Mobility AND Development

INNOVATIONS, POLICIES AND PRACTICES

WORLD BANK GROUP
Transport

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1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

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Nicolas Peltier-Thiberge
Global Director for Transport,
The World Bank

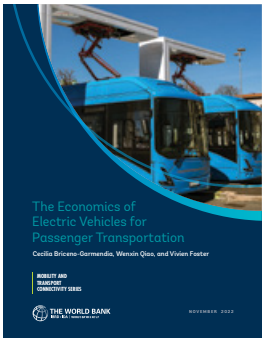
Note from the Global Director

The World Bank's Transport Global Practice has a clear mission: help ensure people and firms get access to transportation while reducing the negative externalities of transport, such as air pollution, road crashes, and climate emissions. The World Bank Transport Team is partnering with developing countries and many development partners to find effective and innovative mobility solutions that can deliver better connectivity on a smaller carbon footprint. This may sound like a tough equation, but it is by no means an impossible one. By investing in knowledge and promoting innovation, we have joined efforts with low- and middle-income countries around the world to develop transformative projects and make sustainable transport a reality.

Today, our portfolio features 176 active transport projects and $35.33 billion in commitments, accounting for 11.6 percent of World Bank lending. In Fiscal Year 22 alone, the World Bank approved 40 new transport projects for a total of $8.3 billion, with a marked shift toward climate-smart mobility.

World Bank Transport experts also deliver an average of 65 advisory services and analytical reports per year. This knowledge is essential to our operations, especially in a context where our clients are grappling with so many challenges, from COVID-19 and climate change to conflict, food insecurity, and supply chain disruptions. Now more than ever, we need to have actionable knowledge at our disposal so that we can develop quick and appropriate responses as soon as a new challenge emerges. For instance, recently, the war in Ukraine prevented the export of 20 million metric tons of wheat, maize, and sunflower seeds. This caused an increase in global grain prices and limited storage capacities for future harvests. Our modeling work enabled the country to identify alternative routes that can quickly be developed to evacuate the grains.

Knowledge is also at the heart of our climate work. Currently, transport accounts for 20 percent of all greenhouse gas emissions. I believe strong analytical work is important to help developing countries determine the most optimal and cost-effective path for decarbonization. The World Bank is committed to make all of its operation align to the Paris climate goals for mitigation, adaptation, and resilience. Transport projects financed by the Bank will make major contributions to the achievement of the Paris climate goals and help in reducing carbon emissions and make the economy more resilient. Our transport projects are designed following the well-known avoid-shift-improve approach for transport decarbonization to avoid unnecessary trips, shift to more environment-friendly modes, improve the energy efficiency of transport systems, and enhance resilience.



Our new report, The Economics of Electric Vehicles for Passenger Transportation, shows that e-mobility is becoming an increasingly relevant solution for developing countries, with significant potential for climate action and development. While electric cars capture most of the attention, our study demonstrates that e-buses and electric two- or three-wheelers can be another promising avenue toward decarbonization for many countries. The World Bank is playing an increasing role in helping countries to accelerate their e-mobility adoption.

In many parts of Sub-Saharan Africa, Europe, and Asia, there is need for inter-regional connectivity to smooth the flow of goods and services. However, a one-size-fits-all approach will not work. Delivering last-mile connectivity may look different in every case but investing in resilient infrastructure and mobility solutions is critical for economic growth, food security, and climate resilience.

We must carry this creative thinking to policy, too. For instance, faced with growing consumer aspirations, many countries in Africa are importing used vehicles that do not meet basic safety or environmental standards. In the face of this challenge, the priority is to adapt the global, national, and local policies surrounding motorization management. We need to think through ways to ensure cleaner fuel choices, improve vehicle emissions standards, and promote public transport and shared mobility options for consumers.

Nicolas Peltier-Thiberge is the Global Director for the Transport Sector in the Infrastructure Practice Group of the World Bank. Mr. Peltier-Thiberge joined the World Bank in 2002 as a Young Professional and he has since held various positions in the Transport Global Practice, managing World Bank-financed transport investments in multiple regions, including North Africa and the Middle East, Latin America and the Caribbean and Africa.

Between 2012 and 2015, Mr. Peltier-Thiberge was a Portfolio Assistant in the Office of the World Bank Group President. From 2015 to 2022, Mr. Peltier-Thiberge has been a Practice Manager in charge of the World Bank's Transport business in North Africa and the Middle East, West and Central Africa and Latin America and the Caribbean. In May 2022, he became the Global Director for the Transport Sector.

Prior to joining the World Bank, Mr. Peltier-Thiberge worked in the French Ministry of Economy and Industry and in the French Treasury. Mr. Peltier-Thiberge holds graduate diplomas in science and civil engineering, as well as technology and policy from Ecole Polytechnique (France), Ecole Nationale des Ponts et Chaussées (France), and the Massachusetts Institute of Technology (United States).

The launch of our Global Facility to Decarbonize Transport (GFDT) and the expansion of the Global Road Safety Facility (GRSF) will help us gain momentum by leveraging funding, building technical partnerships, and supporting advocacy and communications. The Road Safety Screening and Appraisal Tool (RSSAT) developed by the GRSF to evaluate and improve road safety performance is timely in view of the 1.35 million lives lost annually to road crashes, mostly in developing countries.

Clearly, we have made progress on many fronts. But cooperation and sharing of knowledge on a global scale is key to addressing our increasingly connected challenges. So, let's share our successes and ideas on this journey as we work together with our client countries to deliver clean, safe, inclusive, and resilient mobility solutions.

Nicolas Peltier-Thiberge

Binyam Reja
Global Practice Manager for Transport,
The World Bank

Note from the Editor-in-Chief

Every winter, we look forward to shaking off the chill and welcoming the warmth and promise of spring. In a similar way, the world is now eagerly emerging from under the shadow of the COVID-19 pandemic. In response to the virus easing its crippling grip, the World Bank's Transport Global Practice takes the opportunity to examine the impacts felt across the transport sector scattered in the pandemic's wake.

Even more than a year ago in the fall of 2021, our inaugural issue already looked ahead toward solutions for improving low-carbon and resilient mobility in a world finally free from the constraints of the global pandemic. And then again in the Spring 2022 issue, though the focus spread across a range of transport-related topics, the aftereffects of the pandemic filtered through nearly every article.

For this, our third issue (Spring 2023), we are once again pleased to share the work of World Bank staff, allowing the submissions to shape the periodical. It will come as no surprise that the challenges of COVID-19 thread their way throughout, even if the pandemic is not explicitly addressed in every article.

We start with a note from new global director for transport, **Nicolas Peltier**, who discusses the decarbonization of transport—a topic we find more and more relevant and integral to our current and future efforts. Let us know what you think about the role the transport sector is playing and will continue to play in the overall challenge of reducing carbon emissions.

Underscoring the growing attention given to transport-related carbon emissions, our opening article, written by **Vivien Foster** and **Mathilde Lebrand**, brings together two recent pieces of research from the office of the Chief Economist for the Infrastructure Vice Presidency of the World Bank to shed light on how well the transport decarbonization process is going and discuss the underlying challenges involved. In the article, the team seeks to understand the emerging challenge posed by carbon emissions generated across the sector—calling the decarbonization of transport one of the most pressing challenges in the transition to net zero. They glean lessons from the past, looking at the factors driving growth and how much further this is likely to go in the coming years—in the absence of adequate policy action.

Maria Lopez Conde and **Grace Naa Merley Ashley** then consider how the series of unprecedented events over the past three years have left the global trade and supply chains in disarray. From the impact of the COVID-19 pandemic on supply chains and trade, to the lodging of the Ever Given in the Suez Canal and the Russian invasion of Ukraine, these shocks have exposed the vulnerability of globalized and interconnected supply chains, leading to higher shipping costs and lower maritime connectivity, and consequently, inflation and food shortages. These stresses have highlighted the importance of increasing resilience and robustness in supply chain design and operation. The study team discusses digitalization as the solution that can leverage technological advances and the ongoing digital revolution to boost resilience in supply chains, increase business confidence, and enhance food security. The article summarizes the features of the main supply chain shocks that have affected the maritime and logistics sectors in the past three years and proposes digitalization alternatives that can help prevent or mitigate the impact of these shocks on supply chains, food security, and inflation.

Turning the page, we find an article by the World Bank's **Megersa Abate**—along with guest authors **Tommy Cheung** from Swinburne University of Technology in Victoria, Australia, and **Anming Zhang** and **Yilin Zhang** from the University of British Columbia. Together, they analyzed the factors determining intraregional air transportation in Southern Africa region during the COVID-19 pandemic and the how the pandemic changed the pattern of air connectivity. The article examines the geospatial characteristics of air transport networks, airport connectivity, and market structure before and after the pandemic in five countries, while also exploring the progress of air transport liberalization in the region and its impact on market structure and airline privatization.

Binyam Reja serves as global practice manager for transport in the Infrastructure Vice Presidency of the World Bank. Dr. Reja oversees the World Bank's Transport Global Unit's knowledge program, analytical studies, technical support to operational units, partnerships, and corporate mandates. He directs an extensive technical assistance program and analytical studies and leads a team of technical professionals and experts in the delivery of the program. Prior to being selected to this position in November 2020, Dr. Reja was the regional practice manager for China, Mongolia, and Central Asia where he oversaw a lending program totaling US$8 billion for China, Mongolia, and Central Asia covering all subsectors, including urban transport, BRT, metros, highways, railways, intermodal freight transportation, and logistics. He holds a Ph.D. in economics from the University of California, Irvine, and attended the Executive Education program at Harvard's Kennedy School of Government.

The study team highlights four key results of the study and concludes with three important policy implications needed to facilitate recovery from the damages incurred to supply and demand of air travel in the region during the pandemic and to improve intra-regional air transport connectivity over the long term. Proposed solutions include the need for full commitment by the five countries to implement liberalization policies as well as encouraging the participation of private and low-cost airlines to promote market competition, air connectivity, and traffic.

Arnab Bandyopadhyay, **Shomik Mehndiratta**, and **Reenu Aneja** head to South Asia, shining a light on the Indian roads sector—specifically the state highways agencies and networks—which function as the critical "middle" layer between the national highway system and the village roads providing basic access. Basing their research on a 2002 World Bank report, which found that both the networks and the agencies were in dire need of attention, along with the World Bank's sustained program of investments that has worked with 13 states over the past two decades, the study team conducted a review of this experience—combining the rich existing knowledge with selected surveys and reviews of the broader experience outside of World Bank projects. In the article, the study team draws on that work to characterize the state of the state highway system today, highlighting 10 key insights from the past two decades of state road development.

We then unpack the impact of transport investments with **Advitha Arun** and **Alice Duhaut** as they consider transport infrastructure and its potential to bolster economic development at the national level by connecting several economic pillars. The discussion focuses on the impact evaluation of transport corridors, and the study team presents a programmatic approach for evaluating the impact of transport infrastructure investments with respect to their short- and long-term goals. Building on existing data, the article reviews newly available high frequency geospatial data and innovations on outcome measurements, offering substantive examples of projects—such as those in Ethiopia, Pakistan, Rwanda, and Iraq—currently evaluated under the ieConnect for Impact program at the World Bank.

Next, **Aiga Stokenberga** and **Javier Moreles Sarriera** take us to South America, where they discuss a study that examines how the COVID-19 pandemic and the lockdown measures implemented in 2020 disrupted mobility and constrained the travel behaviors of residents and businesses in Buenos Aires, Argentina. However, while various policy responses followed over the subsequent months, including by the authorities governing the Buenos Aires Metropolitan Area, these were implemented in the absence of adequate data that would allow understanding exactly how travel patterns had changed, their drivers, and the likely persistence of the pandemic-induced changes going forward. Conducted at a time that could already be called the "new normal," the study aimed to fill this knowledge gap by drawing on mobile phone, mobility app, and public transport smart card based "big data" and by surveying over 20,000 private motorized mode users on the ground.

Our final stop is Southeast Asia, where the World Bank's **Sadig Aliyev** and **Sombath Southivong**, along with **Corey Wong** and **Makito Shirahige** from Arup, share findings of a World Bank study that explored how to enhance green mobility through leveraging data and innovation in the UNESCO heritage cities of Siem Reap in Cambodia and Luang Prabang in Lao People's Democratic Republic. Both cities face common issues in population growth, urban development, the prominence of two-wheeled vehicles as the preferred mode of transport, an increasing vehicle fleet, and road safety challenges, along with emissions and congestion. To facilitate green mobility in both cities, the study team supported each city in developing an overarching Green Mobility Vision and Investment Plan, supported by three evidence-based analytical frameworks, including a "city-level" green mobility index, a "street-level" green mobility index, and the use of mobile device geolocation data to inform investment planning and public transport planning. The COVID-19 pandemic presented key challenges, which allowed innovation and experimentation to still deliver these three frameworks and the Green Mobility Investment Plan. The lessons learned through the study are applicable to other UNESCO heritage sites experiencing similar "growing pains" and seeking a transition from a vehicle-oriented future to one encompassing more sustainable green mobility modes.

On behalf of the editorial team, I extend my warmest appreciation to all those who contributed their research to this issue. What a privilege it is to work alongside each of you as we move forward in our efforts to develop and innovate a stronger, more efficient, and more resilient transport sector.

Which topics would you like us to explore in future issues? Contact the editorial team with your suggestions at WBGTransport@worldbank.org.

Authors:
Vivien Foster and
Mathilde Lebrand,
The World Bank

Understanding Transport-Related Carbon Emissions: Learning from the Past, Looking into the Future

The decarbonization of the transport sector has recently emerged as one of the most pressing challenges in the transition to net zero. With transport-related emissions growing rapidly across much of the developing world, it becomes critical to understand what has been driving this growth—and how much further this is likely to go in the coming years—in the absence of adequate policy action. This article brings together two recent pieces of research from the office of the Chief Economist for the Infrastructure Vice Presidency of the World Bank to shed light on how well the transport decarbonization process is going and discuss the underlying challenges involved.

The Evolution of Transport-Related Carbon Emissions since 1990

About the Authors

Vivien Foster is the Chief Economist for the Infrastructure Vice Presidency of the World Bank.

Mathilde Lebrand is a Senior Economist in the World Bank's Transport Global Practice.

The transportation sector, which relies heavily on fossil fuels, is a major contributor to total global greenhouse gas emissions, representing roughly 24 percent of all global carbon dioxide (CO_2) emissions in 2018. Carbon emissions from transport have more than doubled since 1970 and, under business as usual, are expected to double again between now and 2070 (IEA 2020). According to the International Panel on Climate Change (IPCC), emissions linked to transportation will likely increase faster than those from any other sector, unless the link between transportation and economic growth can be severed (IPCC et al. 2014). Recent research investigates the extent to which countries have historically succeeded in curbing transport-related carbon emissions, while continuing to develop economically, and explores the underlying factors driving this process (Foster et al. 2021).[1]

How far along is the decoupling process?

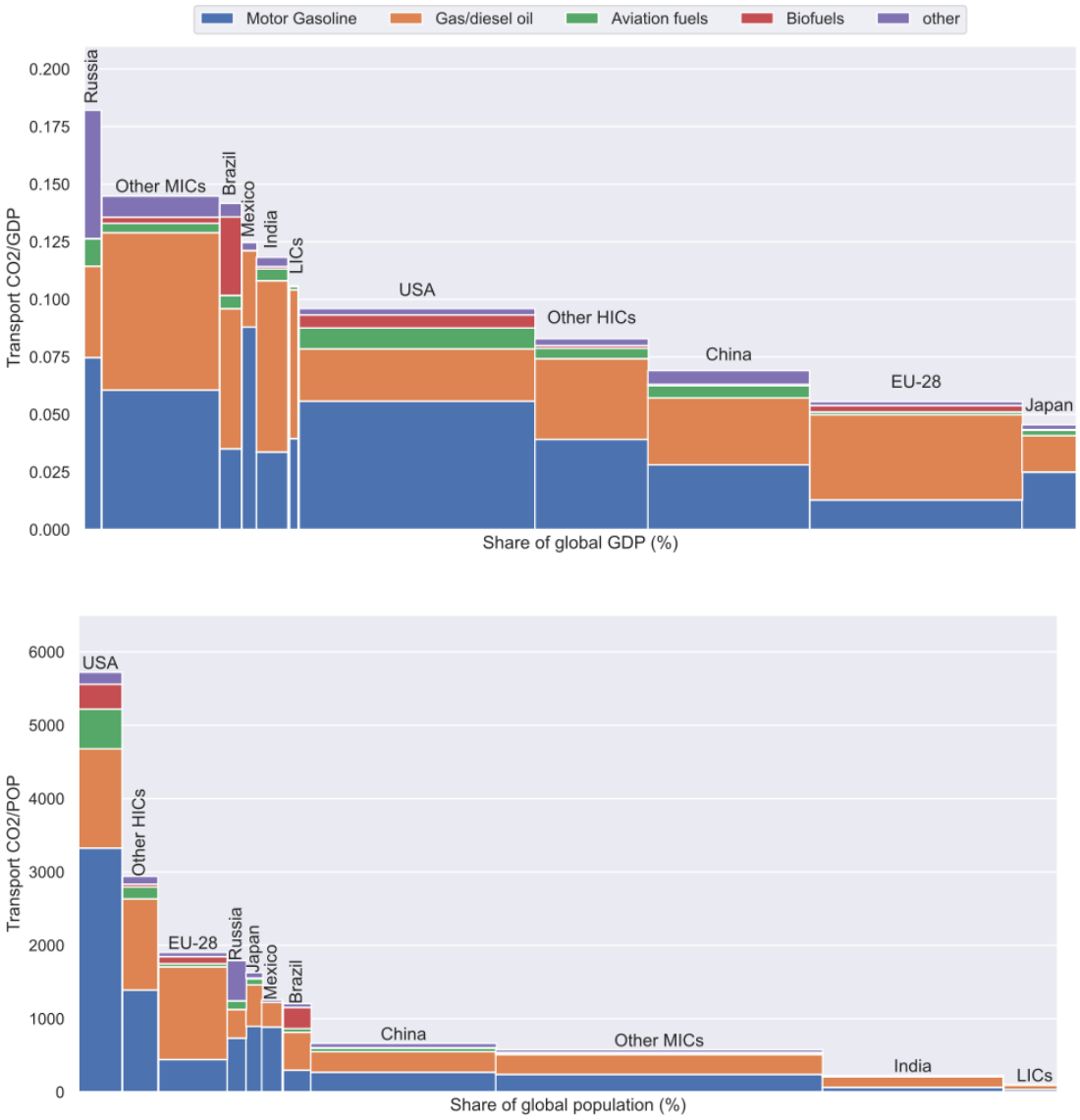
Reducing transport-related carbon emissions without undermining economic growth is pivotal to combating climate change and maintaining living standards. This is known as "decoupling" and means that a country continues to grow economically while at the same time reducing transport-related carbon emissions. An examination of decoupling trends in 145 countries worldwide over the period from 1990 to 2018, reveals that only 12 of them achieved "absolute decoupling," meaning they are actually reducing emissions in absolute terms even as incomes continue to rise. A further 78 of the 145 countries achieved "relative decoupling," defined as slowing down the growth rate of emissions below the growth rate of national income.

The extent to which countries have succeeded in decoupling transport related CO_2 emissions from economic growth varies considerably according to the income level of the country. About 70 percent of high-income countries (HICs) have managed to achieve absolute or relative decoupling. Among the countries most successful at decoupling transport emissions are Finland, Germany, Japan, and Sweden.

By contrast, about 70 percent of low- and middle-income countries (LMICs) have not managed to achieve decoupling and continue to experience per capita transport emissions growing at a much faster rate than per capita gross domestic product (GDP). Notably, between 1990 and 2018, transport emissions grew six times as fast as GDP in Nepal, and twice as fast in Nigeria, Iran, Croatia, Guatemala, Iran, and Nigeria. In the few cases where decoupling has taken place in LMICs, it has been solely as an unfortunate consequence of dire conflict situations.

1 This article was prepared by Vivien Foster and Mathilde LeBrand, drawing on material from two recent research papers published by the World Bank's Infrastructure Vice Presidency Chief Economist's Office. The first is "Understanding Drivers of Decoupling of Global Transport CO_2 Emissions from Economic Growth: Evidence from 145 Countries," by Vivien Foster, Jennifer Uju Dim, Fan Zhang and Sebastian Vollmer, published as World Bank Policy Research Working Paper No. 9809 in October 2021. The second is "Rising Incomes, Transport Demand and Sector Decarbonization," by Mathilde Lebrand and Ewane Theophile, and published as World Bank Policy Research Working Paper No. 10010 in April 2022.

Figure 1. Carbon Footprint of the Transport Sector Relative to Country GDP and Population

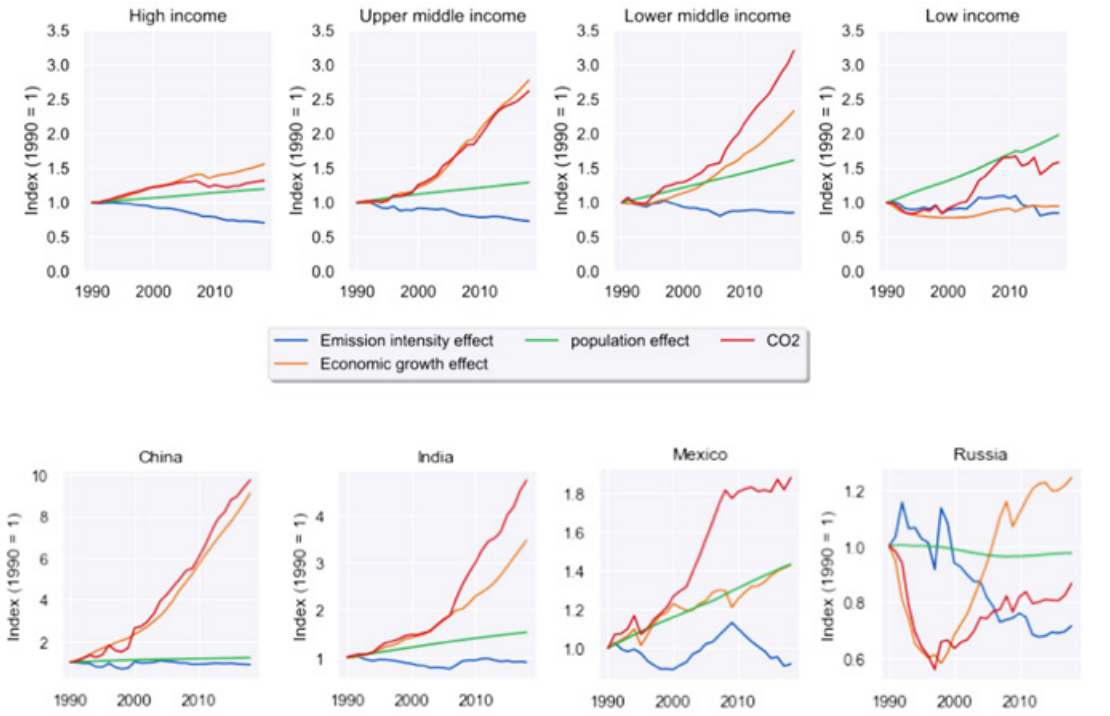


Source: Foster et al. 2021.

The rising pace of transport-related CO_2 emissions has been particularly pronounced in the two largest middle-income countries—China and India—where emissions have increased by tenfold and fivefold respectively since 1990. Nevertheless—despite their rapidly growing emissions—both are still contributing less to global transport CO_2 emissions than their population shares would indicate (**figure 1**). The United States, on the other hand, remains by far the leading contributor to global transport CO_2 emissions; it generates 21 percent of such emissions, while accounting for less than 5 percent of the world's population (**figure 1**).

To understand what is behind a country's transport-related CO_2 emission trends, it is helpful to break these down into three underlying components or drivers. The first driver is transport emissions intensity, which concerns the amount of transport-related CO_2 emissions needed to produce one unit of GDP. This, in turn, reflects numerous underlying structural factors such as the geographic configuration of the country, its portfolio of economic activities, the modal composition of the transport system, as well as the fuel efficiency of each transport mode. The second driver of transport emissions is GDP per capita, since as countries grow richer, they tend to consume more transportation services. The third driver of transport emissions is population itself, since the larger the population, the greater the demand for transportation services.

Figure 2. Decomposing the Trend in Global Transport Emissions by Income Group and for Major Countries



Source: Foster et al. 2021.

Analysis reveals that the first driver of transport emissions intensity has declined significantly in most countries. At the global level, the volume of transport emissions associated with one unit of GDP declined by approximately 25 percent between 1990 and 2018. The decline in emissions intensity is particularly evident in HICs and upper-middle income countries (UMICs), but less so in LMICs and low-income countries (LICs) (see the blue line in **figure 2**). Such gains reflect systematic improvements in the fuel efficiency of vehicles, which has been improving at 1.4 percent per annum on average over the period. However, over the same time frame, global population expanded by around 40 percent and GDP per capita grew by around 75 percent. The combined effect of population and

In the future it will be increasingly important for transportation to substitute toward lower carbon sources of energy.

income growth overwhelmed the improvements in transport emissions intensity, leading to an increase in global transport emissions of 80 percent over this period. This is evident across all country income groups, except for the HIC category (see the red line in **figure 2**). The growth in emissions is particularly dramatic in the largest emerging economies (see China, India, and Mexico), except for Russia due to the economic disruption caused by the transition (**figure 2**). If present trends continue, achieving the goals of the Paris Agreement with improvements in vehicle fuel efficiency alone seem unrealistic.

Beyond improving fuel efficiency, in the future it will be increasingly important for transportation to substitute toward lower carbon sources of energy, such as biofuels or electricity. With fossil fuels, notably petrol and diesel, continuing to account for about 90 percent of vehicle kilometers in 2018, there is still a long way to go. However, the experience of a few pioneering countries helps to illustrate what might be possible for others going forward. A notable exception is Sweden, where the share of nonfossil fuel in transport increased from 3 percent in 1990 to 24 percent in 2018. Albania, Finland, and Norway have also made significant strides in increasing the share of nonfossil fuels, going from less than 1 percent in 1990 to about 10 percent in 2018.

What Policies Are Most Helpful in Facilitating Decoupling?

Comparing trends around the world makes it possible to identify what underlying factors are most important in explaining why some countries have been more successful than others at uncoupling transport-related carbon emissions from the growth of the economy.

There is no doubt that structural factors, such as the degree of urbanization and the stage of economic development, can significantly affect transport emissions intensity. As urbanization increases transport emissions intensity initially increase as well—likely due to rising motorization and congestion. However, beyond urbanization rates of around 60 percent, carbon emissions intensity starts to fall—perhaps due to higher urban density and more efficient management of urban transport systems. Transport emissions intensity is also closely related to a country's economic vocation. In general, emissions are higher in countries focused on agriculture, perhaps due to the more geographically dispersed nature of production. Given that these structural factors are not under the immediate control of policy makers, unfortunately they cannot be used as an immediate lever to influence the trajectory of transport emissions. However, they can be expected to yield some benefit over time as countries pass through the typical stages of economic development.

Fortunately, however, transport policy measures also emerge as a significant driver of uncoupling, and these are can be influenced by governments. Perhaps unsurprisingly, the price of transport fuels is found to have a significant impact on emissions intensity. Specifically, a one-standard-deviation increase in diesel price is on average associated with a 3.8 percent reduction in per capita transport CO_2 emissions. In addition, evidence shows that efficient public transport systems—notably the presence of a bus rapid transit (BRT) system—is associated with a lower emissions intensity. Furthermore, stricter environmental regulations on the transport sector—including fuel efficiency standards, tailpipe emissions regulations, driving restrictions, promotion of electric vehicles, promotion of biofuels, research and development, and vehicle emission standards—are found to have a substantial effect sharply reducing per capita transport-related emissions.

