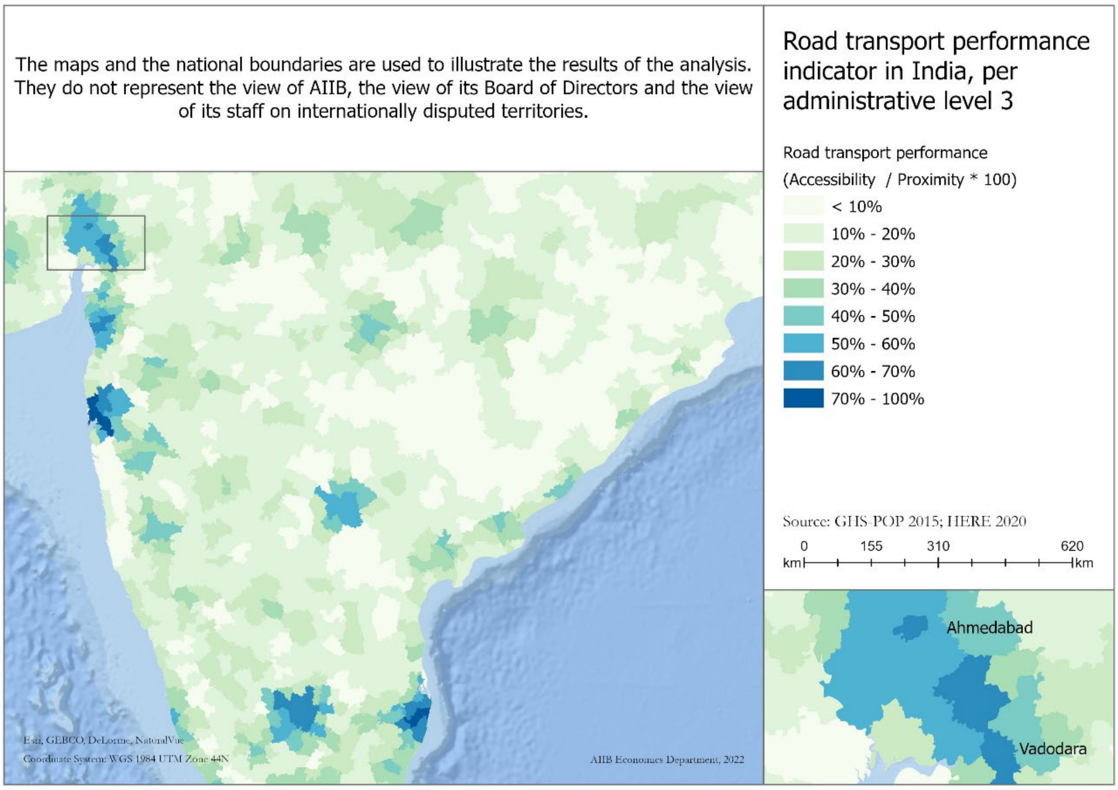
The India-wide results on each indicator are given in Table 5 which are aggregated per degree of urbanization (for a description, see Dijkstra and Poelman, 2014). Figure 9 additionally gives results for selected states and per degree of urbanization. In India, a person living in a rural area can reach almost 23 million people within a 120 km radius; this number becomes 29 million people for a dweller located in a city. When a transport network is taken into consideration, a person living in a rural area can reach 4.2 million people on average within 90 minutes travel time by car; it is almost double (10.3 million people) for a person living in a city. The difference between the two – proximity and accessibility – points to a difference between transport infrastructure quality and connectivity. Unfortunately, transport network quality and connectivity are not equally developed in rural areas, unlike in cities. This is clearer with the road transport performance indicator, which follows the pattern of accessibility, with values averaging 18.2 percent in rural areas and 34.8 percent in cities (Table 5).

Figure 6: Road Transport Performance Indicator in India, per Square Kilometer



Source: Author's own elaboration

Figure 7: Road Transport Performance Indicator in India, per Administrative Level 3



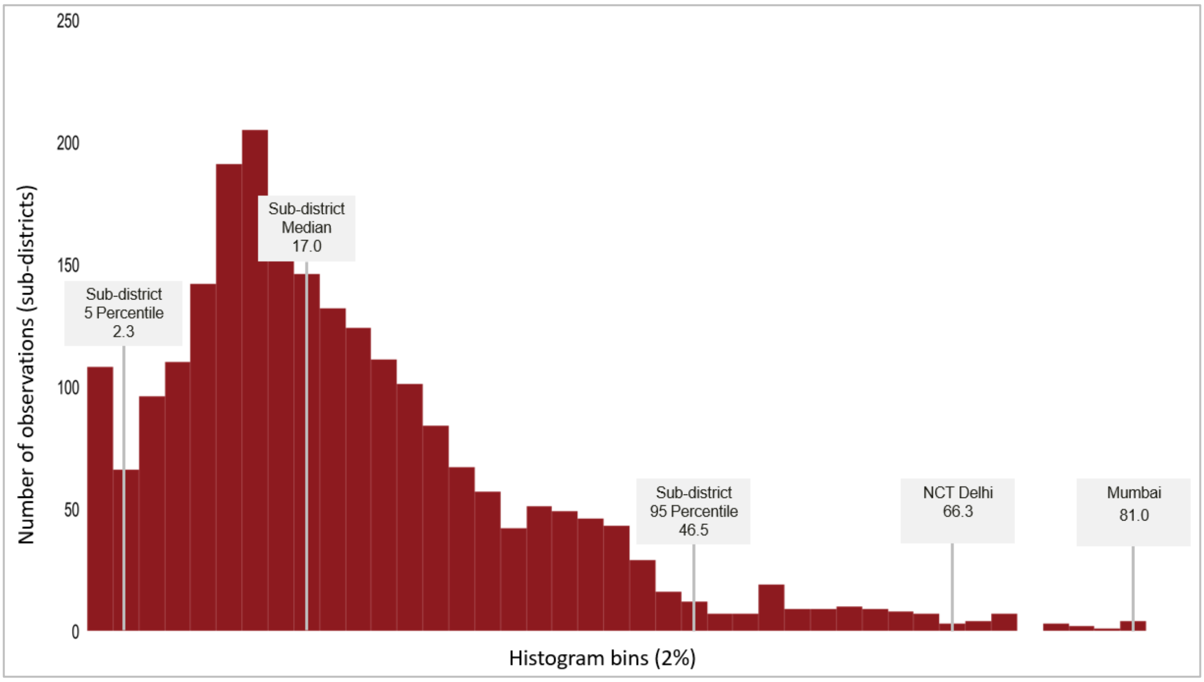
Source: Author's own elaboration

Table 4: Proximity, Accessibility and Road Transport Performance Indicators for Selected Populated States in India

India (Most populated states)	Population (milllion inhabitant)	Population density (people/km^2)	Proximity (million inhabitant)	Accessibility (million inhabitant)	Road Transport Perform. (Accessibility/Proximity*100)
NCT of Delhi	18	12059	61	41	66
Maharashtra	121	392	20	8	41
Gujarat	66	350	18	7	40
Haryana	28	625	43	17	39
Karnataka	65	339	17	6	37
Tamil Nadu	76	586	21	8	36
Kerala	33	874	19	7	36
Punjab	30	595	22	7	31
Telangana	38	328	17	5	29
Uttar Pradesh	217	902	42	10	25
West Bengal	98	1132	41	10	25
Andhra Pradesh	52	324	13	3	22
Bihar	117	1231	50	10	20
Rajasthan	76	220	15	3	20
Chhattisgarh	28	204	12	2	20
Madhya Pradesh	78	253	14	2	18
Jharkhand	37	454	26	4	16
Assam	35	426	12	2	15
Odisha	45	290	13	2	13
India (All)	1311	412	26.9	7.4	27.5

Source: Author's own elaboration

Figure 8: Distribution of Subdistrict Road Transport Performance Divided in 50 Equal-Width Bins



Source: Author's own elaboration

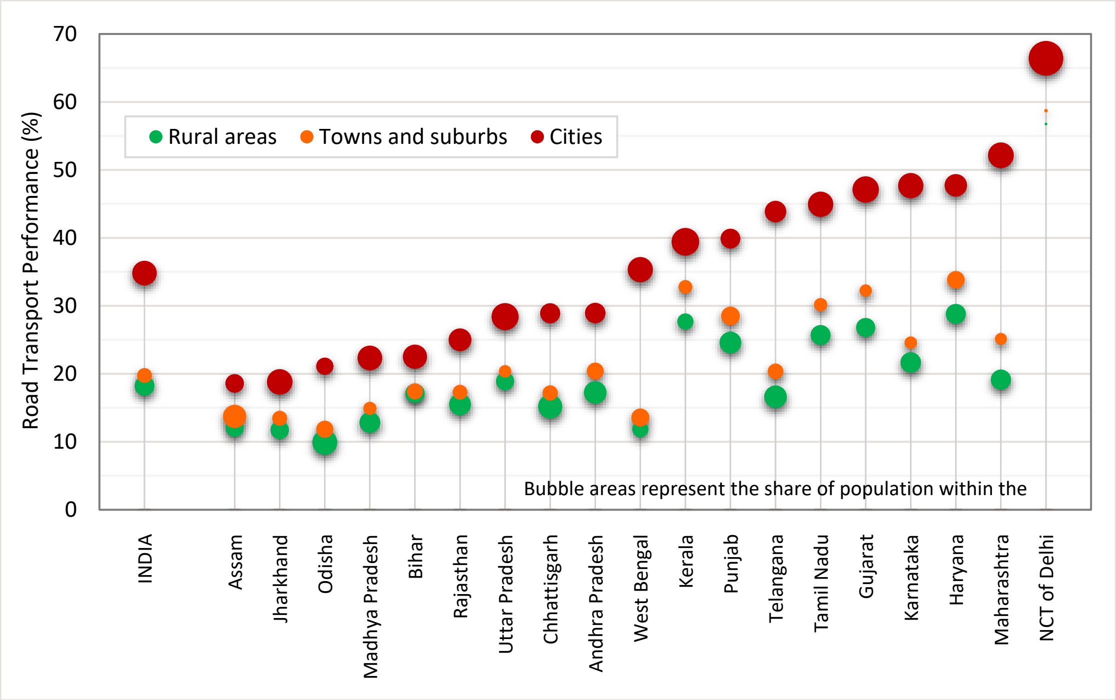
Table 5: Proximity, Accessibility and Road Transport Performance Indicators, per Degree of Urbanization in India