In sum, LMICs remain far from achieving decoupling of transport-related emissions from economic growth. Given rapid rates of economic and demographic growth in these countries, historic improvements in transport emission intensity are nowhere near high enough to bend the emissions curve. Looking ahead, it will be critical to both accelerate improvements in the energy efficiency of transportation and switch vehicles increasingly toward less carbon-intensive fuels. Countries with relatively high fuel prices, strong transport sector environmental policies, and well-developed public transport systems are already doing significantly better than others.

The Anticipated Evolution of Transport-Related Carbon Emissions through 2035

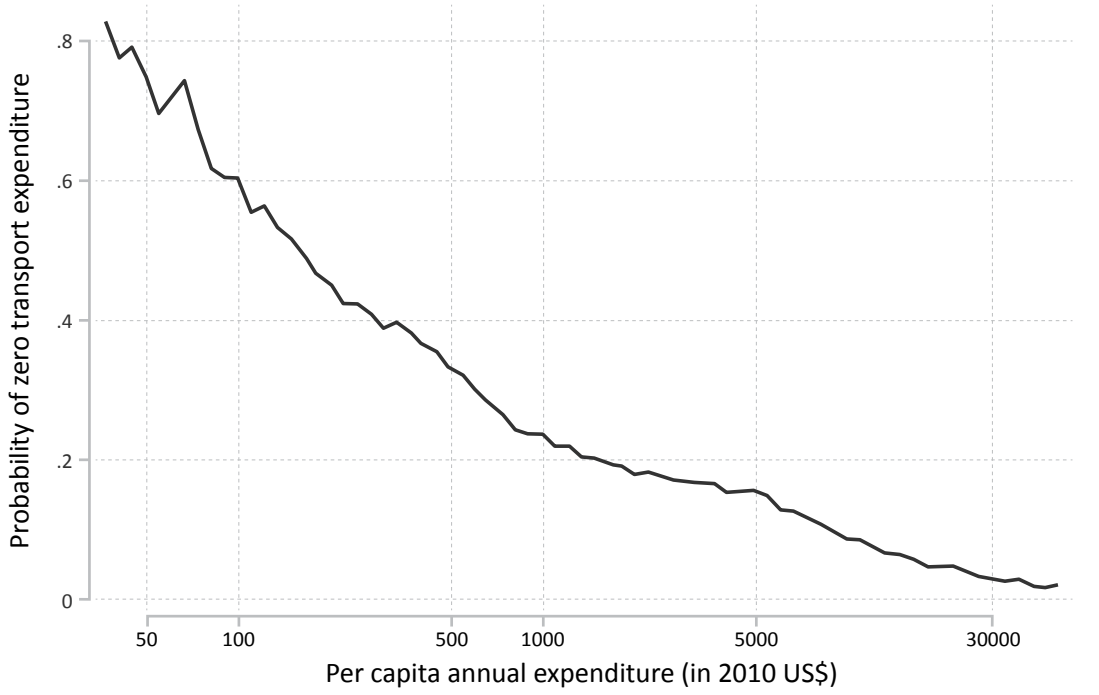
The rapid historical growth rate in transport-related carbon emissions is likely to continue in the absence of major policy shifts. Economic development is associated with higher mobility and associated emissions, as households progress from mainly walking to relying on public transportation services, to acquiring their own two-wheel and, eventually four-wheel vehicles. Little is known about the demand patterns for transportation services in developing countries and how these can be expected to shape emission trajectories over time. Recent research digs deeper into current transport expenditure patterns and uses these insights to project how future transport emissions are likely to unfold (Lebrand and Theophile 2022).

How do transport demand patterns shift as incomes rise?

From recent household survey evidence, it is possible to gain insights into how transport demand patterns are affected by household income. Such surveys report on household transport expenditures, often broken down by different types of transport services. They also typically record ownership of vehicles, and the breakdown between capital costs on vehicle purchase and operating costs on vehicle maintenance and ownership.

The first striking thing is the extent of pent-up demand for transportation. In many of the world's poorest countries, most people do not register any transport expenditures at all, suggesting their mobility is limited to the places they are able to travel on foot. This percentage of zero-transport expenditure observations is very high in countries like Sierra Leone and Malawi (82 percent and 65 percent respectively), but declines steeply as per capita income rises, being negligible in a middle-income country (MIC)—South Africa, for instance. The percentage of zero expenditures is particularly high in countries with annual per capita expenditure below US$1,000 (in 2010 terms), leveling off thereafter (**figure 3**).

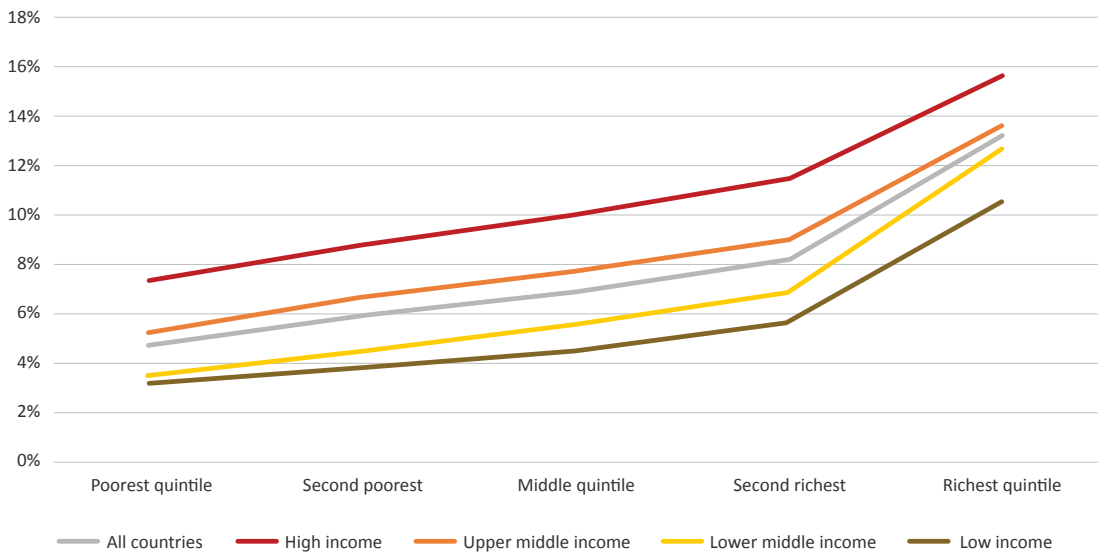
Figure 3. Probability of Spending Zero on Transport Drops Exponentially As Income Rises



Source: Lebrand and Theophile 2022.

Once transport expenditures are registered, these rise steeply with overall household expenditure. On average, households in LICs already dedicate as much as 8 percent of their expenditures to transportation, and this rises steeply to 12 percent in MICs (**figure 4**). The same phenomenon is observed between richer and poorer households within countries, with households in the poorest budget quintile dedicating just 5 percent of their meager budgets to transportation, whereas households in the richest budget quintile allocate as much as 15 percent of their much higher expenditures to transportation (**figure 4**). Indeed, household expenditures on transportation are found to rise much more rapidly than overall family budgets.

Figure 4. Transport Expenditure Shares Rise with Income Both Across and Within Countries



Source: Lebrand and Theophile 2022.

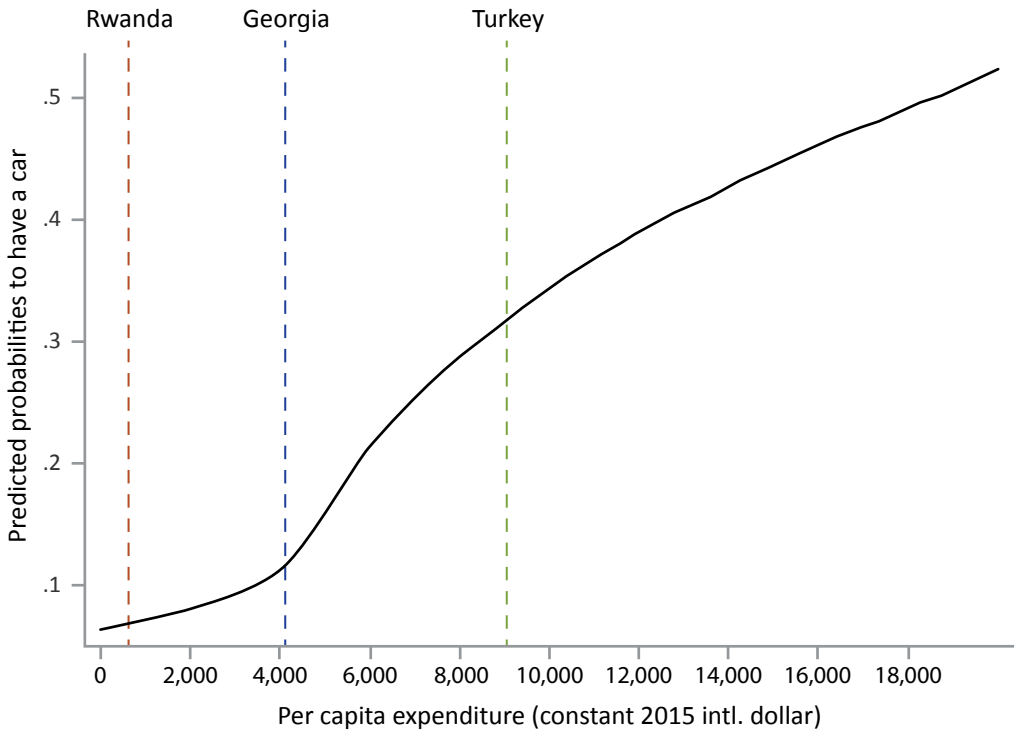
Further insights on spending patterns can be obtained by unpacking transport expenditures between those allocated to the purchase of public transportation services (including buses, trains, and ride sharing) versus those associated with the acquisition, maintenance, and operation of private vehicles. Interestingly, expenditure on public transportation services tends to occupy a constant expenditure share as household budgets rise, whereas expenditure on private vehicles rises twice as rapidly as household spending overall—suggestive of a luxury good.

In fact, doubling per capita income is found to increase the probability of private car ownership by 10 percentage points. The relationship between household budget and the probability of owning a car follows an S-shaped curve, which shows that as countries get richer, household budgets increase, and more households acquire cars (**figure 5**). Indeed, the probability of car ownership rises most steeply for countries with per capita

expenditure levels higher than US$4,000 per year—equivalent to those found in Georgia in 2015 (**figure 5**). The intensity with which cars are driven is also strongly related to income, in that a one percent increase in per capita budget was found to increase miles driven by 0.5 percent.

Interestingly, while motorcycle ownership is also highly sensitive to rising incomes, motorcycle ownership patterns are more idiosyncratic than those for cars. Ownership rates differing dramatically across countries, reflecting local preferences, based on factors such as culture, weather, and ready availability of vehicles.

Figure 5. The S-Shaped Relationship between Expenditure and Car Ownership in Rwanda, Georgia, and Turkey, in 2015

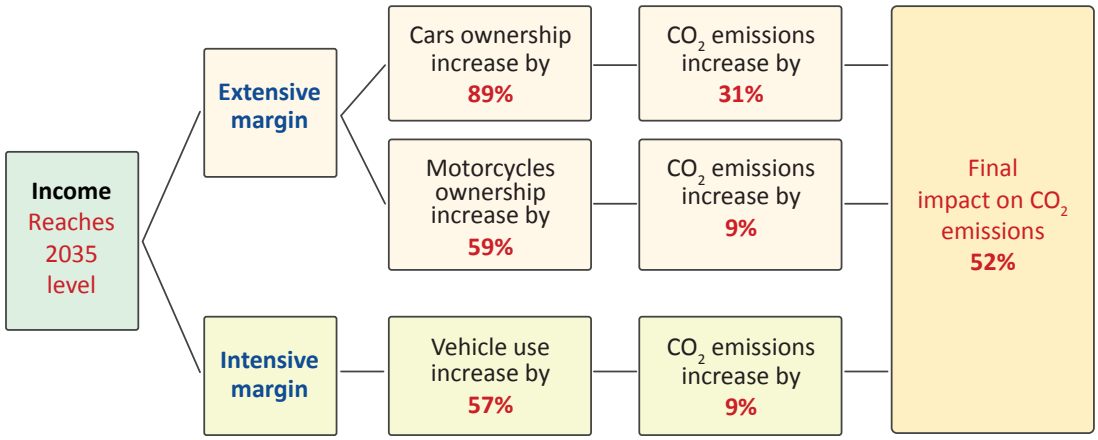


Source: Lebrand and Theophile 2022.

What does this entail for future transport-related carbon emissions?

Overall, the carbon footprint of the transport sector for the subset of countries included in the study is anticipated to increase on average by 52 percent by 2035 (**figure 6**). The percentage increase ranges considerably across countries, ranging from around 25 percent in Mali to 175 percent in Sierra Leone. These increases are attributable primarily to increases in first-time car ownership, which almost doubles over this period. Motorcycle ownership is also projected to rise by more than 50 percent, however the impact on emissions is considerably smaller. While carbon emissions per capita from transport increase by about 35 percent when the average number of cars per household doubles, the equivalent increase for a doubling of motorcycle ownership is just 15 percent. Additionally, existing vehicle owners also expand their use by more than 50 percent, although the impact of this on carbon emissions is much smaller than that coming from the expansion of vehicle ownership (**figure 6**).

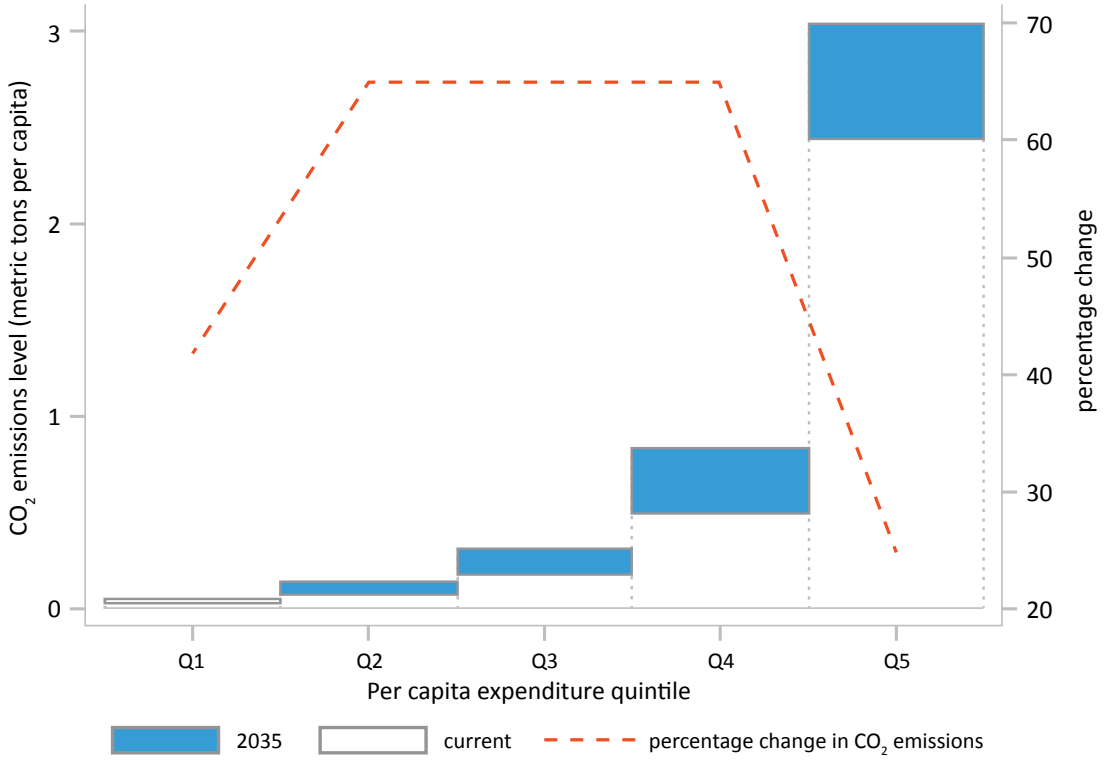
Figure 6. Understanding the Contribution of Different Factors to Transport Emissions Growth



Source: Lebrand and Theophile 2022.

Transport-related carbon emissions are already highly concentrated among the richest, with the top budget quintile currently responsible for more than twice as many emissions as all the remaining quintiles put together (**figure 7**). While the percentage growth of emissions for the top quintile is relatively low compared to the others, in absolute terms the additional emissions generated by those at the top of the distribution continue to exceed the growth in emissions from all other quintiles combined. Overall, the inequality of transport-related carbon emissions is projected to increase in some countries, while decreasing slightly in others.

Figure 7. Distributional Incidence of Current and Projected Carbon Emissions from Transportation



Source: Lebrand and Theophile 2022.

In sum, as countries get richer, households will increase their relative spending on transport, be more likely to own a car, and switch from public to private transport mode. In poorer countries, a large share of households, currently not spending on transport, will start using transport services or want to own a vehicle. The demand for private vehicles is therefore expected to increase significantly as countries get richer. These results suggest a future steep growth of emissions as incomes expand and one that is relatively concentrated among the richer segments of the population.

Policy Implications

The findings of this research suggest several important policy recommendations relevant for countries striving to reduce the carbon footprint of their transportation sectors. First, given the pace of demographic and economic growth and its impact on carbon emissions, policies that help to manage this demand through transit-oriented urbanization patterns have an important role to play.

Second, for uncoupling to be achieved, the rate of improvement of transport emissions intensity needs to be substantially higher than the combined pace of demographic and economic growth. This means setting much more ambitious targets for the reduction of emissions intensity, both through improved energy efficiency of the transportation system, and via switching toward less carbon intensive fuels.

Third, the pricing of fossil fuels for transportation is an important policy instrument for curbing transport-related emissions, suggesting the importance of prioritizing fossil fuel subsidy reform.

Fourth, development of well-functioning public (and increasingly shared) transportation systems is a critical component of any transport decarbonization strategy.

Fifth, many countries sit on the cusp of a rapid increase in car ownership rates, which are the single largest determinant of future transport sector emissions. Tight management of this process will be critical to curbing future sector emissions.

Sixth, we see a strong equity dimension to transport sector decarbonization, given that the poorest make almost no use of transportation services, and carbon emissions are highly concentrated in the richest quintile. This suggests the importance of ensuring that basic mobility needs continue to be met, while penalizing high carbon transportation patterns among the richest.

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Authors:
Maria Lopez Conde and Grace Naa Merley Ashley,
The World Bank

Role of Digitalization in Overcoming Supply Chain Challenges

The past three years have been marked by disarray in global trade and supply chains caused by a series of unprecedented global events. From the impact of the COVID-19 pandemic on supply chains and trade, to the lodging of the Ever Given in the Suez Canal and the Russian invasion of Ukraine, these shocks have exposed the vulnerability of globalized and interconnected supply chains. These events have led to higher shipping costs and lower maritime connectivity, and consequently, inflation and food shortages that have dealt a blow to the world's poorest populations (UNCTAD 2022). While some critical logistical chains remained operational and allowed essential goods to flow between and within countries, these stresses have highlighted the importance of increasing resilience and robustness (Iakovou and White 2020) in supply chain design and operation. Enter then, digitalization, a solution that leverages technological advances and the ongoing digital revolution to boost resilience in supply chains, increasing business confidence and enhancing food security. This article summarizes the features of the main supply chain shocks that have affected the maritime and logistics sectors in the past three years and proposes digitalization alternatives that can help prevent or mitigate the impact of these shocks on supply chains, food security, and inflation.

PART I

COVID-19

About the Author

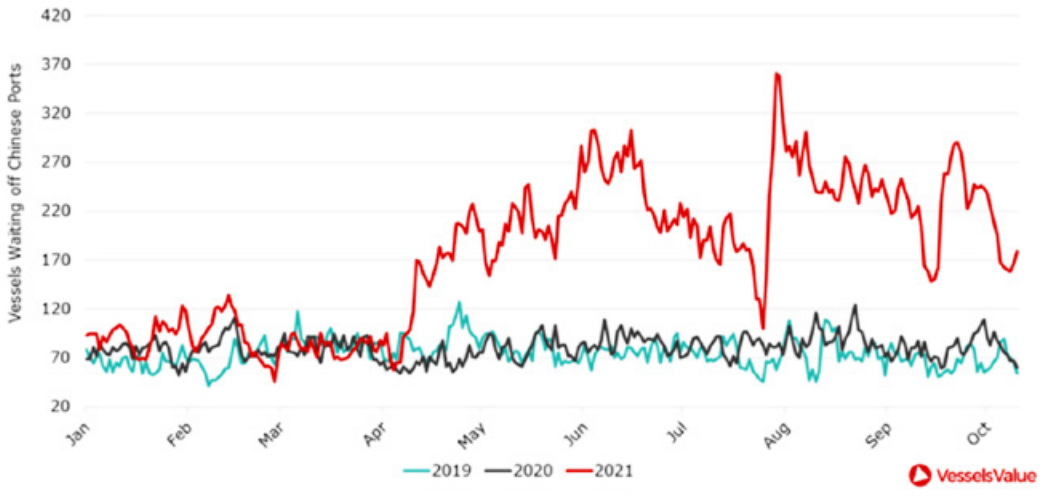
Maria Lopez Conde is an Associate Operations Officer at the World Bank.

For one, the COVID-19 pandemic, which has and continues to take a significant human toll, has also caused disruption in supply chains around the world, keeping valuable medical supplies, food, and critical agricultural products, energy streams, and other products from reaching their final destinations.

This impact is evident in the shipping sector, which is responsible for carrying over 80 percent of global trade (UNCTAD 2022) by volume. The uncertainty brought about by the COVID-19 pandemic as well as the measures to curb it, resulted in substantial imbalances between supply and demand that affected world trade. This was felt most severely in the second quarter of 2020, when goods trade fell by 23 percent in value terms (WTO 2021a). There was a modest recovery of trade in the second half of 2020, driven by partially reopened households and businesses, plus fiscal transfers in several countries; however, this has varied across regions. World trade improved as lockdowns and mobility restrictions shifted spending away from services to goods, such as computer-related equipment, personal protective equipment, and other items. As a result, world merchandise trade fell less than expected, contracting by only 5.3 percent in 2020 (WTO 2021b).

As demand for consumer goods began to rise in mid-2020, bottlenecks and constraints appeared in global supply chains, resulting in record-high shipping rates. Container freight rates were five times their prepandemic levels in 2021 (UNCTAD 2022). Shipping analytics firm Drewry's World Container Index (WCI), which is a composite of container freight rates on eight major routes to and from the United States, Europe, and Asia, hit a record US$10,377 in September 2021 (Kang 2023)—much higher than the average 2019 (prepandemic) rate of US$1,429.

Figure 1. Daily Container Vessels Waiting in China 2019 to 2021



Source: VesselsValue.

Port handling capacity constraints: Port handling capacity constraints were one symptom of the imbalance. These resulted in congestion and long queues at import and export ports globally. Landside container handling constraints, a limited labor pool (Dixon and Hadland 2021) for truck drivers as well as port and warehousing staff due to COVID-19, also played a role. While liners can dispatch more vessels to meet higher demand, ports cannot easily do the same with labor or container handling equipment. High absenteeism due to COVID-19 or quarantine requirements also affected the trucking industry, reducing the number of vehicles available on which to offload cargo. All these factors cascaded through the supply chain, causing significant disruptions and delays. One visible symbol of the congestion were the multiple reports of vessels waiting offshore outside major ports, such as Los Angeles and Shanghai. As seen in **figure 1**, there were nearly 370 container vessels (Cook 2021)—much higher than previous months—waiting at anchorage outside major Chinese ports in August 2021. For example, the Port of Los Angeles saw ships waiting an average of 16 days for a berth (Murray 2021) in mid-2022, compared to two days in mid-December 2022.

High demand for consumer goods out of Asia led to a shortage of containers, primarily there, but also around the world.

Container shipping services follow fixed schedules (World Bank 2022) with vessel turnaround at each of the ports of call within the allocated time for port stay. Berthing windows are pre-agreed, which allows for additional predictability and reliability. Poor performance at one port on the route can disrupt the entire schedule, leading to canceled calls, blanked sailings, or stranded containers. This is what happened in the congestion hot spots: the United States, Europe, and China. Unplanned time in port or at anchorage requires increasing fuel consumption, costs, and emissions—both while waiting and while speeding up to make up for lost time.

Empty container shortage: To further complicate matters, the high demand for consumer goods out of Asia led to a shortage of containers, primarily there, but also around the world. This was also driven by trade imbalances. The United States and Europe receive more containers from China than they send back. When there is an equipment shortage, higher-value goods crowd out low-value goods (Murphy 2021) so the adverse impact is more significant for low-value cargo shippers.

Impact on the world's poor: The ongoing supply chain disruption triggered by the COVID-19 pandemic has also led to an increase in consumer prices as high shipping rates have been passed on to the consumer. As inflation began to rise, countries began tightening monetary policy, resulting in an overall cost-of-living crisis that would later be exacerbated by the grounding of the Ever Given and the War in Ukraine. In 2022, global inflation levels hit their highest point since 2008 (Vorisek et al. 2022). High inflation eats up most of the poor's income, which, in many places, is already spent mostly on food.

Figure 2. The Ever Given in the Suez Canal, March 2021

Source: Planet Labs, Inc.

The Ever Given

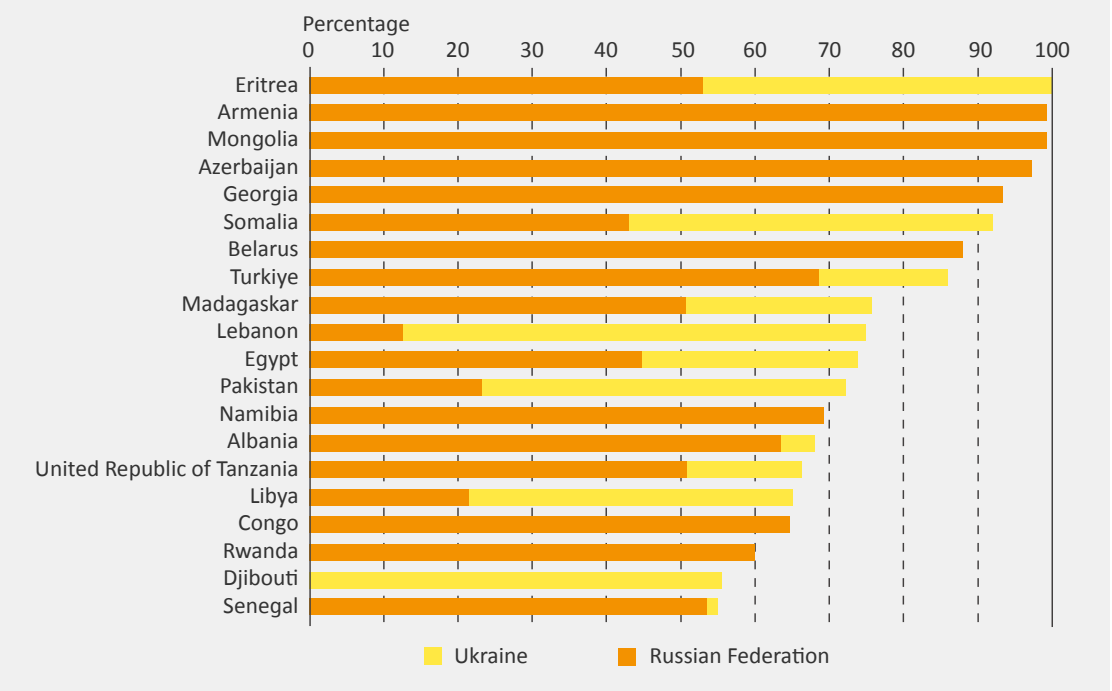
Add to that the chaos resulting from the grounding of the Ever Given, the massive containership that became firmly lodged in the Suez Canal in March 2021 (see **figure 2**). The Ever Given's widely documented plight created a large backlog of ships and merchandise in one of the world's key shipping hubs.