Degree of urbanisation lvl II	Population Share (%)	Proximity (million inhabitant)	Accessibility (million inhabitant)	Road Transport Perform. (Accessibility/Proximity*100)
Mostly uninhabited areas	11	24.3	4.2	17.2
Dispersed rural areas	6	21.2	4.3	20.2
Villages	16	23.5	4.3	18.2
Suburbs	3	24.3	5.8	24.0
Towns	15	26.1	4.9	18.9
Cities	49	29.7	10.3	34.8

Degree of urbanisation lvl I	Population Share (%)	Proximity (million inhabitant)	Accessibility (million inhabitant)	Road Transport Perform. (Accessibility/Proximity*100)
Rural areas	32	23.3	4.2	18.2
Towns and suburbs	18	25.8	5.1	19.7
Cities	49	29.7	10.3	34.8
India (All)		26.9	7.4	27.5

Source: Author's own elaboration

Figure 9: Road Transport Performance Indicator in India, per State and Degree of Urbanization



Source: Author's own elaboration

In EU countries, road transport performance indicator value is 80 percent on average. It is more than 80 percent in most of the EU cities - cities in France, Germany, Finland, the Netherlands and Belgium have a value of more than 100 percent with dense and well-connected road infrastructure. By country, the average is the highest in Belgium and the Netherlands at nearly 100 percent. The lowest average value at country level is seen in Romania, Slovakia and Bulgaria, ranging from 40 percent to 60 percent (EC, 2022, pp. 117). European values are still above the values computed in India (on average 27 percent). In terms of road transport performance indicator values, the metropolitan areas compare equally with European countries. With densely populated spatial structure and relatively well-connected network configuration – Mumbai city center and suburban areas are among those areas which perform relatively high with an average road transport performance value of 80 percent. Chennai, Surat, Bangalore, Delhi and Ahmadabad metropolitan areas also have high road transport performance as these have among the well-connected, quality road transportation infrastructure in India.

5. Project Simulation Studies

5.1. Planned Dholera Airport

Air transport and airports play an important role in terms of connectivity and accessibility of a region. A well-connected and fully functioning international airport contributes to the development of a region and is seen as crucial for several economic sectors such as tourism, industry and logistics. This study analyzes the connectivity and accessibility of a planned airport in India using the already applied proximity, accessibility and road transport performance indicators. The analysis aims to show another potential use of the developed indicators for policy analysis while exploring and evaluating existing infrastructure components of a planned airport with likely development directions.[4]

Gujarat, as one of the growth engines of India, hosts many major industries comprising large numbers of small and medium-sized enterprises as well as multinational companies. The Dholera Special Investment Region (DSIR) is among priority special economic zones being developed by the Government of Gujarat. DSIR will be the global hub for economic activities in Gujarat. To serve the logistics and cargo need of DSIR, the Government of Gujarat is planning to set up an international airport in Navagam village of Taluka Dholera. Besides handling the logistics requirement of DSIR, the proposed Dholera International Airport will handle the spillover traffic from Ahmedabad International Airport (Dholera International Airport Company Limited, 2022).

According to the consortium that deals with the project, the airport will have the following main features (Dholera International Airport Company Limited, 2022):

- *The airport is strategically located among the big cities of states like Ahmedabad, Rajkot, Vadodara, Anand, among others (Figure 10).*
- *Around 1,426 hectares of government land has been reserved for the airport at Navagam Village.*

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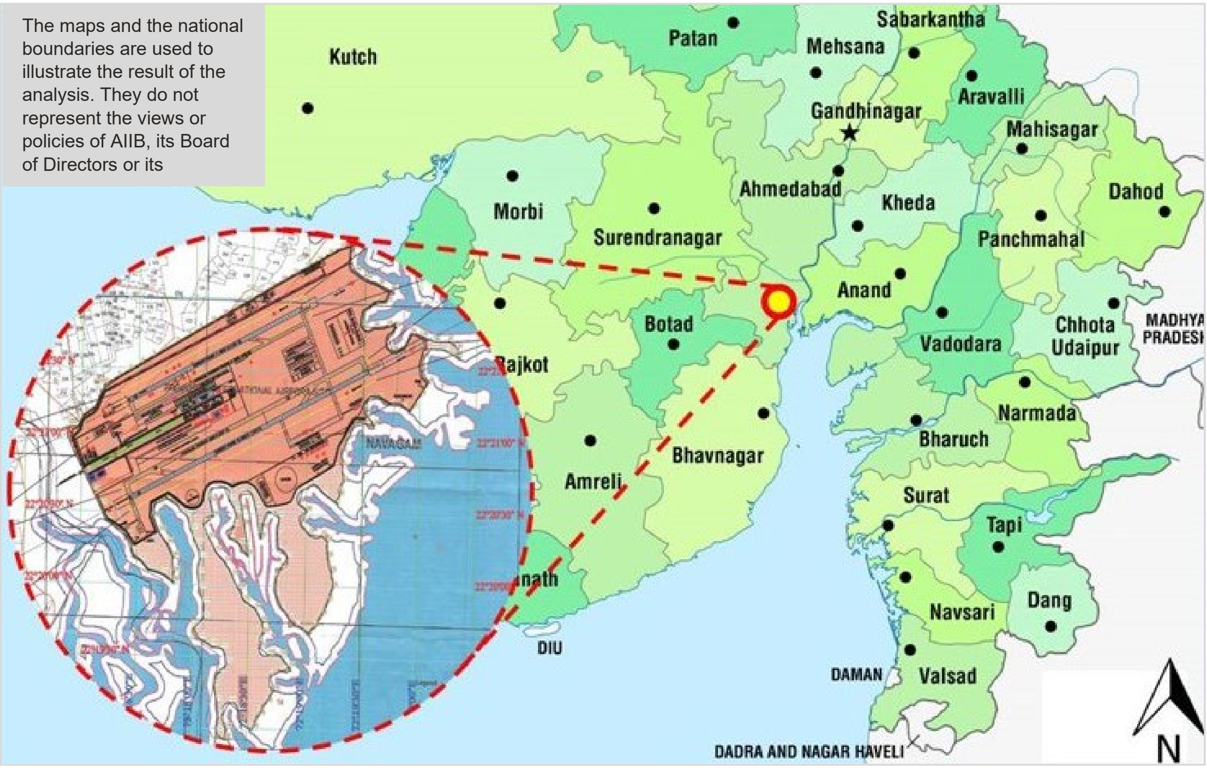
[4] Airport accessibility has been given high importance and studied many times in terms of catchment areas and travel time patterns (Sun et al., 2020), number of flights (Poelman, 2013) and competition components (Bao et al., 2016). This study focuses more on implementing the already developed road transport performance indicator in the case of a planned airport.

- *The project site can accommodate two runways – measuring 2,910 meters and 4,000 meters – with parallel taxiways.*
- *The project will be developed using a public-private partnership model adhering to the guidelines of the Greenfield Airport Policy of Government of India.*

Figure 10: Dholera International Airport – Project Area Location


The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors or its

Source: Gujarat Infrastructure Development Board. Dholera International Airport. https://www.gidb.org/dholera-international-airport (accessed in January, 2023).

Table 6 shows main airports in the area, among them International Ahmedabad Airport which dominates air transport in Gujarat with 9.3 million passengers annually. There are more than 25 million inhabitants living close by and it has relatively good road transport performance (58 percent). Vadodara Airport has also a similar population potential and even better road transport performance (67 percent) due to its strategic location close to the main cities in the area.

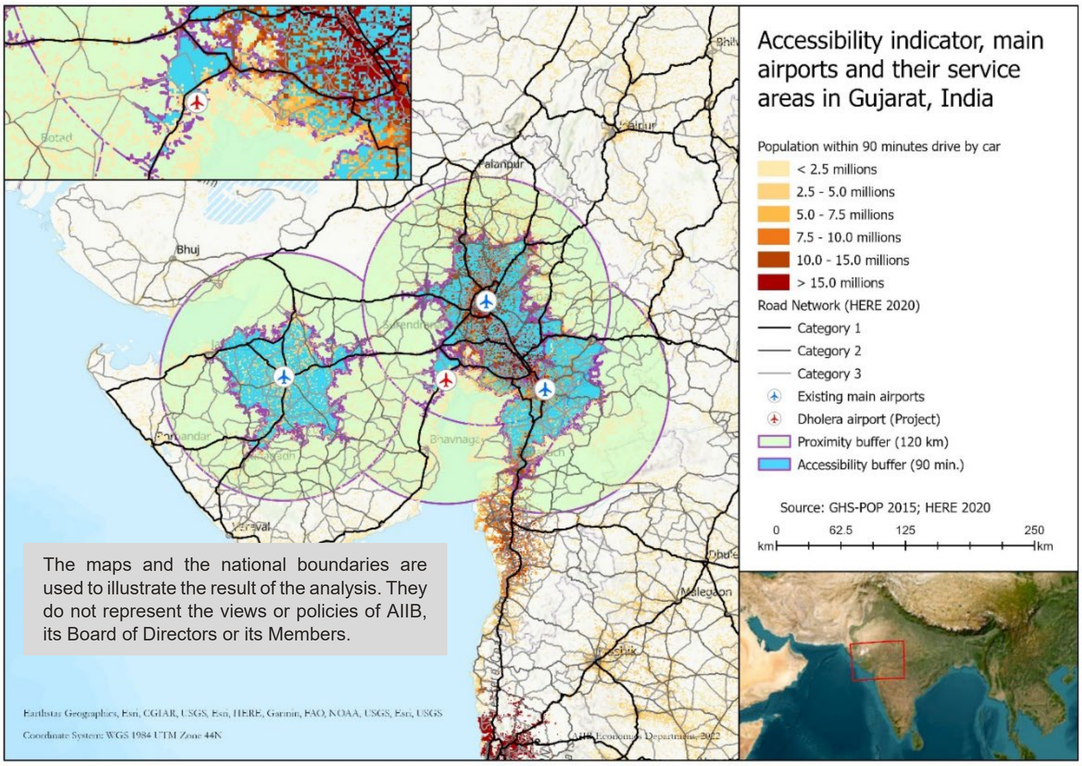
Table 6: Road Transport Performance Indicators for Dholera Airport and Other Nearby Main Airports[5]

Airport name	Number of passengers in 2019 (million)	Proximity (mil. People)	Accessibility (mil. People)	Road transport performance (%)
Vadodara	1.2	25.7	17.3	67.3
Ahmedabad	9.3	26.4	15.3	58.0
Rojkat	0.2	11.4	5.1	45.0
Dholera (planned)	-	23.3	0.4	1.8

Source: Author's own elaboration

There are 23 million inhabitants living close to the planned Dholera Airport. While it has very high potential, at present the lack of transportation infrastructure translates to low road transport performance at only 1.8 percent. One can reach only 400,000 people with 90 minutes' drive from the airport. Therefore, to become a well-functioning international airport, the proposed Dholera Airport has to be connected first to existing motorways. Then, it should be made accessible, within proper travel time, from the main cities of Ahmedabad, Rajkot, Vadodara and Anand. Figure 11 shows the airport locations and their respective service areas.

Figure 11: Accessibility of Main Airports and Their Service Areas in Gujarat



The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors or its Members.

Source: Author's own elaboration

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[5] Source: Airport Authority of India. Passenger Traffic. https://www.ceicdata.com/en/india/airport-authority-of-india-passenger-traffic (accessed on Jan. 5, 2022).

Table 7 describes a set of possible road infrastructure interventions to connect the planned Dholera airport to main roads and cities. It also indicates potential impacts through scenario analysis taking into account these interventions. According to this approach, the airport is first connected to the nearest motorway with a new 11 km long circular road that connects particularly to the airport; second, the motorways that passes through Ahmedabad, Vadodara, Bhavnagar and Surendranagar have been improved, i.e., free-flow speeds increased from 50 kph to 70-100 kph.

Overall, the potential impacts of this set of interventions on accessibility and road transport performance of the planned airport are estimated to be very positive. After having 367 km long road improvements (of which only a small portion is newly constructed), the airport becomes potentially much more accessible and connected to main settlements as much as other airports in the area. Its accessibility is estimated to increase from 400,000 people to 14.2 million people reached, while road transport performance increases in value from 1.8 percent to 61.2 percent.

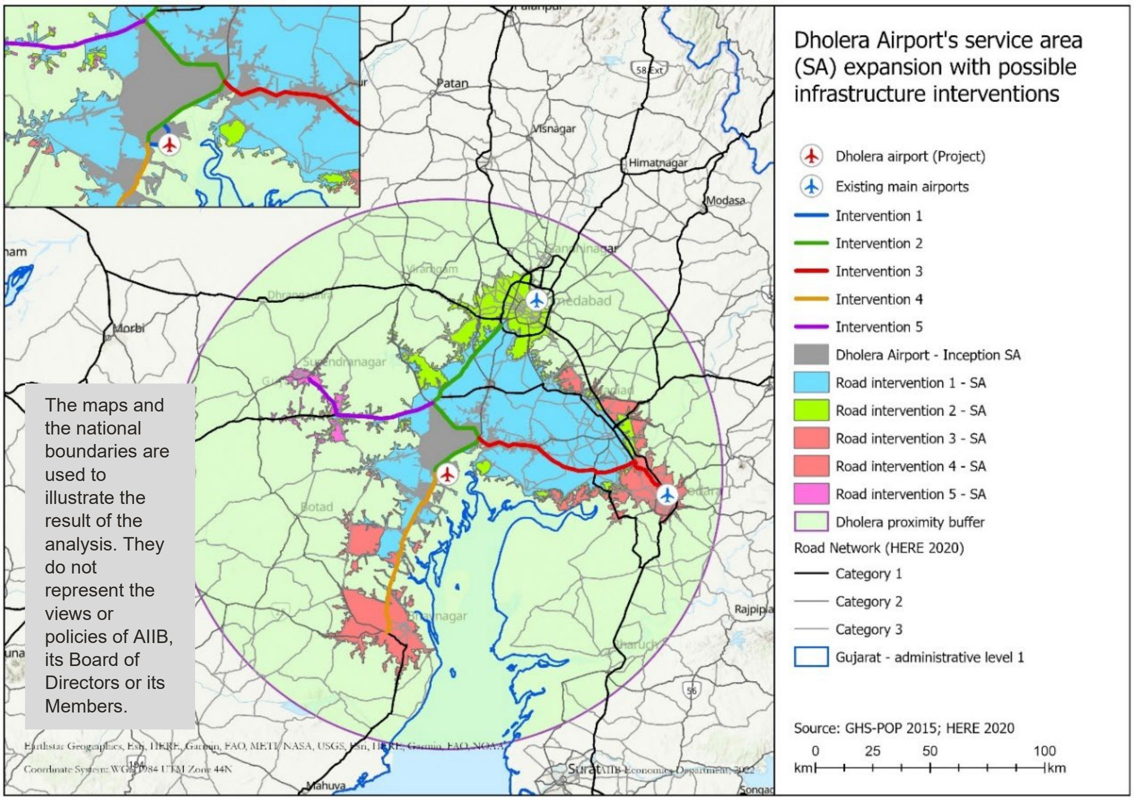
Table 7: Possible Road Infrastructure Improvements for Planned Dholera Airport in Gujarat and Potential Impacts

Intervention no	Composition	Description	Baseline speed	Scenario speed	Length of each single intervention (km)	Number of people reached within 90 minutes' drive (million – cumulative)	Road transport performance (%)	New people reached per km of intervention (thousand – incremental)
-	Inception (no intervention)	Status quo	-	-	-	0.42	1.8	-
1	Intervention 1	Connect Airport to the nearest motorway	New connection roads	50 kph direct connection	11	3.76	16.3	304
2	Intervention 1+2	Improve motorway to Ahmedabad	50-70 kph motorway	100 kph highway	115	10.25	44.2	56
3	Intervention 1+2+3	Improve motorway to Vadodara	50-70 kph motorway	100 kph highway	105	12.66	54.5	23
4	Intervention 1+2+3+4	Improve motorway to Bhavnagar	50-70 kph motorway	100 kph highway	76	13.75	59.1	14
5	Intervention 1+2+3+4+5	Improve motorway to Surendranagar	50-70 kph motorway	100 kph highway	60	14.24	61.2	8
				Overall results after all interventions	**367**	**14.24**	**61.2**	**38**

Source: Author's own elaboration

With every kilometer of road improved or built with this intervention set, it is estimated that an additional 38,000 people can potentially reach the planned airport within 90 minutes by car. Figure 12 shows each specific road infrastructure intervention and its impact to the Dholera airport service area expansion.

Figure 12: A Policy Scenario Analysis - Dholera Airport Service Area Expansion with Possible Road Infrastructure Interventions



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Source: Author's own elaboration

In addition, Table 8 provides final and updated accessibility and road transport performance indicator values of all airports that benefit from road infrastructure improvements and interventions.