Built between 1850 and 1869, the 120-mile-long Suez Canal connects the Mediterranean Sea to the Red Sea through the Isthmus of Suez. About 10 to 13 percent (Jones, Faucon, and Paris 2021) of global trade, including 7 percent of the world's oil (Debre 2021), is estimated to pass through the canal, which is the most efficient marine shortcut between Asia and Europe. Nearly 19,000 ships (The Economist 2021) passed through the canal in 2020. This means that around 50 vessels per day were getting stuck behind the Ever Given, feeding congestion and uncertainty for shippers worldwide as well as higher consumer prices. During the six days it blocked the canal, the Ever Given held up U$60 billion in trade (Christian 2021) based on the value of goods moved through the canal (westbound U$5.1 billion a day, and eastbound U$4.5 billion a day). This does not include the US$400 million in merchandise that the more than 20,000 twenty-foot equivalent unit (TEU) vessel was carrying.

Russian Invasion of Ukraine

Finally, the Russian invasion of Ukraine in February 2022 dealt another blow to supply chains, capping off a year of turbulence for transport and logistics operators, and those that depend on the goods they carry. Russia's war on Ukraine and the sanctions imposed against the former have exposed the vulnerability to the security of the supply of raw materials (OECD 2022a) critical for industrial production. This is due to the widespread destruction of Ukraine's infrastructure, including roads, bridges, seaports, and railways. Estimates from the Kyiv School of Economics place infrastructure damages at US$95.5 billion as of June 13, 2022. Another analysis from August 2022 (World Bank 2022), places damages and losses to Ukraine's transport infrastructure at US$29.9 billion and US$26.1 billion. Overall damages include 8,699 kilometers of motorways and other roads, 1,199 kilometers of railway lines, 93 railway stations, and 16 airports. Losses include the lack of Black Sea transport.

Figure 3. Russian Federation and Ukraine Wheat Export Dependency

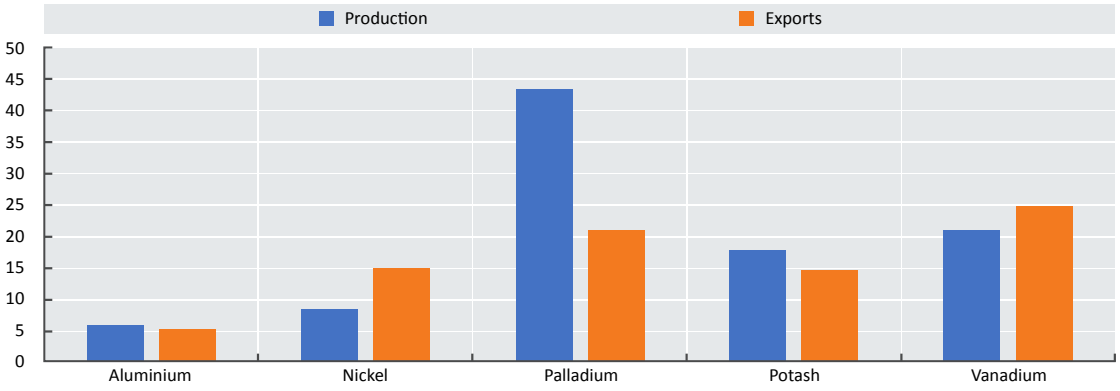


Source: FAO 2022.

The price of oil, gas, and some agricultural products increased, escalating inflation pressures and threatening food security. With 55 percent of its land suitable for agriculture, agriculture, forestry, and fishing represented over 10 percent of Ukraine's gross domestic product (GDP) in 2021 (World Bank 2021). Contrast that with the United States, where the same figure is slightly above 1 percent (World Bank 2021). Ukraine's wheat production (FAO 2021) is 3.2 percent of global production, and exports are 9.1 percent of the global wheat exports.

With life disrupted by war, many agricultural laborers are involved in the war effort and crops have not been harvested. A lack of fertilizers, often produced in Russia, is another factor affecting the food supply in the country and low-income food importing countries. With key transport hubs closed or damaged because of the conflict, exports cannot easily depart, and freight rates have gone up. This has an impact on food security elsewhere, given that many countries, including low-income countries, source their key grain imports from either Ukraine or Russia. The most recent data show that 25 countries (FAO 2022) depended on Russia and Ukraine for at least 50 percent of their wheat imports in 2021 (see **figure 3**). The list of 25 includes nations in Africa and Western Asia, especially vulnerable to the situation in Ukraine, specifically the "low-income food deficit countries" such as Eritrea and Somalia (FAO 2022). Though precise data is not available, research suggests the number of undernourished people in 2022 has increased by anywhere between 7.6 and 13.1 million (FAO 2022). Freight rates for dry bulk increased due to the war in Ukraine. An UNCTAD simulation shows that higher grain prices and dry bulk freight rates in early 2022 led to a 1.2 percent hike in consumer food prices, with higher increases in middle- and low-income countries. Price increases to an already food insecure or hungry population, estimated to be around 850 million (Strubenhoff 2022) worldwide, could lead to greater poverty and social unrest, according to the Global Hunger Index.

Figure 4. Russia's Share of Global Production and Exports of Selected Raw Materials in 2020



Source: USGS Mineral Commodity Statistics and UN Comtrade, published in OECD 2022b.

In addition, sanctions on Russia affect the metal trade—the raw materials essential to manufacturing supply chains (**figure 4**). Take aluminum, an important input into the manufacturing of cans, kitchen appliances, and vehicles. Russia represents 5.5 percent of the world aluminum production and around the same for exports. Russia's share might seem small, but some countries are highly dependent on those imports. For example, Turkey sources 35 percent of its aluminum from Russia (OECD 2022b) and Japan imports more than 10 percent of its aluminum from Russia.

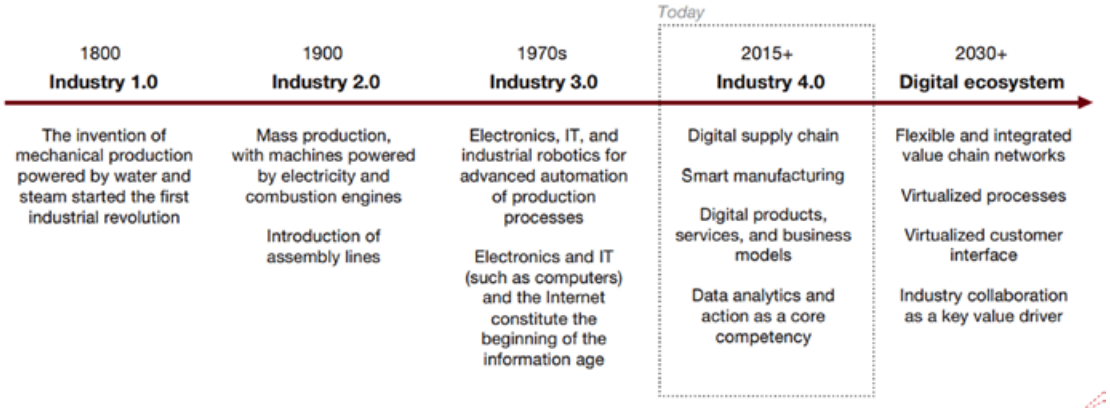
PART II

About the Author

Grace Naa Merley Ashley is a Transportation Consultant at the World Bank.

The global supply chain comprises several isolated procedures like product development, manufacturing, and distribution, which ultimately result in delivery to the customer or consumer. For years now, many supply chains have been run on outdated technology that seemed to be adequate until the intensity and nature of challenges changed recently. Although risks are now higher for all establishments connected to the supply chain, smaller establishments are struggling more to stay afloat (Macfarlane 2022). To overcome current challenges and in anticipation of any further catastrophes, steps must be taken to exponentially improve risk mitigation by converting the largely isolated procedures in the supply chain to a seamless and integrated system with enough transparency about the various processes to give all stakeholders confidence in the system (PWC 2016). Digitalization of the supply chain is a great way to connect suppliers, transporters, and customers in this manner. Digitalization is part of the fourth industrial revolution (see **figure 5**) where establishments are encouraged to connect with patrons using vehicles such as digital marketing, social media, and ecommerce (Gadaev 2022).

Figure 5. Stages of the Industrial Revolution



Source: PWC 2016.

Generally, an organization connected to the supply chain has a vision with clearly stipulated goals, which is directly related to its specific role within the chain. Digitalization of the supply chain starts with each organization adopting and integrating digital technologies into the processes, which lead them to achieving their objectives. Some of the immediate advantages realized upon implementing this include operational and energy efficiency as well as schedule reliability. Examples of digital technologies that can be adopted include the Internet of Things (IoT), cloud computing, predictive technology, and big data analytics. Discussions around implementing digitalization often boil down to the role of individual technologies and how they can be combined to overcome current supply chain challenges. Some of these are presented below:

The Role of IoT

IoT is simply explained as a system where multiple physical devices are connected via the internet. Operational efficiency can be improved when robots and automation are introduced into the supply chain. Ports can benefit from real-time tracking of their processes through sensors designed to detect bottlenecks and resource leakages (Zubovich 2022). Rubber tiered gantry cranes (RTGs) used to stack containers can be autonomously controlled to increase efficiency by automating the movement of containers to increase safety. RTG automation is projected to produce a 20 percent reduction of maintenance in ports. Maintenance scheduling can be improved using trackers designed to monitor equipment health. Warehouses are now leveraging radio frequency identification (RFID) to get access to real-time inventory tracking data. In freight fleet management, sensors are employed to obtain information on tracking of location and traffic patterns. These boost transparency and reliability.

The Role of Blockchain

Blockchain is a category of distributed ledger technology (DLT), which is typically shared and immutable for the purposes of recording transactions and keeping tabs on assets. This makes it a prized asset when establishing audit trails for companies embedded in the supply chain (**figure 6**). Blockchain helps in tracking goods, thereby providing information on counterfeit goods and attempted fraud, given the security challenges that plague the supply chain (Singh 2022).

Miscommunication between parties in an outsourced contract can be managed with blockchain technologies. Errors created in the process of data transfer can also be minimized, especially when establishments are trying to increase reliability. Time spent doing this manually can then be allocated to improving other processes in the supply chain (Laaper et al. 2017).

Figure 6. Global Blockchain Market in Supply Chain Industry

Source: Singh 2022.

The Role of Big Data Analytics

To improve efficiency in the supply chain, strategies founded on big data analytics can be developed. Some of these include:

- **Delivery promise optimization:** Artificial intelligence (AI) algorithms can be used to analyze in real time the factors that affect schedule reliability to optimize the process. To undertake this analysis, data on historical and current origins, port efficiency, lead times, vendors, service-level agreements, customers, and locations must be available (Verma and Shivsharan 2022).

- **Transportation optimization:** In the face of a crisis, optimization algorithms rooted in AI can determine the right proportions of rail, road, sea, and air transport that can effectively transport goods in the most effective manner, saving time and money. Utilizing origin-destination (OD) data on all modes of transport can provide multiple solution scenarios, each of which can be used depending on the current and advancing nature of a crisis situation (Verma and Shivsharan 2022).

- **Inventory planning:** In this age of digital development, many companies have recognized the advantages of using smart inventory management tools to monitor inventory and forecast disruptions and delays in obtaining new stock. The use of these smart tools often creates an avenue to obtain high quality data that can be fed into AI optimization algorithms that can produce information on road traffic, port congestion, and changes in lead-time (Verma and Shivsharan 2022).

Certifiable global examples of digitalization exist where the use of big data has enhanced regular port operations. First is the "PortXchange" platform used by the Port of Rotterdam for port call optimization. Another is "Project Portify," a data platform that provides time-related vessel data (Inkinen, Helminen, and Saarikoski 2021).

The Role of Cloud Computing

Cloud computing gives stakeholders the opportunity to make swift decisions concerning the supply chain by making sure that they have the real-time visibility needed to make the best choices. Challenges concerning scalability of operations can be overcome in a cost-effective manner through cloud computing. Forecasting and planning has been made much easier through cloud computing despite the increasing rate of demand currently being experienced in many sectors. It is used to obtain and centralize information on all stakeholders in the chain in anticipation of analytics that could give insight into different aspects of supply chain processes (PAT Research 2021). Finally, cloud platforms can develop contracts automatically and order supplies when they are almost out of stock. Wabtec Corporation launched the Port Optimizer, a cloud-based software initiative that utilizes data from the port system (Wabtec Corporation 2022). Its role in the supply

chain involves monitoring and responding to changing port conditions and matching human capital to resources. These have resulted in a success story that has seen the Port of Los Angeles increase throughput and improve delivery performance.

Although digitalization aids in risk mitigation, accurate forecasting, detection of errors, improvement of schedule reliability, and technology management, some organizations are quite skeptical about its adoption (Naz et al. 2021). The skepticism is largely because of issues related to cybersecurity and perceived risks. This perception is principally due to ignorance about cybersecurity and insufficient funds to properly invest in it (Almeida, Santo, and Monteiro 2020). Incident-free successes chalked by organizations that have embraced digitalization can be used as vehicles to quash negative perceptions about its adoption.

How the World Bank Can Support Digitalization

Friction in global trade and supply chains caused by a series of unforeseen global events can eventually escalate, resulting in food insecurity and increased food prices in the more vulnerable countries. These countries are therefore mobilizing internally and seeking help to better their policy structures, create technical and training programs, and fund enterprises that promote digitalization.

The World Bank Group (WBG) is currently one of the world's largest sources of funding and knowledge for developing countries. The WBG considers digitalization to be aligned with its agenda to reduce poverty, increase shared prosperity, and promote sustainable development in client countries. In the maritime sector, WBG offers support to developing countries through policy advice, research, and analysis—along with targeted technical assistance to build capacity and development human capital in client countries.

On the knowledge side, the World Bank is also working with key stakeholders, such as the International Association of Ports and Harbors (IAPH) as well as the World Ports Sustainability Program and their members, to publish technical reports that can stimulate dialogue among key actors in this space and move this essential agenda forward. In late 2020, the World Bank and the IAPH published *Accelerating Digitalization: Critical Actions to Strengthen the Resilience of the Maritime Supply Chain* (World Bank 2020), a report showing that better digital collaboration between private and public entities across the maritime supply chain will result in significant efficiency gains, safer and more resilient supply chains, and lower emissions. In addition, the WBG can also mobilize financing for clients at different stages of their digital development path. The WBG can mobilize grant financing, subject to a successful application, from a range of potential sources—including, the Digital Development Partnership (DPP), the Public-Private Infrastructure Advisory Facility (PPIAF), and the Global Infrastructure Facility (GIF)—to facilitate upstream investigations to support clients in making informed choices about their digitalization path. For example, the WBG can mobilize grant financing to fund a

digitalization readiness assessment to identify investment opportunities and upgrades for port authorities in its client countries.

The WBG can also facilitate financing (concessional or semiconcessional finance) for approved investments or partner with private finance to finance digitalization efforts (World Bank 2020). In countries like Mozambique, Malaysia and Belize, the WBG is facilitating studies that identify the nature and extent of any policy or regulatory impediment to commence or continue the digitalization journey and document the current status of digitalization and cyber-security.

Summary and Conclusion

Recent shocks, such as COVID-19, the Ever Given's blocking of the Suez Canal, and the war in Ukraine, have underscored the importance of increasing resilience and robustness in supply chains. Although some critical logistical chains managed to weather this storm of unprecedented events, these incidents have exposed vulnerabilities in the supply chain that considerably hinder the flow of essential goods between and within countries. Shipping rates multiplied by greater than five times the prepandemic rate due to increased demand and these costs were inevitably passed on to the consumer. Problems emerging from these unforeseen events included port handling capacity constraints resulting in congestion and long queues at ports globally, anxiety fueled by uncertainty, empty container shortage and destruction of critical transport infrastructure (due to the Ukraine war).

The intensity of the challenges shone a light on the fact that the outdated technologies being used by supply chains are woefully inadequate. Digitalization, a solution that leverages technological advances, can boost transparency and resilience in supply chains. IoT, blockchain, big data analytics and cloud computing can allow stakeholders the opportunity to increase efficiency, make better decisions with real-time visibility. This will help manage congestion and shortages that arise from shocks to the supply chain and assuage fears of extreme food insecurity and increased food prices.

The WBG is committed to funding, financing, and sharing knowledge on digitalization, and considers it a useful process that fits in its agenda to reduce poverty, increase shared prosperity, and promote sustainable development in client countries. Sources such as DPP, PPIAF, and GIF can be accessed by interested client countries to pursue digitalization of their supply chains. Recently, many more countries have warmed to the idea of digitalizing the supply chain; however, they must remember that at the heart of this process is the availability of usable data—the building block that needs to be secured to implement the tools of digitalization.

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Authors:
Megersa Abate,
The World Bank,
Tommy Cheung,
Swinburne University of Technology,
Anming Zhang and Yilin Zhang,
University of British Columbia

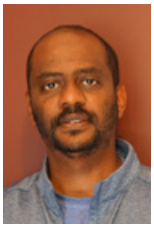
COVID-19 Pandemic and Air Connectivity Trends in Southern Africa[1]

What we did

This article analyzes the factors determining intraregional air transportation in Southern Africa and the impact of the COVID-19 pandemic on the pattern of air connectivity. It does this by examining the geospatial characteristics of air transport network, airport connectivity, and market structure before and after the pandemic in Botswana, Eswatini, Lesotho, Namibia, and South Africa. It also explores the progress of air transport liberalization in the region and its impact on market structure and airline privatization.

1 We would like to thank Xiaoqian Sun and Sebastian Wandelt for providing data support.

About the Authors



Megersa Abate is a Transport Economist at the World Bank.

Tommy Cheung is a Senior Lecturer, Department of Aviation at Swinburne University of Technology.

What we found

Four key results are worth highlighting. First, although an interruptive and negative event, the pandemic has improved Africa's overall airport connectivity relative to the world. In the Southern Africa region, however, this was not the case: airports actually become less connected. Second, the pandemic has altered the structure of the Southern African airline market by lessening competition and reversing the market share in favor of privately owned carriers. Third, a gravity model of the determinants of intraregional connectivity shows that the factors promoting connectivity include economic levels, air transport liberalization, presence of low-cost carriers, airline privatization, and tourism resources, while high market concentration and diplomatic disagreements are among the hindering factors. Fourth, analysis shows that liberalization facilitated market competition and the progress of privatization, but its influence faded quickly, and it appears to be further delayed by the impact of the pandemic.

What we learned

We gleaned three important policy implications from the analysis. First, the pandemic and the associated government restriction measures severely hit the intraregional air transport supply and demand, while the vaccination program significantly promoted the recovery of air transportation. Second, liberalization movements could significantly promote the intraregion air connectivity. Although all five countries in Southern Africa have signed the agreements to establish the Single African Air Transport Market (SAATM), most of them have not fully implemented it. To facilitate intraregional air transport connectivity in the long term, countries' commitment to the full implementation of the liberalization and integration initiative is needed. Third, encouraging both the participation of private airlines in air transportation and the development of low-cost carriers can promote market competition, air connectivity, and traffic.

Background

The COVID-19 pandemic has resulted in an unprecedented downturn in air transport activity globally, impacting economies and livelihoods dependent on travel and tourism. The situation has been exacerbated in developing countries where the aviation sector has long been facing multipronged challenges, including profitability, safety, security, and sustainable financing of critical infrastructure, that predate the current crisis. Due to connectivity disruptions caused by the pandemic, many countries' air transport sectors and key travel-dependent industries are under stress.

About the Authors

Anming Zhang
is the Professor at Sauder School of Business at UBC.

Yilin Zhang
Sauder School of Business at UBC

Much like the rest of Africa, the Southern African region is characterized by the dominance of troubled state-owned airlines, which have been unable to generate meaningful positive returns for many years due to structural inefficiencies and weak governance. At the end of 2019, five state-owned carriers in South Africa, Botswana, and Namibia accounted for 43 percent of capacity share of these domestic markets (down to 30 percent in 2020) and 80 percent of regional international seat capacity (down to 73 percent in 2020). As the main poorly performing state-owned enterprises (SOEs), Air Botswana, Air Namibia, and South African Airways (SAA) contributed to increased government spending, fiscal deficits, and public sector debt through large budgetary transfers and growing contingent liabilities. All three have been unable to generate meaningful positive financial returns for many years due to structural inefficiencies, shady procurement practices, soft fiduciary controls, poor management, and weak governance. They faced elevated costs arising from bloated wage bills and needed several bailouts and turnaround strategies, though these were ultimately unsuccessful. The region, however, is also home to some of the most profitable privately owned airlines on the continent.

While there is a positive link between air transportation and economic development, the air market in Africa as a whole is far from open and sustainable. Efficient air transport can act as a facilitator in the development of more diversified export-based industries, which in the presence of links with other domestic economic sectors can act as a stimulus for broadly based growth (Njoya and Nikitas 2020; Tolcha et al. 2020; Button et al. 2015). However, heterogeneous and delayed implementation of continental liberalization policies have prevented the positive link between air transport and the economy from reaching its full potential. As a result, despite the growth in traffic capacity and the increases in both the number of airlines and the level of competition, air transportation in Africa is still suffering from some long-standing weaknesses, including a lack of interconnectivity, an unbalanced traffic distribution, high fares and airline costs, and sparse demand.

Given that air passengers and air cargo are important drivers for a country's tourism, international trade, industrial and social development, it is essential for policy makers and industry practitioners to better understand which factors determine the growth of the sector. Being the relatively more mature market and accounting for 20 percent of Africa's air traffic, a healthy airline industry and sustainable air transport policies in South Africa are critical in the development of aviation and overall economy for the region. The potential for (among others) tourism-related air traffic is high in the region, yet the market as a whole is not fully open and sustainable. In this context, this article examines geospatial and economic characteristics of the domestic and cross-border air traffic flows in Southern Africa, and empirically explores the factors that shape them and the associated implications of its air transport connectivity. It is concerned mainly with five southern African countries: South Africa, Namibia, Botswana, Lesotho, and Eswatini.

Impacts of COVID-19 Pandemic on Air Connectivity Patterns and Market Structure

Africa Air Connectivity Patterns Pre- and Post-Pandemic

Prior to the COVID-19 pandemic, the "country network" of intra-African air flights shows that several countries along the coastline, including South Africa, Ethiopia, Morocco, Kenya, and Cote d'Ivoire, appeared to act as bridges for connecting African countries (**figure 1**). South Africa was the most intraregionally connected country in Africa, and it was also the continent's largest airline market, accounting for about 20 percent of its air traffic. Starting in March 2020, initial changes have been observed, which mostly consist of flow reductions in the northern parts of Africa. Morocco and Tunisia, in particular, reduced their intracontinental flights. Several other African countries, including South Africa, on the other hand, have shown a less significant reduction in connectivity and flow magnitude, indicating that in March 2020 Southern Africa was still well connected. Starting in April 2020, almost all intra-African flights have collapsed; a recovery gradually started in July/August 2020. By the end of 2020, the connectivity of the African country network largely recovered, but the flows have been smaller compared to the first two months of 2020.

South Africa was the most intraregionally connected country in Africa, and also the continent's largest airline market.

A similar impact has been registered in the Southern African market, one of the essential connectivity nodes in Africa, where connectivity dropped to the point of becoming almost nonexistent during the COVID-19 outbreak of May/June 2020. Somewhat strikingly, these highly connected countries have also been identified as having high correlation with the evolution of the COVID-19 virus. In other words, air transportation could indeed play a critical role in the spread of the virus in Africa, an observation consistent with the literature using data from other parts of the world (Sun et al. 2022). The other African countries, whose air transport volumes and degrees of connectivity have been much lower, were less synchronized between the air connectivity and COVID-19 spread; rather, they appeared to have developed with their own epidemiological characteristics.

Africa was almost disconnected from the other continents and regions between April and June 2020, due largely to the flight bans adopted by the other countries. During the same time period, most African governments also took drastic control measures, all of which helped contain the spread of the virus in Africa.[2] This has been confirmed by Sun et al. (2022) who argue that Africa's low air transport connectivity can be another potential

2 The phenomenon of the much lower number of COVID-19 cases and deaths in Africa has been considered as a "puzzle," in that at the early stage of COVID-19 crisis, the African continent was predicted, by both scientists and the public, to face a tremendous number of cases and fatalities. In the literature, several explanations for the unexpected performance have been proposed, including a relatively young population in Africa, more historical-driven preparedness to other types of coronavirus and diseases, and a limited amount of testing.

explanation independent of the existing explanations. Using flight data for 2020, they explore how changes in the system correlate with evolution of epidemiological indicators and suggest that Africa's low air connectivity is a factor for the relatively smaller spread of COVID-19.[3]

As a result of its relatively less severe COVID-19 crisis, Africa has actually gained in airport connectivity against the rest of the world (**table 1**). No African airports were ranked in the top 70 in the world in 2019. But in 2020, CAI (Cairo International Airport) jumped to no. 67.[4] In 2020, the top three airports in Africa average at no. 87, an improvement of 17 positions in the world (the same average is 104 in 2019). Further, the average ranking for the top 10 African airports is 181 in the world (versus 202 in 2019), whereas the average world ranking for the top 20 African airports is 272 (versus 298 in 2019). Against this trend is JNB's position, however: JNB (Johannesburg O.R. Tambo International Airport) actually falls back, from no. 112 in the world in 2019, to no. 135 in 2020 (and from the second most-connected African airport in 2019, to the fourth position in 2020). Overall, while the pandemic has reduced global air connectivity significantly, 11 of the top 20 ranked airports in Africa improved their global ranking in 2020. LOS (Lagos, Nigeria), for instance, jumps from no. 315 to no. 245, an improvement of 70 positions. We observed similar trends in 2021 as well.

As a result of its relatively less severe COVID-19 crisis, Africa has actually gained in airport connectivity against the rest of the world.

The Southern African region's domestic, regional, and international air traffic and network patterns significantly changed under the impact of the pandemic, and so far, the recovery pattern appears to have favored regional connections. In 2019, airports in South Africa were far more connected than other countries in the region: JNB, Cape Town Airport (CPT), and Durban King Shaka International Airport (DUR) in South Africa were the three busiest airports, accounting for about 74 percent of traffic of all airports in Southern Africa (**figure 2**). Intercontinental flows occupied a larger proportion than the intracontinental traffic in South Africa, reflective of South African Airways' (SAA) previous business model, which flew international routes to and from major international hubs. By contrast, domestic air travel was much smaller in the other four countries and their international flows were all dominated by intracontinental traffic. After the outbreak of COVID-19, the region saw a reduction of over 63 percent in traffic in 2020, with a slight recovery of about 4 percent of total traffic in 2022. Their intra-Africa international traffic improved in proportion to their total international traffic, with an increase of 4 percent and 16 percent in 2020 and 2021, respectively.

3 This conclusion appears to still hold as we see an increase in African cases due to the emergence of Omicron (and to a lesser extent, lags in vaccination) in early 2022. The updated data shows that overall, the Omicron variant has had a relatively mild impact on air connections. Its emergence did lead to a decline in Africa's intracontinental flights, though within a short time impact on air connections. Its emergence did lead to a decline in Africa's intracontinental flights, though within a short time period (no longer than a month or so).

4 Recall that Cairo was ranked no. 127 in 2019. Thus, its improvement is significant. Given its weak connectivity in intracontinental traffic, relative to that of South Africa or Nigeria, this implies Cairo was especially well connected intercontinentally compared to other African airports during the pandemic.