Table 8: Proximity, Accessibility and Road Transport Performance of Airports After Road Interventions

Airport name	Proximity (mil. People)	Accessibility after interventions (mil. People)	Transport performance after interventions (%)
Vadodara	25.7	17.7	69.0
Ahmedabad	26.4	15.9	60.0
Rojkat	11.4	5.1	45.0
Dholera (planned)	23.3	14.2	61.2

Source: Author's own elaboration

5.2. Gujarat Rural Roads Project

It was estimated that 36 percent of villages in India lack all-weather road access. A comprehensive rural road project aims to improve rural road connectivity in India. The state of Gujarat has been selected as a pilot area for the project, with the initial project implementation phase covering 1,060 villages with a population less than 500 inhabitants. Overall, eight million people are expected to benefit directly from the first phase of the project, which include two main components:[6]

Project component 1: Construction and upgradation of non-plan roads:

- *This component includes construction and upgradation of* non-plan roads*, construction of missing links (last mile connecting to the road network) and missing structures (culverts and small bridges), construction of approach roads to educational institutions and construction and upgradation of* roads passing through tribal areas.
- *Uses two-thirds of the total budget.*

Project component 2: Upgradation of planned roads

- *This component includes upgradation of existing earthen and metal roads to black-top roads, resurfacing of village roads and other district roads, upgradation of bridges to prevent flooding and subsequent isolation of flooded villages during monsoon season and widening of village roads and other district roads to ease traffic congestion.*
- *Uses one-third of the total budget.*

It is particularly important to measure the likely impacts of such a rural road project after its implementation to (i) see how and where it helped to achieve project objectives set at the beginning, and (ii) learn from it to better estimate likely impacts of similar projects in the future. Therefore, this section aims to estimate likely impacts of this rural road project in terms of network connectivity and performance. Unfortunately, specific information on the locations of rural road constructions, upgrades and improvements are not available. Instead, settlement categories chosen, i.e., villages with less than 500 inhabitants, and type of road interventions, in general, residential roads, dirt roads, etc., in rural areas, are known.

Based on the available information, an alternative (policy) scenario has been created. In this alternative scenario, roads with the lowest speed categories are assumed to be upgraded within the small villages (<500 inhabitants) of Gujarat.[7] Since it is a past project, the current situation of the road network already includes those rural road improvements, hence, taken as the baseline. For the alternative scenario, to estimate impacts of past changes in the infrastructure, the roads with speed categories 5 (50 kph), 6 (30 kph) and 7 (10 kph) have been downgraded by one level – to speed categories 6, 7 and 8 (5 kph), respectively, in treated (selected) villages (Figure 13). This past years' scenario simulation (policy), which does not yet include any road upgradation, is then compared to the current years' simulation (baseline), which uses the existing infrastructure, in terms of accessibility and road transport performance (Table 9).

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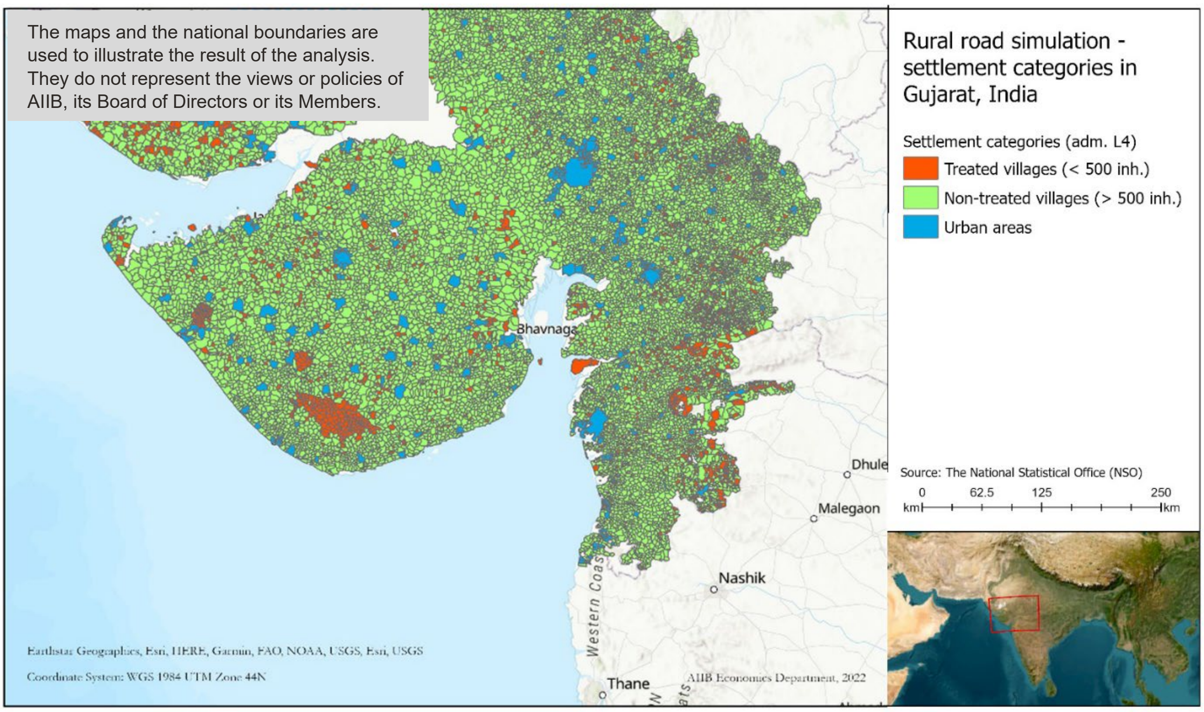
[6] Government of Gujarat and AIIB. 2017. Gujarat Rural Roads (MMGSY) Project – Project Summary Information (PSI). Report No: 000025.

[7] For settlement classification, see Li et al., 2016.

Figure 13: Rural Road Simulation in Gujarat – Settlement Categories and Treated Villages



Source: Author's own elaboration

Table 9: Rural Road Simulation in Gujarat – Characteristics of Baseline and Policy Scenarios

Name of the simulation	Description	Population criteria	Total length of the roads in categories 5 to 7 (thousand km)	Number of districts involved	Population involved (million)	Treated (small) villages	Road speed category intervention (implemented to the selected links)
Baseline Scenario	Business as usual – with the existing road network	No limits	333.2 km (97.6% of all)	18,728	68.3	Do nothing	Do nothing
Policy Scenario	Improve rural roads in treated (small) villages	Less than 500 inhabitants	20.1 km (98.6% of all)	2,867	1.1	Downgrade roads in those villages	Category 5 to category 6 Category 6 to category 7 Category 7 to category 8

Source: Author's own elaboration

Table 10 indicates results of the scenario simulations for Gujarat. Based on this, with the rural road project, the average accessible population within the treated villages is estimated to be 2.7 million in the past. Today, the average is 3.45 million, which points a 27.4 percent difference between the baseline and policy scenarios. In other words, this project, simulated with the assumption of 20.1 thousand kilometers of road construction and upgradation in small villages of Gujarat, an additional 750,000 people are made accessible to an average person living in those villages.

Table 10: Rural Road Simulation in Gujarat – Results of Baseline and Policy Scenarios

Gujarat SIM 1 Baseline for today (current situation)	**Proximity (million people)**	**SIM 1 Accessibility (million people)**	**SIM 1 Road Transport Performance**
All districts	18.3	7.27	39.7
Treated Villages (less than 500 inbhabitants)	17.5	3.48	19.9
Non-treated villages (more than 500 inhabitants	17.6	5.07	28.9
Urban areas	19.0	9.10	47.9

Gujarat SIM 2 Policy scenario for the past (an alternative to the current situation)	**Proximity (million people)**	**SIM 2 Accessibility (million people)**	**SIM 2 Road Transport Performance**	**Difference (%) compared to baseline for today**	**New people reached with road improvements, on average (000)**
All districts	18.3	7.10	38.8	2.3%	165
Treated Villages (less than 500 inbhabitants)	**17.5**	**2.73**	**15.6**	27.4%	750
Non-treated villages (more than 500 inhabitants	17.6	4.93	28.1	3.0%	146
Urban areas	19.0	9.00	47.3	1.1%	98

Source: Author's own elaboration

The project has contributed to improved accessibility and connectivity, particularly in the villages where is has been implemented. Estimated Gujarat-wide overall impact is rather limited but positive, with around 2.3 percent difference between the scenarios with and without the implementation of the project. However, it is important to emphasize that apart from the treated villages, urban areas (1.1 percent) and non-treated villages and rural areas (3.0 percent) are also estimated to have been benefited from the Gujarat rural road project.

6. Conclusions

Regional and transportation policy aims to connect people, goods and places with the objective of making settlements and services more accessible. Establishing and maintaining better transport connectivity and accessibility in remote regions, cross-border areas and other underserved areas is given particular importance in transportation policy. A well-connected and accessible area has higher potential to achieve enhanced social and economic activities, and is more likely to reach better regional opportunities and global value chains (AIIB, 2021; EC, 2021).

This study measures road transport connectivity and accessibility in India using a transport accessibility framework recently implemented in European Union countries. It provides information on the quality (e.g., density, connectivity and average speed) of transport networks and highlights spatial patterns and territorial differences encountered in India. It also shows potential on how this methodology can be applied for policy analysis – particularly in evaluating the connectivity of a planned airport and the likely impacts of rural road project in Gujarat. Overall, results discussed throughout the study indicate useful insights for transport policy analysts and decision-makers. It is crucial for Asian countries to have a well-connected and resilient transport infrastructure. One way to achieve this objective is to establish more studies that deal with ex-post and ex-ante analysis of transport policies and investments. Considering its features included in this study, the road transport performance indicator can be seen as an effective tool and can be used to highlight connectivity gaps between and within Asian countries.

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Appendix A

Table A1: Comparison of Gridded Population in India with Descriptive Statistics - GHSL 2015 1 km^2 vs. WorldPop 2020 1 km^2

Layer / raster name	Cells included	# of cells	Min	Max	Mean	Std. dev	Sum
GHSL 1km	all	3 180 559	0	415 205	412	2 714	1 312 850 571
WP 1km	all	3 180 559	0	176 153	434	1 566	1 380 004 384
GHSL 1km	>= 1	815 498	1	415 205	1 609	5 177	1 312 847 700
WP 1km	>= 1	1 501 948	1	176 153	870	2 179	1 380 004 064
GHSL 1km	>= 100	631 609	100	415 205	2 065	5 803	1 304 523 870
WP 1km	>= 100	1 197 480	100	176 153	1 138	2 390	1 363 132 619
GHSL 5km	all	129 470	0	1 750 820	10 140	35 933	1 312 850 571
WP 5km	all	129 470	0	1 314 987	10 658	28 595	1 380 004 384
GHSL 10km	all	32 963	0	4 430 448	39 828	108 219	1 312 850 571
WP 10km	all	32 963	0	4 225 134	41 865	97 227	1 380 004 384
GHSL 1km (2 regions)	>= 1	102 892	1	205 601	1 386	4 951	142 682 869
WP 1km (2 regions)	>= 1	258 974	1	126 236	579	1 692	150 005 463

Note 1: WorldPop 2020 one-kilometer (km) population grid has been aggregated from 100-meter constrained grid adjusted based on United Nations (UN) population estimations (UN, 2019). No data values in WorldPop raster have been converted to zero when the corresponding cell value in the GHSL raster is equal to zero.

Note 2: UN population estimations (UN, 2019) for India is 1.310.152 for 2015 and 1.380.004 for 2020, which are in line with the gridded population estimates for 2015 (GHSL) and 2020 (WorldPop).

Note 3: The table includes comparisons of the rasters created with some thresholds (e.g., populated cells equal or greater than one inhabitant, cells with more than 100 inhabitants or cells aggregated from one km to five km, etc.) or based on the selected states in India, i.e., Gujarat and Rajasthan.

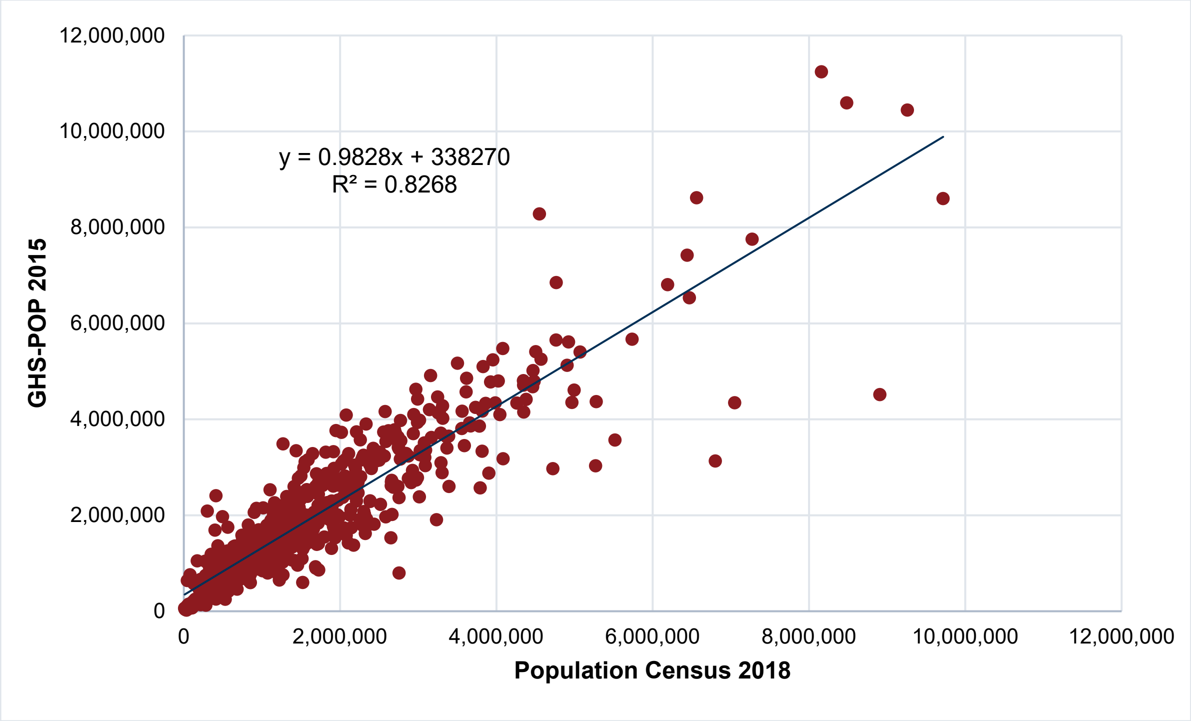
Note 4: 2011 population census results for Gujarat region are 60,439,692; it is 68,548,437 for Rajasthan region; total population of the two regions is 128.988.129 for 2011 (https://www.census2011.co.in/states.php).

Table A2: Comparison of Gridded Population in India with Correlation Analysis - GHSL 2015 1 km vs. WorldPop 2020 1 km

Correlation pairs	Cells included	Correlation coefficient (Pearson's r)
GHSL 1km & WP 1km	all	0.54
GHSL 1km & WP 1km	>= 1	0.51
GHSL 1km & WP 1km	>= 100	0.50
GHSL 5km & WP 5km	all	0.84
GHSL 10km & WP 10km	all	0.90
GHSL 1km & WP 1km (2 regions)	>= 1	0.50

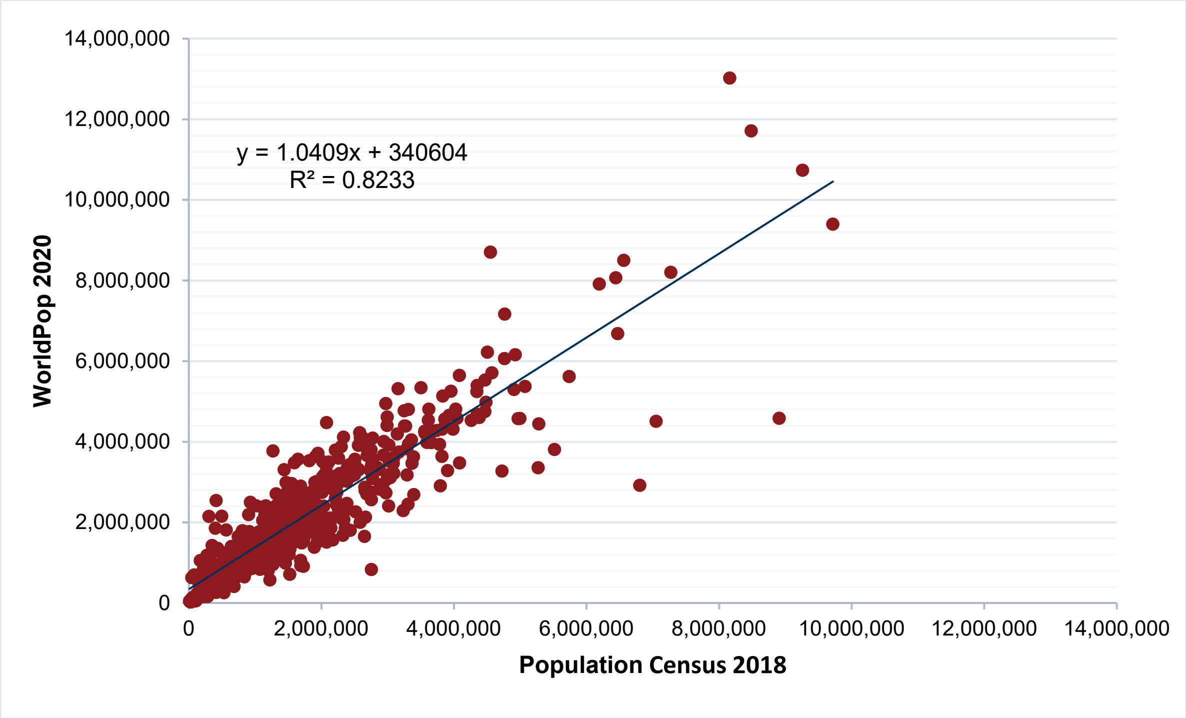
Source: Author's own elaboration

Figure A1: District-Level Population Comparison in India – GHS-POP 2015 Population Grid vs. Population Census 2018