Prior to the pandemic, South Africa's domestic network was dominated by the Johannesburg–Cape Town, Johannesburg–Durban, and Cape Town–Durban routes, which form the so-called "golden triangle." As the pandemic hit in 2020, domestic air flights in South Africa were even suspended, due to stringent lockdown measures implemented by South Africa, the most hard-hit country in Africa and in the world from 2020 to 2021. In the first year of the pandemic, the already thin international traffic flows became thinner, but most of the routes were kept (with each route having fewer passengers). The total traffic within the region, however, increased by about 4 percent in 2021 compared to 2020, suggesting the traffic became more concentrated at the major routes and hubs in 2021. Similarly, intra-Africa international traffic share improved in proportion to their total international traffic, with an increase of 4 percent and 16 percent in 2020 and 2021 respectively. This overall result aligns with several recent studies, which indicated a silver lining of the pandemic is that its disruption stimulated Africa's regional and continental integration (Arezki et al. 2020; Isaac 2020; Medinilla, Byiers, and Apiko 2020; Morsy et al. 2021; Yingi 2022).[5]

Impact of COVID-19 Pandemic on Airline Market Structure

The pandemic has altered the structure of the Southern African airline market, resulting in less competition. In 2019, most routes in the region were monopolized by the three national airlines, South African Airways (SAA), Air Namibia, and Air Botswana. Six duopoly routes, with two kinds of duopoly competition—one involving two airlines—had about the same market shares (for example, routes between Johannesburg (JNB) and Maun (Botswana) as well as between Cape Town and Walvis Bay (Namibia), and another type, where one airline dominated the route with about two-thirds market share (for example, the JNB–Windhoek route, which was dominated by Air Namibia). There were also limited "competitive" routes on which three or more airlines were operating. Those "competitive" routes linked major hubs in Namibia (Windhoek and Walvis Bay) and Gaborone (Botswana) with the biggest hub in this region, JNB. As the effect of the pandemic continued, 14 routes that had been active in 2019 were suspended for the whole year of 2021. SA Airlink, a South African-based privately held carrier, monopolized 16 out of 22 routes and occupied more than two-thirds of the traffic on the bidirectional routes between Cape Town and Windhoek, replacing the roles played by SAA (under administration) and Air Namibia (liquidated in 2020). In fact, SA Airlink took the position of SAA by grabbing about an 82 percent market share of international traffic within Southern Africa. In sum, the market structure was significantly influenced by the pandemic, leaving only four airlines serving the international air passenger market within the region in 2021.[6]

5 As for the cross-border traffic, the passenger flows between South Africa's main hubs and Namibia's two hubs, Hosea Kutako International Airport (WDH) in Windhoek and Walvis Bay International Airport (WVB), were the most active. This might be related to a bilateral liberalization development: in October 2016, South Africa and Namibia signed a bilateral air service agreement (BASA) to operate an unlimited number of flights per week per side and the relaxation of fifth-freedom traffic rights at intra-African points (Mhlanga and Steyn 2016). This is followed by the air routes between Gaborone (GBE) in Botswana and South Africa's hubs, especially JNB. Surrounded by South Africa, Lesotho and Eswatini had the lowest level of intraregional and international air passenger flows in Southern Africa.

6 Air Botswana shared portions of traffic across major airports in Botswana and South Africa. After the suspension of Air Namibia, privately owned airlines Westair Aviation and FlyNamibia, Namibia's first private scheduled passenger airline, shared a small portion of the traffic linking hubs in South Africa and Namibia left by SA Airlink.

The long-term pattern of the market structure, which was being shaped by liberalization policies has been visibly disrupted by the pandemic (**figure 3**). Before 2015, monopoly routes accounted for around 70 percent of the total international routes. However, a significant increase in shares of nonmonopoly routes, occupied by two or more airlines, had been seen since January 2015. The routes competed by four airlines emerged after the declaration on the Single African Air Transport Market (SAATM) in the same year. The percentage of monopoly routes was at the lowest level from June 2015 to September 2015, at less than 40 percent. Another trough in the share of monopoly routes between October 2016 to January 2017 was also seen, as South Africa and Namibia signed a liberal bilateral air services agreement (BASA) in October 2016, which granted an unlimited number of flights per week per side for passenger services and allowed flexible fifth-freedom traffic rights at intra-African points (Mhlanga and Steyn 2016). The proportion of monopoly air routes fluctuated around a relatively low level from 2015 to the first half of 2017, reflecting the impetus of the liberalization movements for increasing competition. But the implementation of SAATM by the governments seemed insufficient to exert its benefits in the long run as time went by, and the double-whammy coming from the pandemic, and longstanding struggles of troubled of state-owned airlines have also significantly limited competition.

The pandemic has altered the structure of the Southern African airline market, resulting in reversal of market share in favor of privately owned carriers.

The pandemic has altered the structure of the Southern African airline market, resulting in a reversal of market share in favor of privately owned carriers. The evolution of the market share by privately owned carriers in Southern Africa shows the influence of the new liberalization movement, reflected by the wave crests appearing in 2015 (**figure 4**, **panel a**). But, its influence, as in the market structure case, did not last long, implying that the countries might still need improvements in fully implementing their commitments for SAATM. May 2020 witnessed a dramatic increase in the market share of private airlines (**figure 4**, **panel b**), which peaked at 100 percent in July 2020. After October 2020, it fluctuated around a high level, nearly 90 percent. In South Africa, private airlines also increased their market share to 90 percent in 2021.

In South Africa, three state-owned carriers existed within a competitive air transport market, accounting in 2019 for 50 percent of the market share, which fell to 10 percent in 2021 (**figure 5**). These include: SAA, an integrated full-service network carrier (FSNC) that operated on long-haul routes, domestic routes—although in a multiyear domestic consolidation, and on African regional routes with wide-body and narrow-body aircraft until it temporarily ceased operations in September 2020 and recommenced a year later; SA Express Airways (SAX), which operated smaller turboprop aircraft and regional jets under a franchise agreement with SAA until April 28, 2020, when it ceased operations and was subsequently placed under provisional liquidation that is still ongoing; Mango Airlines, the low-cost carriers (LCC) fully owned by SAA, which operated primarily on domestic

routes within South Africa (and previously, a single regional route) until it was grounded on April 28, 2021, due to nonpayment of outstanding debt and placed in business rescue by court order on August 10, 2021, with an effective date of July 28, 2021. Altogether, all LCCs (Mango Airlines, FlySafari, and Kulula.com) reached a dominant position in South Africa, accounting for more than 60 percent share in 2019. Together with LIFT Airline, a new LCC entrant amid the pandemic, these carriers now account for an 86.6 percent share. At the same time, the overall market share of the traditional airlines has dropped from 81.7 percent in 2019 to 13.4 percent in 2020.

Determinants of Air Transport Connectivity and Impact of Pandemic

In the Southern Africa region, the potential for international air traffic is high, yet the markets still need to mature and several airlines are financially weak and unstable. In addition to tourism, air transport connectivity is critical to trade and economic development as well as to human mobility, especially in the context of Africa with vast landmass and relatively limited road, rail, and water transport. This calls for a closer scrutiny of which factors promote or discourage air transport connectivity in the region, and how they might have been shaped by the pandemic.

What follows presents the main findings from a gravity model, which identify and quantify the determinants of intraregional (cross-border) air transport connectivity measured both from the demand and supply side, using air passenger traffic, air transport capacity, and flight frequency. The main factors promoting air connectivity are economic levels, air transport liberalization, presence of low-cost carriers, airline privatization, tourism resources, colonial relations, and common language, while high market concentration, distance, and diplomatic disagreements are among the hindering factors.

- Gross regional product (GRP) density (proxied by nighttime light intensity) in origin and destination cities is conducive to air connectivity in terms of frequency, capacity, and passenger volume, suggesting economic development is still an engine for air travel. The effect of GRP in the origin country is about 2 percent higher than the effect of GRP in the destination country, which means that passengers from richer countries are slightly more likely to travel by air to other countries.

- The implementation of the Single African Air Transport Market (SAATM) has a significant positive effect on the intraregional cross-border air connectivity in Southern Africa. Its adoption would increase the intraregional flight frequency, capacity, and air passenger traffic, by about 8.5 percent, 27 percent, and 45 percent, respectively.

- The effects of tourism resources in origin and tourism resources in the destination are significantly positive, with the latter being slightly higher than the former (by about 3 percent). It indicates that high natural and cultural resource levels are beneficial to air passenger transport in the Southern Africa region.

- Market competition (measured using the Herfindahl–Hirschman Index, or HHI) is negatively correlated with air passenger traffic, total seats, and flight frequency, indicating a higher degree of competition increases the total supply for air transport and promotes air passenger traffic. The positive impact of competition on air traffic is through the channel of airfare—that is, competition lowers fares—which in turn stimulates demand. The study found that an increase in HHI by 1 percent would cause a 67 percent increase in average airfare.

- The presence of LCCs significantly increases the flight frequency, capacity, and air passenger volume in Southern Africa. Specifically, every 1 percent increase in LCCs in a route increases the flight frequency, capacity, and air passenger volume by 58 percent, 152 percent, and 90 percent respectively. Essentially, the entry of LCCs can expand the market by increasing supply and creating new air transport demand.

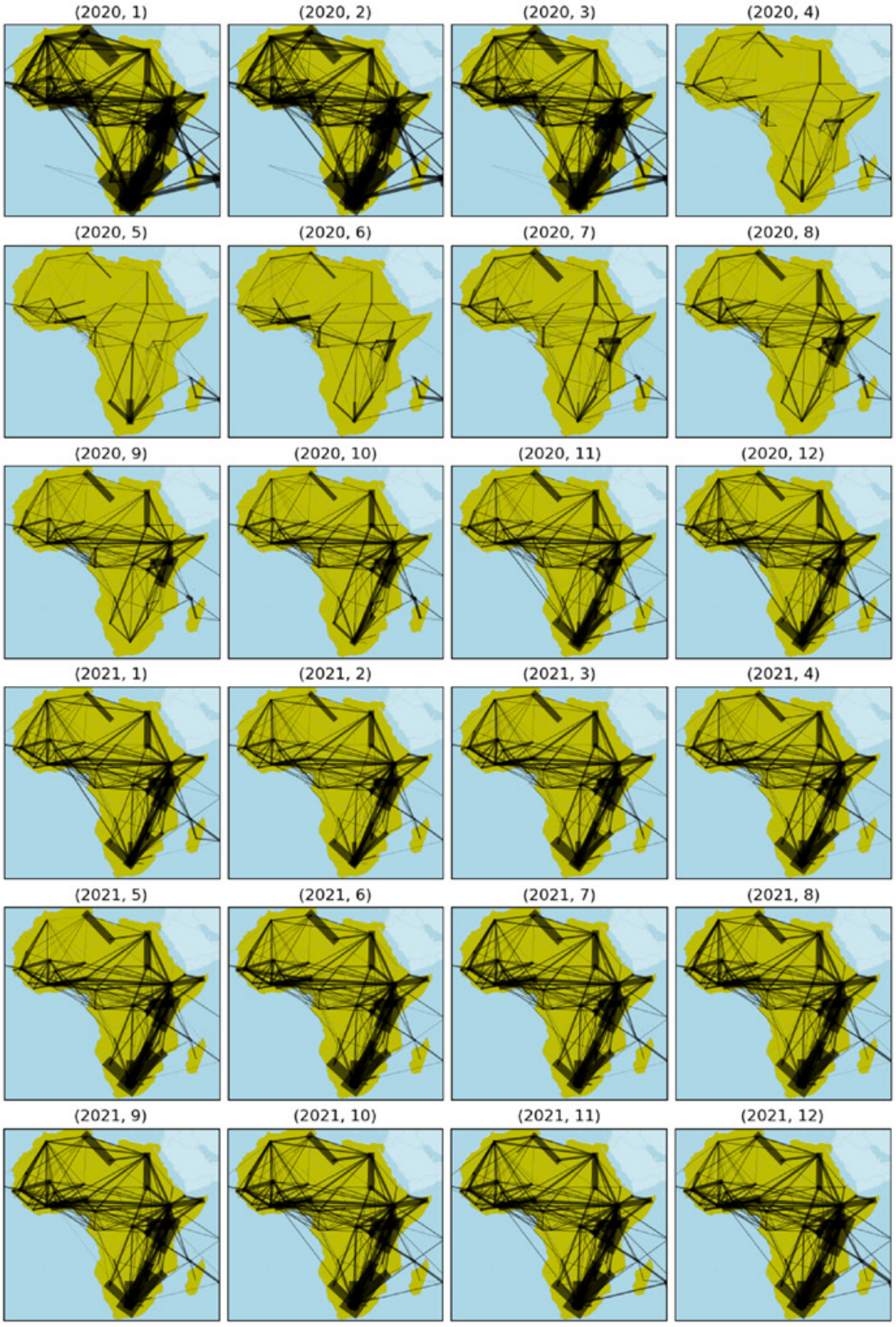
- The presence of a private airline in a route leads to a 31 percent increase in flight frequency, 73 percent increase in airline capacity, and 639 percent increase air traffic. As the South African government turned to a more acceptable attitude to private investment in 2021, we could ambitiously expect a more extensive privatization of the operating airlines in Southern Africa and even the whole continent, which would result in significant improvement in intraregional air connectivity in the near future.

- Historical colonial relations still significantly affect international air connectivity in Southern Africa: having colonial relations post-1945 could increase by about 122 percent of flight frequency, 176 percent of total seats, and 114 percent of passenger volume, which is in line with the results of Button, Martini, and Scotti (2015).

- The spread of the COVID-19 virus negatively influenced air connectivity in the region. Every 1 percent increase in new confirmed cases caused a 33.6 percent decrease in passenger traffic, 12.7 percent decrease in scheduled seats, and 9.1 percent decrease in flight frequency. The impact of the pandemic presents seasonality, which is more severe in cold months and milder in hot months.

- Governments' restriction measures significantly abated air transport connectivity, while vaccination helped to recover air connectivity from the demand side and supply side. Every 1 percent increase of people who got vaccinated brought about 3 percent increase in flight frequency, 1.3 percent increase in airline capacity, and a 2.3 percent increase in demand.

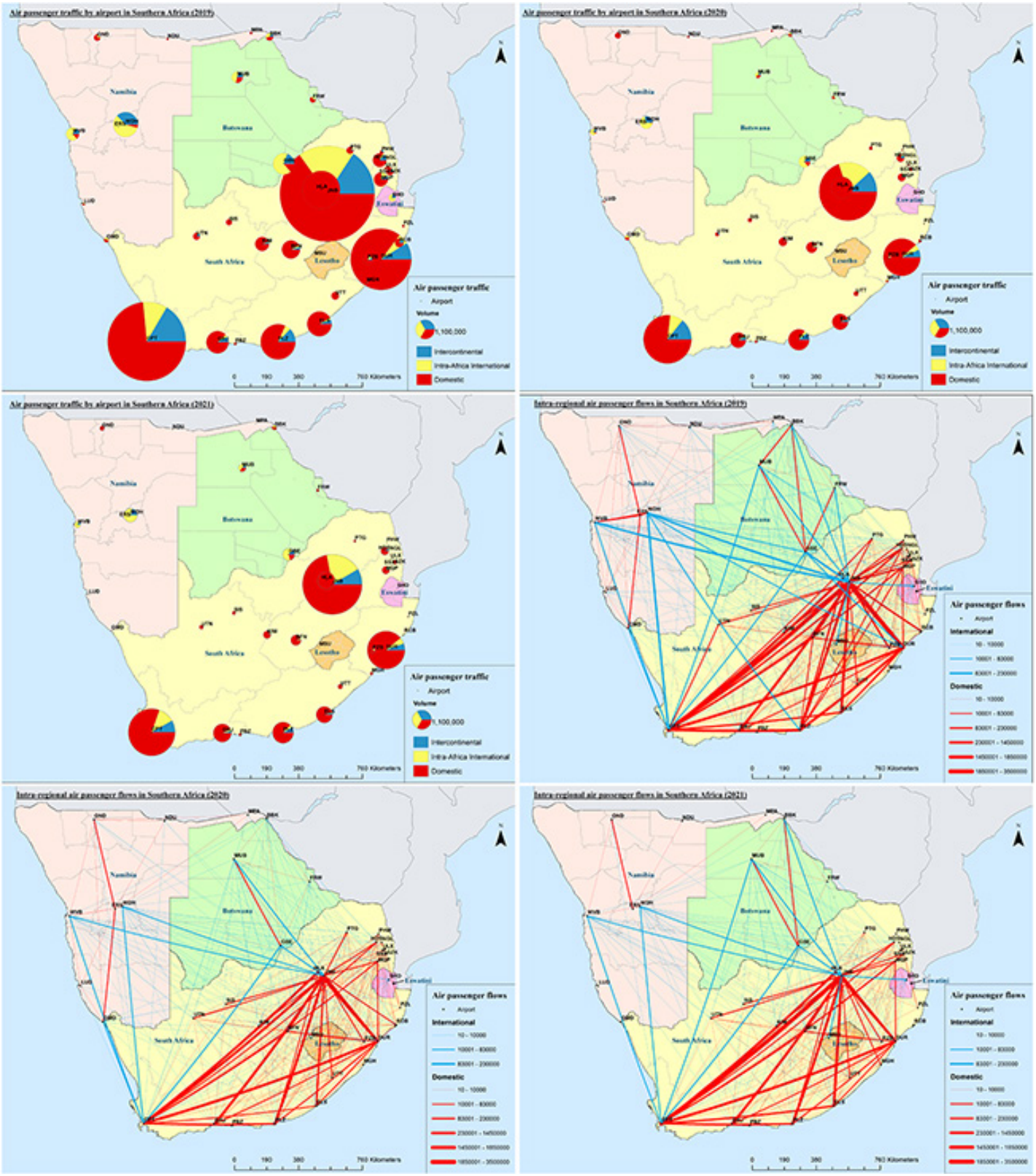
Figure 1. Evolution of Air Transport Country Network, Monthly Flights in 2020 and 2021



Source: World Bank 2022, based on data from Flightradar24.

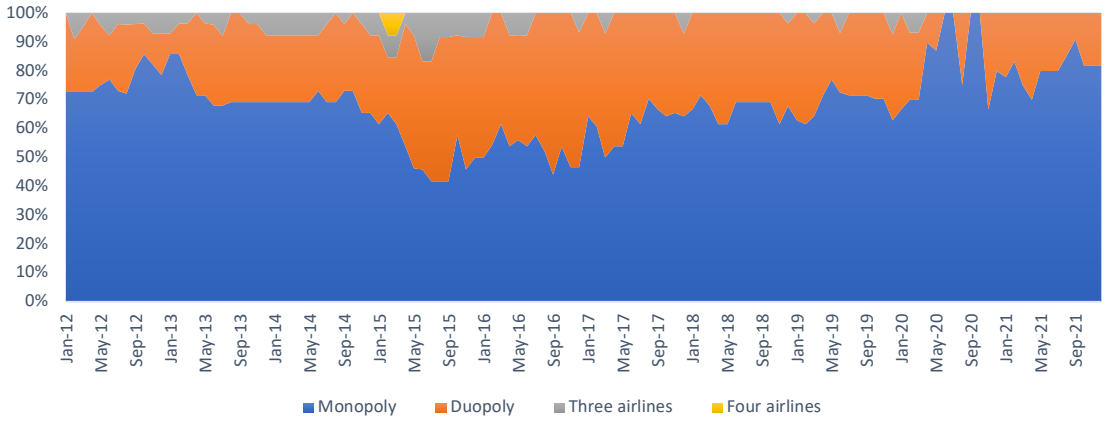
Note: The thickness of a link corresponds to the total number of flights between a pair of countries. Each subplot corresponds to the country network at a given month in 2020 and 2021. The figure shows that several countries along Africa's coastline appear to act as bridges to connect African countries. These countries include South Africa, Ethiopia, Morocco, Kenya, and Côte d'Ivoire.

Figure 2. Decline of Air Passenger Flows Across All Southern Africa Airports and Regional Networks



Source: Original figure produced for this publication, based on OAG data.

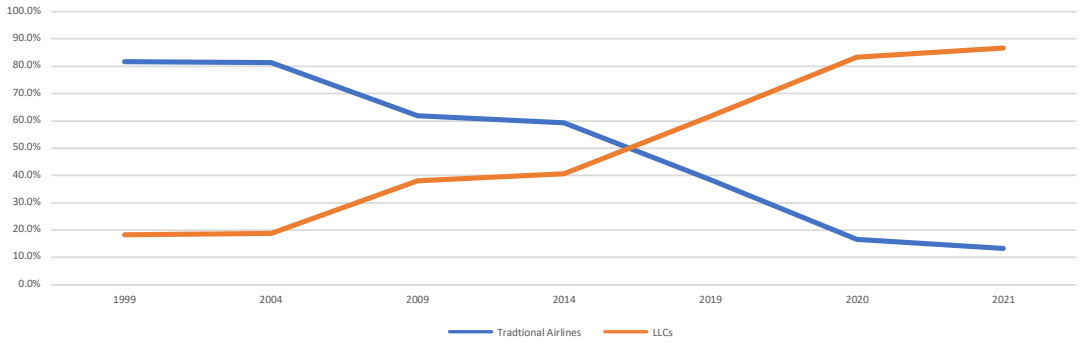
Figure 3. Evolution of Airline Market Structure in Southern Africa, January 2012 to September 2021



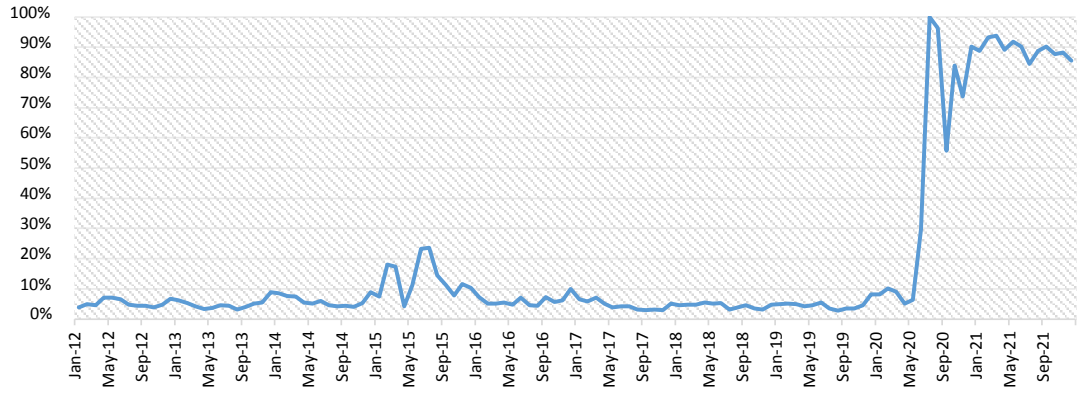
Source: Original figure produced for this publication, based on OAG data.
Note: The vertical axis denotes the percentage of routes dominated by one, two, three or four airlines. We use the 1/(Herfindahl–Hirschman index) to define the number of dominating airlines.

Figure 4. Evolution of Market Shares

a. Shares of market by business model in South Africa



b. Shares of private airlines and low-cost airlines in Southern Africa



Source: Original figure produced for this publication, based on OAG data.
Note: World Bank 2022.

Table 1. Key Characteristics of Existing Road Funds in India

ICAO Code	City, Country	World Rank			Change in rank	
		2019	2020	2021	2019–2020	2020–2021
ADD	Addis Ababa, Ethiopia	72	87	57	▼15	▲30
JNB	Johannesburg International, South Africa	112	135	149	▼23	▼14
CAI	Cairo, Egypt	127	67	56	▲60	▲11
CMN	Casablanca Mohammed V Apt, Morocco	142	106	148	▲36	▼42
NBO	Nairobi Jomo Kenyatta International Apt, Kenya	178	209	177	▼31	▲32
RAK	Marrakech, Morocco	232	244	340	▼12	▼96
ALG	Algiers, Algeria	253	229	262	▲24	▼33
TUN	Tunis, Tunisia	278	238	260	▲40	▼22
CPT	Cape Town, South Africa	308	355	382	▼47	▼27
LOS	Lagos, Nigeria	315	245	239	▲70	▲6
HRG	Hurghada, Egypt	316	254	111	▲62	▲143
MRU	Mauritius, Mauritius	341	426	470	▼85	▼44
SID	Sal Island, Cape Verde	382	238	435	▲144	▼197
LAD	Luanda, Angola	385	416	475	▼31	▼59
MIR	Monastir, Tunisia	393	588	567	▼195	▲21
AGA	Agadir, Morocco	403	436	406	▼33	▲30
DAR	Dar Es Salaam, Tanzania	415	355	314	▲60	▲41
ABJ	Abidjan, Cote D'Ivoire	429	391	444	▲38	▼53
DSS	Dakar Blaise Diagne, Senegal	434	369	409	▲65	▼40
ABV	Abuja, Nigeria	446	379	421	▲67	▼42

Source: Original table produced for this publication, based on Cheung et al. 2020.

Note: The first column is the three-letter International Civil Aviation Organization (ICAO) code for airport. To see Africa's connectivity from the perspective of its airports, we update the "global airport connectivity index" (GACI) developed by Cheung et al. (2020). The GACI is a composite representation of five individual connectivity measures, with the weights being determined by a principal component method.

The analysis includes a total of 3,737 airports worldwide. The GACIs for all the African airports with scheduled flight connections—a total of 476 such airports—are then extracted from this world set. These are yearly GACIs, covering a period between 2006 and 2021 (note Cheung et al. 2020 cover the index for 2006–2016). **Table 1** shows the top-twenty most connected African airports for 2019 to 2021 in terms of GACI.

References

Authors:
Arnab Bandyopadhyay, Shomik Mehndiratta, and Reenu Aneja,
The World Bank

India State Roads Sector: Ten Key Insights

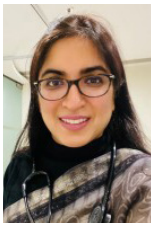
A World Bank report on the Indian highway sector (World Bank 2002) put the spotlight on state highways agencies and networks. This critical "middle" layer of the network is between the national highway system and the village roads providing basic access. While both the national and last-mile layers had and still attract a lot of attention from the national government,[1] the state highway system is managed by the states with no national attention or funding. This middle layer was and remains critical to India's economic and social aspirations: to connect agricultural goods and small and medium-scale enterprise (SMSE) outputs to markets to bring goods to rural India. This feeder network providing crucial interlinkages, connectivity, and access accounts for around 3 percent of the total network length, carrying 40 percent of total traffic (medium to heavy). However, almost 60 percent of this network has a carriageway width of less than the two-lane standard. The five states of Maharashtra, Karnataka, Gujarat, Rajasthan, and Andhra Pradesh account for 56 percent of total length of state highways in India.

1 These layers include the National Highway Development Plan and now the Bharatmala road development plan for the National Highway System, and the Pradhan Mantri Gram Sadak Yojana (PMGSY), which provides good all-weather road connectivity to unconnected, rural villages.

About the Authors

Arnab Bandyopadhyay is a Program Leader and Lead Transport Specialist of the World Bank.

Shomik Mehndiratta is the World Bank's Practice Manager for Transport in South Asia.



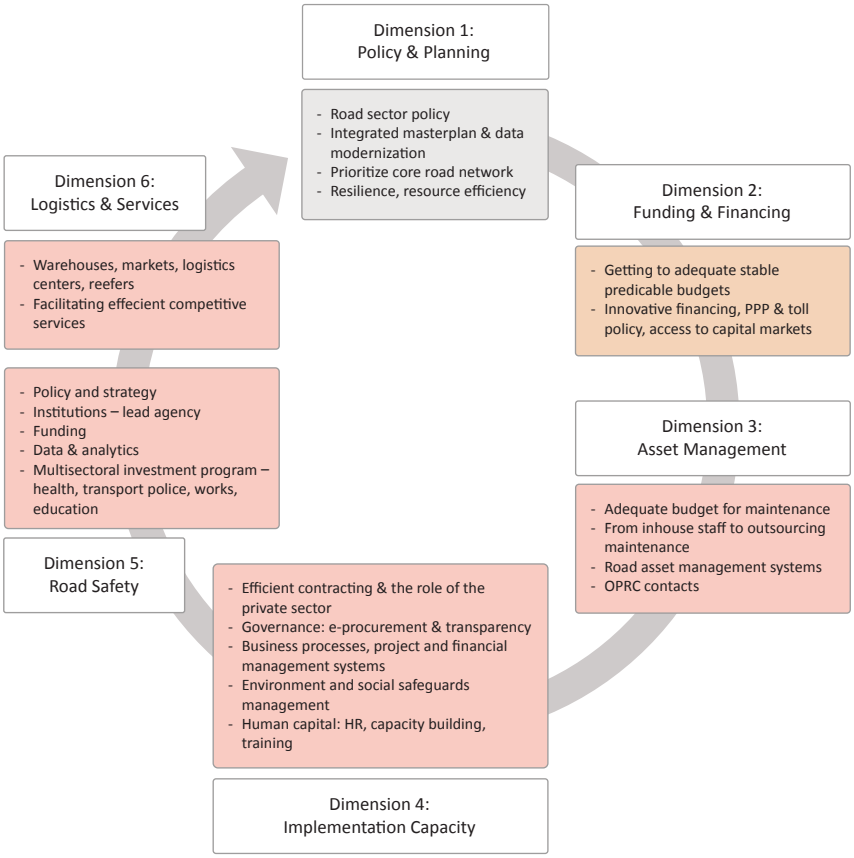
Reenu Aneja is a Transport Specialist at The World Bank.