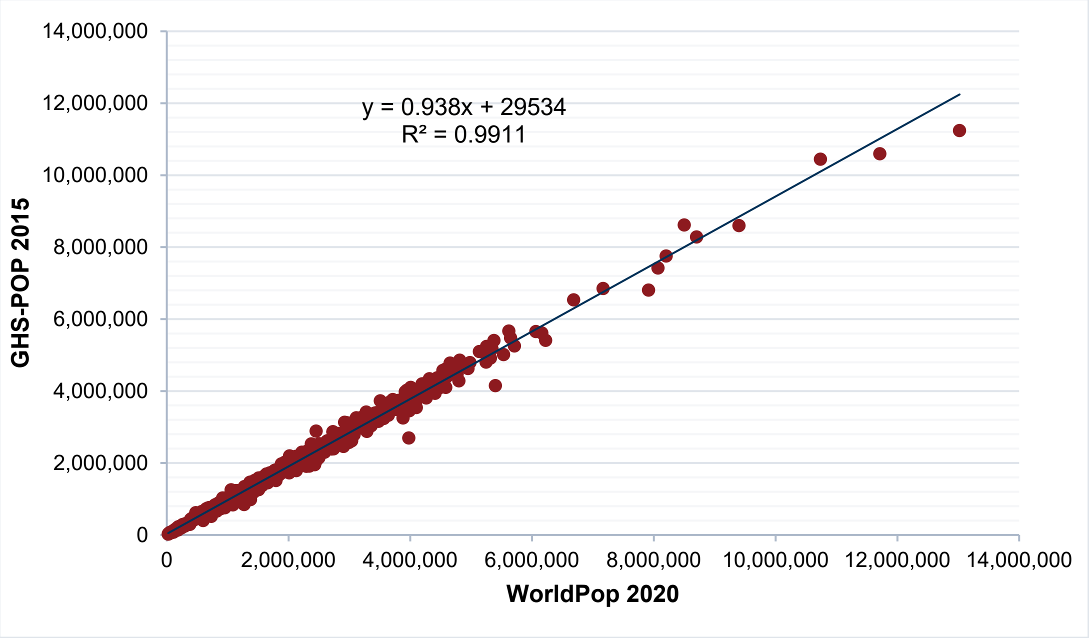
Source: Author's own elaboration

Figure A2: District-Level Population Comparison in India – WorldPop 2020 Population Grid vs. Population Census 2018



Source: Author's own elaboration

Figure A3: District-Level Population Comparison in India – GHS-POP 2015 versus WorldPop 2020 (in 588 districts)



Source: Author's own elaboration

Table A3: District-Level Population Comparison in India – Descriptive Statistics: Population 2018 (census-based) vs. GHS-POP 2015 vs. WorldPop 2020

Population 2018 (census based)		*GHSL 2015*		*WorldPop 2020*	
Mean	1668525	Mean	1978089	Mean	2077380
Standard Error	60181	Standard Error	65047	Standard Error	69039
Median	1326569	Median	1613542	Median	1689864
Mode	2990029	Mode	#N/A	Mode	#N/A
St. Dev	1459322	St. Dev	1577316	St. Dev	1674100
Kurtosis	5	Kurtosis	6	Kurtosis	7
Skewness	2	Skewness	2	Skewness	2
Range	9704988	Range	11219232	Range	12998400
Minimum	11353	Minimum	21574	Minimum	23588
Maximum	9716340	Maximum	11240806	Maximum	13021988
Sum	981092494	Sum	1163116235	Sum	1221499329
Count	588	Count	588	Count	588

Source: Author's own elaboration

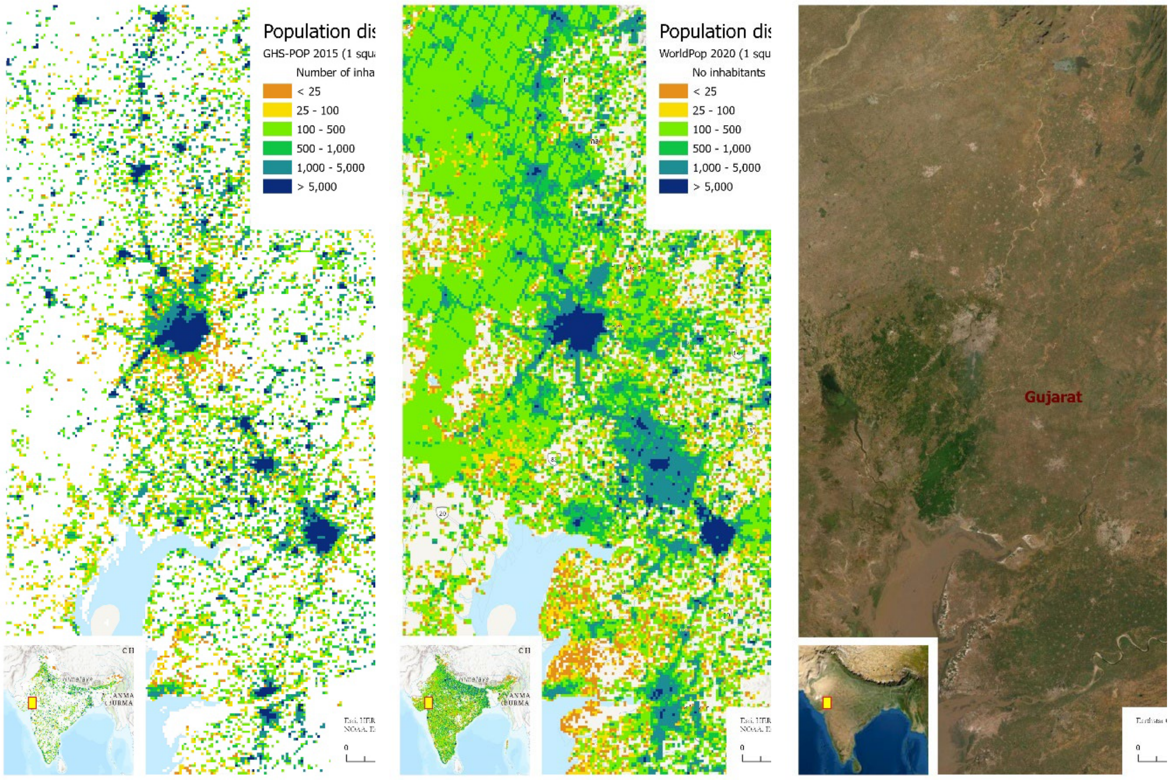
Table A4: District-Level Population Comparison in India – Correlation Analysis

Correlation matrix	**Population 2018 (Census based)**	**GHSL Pop 2015**	**WorldPop 22020**
Population 2018 (Census based)	1.000		
GHSL_Pop_2015	0.909	1.000	
WorldPop_22020	0.907	0.996	1.000

Source: Author's own elaboration

Figure A4: Population Distribution in Gujarat, India – A Visual Comparison of GHS-POP 2015, WorldPop 2020 and Satellite Imagery

The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors or its Members.



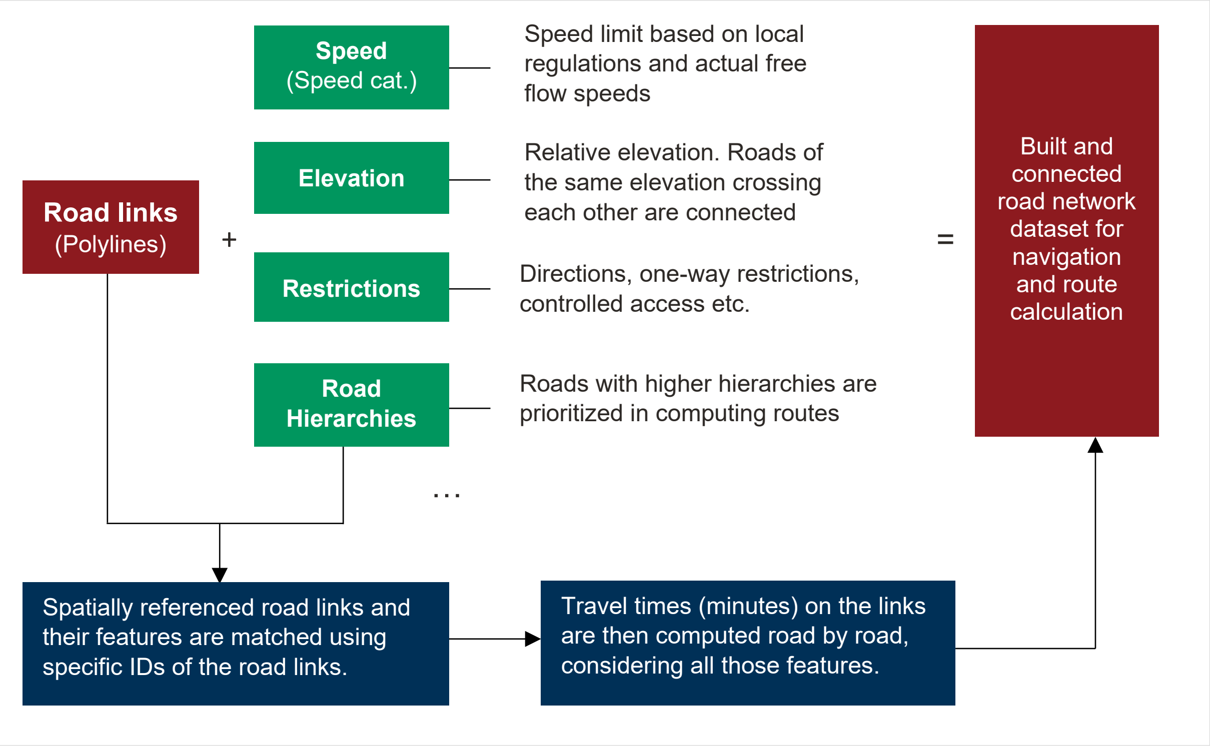
Source: Author's own elaboration

The maps and the national boundaries are used to illustrate the results of the analysis. They do not represent the view of AIIB, the view of its Board of Directors and the view of its staff on internationally disputed territories.

Appendix B

Building a connected and navigable road network is demonstrated in Figure B1 with its main components. HERE Technologies (HERE) road network data offers required components in the form of geospatial tables, and ArcGIS PRO has functions to assemble a navigational road network from scratch using those components.