The 2002 report found that both the networks and the agencies were in dire need of attention. In the two decades since that report, the World Bank has followed up with a sustained program of investments, working with 13 states. Many states have had multiple engagements. In the past year, the World Bank team conducted a review of this experience, combining the rich existing knowledge with selected surveys and reviews of the broader experience outside of World Bank projects. This article draws on that work to characterize the state of the state highway system today, highlighting 10 key insights from the past two decades of road development.

Highway agencies in most states across India entered the 21st century with similarly antiquated networks and agencies. Traditional government departments operated as they had been at least since India's independence in 1947. There was usually no high-level policy or vision to guide decision making. The state budget provided the primary source for both funding and financing. New road capacity was added using traditional input-based item-rate contracts, which were extremely effort intensive for the government in terms of design and supervision. The network was in a state of disrepair: maintenance was significantly underfunded, and politics rather than technical rationale determined where available resources were used. Much of the available maintenance funds were used to pay salaries for in-house maintenance staff. Business processes were manual (computerization/digitization was in its infancy), and the human capital required significant strengthening.

The road development story of the past two decades in India has been one of incremental modernization along six dimensions (see figure 1), with significant differences across states in their appetite and pace for modernization. Four interrelated dimensions have characterized the change process: (1) policy and planning; (2) funding and financing; (3) asset management; and (4) implementation capacity, with the last being a combination of developing a more sophisticated role for the private sector in contracting and financing, modernizing business processes, and building human capital. As traffic volumes and vehicle operating speeds increased, negative externalities—such as road traffic crashes (road safety) and quality of transport logistics and services—have emerged as two other important priorities. Finally, an important characteristic of the Indian state highway modernization process has been its incremental gradual character. Unlike some countries—South Africa being a good example (see **box 1**)—where change was structural and elements of highway system management were turned over to an autonomous, professionally managed authority, Indian states continued to rely on government departments.

Figure 1. Six Dimensions of Incremental Modernization of India's Road Systems



Source: Original figure produced for this publication.

Box 1. South Africa's Successful but Uncommon Structural Change

With the objective of commercial management of roads, South Africa undertook structural realignment of the Department of Transport and established South African National Roads Agency, Ltd. (SANRAL) in 1998 by separating policy-making functions from operations to achieve greater efficiency and effectiveness in the management of national roads. It has greater autonomy under the oversight of a board of directors, along with highly decentralized organizational structure to regional and project manager's levels, built around the notion of "competency clusters" resulting in reduced bureaucratic lag times and increased efficiency. After the initial structural changes, there has been an incremental evolutionary change process, requiring unbundling of core and noncore functions, setting new legislation, institutional and governance framework, and stable funding.

Source: Gericke 2016.

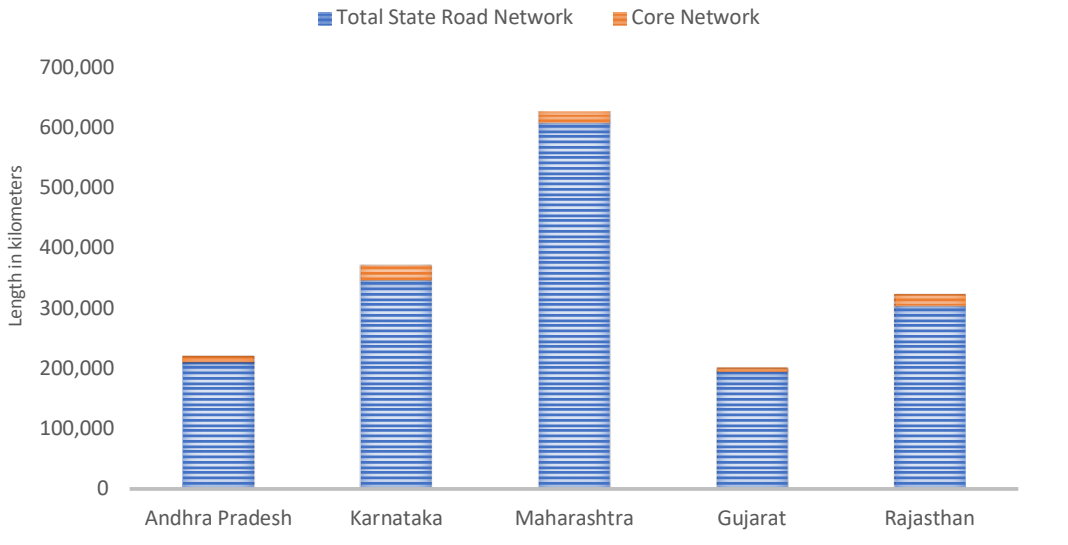
10 Key insights

1. Core-road network facilitated the prioritization of resources for capacity augmentation of the strategic network, serving as the backbone of state economic development.

The identification and adoption of a "core-road network" (CRN) has been the most significant planning related advance. Most states have found that a relatively small part of their network carries much of the traffic, that is, on an average 80 percent of the vehicular traffic moves along 20 percent of the road network. The designation of this "core-road" network—increasingly based on a data-driven scientific, geographic information systems (GIS) mapping-based approach—has helped to better integrate transport demand and infrastructure supply, plan multimodal integration, and focus resources both for capacity augmentation as well as asset management.

This identification of CRN has helped prioritize investments, leading to development of state road development programs for capacity expansion, upgradation, and maintenance. Defining the CRN based on traffic factors leading to high propensity for crashes and injuries also helps mitigate the burden of externalities in the highest risk sections of the network, thus maximizing the benefits of the interventions and constrained resources (**figure 2**). Some states, such as Kerala, have a dedicated budget head for CRN. Designation of CRN has significantly impacted enhanced resource allocation[2] in early mover states and enabled faster movement to the maturity phase of service delivery. States such as Gujarat and Tamil Nadu, which continue to more stringently apply the CRN framework in budgeting and overall management of state highway network, have displayed a higher share of core network in good condition and continue to invest a higher share of gross state domestic product (GSDP) in the state highway sector.[3]

Figure 2. Core Road Network Budget versus Total State Road Network Budget in Various Indian States



Source: Original figure produced for this publication.

Note: States that have adopted core road network (CRN) as a central element of planning: Assam, Punjab, Himachal Pradesh, Odisha, Telangana, Tamil Nadu, Kerala, Uttar Pradesh.

2 Annual road sector allocation in Gujarat, an early adopter of the CRN concept, increased from US$30 million in 1995–96 to US$610 million in 2010–11, an impressive twenty-fold increase in 15 years.

3 Gujarat and Tamil Nadu have more than 70 percent core network in good condition and spend 5.1 percent and 4.5 percent of their state budgets for state highways respectively, against the national average of 4.1 percent (2018–2019).

2. Despite creation of different revenue streams, government budget remains the primary source of funding. Significant resource gaps persist.

There has been significant movement in creating new streams of revenue from users. Several states have instituted some form of road user charges, fuel levies (cess on petrol/fuel), and in some cases, toll roads. Some states have also established dedicated road funds (see table 1), although none of these are managed yet in a commercial and transparent manner. Vehicle populations and traffic levels have increased significantly in the past two decades, and so have these revenue streams. However, in all cases, these revenues are absorbed into the general treasury, which remains the key source of funding both for new capacity as well as expenditures related to asset management. The allocations to the road sector have grown year-to-year; however, this growth has not kept up with demand for expenditures indicating in many states the user-based charges are generating more revenue for the state than is being spent on the sector. The general experience shows a shortfall of over 40 to 50 percent in respect of allocations for maintenance of state highways and major district roads resulting in accumulated loss in asset value. Increasing resource gaps have compelled states to transfer some of the state highway assets to the national government and redesignate as national highways, further weakening the strategic state highway asset base and constraining opportunity for asset recycling and monetization, as is being attempted currently at the federal and state levels. Further, the allocations are unstable and erratic, primarily impacted by fiscal constraints, making the planning process difficult. Multiyear planning and budgeting is still absent.

Major Sources of Funding & Challenges

1. Consolidated Fund of the State (Budget Allocation) — *allocation often unstable*
2. Allocation from Central Road and Infrastructure Fund — *allocation reduced due to diversification of funds to other sectors*
3. Fuel Cess — *revenue to treasury; not dedicated fully to road sector*
4. Proceeds from Toll Roads — *limited to higher order and economical roads; not necessarily ring-fenced*
5. Loan from Multilateral Institutions/ NABARD/ HUDCO — *limited funding*
6. Finance Commission Grants — *mainly for maintenance of rural roads*

Source: Original table produced for this publication.

Table 1. Key Characteristics of Existing Road Funds in India

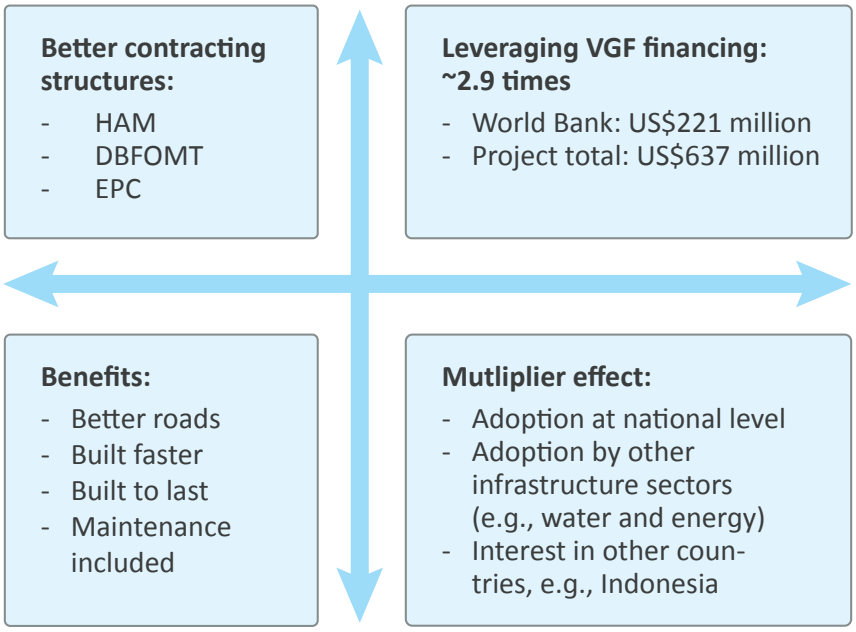
Characteristic	National	Uttar Pradesh	Rajasthan	Assam	Kerala
Law	Central Road and Infrastructure Fund, 2000	Government orders, 1998 and 1999	Rajasthan State Road Development Fund Act, 2004	Assam Road Maintenance Fund Rules, 2014	Kerala Road Fund Act, 2001
Source of revenue	Fuel cess	Fuel cess	Fuel cess	Funds/cess/ grants	Funds/ contributions/ user fees/grants
Eligibility of uses	National highways, state highways, rural roads, and other Infrastructure sectors	Maintenance of state roads (though often also used for upgradation)	Development of state roads, no maintenance	Maintenance of roads	Transport facility projects
Deposit mechanism	Consolidated fund of India	Consolidated state fund	Consolidated state fund	Fund account	Fund account
Overseeing/ management	Ministry of Finance	Ministry of Finance and Public Works Department	State Road Fund (SRF) Board	Road Board	Kerala Road Fund (KRF) board, led by chief minister

Source: Original table produced for this publication.

3. State highway agencies have become important testbeds of financing innovations, with some of the most successful innovations such as the hybrid annuity model (HAM) spreading to the center and other infrastructure sectors.

The four states of Gujarat, Maharashtra, Karnataka and Tamil Nadu in particular have experimented with various forms of public-private partnerships (PPPs) including the build-operate-transfer (BOT) model, annuities, the design-build-finance-operate-maintain-transfer (DBFOMT) model, and the modified/hybrid annuity model (HAM) to boost private-sector participation and investment in construction and maintenance of road assets (**figure 3**).

Figure 3. Results of Financing Innovations in India



Source: Original figure produced for this publication.
Note: HAM = hybrid annuity model; DBFOMT = design-build-finance-operate-maintain-transfer model; EPC = engineering, procurement, and construction model; VGF = viability gap funding.

Particularly noteworthy has been the innovation of HAM contracts. These contracts eliminate traffic risk, and make availability based payment structure more market friendly, using viability gap funding (VGF) to mobilize construction finance. A highly successful pilot project in Karnataka leveraged US$221 million in VGF financing provided by the World Bank, with US$347 million of debt and equity from the private sector and US$27 million from commercial banks. This model has since been replicated in other states including Tamil Nadu, Andhra Pradesh, Gujarat and at the national level. The HAM innovation has been far-reaching, including across other sectors (for example, urban infrastructure) and regions such as East Asia, and heralds promise on developing future models of market de-risking and crowding in private finance in seemingly hard-to-attract private capital mobilization challenges.

From a contracting perspective, the HAM contract represents a fundamental shift from traditional inputs to an output-based approach by focusing on the "what" rather than the "how" in relation to delivery of service. HAM contracts have shown substantial reduction and/or elimination of time and cost over runs due to the inbuilt incentive mechanism of concession stake in capital expenditure.

4. Asset Management—Maintenance practices have evolved from traditional in-house to outsourced long-term performance and output-based maintenance contracts resulting in maximizing the life and utility of public assets in a cost-effective manner.

The maintenance of roads using force account has been discontinued except in few states for certain categories of works such as in Himachal Pradesh, Uttarakhand, and northeastern states. The maintenance management has meaningly evolved from in-house maintenance to outsourced and among the most advanced states, toward longer-term more sophisticated contracts that incentivize performance, improve economies of scale, and bolster implementation capacity. Increasing use of engineering, procurement, and construction (EPC) contracts, with a built-in four to five-year performance-based maintenance phase, has helped break the erstwhile vicious "build-neglect-rebuild" cycle in the sector with a well-managed level of service-linked, availability-based payment structure. Performance-based contracts (PBCs) have been successfully implemented in Andhra Pradesh, Punjab, Telangana, Gujarat, Tamil Nadu, and Karnataka. The overall performance of the network and percentage of networks in poor and bad conditions has significantly reduced in these states. Learning from these successes, PBCs—see the blog post by Tvgssshrk (2018b), Our Infrastructure Projects Can Help Build Many Things Including Stronger Institutions—have been mainstreamed[4] in these states at the network level and are increasingly being adopted in other states (Odisha, Madhya Pradesh, Maharashtra).

4 Multiyear performance-based maintenance in Punjab and Tamil Nadu (1,000 kilometers) and Andhra Pradesh and Telangana (6,000 kilometers), DBFOMT (680 kilometers in Karnataka, 61 kilometers in Gujarat, and 150 kilometers of four-lane highways in Tamil Nadu), EPC lumpsum + maintenance (Tamil Nadu).

5. Road asset management systems (RAMS) have been a game-changer in establishing a transparent scientific approach to prioritization and management, leading to better use and higher allocation of resources.

Inadequate allocation of resources for asset management is the fundamental problem for the sector. Traditionally, asset management decisions were predominantly based on prescribed funding formulas and subjective assessment of road quality and maintenance needs. But without a systematic asset management system in place, there is no assurance that even the resources allocated are being efficiently utilized. RAMS were originally meant to solve the second problem—using a structured scientific process to prioritize better use of resources. However, state highway departments found that the use of RAMS[5] output to frame allocation requests had an important unexpected benefit—finance departments started allocating higher levels of resources for asset management. The experience was uniform across Indian states—in states such as Assam and Gujarat, the increase has been as much as five- to seven-fold (see **figure 4** for details on how road asset management allocation has increased in Assam from 2001 to 2017).[6]

Fundamentally, the use of RAMS and its institutional integration (as in Karnataka, discussed in **box 2**) has increased credibility of budget requests from the Public Works Department (PWD)—and it became more clear that part of the problem was a perception that the earlier, more subjective assessments of maintenance needs were inordinately driven by political and personal preferences.

Box 2. Planning and Road Asset Management Center in Karnataka

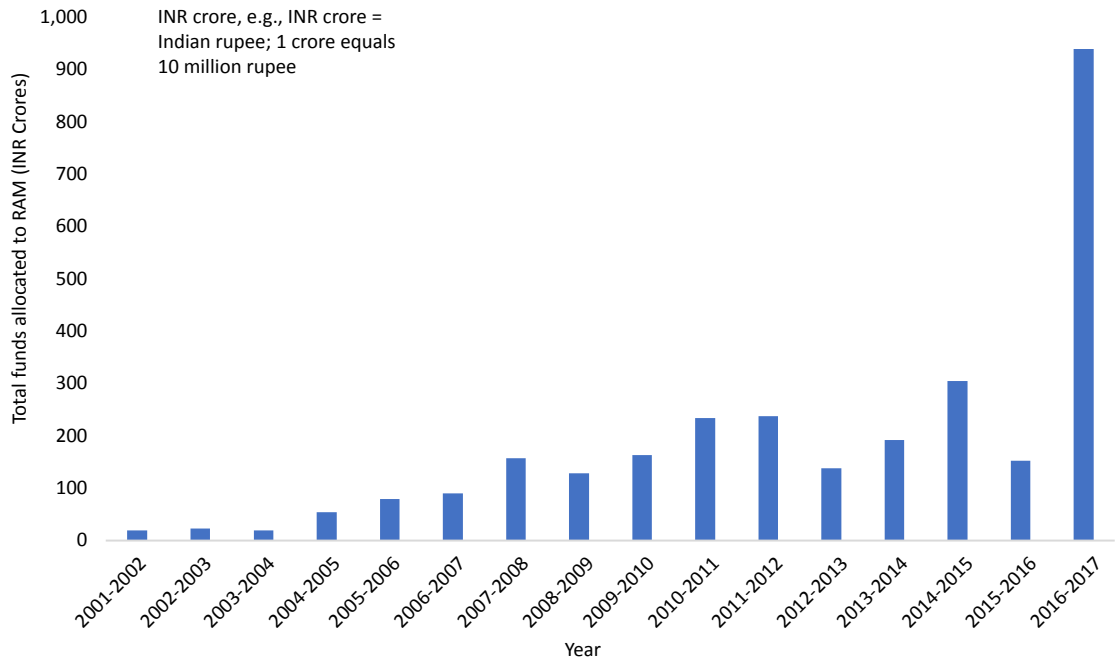
Karnataka established the Planning and Asset Management Center (PRAM-C) in 2012, jointly supported by the Asian Development Bank and World Bank. This represented a watershed event in the state's asset management and planning journey, as PRAM-C evolved as the center for prioritized planning and redefining the core road network, prioritized its asset management system based on scientific data collection and analysis, and several innovations on maintenance budgeting, financing, and technology standards. The state started allocating separate output-based budget streams for PRAM-C and in 2021 assigned the responsibility of integrating road safety with asset management using common data collection, analysis, and a contracting framework.

Source: World Bank 2019. https://documents1.worldbank.org/curated/pt/736541572357379601/pdf/India-Second-Karnataka-State-Highway-Improvement-Project.pdf.

5 RAMS ensures systematic management of the network in a sustainable and cost-effective way using a scientific life-cycle based approach affecting the full range of activities, including planning, engineering, finance, programming, and actual works. It supports preparation of both annual and multiyear investment plans for maintaining the road network, considering the condition, function, available funding, resources, and prioritization. A comprehensive and integrated RAMS includes the following: pavement management, bridge management, traffic data management, a transport modeling tool, traffic incident management, monitoring and evaluation, an environment and social information system, road safety management, and cross-asset prioritization system.

6 In Gujarat, maintenance allocation for state highways from 1998 to 2008 increased by 450 percent. In Assam, from 2008 to 2018, allocation for maintaining state highways increased by 700 percent.

Figure 4. Key Features of the Successful RAMS Allocation in the State of Assam, 2001 to 2017



Source: World Bank 2019. https://documents1.worldbank.org/curated/pt/736541572357379601/pdf/India-Second-Karnataka-State-Highway-Improvement-Project.pdf.

6. Altogether, the private sector plays a much more important role in the road sector in India than it did 20 years ago, a more appropriate role given its sophistication and implementation capacity.

The innovations in financing and long-term maintenance described above are part of a broader evolution of contractual mechanisms that reflect the emergence of a more sophisticated contracting sector, with more technical and financial capacity and more ability to take elements of project risk. We have already talked about performance-based contracts, and a range of sophisticated contracting mechanisms has encouraged private sector finance in capital works. These contracts reflect the apex of a largely successful evolution of contract types from the traditional input-based contracts—the mainstay of state highway agencies at the turn of the century—to an output and performance-based approach, as discussed in a 2018 blog post, "Our Infrastructure Projects Can Help Build Many Things—Including Stronger Institutions" (Tvgssshrk 2018b) on the World Bank's Transport for Development blog. The workhorse is the engineering procurement construction or EPC contract, which shifted the risk of the final design to the contractor who had to optimally meet functional specifications.

7. Road safety is widely recognized as growing challenge. However, Tamil Nadu's success shows that a sustained comprehensive approach supported by the right institutions can reduce fatalities.

India has a significant road safety problem—the country accounts for 25 percent of the world's traffic fatalities, with only 10 percent of the vehicle fleet. About one-third of these fatalities occur on the state highway system. Addressing road safety on the state highway network is particularly challenging due to varying functional use of the road, including nonhomogeneity in operating speeds and traffic mix, and therefore requires acute attention to design appropriate safety interventions. In the past two decades, states have started taking on this challenge.

As discussed in a 2021 blog post, "Road Safety: How a State in India Is Leading the Way to Lower Road Crash Deaths "(Markland, Bose, and Haazen 2021), on the World Bank's End Poverty in South Asia blog, the most successful is the Tamil Nadu experience. Tamil Nadu has reduced state-wide traffic fatalities by 29 percent over a three-year period through a successful implementation of (1) "first of its kind" crash database system using data-driven, scientific approaches to road safety management, including traffic management linked to medical facilities across the state; (2) trauma care system resulting in reducing the post-crash response time of emergency medical teams to 14 minutes, comparable to global best; (3) rolling out safety infrastructure (see "Building Safer Roads through Better Design and Better Contracts" (Tvgssshrk 2018a) on the Transport for Development blog), both anchored in demonstration corridor and network, adaptive to fast urbanizing ecosystem with significantly increasing risk of vulnerable road users; and (4) adoption of rapid digitization in enforcement, access management (licenses and registration) and post-crash, in-hospital care (trauma registries) management. Such comprehensive interventions, initiated through two simultaneous Bank supported state highway and health system improvement projects, have significantly and unprecedently reduced the road crash fatalities in one of the fastest motorizing and urbanizing states.

Complementing the above interventions is a comprehensive and results-based approach of road safety management model deployed across the state of Tamil Nadu (see box 3). The physical/engineering measures, accompanied by robust programs for enforcement, education and awareness, and post-crash management requires a coordinated effort between various stakeholder departments, which—with proper institutional structure and synergies—can be achieved if designed and integrated well with other programs being implemented by the respective departments. The success of Tamil Nadu has also led to national roll out of the Integrated Road Accident Database (iRAD) by the Ministry of Road Transport and Highways (MoRTH).

Box 3. Statewide Institutional Framework for Addressing Road Safety Management in Tamil Nadu

While a decade ago Tamil Nadu had the dubious distinction of having the second highest numbers of crash fatalities of any state in India, the state has in recent years shown remarkable progress in managing road safety through strong institutional commitment, coordination, and implementing results-oriented actions. With World Bank support spanning more than 10 years, the state focused on coordinated management of multisectoral interventions, bringing all key stakeholders to the table, and establishing a Road Safety Executive Leadership Group, responsible for decision making across the state. A road safety management cell has supported the leadership to implement actions, review monthly road safety initiatives, statistics, and targets at the district level, while crash trends were reviewed on a monthly basis by the police at the highest level.

The joint ownership of road authorities leading the state's agenda on road safety—police, health, and transport—while uncommon in India, proved invaluable to its success. Interdepartmental coordination and standard operating procedures included teams from the police, highways, and transport departments responsible for visiting every fatal crash site and reporting on causative factors as well as remedial and punitive measures within three days. This procedure has provided the recipe for sustained and holistic management of the road safety problem in the state.

Tamil Nadu, also at the forefront of adopting information technology (IT) and developing close ties with the local academia, led the use of data-driven, scientific approaches to address road safety challenges with its web enabled GIS-based Road Accident Database Management System (RADMS) developed over a decade ago. This "first-of-its-kind" system, which maps road accidents, identifies the most crash-prone hot spots, and pinpoints corrective action, has now been adopted as the template for replication at a national level for all other states.

Improving the trauma care system was an essential component of road safety management in Tamil Nadu (Markland, Bose, and Haazen 2021). The state established emergency care centers and accident relief centers on high crash-prone road stretches on national and state highways. Response time was dramatically improved through a dedicated call-line as well as proactive allocation and dynamic positioning of ambulances. The state also introduced triage and acuity scoring systems at the pre-hospital level to ensure prioritization of patients.

With regard to road engineering, Tamil Nadu adapted its infrastructure to urbanizing conditions through pedestrian footpaths, fencing and crossing facilities, traffic calming, signage, and channelization. Between 2014 and 2018, the state Highways Department spent almost US$200 million on special road safety programs and on rectifying more than 200 crash hotspots; about 2 percent of the capital expenditure under its Core Road Infrastructure Development Program has been earmarked for road safety, and the state also effectively utilized the Central Road Fund earmarked to states for safety engineering works.

Stringent enforcement has significantly improved road user compliance and transparency. Enforcement of helmet laws, working hours of tourist/maxi cab drivers, and wine shops along highways was tightened; district collectors were asked to rationalize the speed limits on highways and a control room was activated to monitor highway police patrol; and traffic regulations were strictly enforced with e-challans (citations) issued through smart integration with the national vehicle and license databases.

Going forward, the Tamil Nadu model of road safety management provides a glimpse that coordinated delivery from all stakeholders on data driven measures can create a significant shift, changing the trajectory of road safety performance. Other states in India would do well to traverse a similar road toward lower road crash deaths.

Source: Markland, et al. 2021. https://blogs.worldbank.org/endpovertyinsouthasia/road-safety-how-state-india-leading-way-lower-road-crash-deaths/.

Karnataka (Kumar, Tvgssshrk, and Tadimalla 2019), Andhra Pradesh (Gupta 2018), Kerala and Gujarat (iRAP 2021) have also had some important successes with demonstration "safe corridors" and in the case of Kerala and Gujarat, launching legislated lead agencies and dedicated financing arrangements, significantly enhancing the road safety coordination, financing and monitoring mechanisms.

8. Environment and social safeguard management principles have been embedded in technical standards and specifications and integrated in the project cycles, with Gujarat pioneering in green highway pilot initiatives.

Safeguard reforms in the road sector (both state and national) were initially designed to address the preconstruction and implementation challenges with the help of systematic environment and social impact assessments. Environmental and social management plans have been integrated in the bidding and contract documents with increasing focus on occupational, health, and safety requirements. Over the past decade, initiatives undertaken toward labor reform (basic human rights), and occupational, health, and safety norms have been increasingly mainstreamed in the contracting structure. Over time, the demonstrated success of these reforms encouraged its adoption outside the project, such as in the case of Kerala where the rest and recuperation (R&R) policy was adopted for all road sector projects and in the case of Rajasthan, it was adopted for all linear projects; Gujarat's digital management of land acquisition and compensation processes has been adopted in other sectors and regions; Tamil Nadu's innovative practice of escrow accounting mechanism for land and R&R compensation has been adopted for national highway programs; standard environmental management requirements were introduced both in the *Specifications for Roads and Bridges* (Orange Book) and Public Works Department codes (as done in Karnataka) during the course of Bank engagement at the national and state levels respectively. The highway sector team also recently fronted the drafting of the labor reforms toolkits, which have been adopted statewide in Kerala, Assam, and Uttarakhand as well as across other sectors such as energy (power grid projects) and railways.