Figure B1: Building a Connected and Navigable Road Network



Source: Author's own elaboration

Speed categories provided with the HERE road network data have been one of the main inputs for the network-building process (Table B1). They are utilized to calculate link traversal times which then are used to calculate travel time and service areas.

Table B1: HERE Technologies Road Network Data for India - Speed Categories and Speed Intervals

Value	Description in KPH	In MPH
(space)	Not Applicable	Not Applicable
1	> 130KPH	> 80KPH
2	101-130 KPH	65-80MPH
3	91-100 KPH	55-64 MPH
4	71-90 KPH	41-54 MPH
5	51-70 KPH	31-40 MPH
6	31-50 KPH	21-30 MPH
7	11-30 KPH	6-20 MPH
8	< 11 KPH	< 6 MPH

Source: HERE Navstreets Reference Guide, 2020, p. 386

Speed Category (HERE Navstreets Reference Guide, 2020, pp. 385-386): Speed Category classifies the general speed trend of a road based on posted or legal speed and is provided to enhance route calculation and the timing of route guidance. Speed Category values represent the combination of several factors besides legal speed limit (e.g., physical restrictions or access characteristics). Therefore, Speed Category values can differ from Speed Limit values, which represent the legal speed limit only. On roads that have physical restrictions such as speed bumps or chicanes, the Speed Category can be lower than the legal speed limit. Speed Category may be used to estimate link traversal times, to prioritize link selection during route calculation, and to calculate timing of the route guidance.

There are various options to choose proper speed values for each speed category (Table B2). Lower points, midpoints or higher points of the speed intervals can be chosen. At this stage, the most reliable and realistic speed values have been identified based on a comparison with selected real-life examples. The built road network has been compared in terms of shortest travel distance, travel time and average speed for randomly selected 30 destinations in Gujarat, India. Among them, 15 pairs are selected from city or town centers and the other 15 pairs are selected from random rural areas. Figure B2 shows these 30 destinations and the shortest routes generated by the HERE data using the ArcGIS Network Analyst tool. In a later stage, modeled values have been compared with the measurements achieved via Google Map Service (e.g., directions, distance and travel time information from location A to B). Departure times have been set to 1:00 a.m. in Google Maps to avoid traffic congestion during peak hours, because the modeled routes assume free-flow speeds and congestion-free travel time. In any case, modeled travel times are expected to be lower than they are in real life, because it does not count into account actual occupancy of the roads, temporary barriers or traffic lights or arrangements, etc.

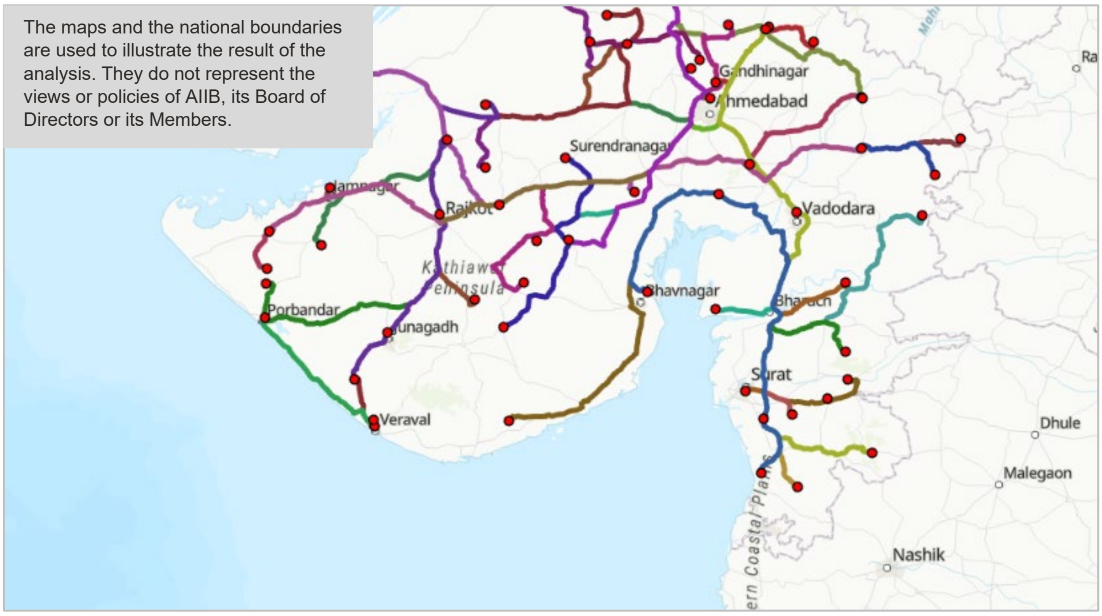
Table B2: Descriptive Statistics on Road Network Data in India, HERE 2020

Speed Category	HERE speed category values – mid points	HERE speed category values – lower points
1	130	130
2	115	101
3	95	91
4	80	71
5	60	51
6	40	31
7	20	11
8	5	5

Source: Author's own elaboration

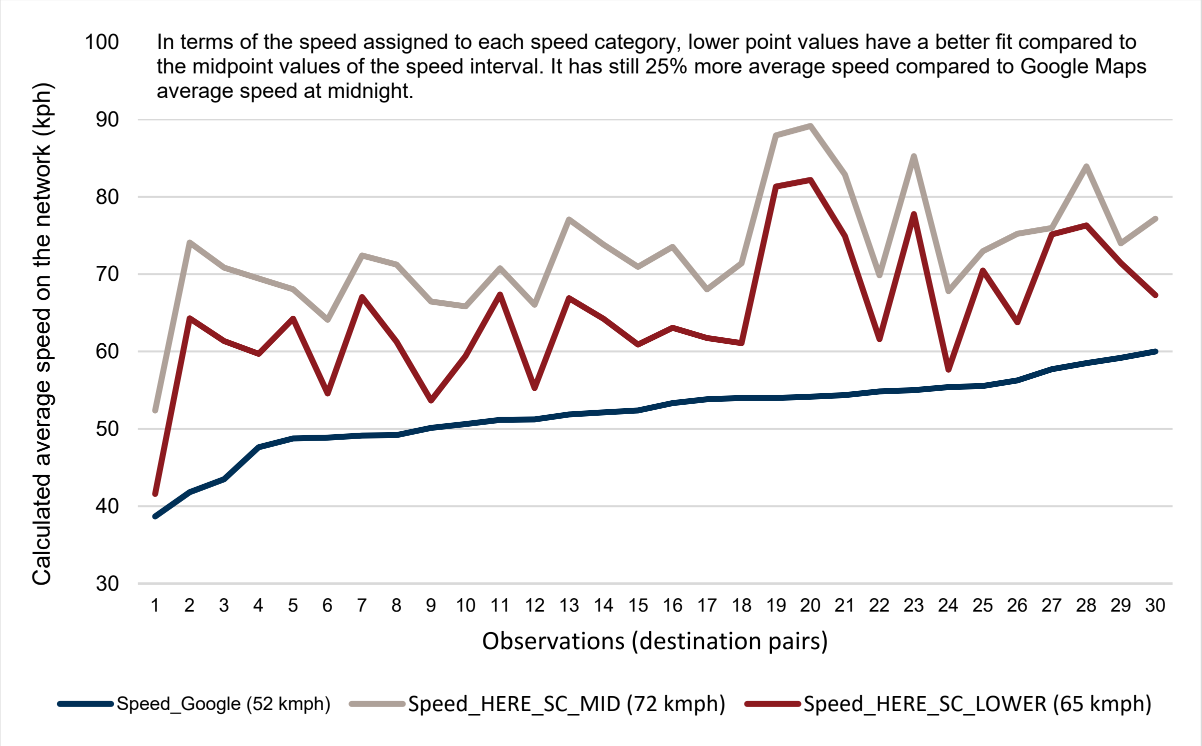
According to this comparison exercise, travel time measurements with lower point speed values of each speed category (i.e., 51 kph for category 5) produced the most realistic results. The results show that the shortest routes computed using HERE data match relatively well with Google Map results. Figure B3 shows a comparison with average speeds, Figure B4 and Figure B5 show comparisons with average travel distance and average travel time. High r-square values for the compared data sets, over 90 percent, indicate that for both distance and travel time variables modeled and observed values match well. Slight deviations in travel time appear to be slightly bigger than distances as it is anticipated because theoretical or modeled travel times are always slightly less than reality. Another reason for those differences would be that the Google Maps measurements are based on 2021 November where HERE data is for 2020. In addition, data deviations in rural destinations were found to be higher than those in cities and towns, which is also expected as data quality (e.g., coverage, speed assumptions) of rural road network might be lower in HERE road network data.

Figure B2: Randomly Selected Destination Pairs for Measuring Travel Distance, Time and Average Speeds In Gujarat, India


The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors or its Members.