9. Modernization and digitization of business processes have shown to enhance operational efficiency, implementation capacity, and cost savings.

States are increasingly adopting digital information, communication, and technology (ICT) based tools and applications, resulting in modernizing the business processes of road agencies. Among these tools, adoption of e-procurement has been most impactful and widespread, enhancing overall transparency and cost savings. Some of the other tools and applications such as digital project management systems are also being mainstreamed for monitoring and supervision of construction and maintenance works in several states. These systems have been further integrated with the GIS-based IT command and control center in Andhra Pradesh, and used for performance assessment (PAT) and benchmarking among divisions in Rajasthan. The digital tools are also being used to ensure better management of environmental and social safeguards and work zone health and safety management in Rajasthan and Gujarat. However, the adoption and utilization of these systems is not universal across states. In addition, northeastern states such as Bihar and Jharkhand can do much to adopt systems mainstreamed across most of the country.

10. Progress is evident in state highway agency modernization effort, but with significant variability across states and a long way to go.

The two-decade experience of the World Bank across 13 Indian states suggests that while all states have improved their management of their state highway system, there is considerable variability across states in evolution of the state highway system and the effort to modernize management practices:

- Statewise, variability in overall administrative reforms and public sector management has influenced the road sector performance and maturity across states.

- Improvements have been seen in planning, with significant developments in financing and contracting (with the development of the HAMs being an important success), elements of asset management (with the adoption of RAMS being an important success), and interaction with the private sector in general, in the adoption of ICT and safeguards management.

- Less successful has been improving the overall funding situation—with a dependence on general budgets and persisting gaps. Much needs to be done in modernization of human resources as limits to the government agency model are clear. These are related and perhaps the time has come for states to consider corporatized, autonomous agencies operating in a commercial manner with arms-length contracts with government that ensure funding in exchange for service delivery.

- The capacity-building effort has largely been limited to improvement of processes and systems through digitization and training of personnel through a combination of ad-hoc and more recently dedicated research center/center of excellence-based hybrid learning modules in a few states.[7] In order to enhance the impact of these efforts, there is an urgent need to move to competency-based skills training and a qualification system to create a national framework of training, competency, and qualifications[8] for the sector.

7 A cloud-based e-learning management system for staff of public works department (3,000 users) in Karnataka is also operational with specific content and resources and successfully delivering high-impact trainings.

8 The recent efforts of NITI Aayog, the premier policy think tank of the government of India, in creating The Indian Infrastructure Body of Knowledge and a National Framework for Competency Building, open to states, is noteworthy.

What's next for these critical networks? As much as some of the state highway agencies and their networks have improved in the past two decades, India still needs better state highway networks, and the agencies managing those networks still can do more to become more efficient and effective. There are several nonmutually exclusive possible futures:

- **Get all the states to a similar level.** Creating a national framework for performance evaluation and institutional maturity across states could create an impetus toward bridging the gap between the best performing states and the rest. Ideally, such a benchmarking effort could be adequately supplemented through a national level capability-building framework for the state highway sector, supporting states in the six dimensions of the sectoral maturity framework. Proximate imperative of implementing the national infrastructure pipeline can be strategically used to develop such framework and assist the states in the transition.

- **Create corporatized entities to secure funding, institutionalize planning and asset management, get access to capital markets, and increase implementation capacity.** The next frontier for well performing states will be innovation in organizational structure, possibly with corporatized autonomous road development corporations (RDC). RDCs were created in quite a few states in the 1980s and 1990s to modernize state road sector, inculcate commercial principles and enhance resource base. However, without assets, which remained with parent road departments, or functional or human resources autonomy, this first generation of RDCs ended up being little more than parallel implementation bodies for ring-fenced donor financed programs. In recent times, there have been efforts to advance true commercialization of such entities by allowing more functional autonomy, vesting core asset ownership and revenue streams as evident in states like Rajasthan, Himachal Pradesh, and Maharashtra. Such RDCs could help in creating opportunities for enhanced resource mobilization and sustainable management of state highway networks on commercial principles.

- **New funding and financing streams.** There is also significant resource mobilization potential through asset monetization and reinvesting the proceeds of monetization in development of new assets and rehabilitation of state highways. States are beginning to explore such options following the announcement of the national asset monetization policy in 2021. Considering the constraints on scale and credit worthiness of state the highway sector, significant effort would have to be made in clustering, packaging transactions cross-sector (for example, state highways with urban ring roads, bus terminals, and logistics infrastructure), and robust market sounding and de-risking market through investment friendly regulations and financing instruments.

- **Resilience and resource efficiency will be critical elements in the climate/development transition for state highway sector.** Climate and disaster resilience principles need to be firmly embedded in the project development, implementation and asset management cycle of state highways. The institutional and fiscal framework supporting state highway development need to rapidly adapt to this challenge and lessons from PMGSY and a few states (such as Kerala)[10] are worth emulating in that context.

- **Services and safety.** Even as the networks mature, road safety and services come to the fore. From a road safety perspective, the Road Safety State Support Program, which is cofinanced by both the World Bank and the Asian Development Bank, is the flagship national effort to improve outcomes. On services, states such as Gujarat are leading a reframing of road sector development efforts through the prism of efficient multimodal services—but these are early days and much needs to be done at the state level to modernize India's trucking sector and help integrate it into a larger multimodal network.

What will be the role of the World Bank in India's state highway sector in the coming years? Given competing interests, our expectation is that there will be a need to be more selective in the future. While we hope that if we update this article in the next decade—there will be many more successes to tell of—we expect World Bank financing is most likely going to be focused on the most ambitious of these transformations.

9 PMGSY mandates that in order to access the government of India's resources, states must implement climate resilient construction practice and materials in at least 40 percent of all rural roads built under the program; Kerala has embedded a climate resilient module within RAMS to ensure that all maintenance plans and expenditures are climate informed.

References

Authors:
Advitha Arun and
Alice Duhaut,
The World Bank

Impact Evaluation of Transport Corridors: Approach from the ieConnect Portfolio

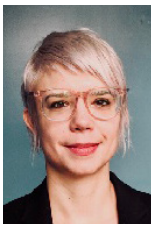
Transport infrastructure has the potential to bolster economic development by connecting several pillars of a nation's economy. Several studies have independently documented the gains and losses from investments in transport infrastructure, such as direct and indirect outcomes, wider economic benefits, and complementary measures. This article presents a programmatic approach for evaluating the impact of transport infrastructure investments with respect to their short and long run goals. It builds on existing data and reviews newly available high-frequency geospatial data and innovations on outcome measurements. The program exposition is substantiated with examples of projects currently evaluated under the ieConnect for Impact program at the World Bank.[1]

1 In addition to the authors, this article covers the contributions of several former and current ieConnect and DIME team members, in particular Sveta Milusheva, Théophile Bougna, Rob Marty, Kevin Croke, John Loeser, Florence Kondylis, and Maria Jones. The authors thank the ieConnect and DIME teams and management for their support and advice. More information on ieConnect's projects can be found here.

Introduction

About the Authors

Advitha Arun is a Research Assistant at the World Bank.



Alice Duhaut is an Economist in the Development Impact Evaluation unit at the World Bank.

Improved access to roads can increase output, reduce costs, and foster economic growth. During the fiscal year 2022, the World Bank listed 176 active transport projects, with US$35.33 billion in commitments. Given the magnitude and pervasiveness of transport investment across the developing world, it becomes essential to evaluate the benefits of such investments. Impact evaluation helps in understanding the return on investment (ROI) and helps policy makers design future corridor investments as well as complementary interventions. However, policy makers and academics seeking to address this question often find themselves impeded by challenges, such as data availability and choosing the appropriate indicator based on the context for statistical analyses.

Traditionally, transport appraisal plans estimate short-term outcomes ex ante, such as reduction in travel time and savings in terms of vehicle operating costs. The highway development and management model (HDM-4) is a widely used system for transport infrastructure investment appraisal and decision making. HDM-4 takes as inputs road conditions, vehicle speeds, traffic volume, and vehicle operating costs, among others. The outputs of the model include road user costs, sensitivity analysis, and a simplified economic evaluation of roads.

However, beyond the immediate benefits, such as reduced travel time and vehicle operating costs, infrastructure investments also aim at generating benefits for households and firms, thereby leading to economic growth and development.

Therefore, measurement of immediate outcomes is a necessary—though not a sufficient—measure of evaluating the impact of roads in developing countries. Monitoring informs the policy makers of the pace and progress of transport infrastructure investment. However, impact evaluation is necessary to understand the reasons for the apparent success of construction of roads in a particular context, if any. In this way, monitoring and impact evaluation complement each other in addressing questions of evaluating transport infrastructure and throwing light on complementary measures that could further increase the benefits of constructing corridors.

Despite their importance, impact evaluations of transport projects accounted for less than 1 percent of all impact evaluation studies globally between 1981 and 2012 (Cameron, Mishra, and Brown 2016). To bridge the knowledge gap, the World Bank's ieConnect for Impact program has undertaken several studies for improving the evidence base for policy making.

Rapid technological advancement during the past decade has enabled data collection using remote sensing technologies at relatively low cost. This advent of geospatial data has provided an opportunity for researchers in policy as well as academia to employ

publicly available high-quality data in their research on topics ranging from economic activity, agricultural productivity and pollution to urban development. A key advantage of geospatial data is its availability at large geographic scale for repeated periods, at relatively low cost. Measurement of these variables would be prohibitively expensive without remote sensing.

While the academic literature on impact evaluation of transport infrastructure has been effectively using these novel data sources, there is scope for the policy makers to tap into these. By reviewing a subset of work done in this space by the ieConnect team, this article seeks to systematically present methods for approaching questions in evaluating transport infrastructure. Though the review is not exhaustive, the article lays out a bare-bones structure policy makers can use to reproduce similar work in their respective contexts and contribute to growing international evidence in this area.

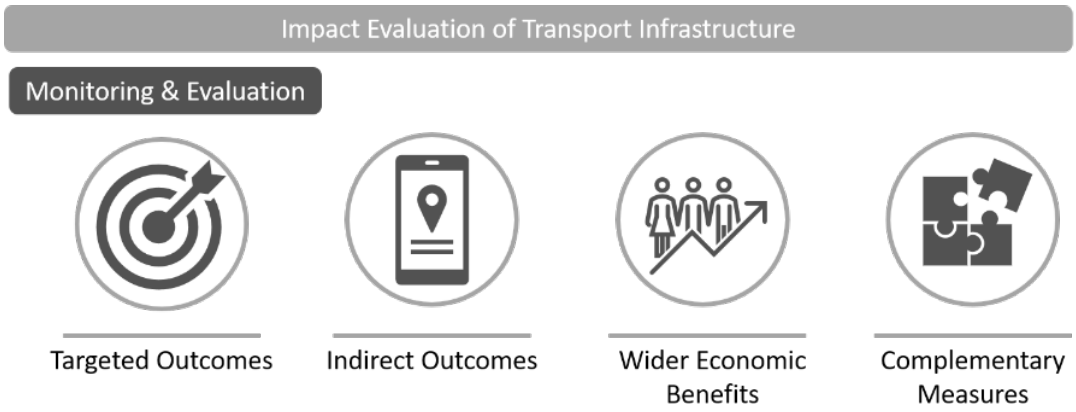
Challenges in Evaluation

Evaluation Beyond Monitoring

Metrics used by multilateral development banks (MDBs) for measuring the success of a transport infrastructure investment are often outputs. This is usually captured in the monitoring and evaluation, or M&E. The challenge posed by evaluating the benefits of transport infrastructure is that these investments are not implemented in a vacuum. Other factors might affect the success of a locality close to the road or intended beneficiaries, such as local industries or other government programs. The challenge that impact evaluations aim to address is to get at the causal effect of the transport infrastructure on the outcomes of interest.

Figure 1 shows the essential difference between impact evaluation and M&E. The role played by complementary policies in amplifying the economic benefits of transport corridors is also important to understand and mitigate the existence of relative "winners" and "losers." Roberts et al. (2020) finds detrimental effects on environmental quality outcomes in some regions and increased spatial inequality, despite overall positive average impact. Evidence-based policy making requires understanding the effectiveness and efficiency of "place-based" policy choices with respect to transport infrastructure (Duranton and Venables 2021).

Figure 1. Impact Evaluation of Transport Infrastructure



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Measuring Causal Impact

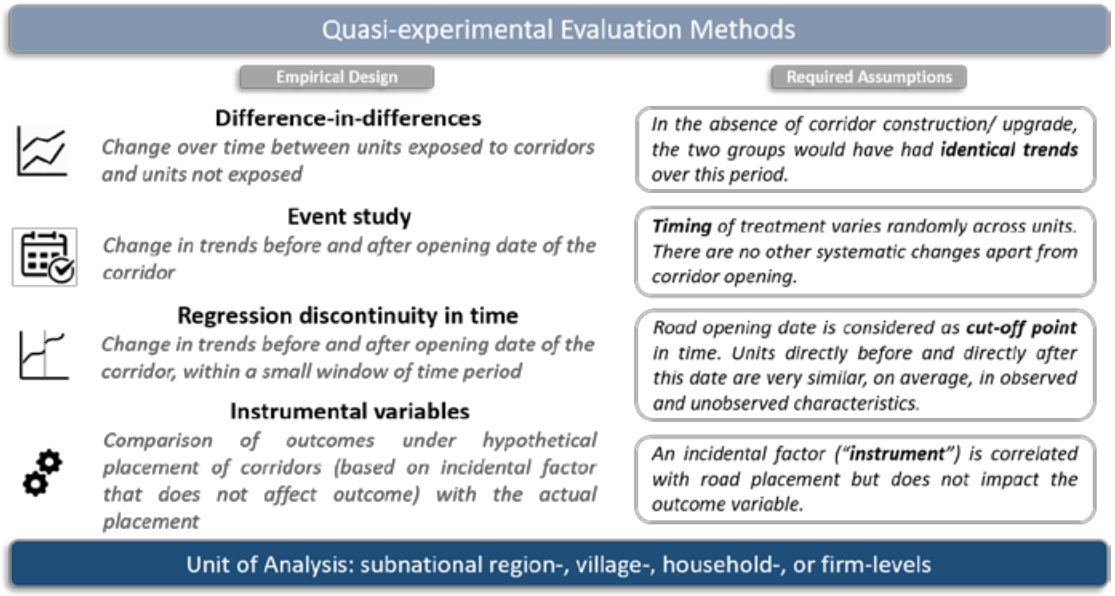
Traditional impact evaluations are based on an experimental design. A key feature of randomized experiments is that they enable comparison of statistically identical groups of individuals, which gives a precise estimate of the intended effect. However, it is impossible to randomize costly highways and roads placement in a geographic space. Policy makers prioritize transport investment in the areas that exhibit specific characteristics or would support a specific growth strategy. Additionally, investment in transport infrastructure could induce relocation of economic activity between places. This movement could not only result in gains in one location at the cost of another, but also makes comparison of outcome indicators between targeted and nontargeted locations insufficient.

Given these constraints, the economics literature has relied on other methods to arrive at the causal effect of the roads. These rely on examination of locations directly targeted by the project, the "in-between" locations along the corridors incidentally served and locations truly unaffected by the transport corridor. Locations affected by corridors, either directly or indirectly due to proximity, are classified as "treatment" units, whereas those completely unaffected are termed as "control" units.

Redding and Turner (2015) note that the recent literature has developed methods such as instrumental variables, difference-in-differences, regression discontinuity designs, matching, and event studies. These methods require larger sample sizes and more assumptions than experimental methods to provide valid and unbiased estimates of the causal impacts, as seen in **figure 2**.

Differences-in-differences compare outcome variables of units exposed to the roads' interventions with those units—villages not exposed but that have similar trends in outcomes ex ante. The change over time in the two groups quantifies the impact of the constructed infrastructure. Instrumental variables, instead, consider the placement of roads to be correlated with an incidental factor that does not impact the outcome variable. Event studies are a flexible form of difference-in-differences, giving estimates for each time period.

Figure 2. Quasi-Experimental Methods for Transport Infrastructure Impact Evaluation



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Inputs in Impact Evaluations

Sound evaluation of transport infrastructure depends not only on the methodological rigor of the proposed evaluation, but also on data quality and availability at high frequency. This is especially true in the case of low- and middle-income countries (LMICs), which have a dire need for both. Advances in technology have enabled the use of novel data sources to answer questions in traditional economics. Data from satellite imagery, aggregated mobile phone and crowdsourced data from social media are used by the ieConnect team. These granular datasets are available at high frequency with high geographic coverage. Combining these data sources with existing administrative data helps in evidence-based decision making for transport infrastructure investments, especially in development research (Donaldson and Storeygard (2016)).[2]

2 Among others, Bleakley and Lin (2012) and Henderson, Storeygard, and Weil (2011; 2012) use nighttime lights data to show agglomeration in areas surrounding portage sites and agricultural regions. Storeygard (2016) estimates the transport costs for cities in Sub-Saharan Africa and Alder (2016) studied the impact of the Golden Quadrilateral in India.

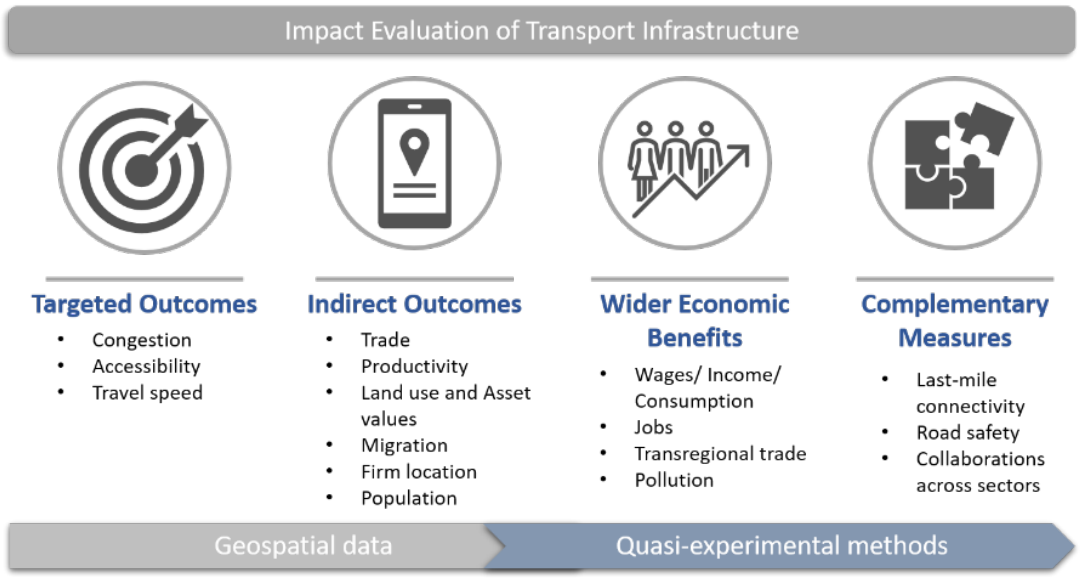
Proposed Approach to Evaluate Corridors Projects

We explain the proposed approach to impact evaluation of corridors in four sections, based on corridor projects, well-defined theory of change derived from policy and research questions and outcomes of interest:

1. Intervention-targeted outcomes
2. Indirect outcomes
3. Wider economic benefits
4. Complementary measures

This framework seeks to bring new and existing data sources together to answer questions in this space, as summarized in **figure 3**. It builds on the project appraisal objectives of transport infrastructure investments, which focus on reduced travel time to measure congestion and accessibility. As the effects of the corridors spill over, we can expect changes in land use and relocation of firms and workers—potentially resulting in urbanization and increased trade in the medium term. Over time, transport infrastructure improvements could induce increased economic activity, job creation, increased household income, and higher firm productivity. Further, the success of a transport corridor in catalyzing economic development depends on complementary measures that enable implementation, such as simplifying border processes for traders, last mile connectivity, or road safety.

Figure 3. Framework for Transport Infrastructure Impact Evaluation



Source: Original figure produced for this publication.

Intervention-Targeted Outcome: Accessibility

Providing accessibility is essential for public service delivery and matching people to jobs. In this way, transport infrastructure paves the path for achieving more than half of the Sustainable Development Goals, or SDGs (Cook et al. 2017) . Target 9.1 of the SDGs aims at developing reliable and sustainable infrastructure, to provide equitable economic opportunities and well-being for all. In developing countries, improving the connection of firms and farmers to national and global markets is crucial for job creation and economic growth. Policy makers often define "accessibility" as the ability and the ease with which people can reach their destinations.[3]

Accessibility in data-poor environments: Example of Tunisia corridors

The challenge of measuring accessibility then becomes that of finding the appropriate data for measuring population density. While this might be relatively easy to obtain in urban areas (using administrative data from municipalities, for example), measuring population precisely in remote and far-reaching rural areas is not usually so. Survey methods have provided a potential solution to the measurement of population density. For example, the Rural Access Index (RAI) designed and used by the World Bank provides a basis for estimating the proportion of rural population with access to the transport system by undertaking a locally representative household survey (Roberts, KC, and Rastogi 2006). In addition to being expensive, the survey method has the disadvantage of being inconsistent across areas, districts, and countries (World Bank 2016). Geospatial data provides a suitable alternative for measuring accessibility. For instance, high-resolution population distribution data by WorldPop, digitized road network data, and mobility data platforms (including navigation apps such as Google Maps). Focusing on population density measures accessibility through a "travel demand" approach alone. In contrast, according to Mehndiratta and Peralta Quiros (2015), combining granular geospatial data helps to link qualities of the transport system (road network, speed, costs) with those of the land-use system (distribution of activities).

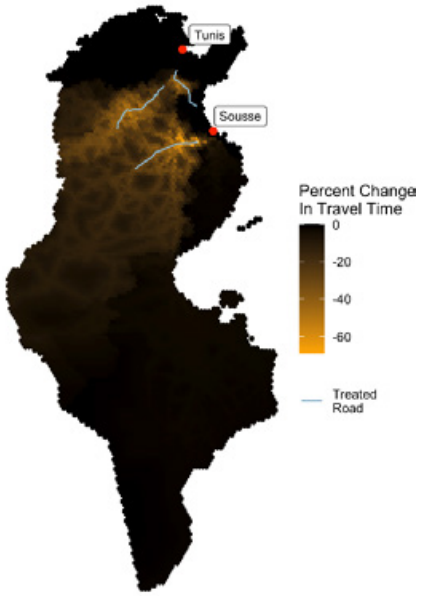
The challenge of measuring accessibility then becomes that of finding the appropriate data for measuring population density.

To address the poor traffic conditions on roads to and from Tunis, the government of Tunisia is working to improve the connections between the coastal economic hubs and the lagging interior regions by expanding the capacity of three road segments in the cental west region of the country. These upgrades seek to reduce travel times, improve road safety, and enable the access of interior regions to the main economic centers and international ports.

3 SDG Target 9.1.1, hence, measures the proportion of rural population who live within 2km of an all-seasoned road.

The targeted outcomes of the project include road upgrades to increase lane capacity for over 146 kilometers of the three road segments and increase the speed limit from 70 to 90 kilometers per hour (kph). To measure progress in these stated outcomes, the ieConnect team collected real-time data from Google Maps and Mapbox on travel times at regular time intervals (for example, every hour) between select locations. This provides useful information about how congestion has changed since the construction started. Using Google Maps API, or application programming interface, also has the advantage of tracking real-time road speed for roads with different traffic conditions, which enables real-time tracking of road congestion.

Figure 4. Accessibility in Tunisia



Source: Original figure produced for this publication

Since the intervention aims at better connection of interior regions in the country to the coastal cities of Tunis and Sousse, we consider these to be the origin locations for measuring accessibility. We then calculate the shortest distance to Tunis and Sousse for each pixel[4] on the map of Tunisia, and the time to travel that shortest distance. Repeating the process to derive the travel time under the improved corridor system, gives us the predicted change in travel time post corridor construction. Using these two measures of travel time, we build an accessibility map, as shown in **figure 4**.

4 A pixel measures an area of 750 meters x 750 meters on the Earth's surface.

Indirect Outcomes: Economic Activity and Land Use Changes

Transport corridor systems are typically planned and constructed with the objective of reducing travel time for people and enabling better connection. However, while this ensures greater mobility, it might not always guarantee better economic opportunities. Often, the aim of the projects is also to bring growth to relatively remote or less advanced areas by improving access to market and inputs for producers, and access to jobs for the population living in relatively remote urban areas. Transport infrastructure can result in improved access to markets through two ways; first is through reduced travel time to existing markets, and the second is through inducing relocation of markets. On the one hand, construction of transport infrastructure reduces travel time and costs for firms and consumers, as explained previously. This implies that inputs to production and finished goods can be transported across space at relatively less, albeit at some, cost—known in the academic literature as transport costs. A potential way to circumvent these transport costs is for the firms to geographically fragment the production process by setting up small local plants (Ottaviano 2008). On the other hand, however, fragmentation comes at the cost of decreased efficiency and increasing returns to scale at the plant level. Firms are also able to enjoy the benefits of "scale economies" such as access to specialized business-to-business services and knowledge spillovers or idea flows (Fujita and Thisse 2002; Duranton and Puga 2004).

In this section, we explore ways to evaluate the impact of transport corridors on this trade-off between transport costs and scale economies via its impact on land use, densification and economic activity using geospatial data.

While rarely targeted by policymakers, land use changes might happen because of the new infrastructure.

Land-use changes: Example from the Ethiopia road sector development program

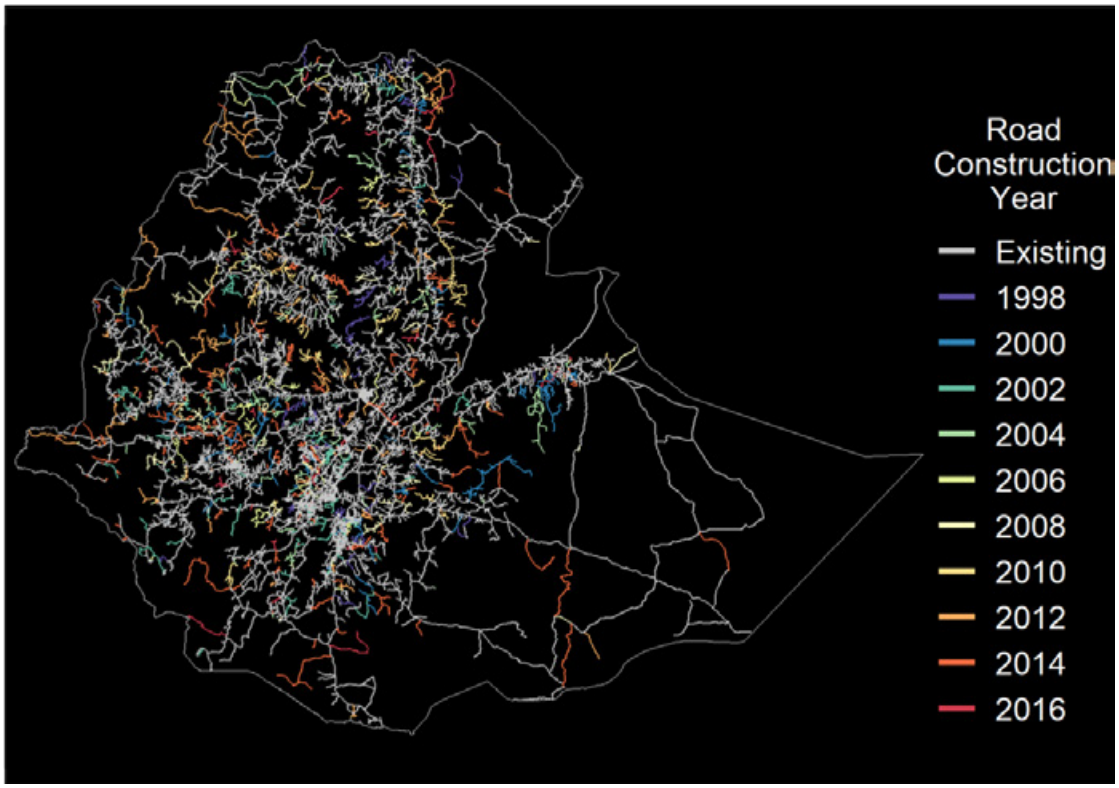
While rarely targeted by policy makers, land-use changes might happen because of the new infrastructure. In economic theory, the impact of transport corridors on land-use changes is a priori ambiguous: while it aims at allowing economic activity to flourish in remote areas, it can also lead to greater specialization, such that agricultural zones see more intensive agriculture take place while urban and periurban areas grow. That is, as transport costs fall, roads could either facilitate migration to periurban and urban areas and specialization of rural economies in agriculture, or lower transport costs could cause emergence and expansion of rural economic activities. Evidence in this area is mixed. For instance, in Peru Escobal and Ponce (2002) find that rehabilitated road access enhances nonagricultural income opportunities, whereas Ethiopia (Gebressilasse 2023) and China (Qin and Zhang 2016) show access to roads is strongly associated with

specialization, while road connections improve household agricultural income. This stresses the importance of evaluations that can uncover the magnitude of impact along sectoral and spatial variations.