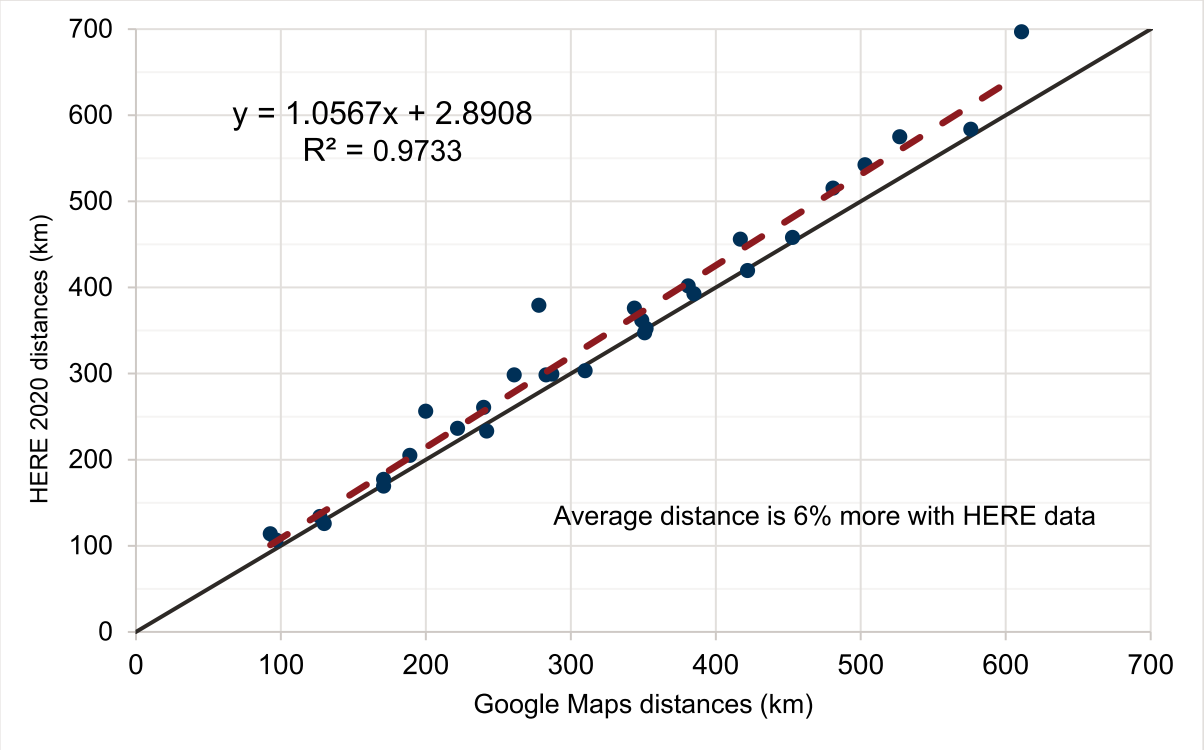
Source: Author's own elaboration

Figure B3: Average Speed between Selected Destination Pairs - Google Maps vs. Modeled Network Configurations Based on Speed Category Values



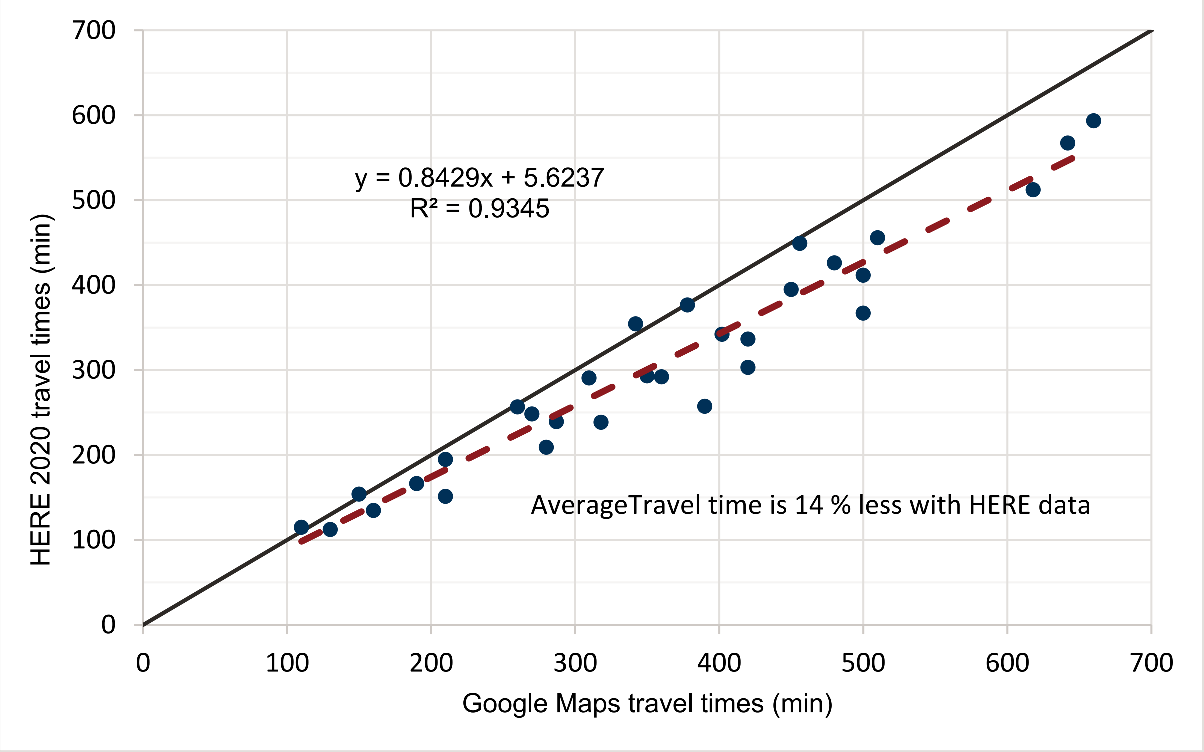
Source: Author's own elaboration

Figure B4: Scatter Plot of Average Distances - Google Maps vs. HERE Technologies 2020 (Speed Category Lower Points)



Source: Author's own elaboration

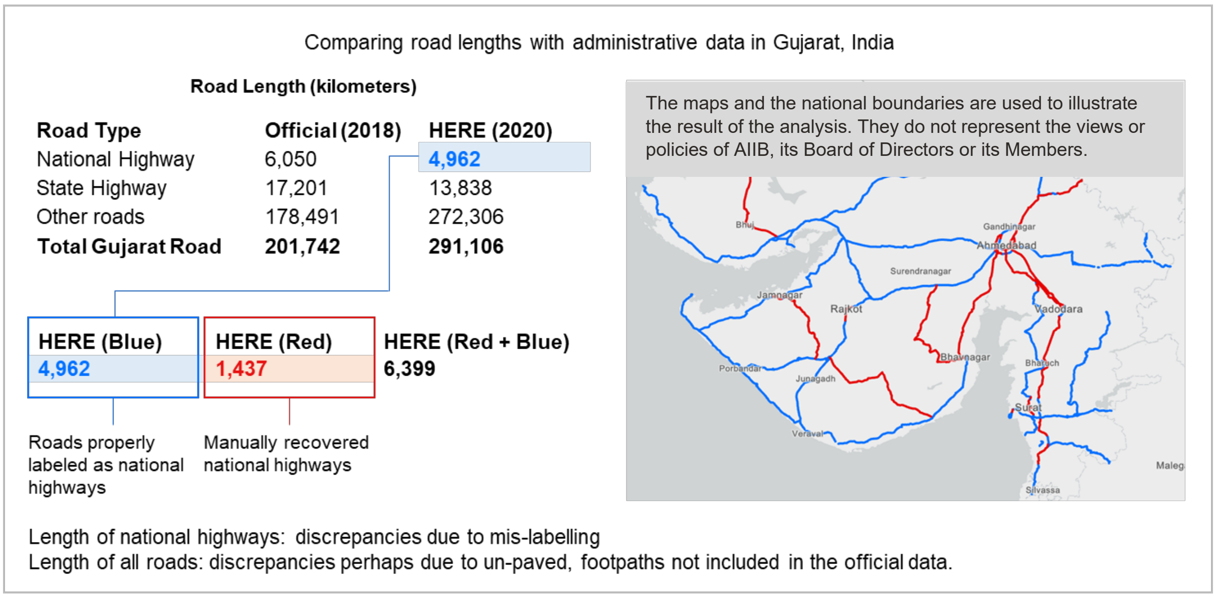
Figure B5: Scatter Plot of Average Travel Times - Google Maps vs. HERE Technologies 2020 (Speed Category Lower Points)



Source: Author's own elaboration

In a final examination, the data has been checked against the official statistics from the Ministry of Transport via total road length by category in Gujarat, India. It was found that the data largely matches with the official data. Discrepancies are usually due to a labeling issue. Some national highways are labeled differently in HERE road network data. When those highways are relabeled as national highways, the recalculated total lengths match with the official statistics of national highways (Figure B6 – National highways in official statistics have 6,050 km, labeled and r-labeled national highways in HERE data have 6,399 km). Given all comparison and testing results, it is concluded that HERE road network data has a decent geographical coverage in India and offers a sufficiently realistic estimates of travel distance and time measurements.

Figure B6: Comparison between Road Lengths and Official Data In Gujarat, India



Comparing road lengths with administrative data in Gujarat, India

Road Length (kilometers)

Road Type	**Official (2018)**	**HERE (2020)**
National Highway	6,050	4,962
State Highway	17,201	13,838
Other roads	178,491	272,306
Total Gujarat Road	**201,742**	**291,106**

HERE (Blue)	**HERE (Red)**	**HERE (Red + Blue)**
4,962	**1,437**	**6,399**
Roads properly labeled as national highways	Manually recovered national highways	

The maps and the national boundaries are used to illustrate the result of the analysis. They do not represent the views or policies of AIIB, its Board of Directors or its Members.

Length of national highways: discrepancies due to mis-labelling
Length of all roads: discrepancies perhaps due to un-paved, footpaths not included in the official data.

Source: Source: Author's own elaboration