However, a key challenge in measuring such outcomes is the availability of reliable granular data. Traditionally, studies have analyzed long-term trends using administrative data or surveys on number of new firms and household income levels. These data sources are available ex post at relatively larger geographic coverage and aggregated over time periods. In the context of developing countries, the issue could be further complicated by potential manipulation of key statistical information. The advent of remote sensing data presents the opportunity to evaluate progress along these measures at granular geographic coverage and higher temporal frequency.

To contribute to this strand of literature, the ieConnect research team has undertaken a study to measure the impact of building roads on urbanization in Ethiopia (Alder et al. 2022). The study combines remote sensing data with administrative data from the government of Ethiopia to study the road sector development program from 1996 to 2016 (**figure 5**). The aim of the program was to improve the sparse network of roads to support agricultural value chains, light manufacturing, and growth in Ethiopia.

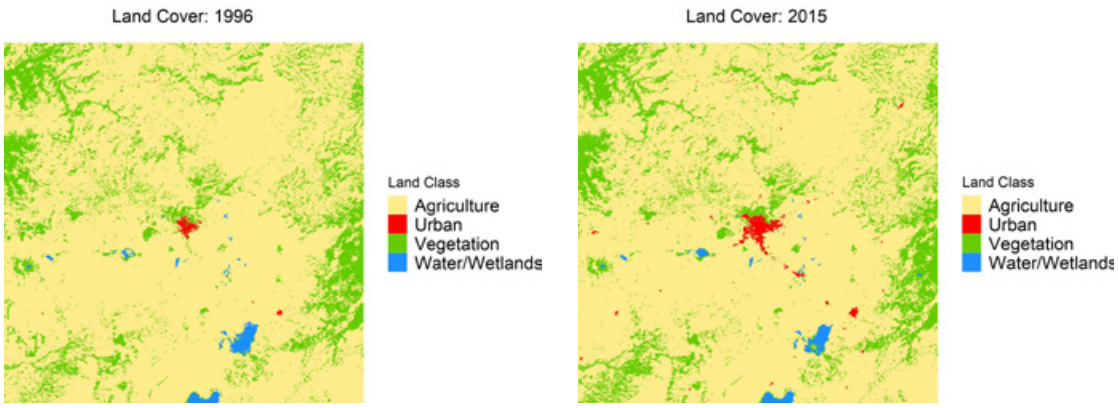
Figure 5. Ethiopa Road Sector Development Program (RSDP)



Source: Alder et al. 2022.

The study is based on an instrumental variable design and a differences-in-differences design. The empirical approaches address the fact that roads are not built at random; the places benefitting from an upgraded road might already have characteristics that lead them to have higher economic growth, or a different trend in employment. The instrumental variable approach addresses this issue by creating an instrument linked to the objectives of the program yet independent from local conditions. Specifically, following an approach from (Faber 2014), the team constructed a hypothetical network in a way that minimizes construction costs proxied by elevation change and existing land cover. To measure urbanization, the team used land cover data[5] (shown in a **figure 6**).

Figure 6. Urbanization in Ethiopia Based on Changes in Land Cover from 1992 to 2018



Source: Alder et al. 2022.

Economic activity through nighttime lights: example from Iraq corridors

Transport corridors are constructed with the objective of bringing economic growth at the national and subnational levels, consequently leading to overall economic prosperity. MDBs aim to stimulate intraregional and global trade and foster market integration through corridor investments. These objectives by planners are guided by economic theory about the distributional effects of transport infrastructure. According to this theory, regions have fixed factor endowments and differing productivity levels. A new road link between two of these regions would lower their bilateral trade costs, thereby allowing consumers to buy goods from the most affordable regions and producers to sell more of what they are best at producing. Hence, increased access to markets through transport corridors could benefit all regions, though in an inequal manner (Donaldson and Storeygard 2016).

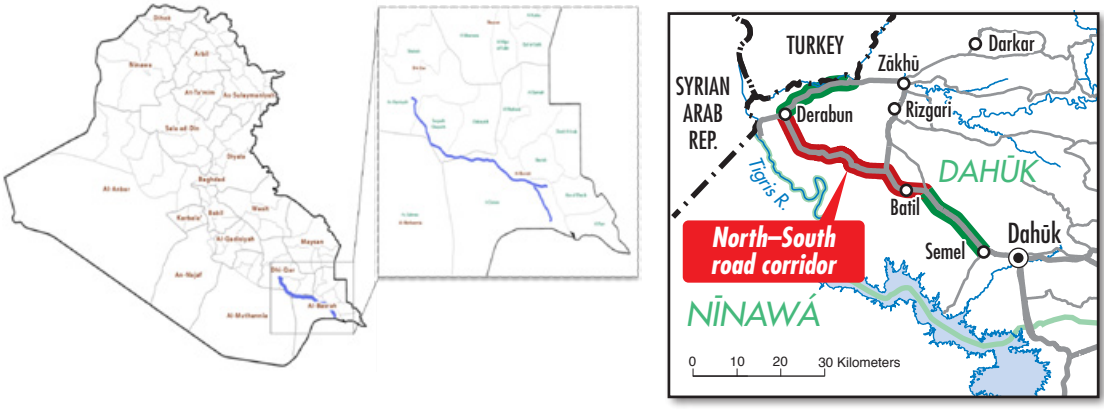
5 Available annually since 1992. Land cover data comes from European Space Agency (Globcover dataset).

The key challenge of impact evaluation along these objectives is that it necessitates reliable and granular economic data at subnational levels. While some studies have focused on using survey on wages, employment, and consumption (Small and Verhoef 2007) or administrative data on firms (Banerjee, Duflo, and Qian 2020), data availability is still an issue for LMICs.

Recent advances in technology and data availability have provided a partial solution to this issue. A key advantage of nightlights data is that it is available at higher spatial resolution, and is also available for regions that may not have official data because of lack of statistical capacity or conflict. For example, the ieConnect team is using geospatial impact evaluation in the fragile context of Iraq (DIME 2019) to evaluate the country's transport corridor. Iraq has sought to address the problem of a weak and underdeveloped infrastructure sector. Most of the population is inadequately serviced by unpaved roads with the impact falling disproportionately on low-income groups. The government of Iraq prepared its national development plan (NDP), where improving transport infrastructure is expected to play a key role.

The corridor project in Iraq aims at rehabilitating a 257-kilometer segment of Expressway 1 and constructing of a 23-kilometer segment of the north–south transport corridor near Turkey and Syria, as shown in **figure 7**.

Figure 7. Expressway Rehabilitation and Construction in Iraq

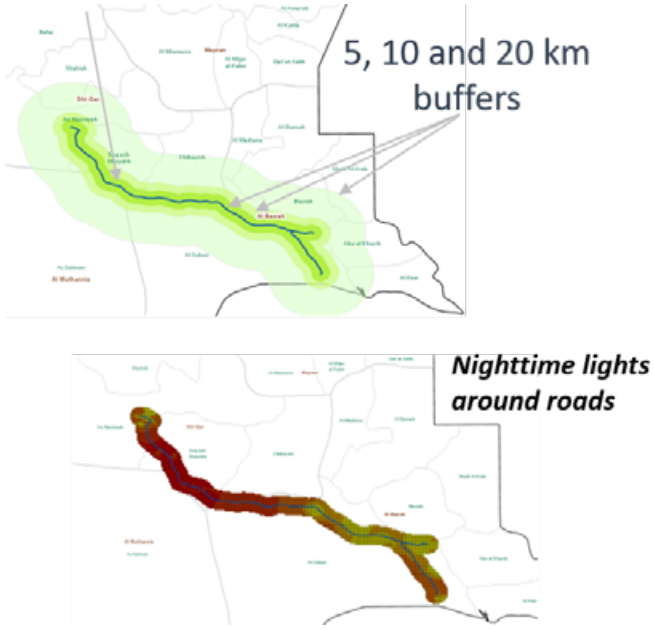


Source: DIME 2019. Map produced by the World Bank Cartography Unit (IBRD 40249).

To estimate the impact of the interventions on local economic development, the ieConnect study relies on a combination of data from satellite imagery as well as administrative data[6] at a monthly frequency. A pixel is "treated" if it lies within 10 kilometers of the improved roads. **Figure 8** shows luminosity surrounding the project roads.

6 In the case of Iraq, survey data such as Iraq Household Socioeconomic Survey (IHSES). and Continuous Household Survey (CHS) are georeferenced.

Figure 8. Nighttime Lights near Project Roads



Source: Original figure produced for this publication.

Wider Economic Benefits and Social Costs

In addition to direct and indirect outcomes, investment in transport infrastructure is also aimed at providing wider economic benefits in the long run, such as increase in intra-national trade, increase in economic activity, and changes in land-use valuation. This is especially relevant in the context of developing countries, where roads pave the path to eliminating extreme poverty.

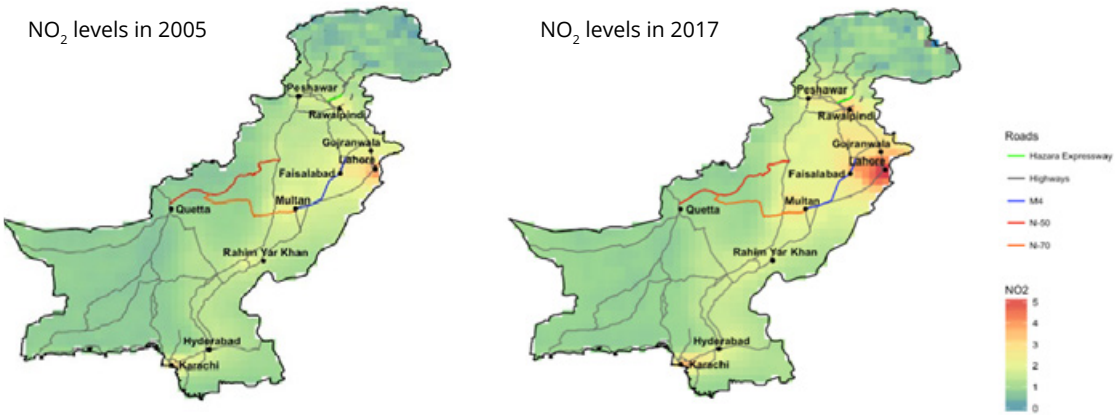
Literature evaluating the impact of transport infrastructure has focused less on the wider economic benefits than on the indirect economic impacts and choice of firm location (Redding and Turner 2015). As travel time and vehicle operating cost reduce, other benefits from the transport infrastructure arise. First, in very disconnected countries, prices of similar goods might differ significantly from city to city. One of the aims of the transport corridors is thus improving national integration by reducing this difference in prices (known as trade costs) between cities and improving arbitrage possibilities for inhabitants. Second, increasing the volume of road users might have consequences on the newly crossed territories and on the environment. The approaches to the latter two question are discussed below.

Social cost of transport corridors – Example from air pollution in Pakistan

Policy makers are concerned with the social costs of constructing transport infrastructure, in addition to the economic costs and benefits. Reduction in travel time should lead to reduction in emissions and air pollution. On the other hand, however, the fundamental law of congestion states that traffic increases proportional to the increase in road capacity. Reduced air pollution will contribute to SDG 3. SDG target 11.6 measures the air quality in cities while target 11.2 measures access to sustainable transport. These emissions generated have adverse health consequences, according to reports by the Asian Development Bank (ADB) and World Health Organization (WHO) (Qui et al. 2017; WHO 2011). A World Bank study in 2000 found that road transport was the largest source of nitrogen oxide (NO_x) emissions, over 40 percent (Lvovsky et al. 2000). Recent studies suggest that reducing congestion reduces nitrogen dioxide (NO_2) and NO_x (Gendron-Carrier et al. 2018) and reduces particulate matter, while Hilboll, Richter, and Burrows (2017) find that rapid growth experienced by India translated into higher concentration in pollutants.

Research by ieConnect in Pakistan focuses on uncovering the effect of intercity transport infrastructure on air pollution. Unfortunately, data on particulate matter and pollutants on the ground have been irregularly released in the past. The NO_2 levels in Peshawar, Islamabad, Lahore, and Karachi were found to be greater than the WHO guidelines in 2014 and it was estimated that 85 percent of the particulate matter of less than 2.5 microns is linked to road transportation (Sánchez-Triana et al. 2014). **Figure 9** shows the change in yearly average of NO_2 levels over the years.[7] The more industrialized areas of Sindh, especially Lahore, have seen their level of NO_2 increase between 2005 and 2017.

Figure 9. Air Pollution in Pakistan



Values are tropospheric NO_2 10^{15} molec/cm^2.

Source: Original figure produced for this publication.

7 Values above $5x10^{15}$ molecules per square centimeter (cm_2) are generally considered polluted and values above $1x10^{16}$ are considered highly polluted.

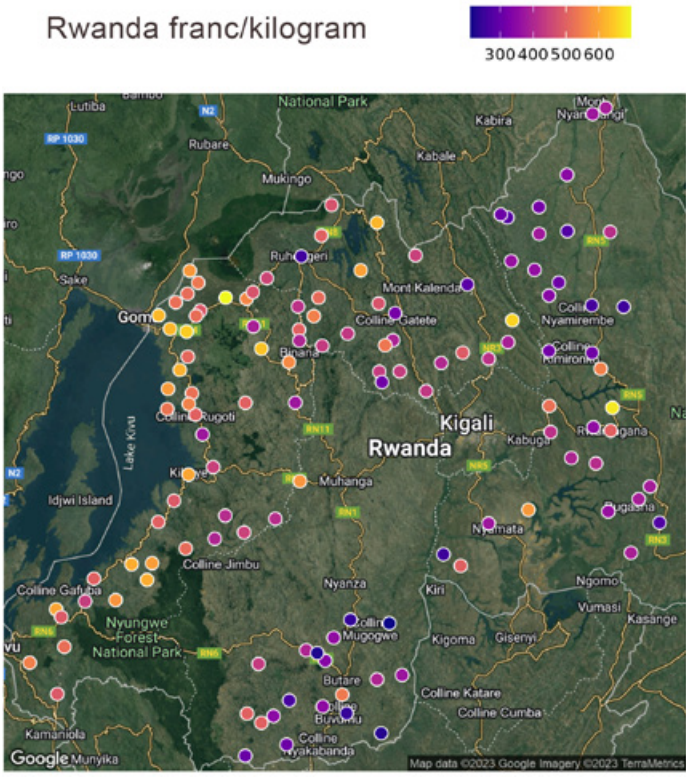
Complementary Measures: Enhancing the Benefits of Infrastructure Investments

Facilitating trade across borders along the corridor: Example from Malawi

As direct transport costs are part of a wider array of trade costs, it is important to identify their relative importance to prioritize intervention and enhance the impact of hard infrastructure (WTO 2015). This impact evaluation studies an ongoing standard trade facilitation intervention in Malawi aiming at simplifying border crossing by streamlining the steps for clearance and final authorization to cross the border by connecting agencies to the customs database and reducing the number of agencies present at the border. The intervention evaluated is part of a larger package of hard and soft infrastructure to enhance connectivity in Southern Africa. The analysis is based on extracts from customs data and trader surveys to have a measure of the relative importance of border crossing-related costs, transport costs, and bribes among the total trade costs and evaluate the impact of the intervention on trade cost and customs' revenue collection.

Last-mile connectivity: Example from Rwanda

Figure 10. Rwanda: Market Prices for Tomatoes and Feeder Roads in Q4 2019



Source: Original figure produced for this publication by the DIME Rwanda research team.

Several countries in the developing world have seen massive amounts of investment in large transport infrastructure projects. Despite these efforts, connectivity remains a primary issue in rural and remote areas. For instance, 40 percent of the rural population in Africa lives within 2 kilometers of an all-season road (Gwilliam et al. 2008). In such a scenario, last-mile connectivity between the national road system and remote areas is a pressing development challenge. Though investment in large corridor projects is undertaken with the aim to increase economic benefits, their individual impact can vary across population groups and locations. Complementary reforms have the potential to catalyze economic growth and development across locations and population groups.

For example, the government of Rwanda is rehabilitating feeder roads to reduce travel times and increase access to markets. The DIME study uses administrative, survey, market prices, and remote sensing data to study the impact of the feeder roads (**figure 10**).

The team finds that remote villages have 23.1 percent lower household income than more connected villages, and that feeder road rehabilitation increases short-run household income in remote villages by 23.4 percent, representing a full catch-up of income.

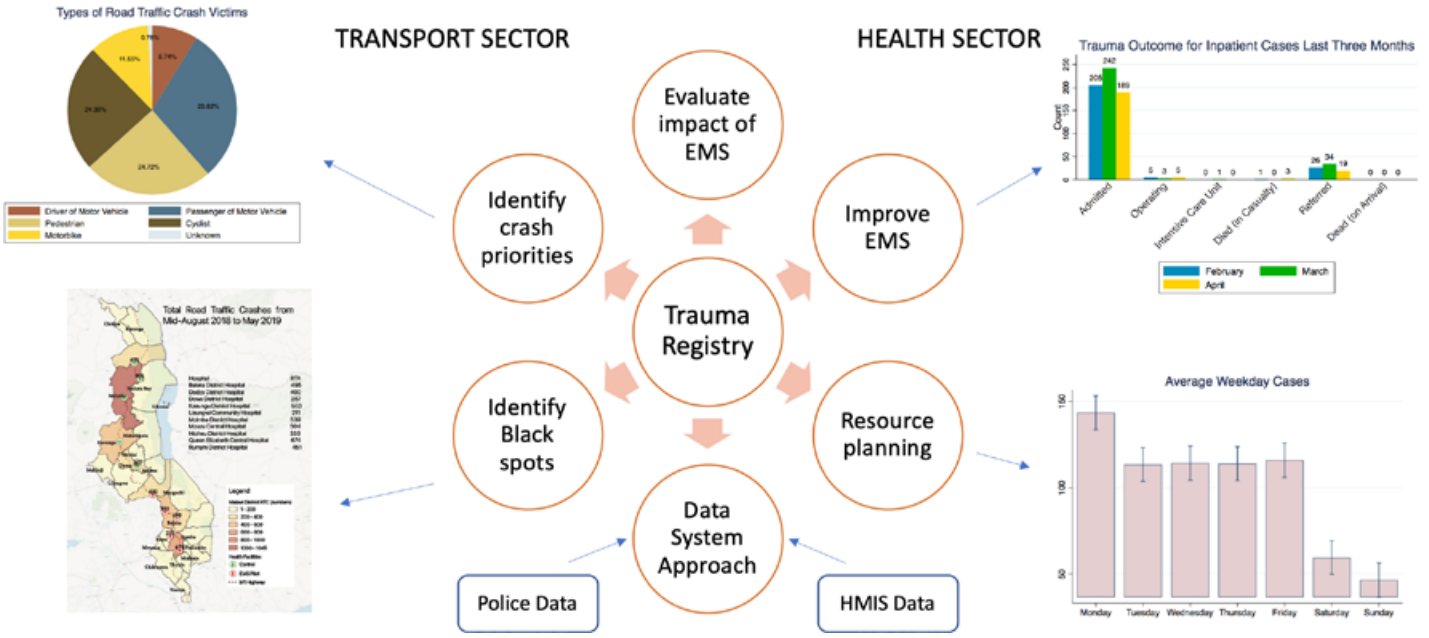
Road safety and cross-sectoral collaboration

Fatalities and injuries from road traffic crashes represent a significant social cost, particularly along major trade corridors. Africa has one of the highest road traffic death rates in the world, with 26.6 deaths per 100,000 people (WHO 2015).

Road safety will only continue to grow as a problem if it is not addressed. As more resources are channeled toward improving corridors, these upgrades often lead to higher road speeds, which can increase the number of injuries and deaths from motor vehicle crashes (Job, Soames, and Sakashita 2016). Yet, achieving the SDG target for reduction in road deaths could add 15 to 22 percent of GDP growth over 24 years (World Bank 2017). Therefore, when evaluating the economic impacts of new transport corridors, it is important to factor in the impacts that this infrastructure could have on road safety. Evidence on the effectiveness of such cross-sectoral interventions between agencies in charge of transport, health and law enforcement, among other agencies, is limited. A key challenge for policy makers looking to evaluate the impact of such cross-sectoral reforms on road safety is the paucity of data on road traffic crashes and outcomes. Significant gaps exist in administrative records on crashes and post-crash medical data in LMICs. As with other outcomes, identifying relevant data sources and strengthening data collection from different institutions is critical.

One example of the addition of a complementary road safety intervention is a pilot program in Malawi, illustrated in **figure 11**. This program is focused on a cross-sectoral collaboration focusing on first responders and trauma center improvements as part of the larger Southern Africa Trade and Transport Facilitation Program (SATTFP). Research by the ieConnect team involved pooling high frequency data from four primary sources to create a data system that can be used for evaluating the complementary reforms and planning future transport infrastructure projects (Croke et al. 2020).

Figure 11. Building Data Systems through Cross-Sectoral Collaborations in Malawi



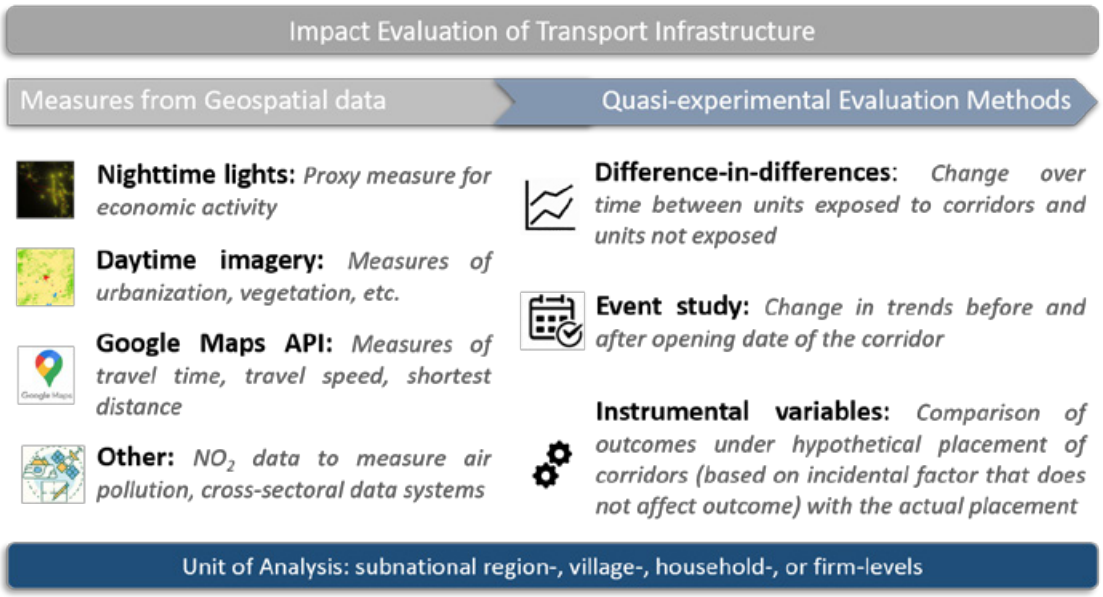
Source: Original figure produced for this publication, by the ieConnect team.

Path Forward

This article presents a framework that can be used by policy makers to understand the wider socioeconomic impacts of transport infrastructure projects. Given the large financial investment and the potential for wide economic benefits of transport corridors, their impact evaluation is essential for evidence-based policy making. The key challenges faced by policy makers and researchers in this area are availability of data and the use of relevant methodology for deriving precise estimates.

With respect to data availability, this article suggests combining geospatial data with the available administrative data in data-poor environments. Advances in technology have enabled the use of remote sensing and satellite imagery, which are used as proxy measures in the economics literature for measures such as local economic activity, travel time, accessibility and land use. Remote sensing data provides granular geographic coverage and higher frequency at lower cost. Cross-sector collaborations (across transport, trade health, and other sectors) can be used to build a comprehensive data system that tracks real-time outputs.

Figure 12. Proposed Framework for Impact Evaluation of Transport Corridors



Source: Original figure produced for this publication.

Given the strategic placement of corridors and the impossibility of randomizing end-users, reliance on quasi-experimental methods is suggested. Further, use of geospatial data provides the additional advantage of verifying long-term trends in unobservable factors such as quality of roads and mode of transportation, which are essential for the methods such as difference-in-differences, event study, and instrumental variables, as summarized in **figure 12**.

In addition to the targeted outputs and economic outcomes, this article highlights the importance of evaluating the impact of wider economic benefits as well as complementary reforms. There is a large scope for policy makers and researchers to evaluate the effects of corridors on equity and environmental welfare, as corridors materialize and their benefits spillover. Complementary policies can help amplify the benefits of transport corridors, and hence evaluating their impact helps the design of an optimal corridor package.

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Authors:
Aiga Stokenberga and Javier Morales Sarriera,
The World Bank

Insights from Leveraging *Big Data* to Track the Impact of the COVID-19 Pandemic on Mobility in Buenos Aires

The COVID-19 pandemic and the lockdown measures implemented in 2020 disrupted mobility in cities around the globe, by adding new constraints to the travel behaviors of the residents and businesses and by at least temporarily changing personal mobility preferences. However, while various policy responses followed over the subsequent months, including by the authorities governing the Buenos Aires Metropolitan Area (AMBA for its Spanish acronym), these were implemented in the absence of adequate data that would allow understanding exactly how travel patterns had changed, their drivers, and the likely persistence of the pandemic-induced changes going forward. Conducted at a time that could already be called the "new normal," the study discussed in this article aimed to fill this knowledge gap by drawing on mobile phone, mobility app, and public transport smart card based "big data" and by surveying over 20,000 private motorized mode users on the ground.

About the Authors

Aiga Stokenberga is a Transport Economist at the World Bank.

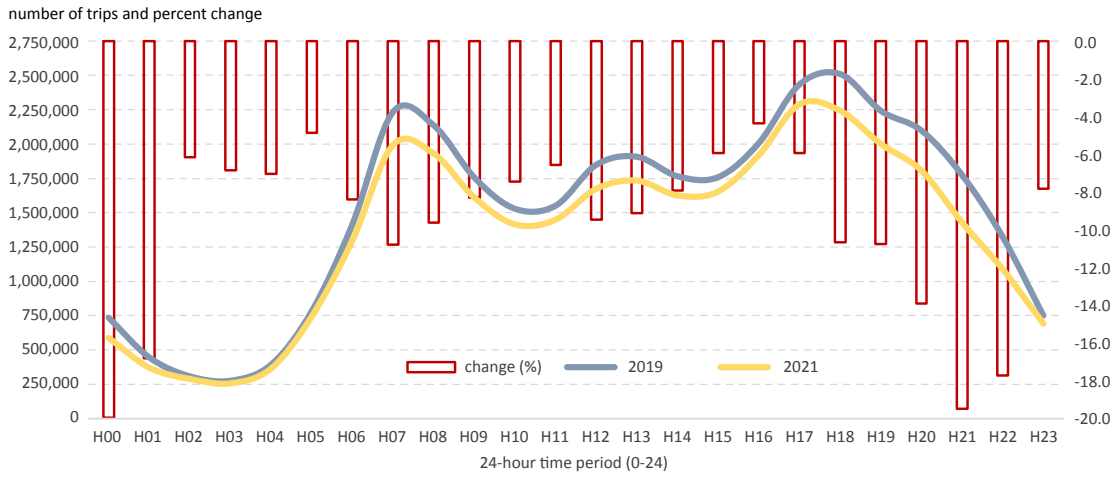
Javier Morales Sarriera is a Transport Economist at the World Bank.

Since the Steep Decline in March 2020, Overall Mobility Appears to Be Recovering

Using millions of observations of mobile phone call detail records (CDRs) covering the Metropolitan Area, the study team analyzed several key mobility indicators at the scale of AMBA for the prepandemic (October 2019), pandemic (October 2020), and "new normal" (October 2021) periods. Overall, the total number of trips made in AMBA on an average weekday was more than 11 percent lower in 2021 than in 2019. Trip generation rates per person in 2021 were still below the 2019 level in the central part of the Metropolitan Area (Autonomous City of Buenos Aires, or CABA) and the first ring of Greater Buenos Aires (GBA), while in the peripheral parts of AMBA they had recovered more.

As shown in **figure 1**, the overall hourly trip pattern in the prepandemic and the "new normal" periods appears to be similar, with the highest peak at around 5:00 to 6:00 p.m. (P017 to P018) and a second one at 7:00 to 8:00 a.m. (P07 to P08) However, while the overall hourly trip distribution did not change much, the intensity of the highs and the lows did. Namely, the morning, mid-day, and evening rush hour peaks in 2021 were lower than in 2019, which can be explained by the lower share of people commuting to in-person jobs, among other factors.

Figure 1. Hourly Trip Distribution in AMBA on a Weekday in October in 2019 vs. 2021

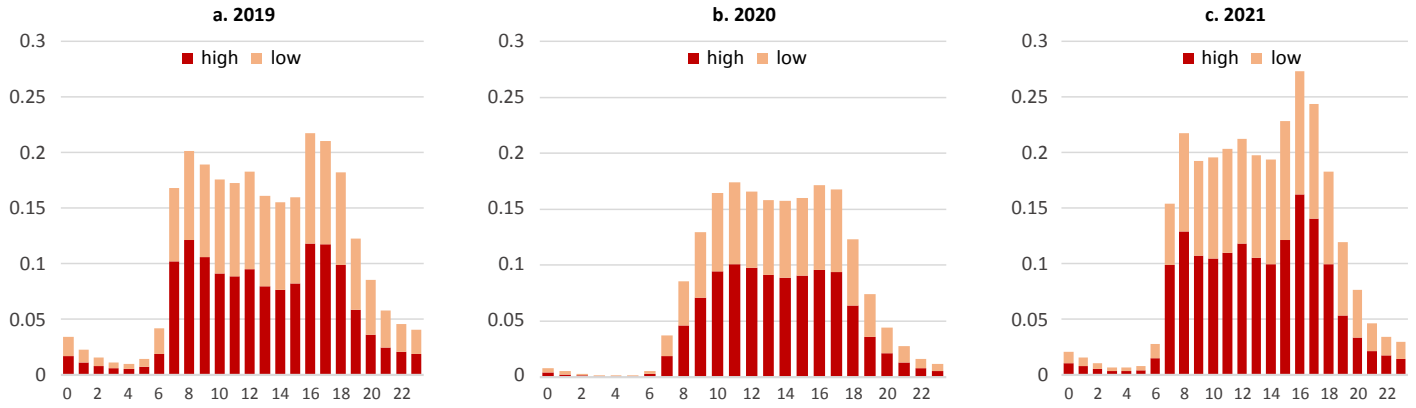


Source: Original figure produced for this publication, based on analysis by study team using call detail record (CDR) data from Claro Argentina.

Interestingly, as revealed by complementary analysis conducted by the team using data tracked by Waze for Cities[1] for the same type periods (see **figure 2**), even though *total* traffic intensity measured across the entire day was 11 percent lower, consistent with the overall figure obtained from the CDR analysis, the amount of "high" congestion in October 2021 (**panel c**) appears to have exceeded the October 2019 (**panel a**) level during the highest activity hours. Moreover, there was a particular increase in the "high" level of congestion in CABA specifically.

1 In the Waze for Cities data, the congestion level is classified as either low (levels 1 and 2) or high (levels 3 and 4).

Figure 2. Changes in Congestion Index in CABA in 2019 to 2021



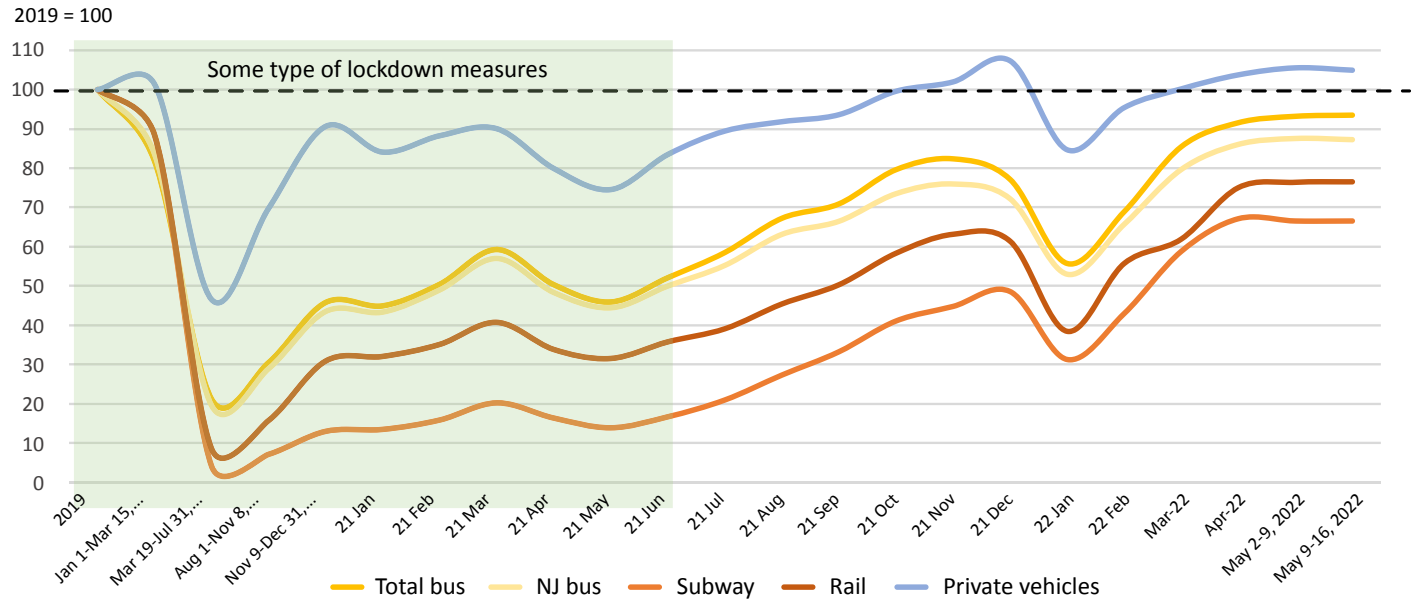
Source: Original figure produced for this publication, based on analysis by study team, using Waze for Cities data.

What Explains a Drop in the Overall Number of Trips, but an Increase in Congestion?

Already on a decline since a peak in 2012, public transport ridership was hit heavily by the pandemic and the associated lockdowns and changes in passenger preferences. Public transport ridership in AMBA declined sharply in March 2020 and by May 2022 it had not yet recovered despite picking up after the end of the lockdown measures (**figure 3**). As inferred from the Sistema Único de Boleto Electrónico (SUBE) smart card transaction data, in mid-May 2022, public transport ridership still stood at only 79 percent of the level of the same month of 2019, ranging from just 61 percent of the 2019 level in the case of the subway (called Subte by locals) to 79 percent in the case of rail to 93 percent in the case of buses. These figures can be explained not only by lower overall mobility, but also a significant shift to private motorized modes. According to the survey implemented as part of the current study of over 20,000 current car and motorcycle users, roughly 12 percent of them had shifted to the motorized mode only since the start of the pandemic, and the vast majority of them had previously relied on public transport.

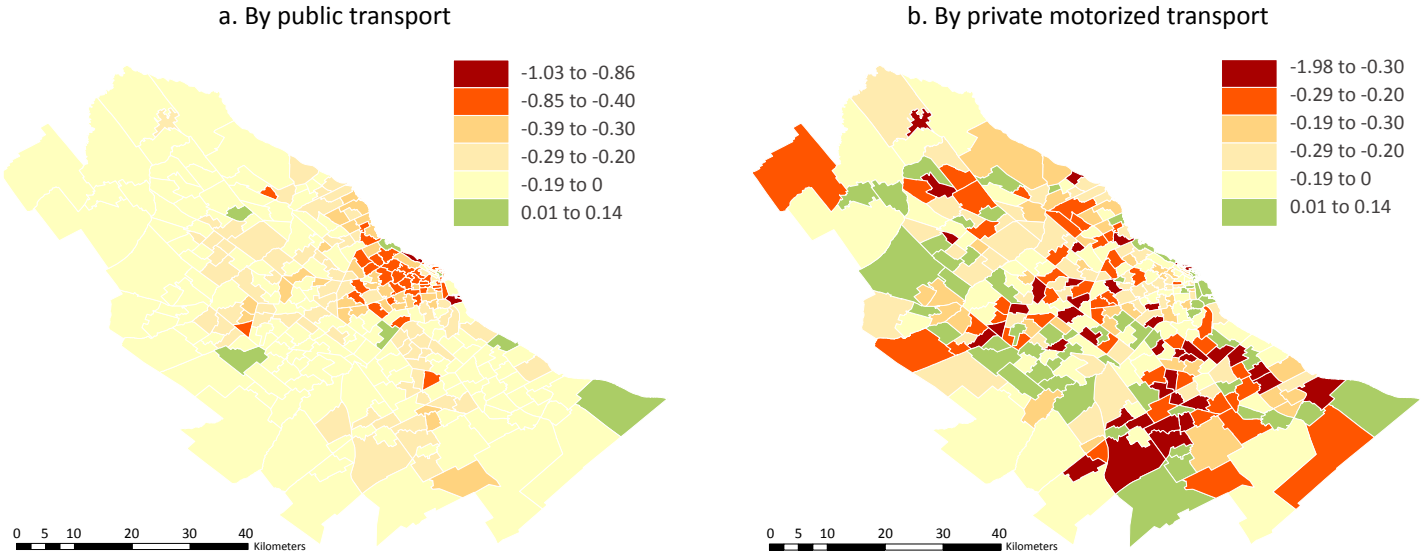
Private motorized mobility saw an immediate drop of about 90 percent at the very beginning of the pandemic due to a government mandated lockdown; however, within a year it had more or less fully recovered. As of mid-May 2022, the volume of private vehicle flows recorded on AMBA's highways stood at 107 percent the level of an average work week in 2019 (see **figure 3**). Also, according to the CDR-based analysis, while most neighborhoods in AMBA in October 2021 were still seeing significantly fewer trips by public transport compared to October 2019, trip generation rates by private motorized transport had already exceeded the prepandemic level in many areas (**figure 4**).

Figure 3. Change in SUBE Transactions and Private Vehicle Flows on AMBA's Motorways, 2020 to 2022



Source: Buenos Aires Government.

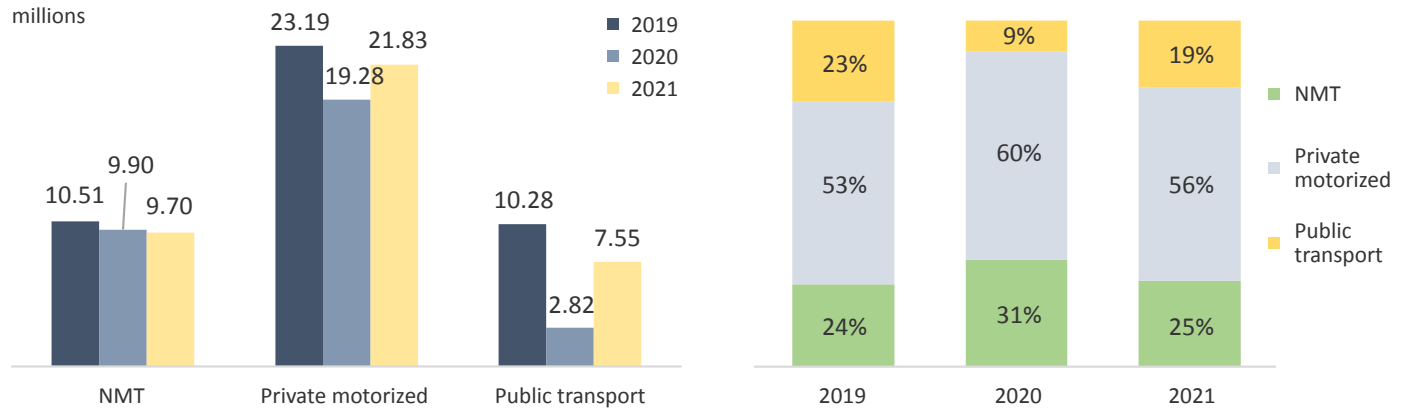
Figure 4. Change in the Trip Generation Rates per Person, a Workday in October 2019 vs. October 2021



Source: Analysis by study team, based on call detail record (CDR) data from Claro Argentina.

Accordingly, private motorized transport increased its modal share during the pandemic, from 51 percent of trips on weekdays in 2019 to 60 percent in 2020, at the expense of public transport which lost 14 percentage points (**figure 5**), according to the CDR-based analysis. By end-2021, the modal share of private vehicles still remained above the prepandemic level. Meanwhile, while nonmotorized transport had gained a significant modal share during the first year of the pandemic, by end-2021 the gain had dissipated. It is important to highlight that the modal share for private motorized transport from the CDR-based analysis is higher than from household surveys; for example, the ENMODO 2009/2010 results showed a 32-percent modal share.

Figure 5. Total Daily Trips in AMBA and Share of Trips by Mode, Weekdays in October 2019 vs. 2020 vs. 2021



Source: Analysis by study team, based on call detail record (CDR) data from Claro Argentina.

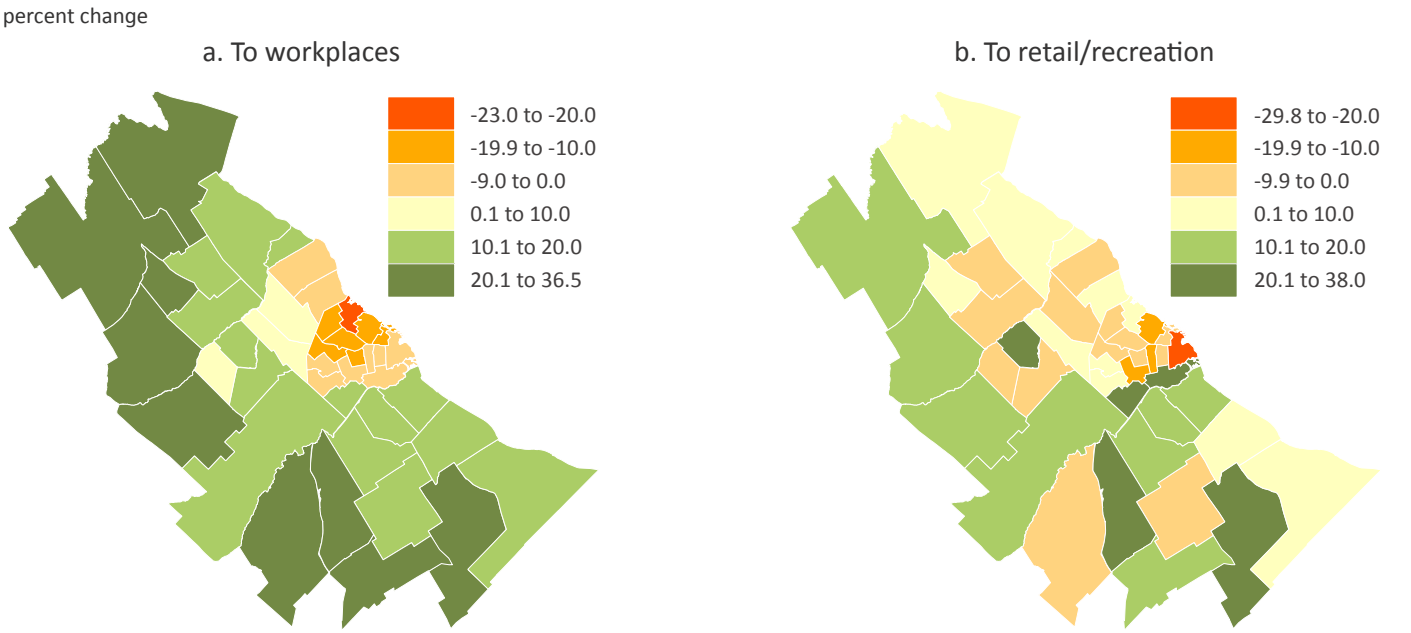
The Pandemic Accelerated eCommerce and Telework, Although They Tapered Off in 2021 . . .

Teleworking grew significantly during the pandemic, with the number of people working from home tripling from prepandemic levels, from 6 percent to 17 percent; an estimated 18 to 29 percent of the jobs in Argentina could conducted remotely, albeit concentrated in high-wage sectors. As revealed by high frequency data tracked by Google, in the last week of March 2022, the volume of trips to workplaces in AMBA overall was still 8 to 9 percent below the prepandemic level, with the remaining gap at least in part due to a continuation of remote or hybrid work arrangements, especially in CABA (**figure 6**).

Having already grown significantly in the last few years, eshopping and food delivery boomed even more during the pandemic, more than doubling in electronic sales in Argentina overall in the first half of 2020 compared to the first half of 2019. The share of online shoppers who selected the goods to be delivered to their home increased to 80 percent, up from 62 percent in 2018. That said, by late 2021, the overall boom in online shopping had slowed somewhat compared to 2020, as people returned to eating out

more and shopping in person. Accordingly, by late March 2022, trips to retail and recreation destinations were already 10 percent or more above the March 2020 level in many parts of the metropolitan area.

Figure 6. Trips to Workplaces and Retail or Recreation in AMBA, March 21–28, 2022 vs. March 7, 2020



Source: Original figure produced for this publication, based on analysis by study team, using data from Google COVID-19 Community Mobility Reports.

How Will Urban Mobility in AMBA Evolve in the Coming Years, in the Context of the Past and Recent Trends?

The "new normal" mobility environment in AMBA appears characterized by less public transport ridership than prior to the pandemic, which could persist for some time. The pandemic has also strengthened some previous trends already taking shape over the past decade and likely to further consolidate—such as increased use of nonmotorized transport (NMT).

As of late spring 2022, the effects of the pandemic and the lockdowns on transit ridership had tapered significantly, though not fully. Having seen the most consistent growth in the decade before the pandemic, the Subte subway system in Buenos Aires was hit the hardest by the pandemic and has recovered the least, while the opposite has been the case for the city's bus system. Among other factors, the ability of the bus system to attract new users and increase its share of public transport trips will depend on whether the public perceives the suburban rail system as a convenient mode for shorter commutes—as the trend toward trips between GBA's municipalities, which accelerated during the pandemic, strengthens.

Despite considerable investment in efficient bus systems over the past decades and associated reductions in travel times, for the foreseeable future, plans for bus rapid transit (BRT) expansion are limited to CABA. Given the congestion already above the prepandemic levels during certain times of the day (as captured by data from Waze for Cities), commercial speeds for buses in GBA could start to decline on the nonsegregated bus corridors, thus impacting service quality and the ability to attract the passengers lost over the past two years.

The "new normal" mobility environment in AMBA appears characterized by less public transport ridership than prior to the pandemic.

During the pandemic, the city saw a significant population relocation to gated communities in GBA, as telecommuting allowed workers to stay at home without the need to spend time commuting. Families that already had a house in a gated community opted for staying there as restrictive measures on personal movement were enforced, which in turn spurred a surge in property prices as more people decided to move to these communities. As a result, plans for new housing developments continued to consolidate through GBA, and new gated communities are currently being built, especially in the western and southern areas.

That being said, the level of service of private motorized transport connecting these communities to central Buenos Aires will likely see a decline as limited room exists for expanding access roads, either from a fiscal or land availability perspective. Therefore, travel times are expected to grow for the fraction of commuters living in gated communities in the second and third ring of GBA, but also for poorer commuters living in GBA using motorized modes. The increasing congestion in AMBA over time, driven by the continuing rise in motorization and the limits to road expansion, is likely to impact the modal split to at least some extent. As suggested by the results of the survey implemented for the current study, if private motorized travel times were to increase by at least 15 minutes for a typical trip, nearly 31 percent of the current car and motorcycle users said they would switch to public transport, and another 5.5 percent and 4.5 percent would switch to NMT modes and taxi respectively.

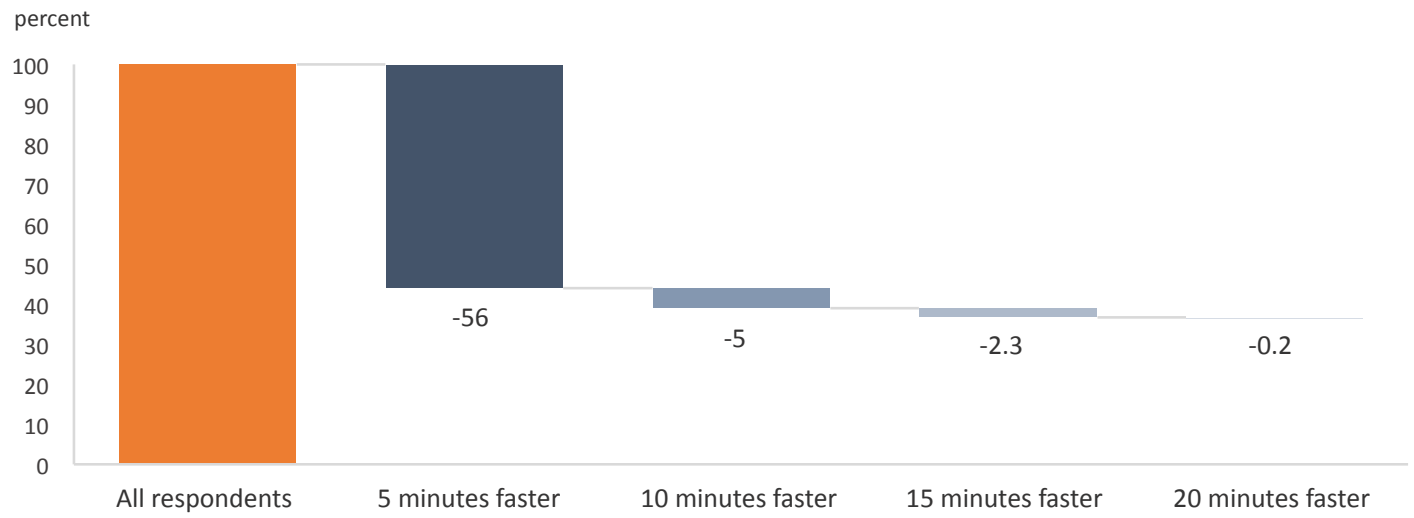
How Can Policy and Planning Tools Shape Future Trends?

The transport planning authorities in AMBA can influence which transport behaviors remain more permanent in the post-pandemic world. Infrastructure investments can be crucial for building trust in public and active transport. On the other hand, pricing and regulatory policies can help—at least to some extent—incentivize travel behaviors that are more environmentally friendly. Finally, as demonstrated by CABA's experience with cycling, public behavior change campaigns can work under the right conditions.

Public transport and NMT expansion and reorganization

During the past decade, price signals favored public transport. To be successful, however, price-based incentives have to be combined with infrastructure supply and improvement. As shown by the results of the demand elasticity analysis, ridership in most public transport subsystems and routes in AMBA has historically responded significantly to changes in the vehicle-kilometers of service supplied and improvements in punctuality. Similarly, the stated preferences of the surveyed current car and motorcycle users indicate that improvements in the public transport *performance* could incentivize a significant modal shift from private to public transport. In fact, the results of the survey suggest that if using public transport allowed saving even just 5 minutes of travel time compared to the current times by private modes, 56 percent of the current private mode users were willing to shift from private to public transport (**figure 7**). In other words, public transport would have to offer travel times that are on par with or slightly better than those offered by private motorized modes to be able to attract significantly more riders.

Figure 7. Share of Current Car or Motorcycle Users Willing to Switch to Public Transport at Different Levels of Possible Time Savings Offered for a Typical Trip



Source: Original figure produced for this publication, based on a survey conducted by study team.

The patterns of private versus public transport use appear to be relatively set in the most well-off localities in AMBA, where nearly half of households own a vehicle. Increasing these residents' use of buses or trains will likely require changing their perception of these modes by improving the safety and security, comfort, and the objective aspects of journey time and frequency. As suggested by the results of the stated preference survey, 36 percent of those current private motorized vehicle users are not sensitive to price signals—that is, those who would not switch to another mode, even if gas prices doubled.

Opportunities for mode shift toward public transport are likely the greatest in AMBA's middle-income localities, located along the axes formed by motorways and public transport lines, where in the past improvements in public transport supply have led to increased public transport use and decreased private car use. Thus, in considering which rail improvement works should be prioritized in order to encourage sustainable mode shift or at least prevent a shift to private mobility, it is likely that investments in the Belgrano Norte or San Martin lines serving middle-income neighborhoods would have a bigger impact. On the other hand, considering rail improvements that will increase accessibility to jobs and services for low-income populations and encourage mode shift from bus transport, rail investments in the Belgrano Sur line would likely have a larger impact. Furthermore, given that GBA in particular has seen a shift toward more local trips, investments in rail connections between localities in GBA could be an effective policy response, especially if well-integrated with the NMT infrastructure.

The city administration and transit operators will need to work together in implementing regulations to create a safe public transport environment.

The city administration and transit operators will need to work together in implementing regulations to create a safe public transport environment. As shown by the study's car and motorcycle user surveys, safety concerns and fear of contracting COVID-19 ranked highly among the mode choice factors among those who became users of private motorized modes only since the start of the pandemic, although the fear of contracting COVID-19 will subside over time.

In addition, to prevent a shift to private motorized mobility going forward—in the post-COVID context where an increasing share of the population could be considering moving to lower density environments, but do not necessarily want to live in gated communities lacking sustainable connectivity options—public transport supply must be accompanied by a proactive land-use policy. The rail infrastructure provides a good opportunity to engage in transit-oriented development (TOD) projects to densify areas around train stations, especially in rings 1 and 2 and attract middle-income households to move into these areas and avoid the connectivity limitations associated with living in more segregated gated communities. TOD near rail could foster multimodality by expanding the effective rail coverage area, especially if rail services were better integrated with municipal bus lines and newly developed NMT infrastructure. As the expansion of gated communities in GBA continues, public policies can also be oriented toward the generation of new mixed-use centralities, thus helping avoid long commuting trips from GBA into CABA.

The decline in public transport ridership over the past two years has further worsened the financial sustainability of the transit system.

In the context of the accelerating trend toward shorter trips, especially within GBA, a policy aimed at promoting nonmotorized travel could attract users throughout the metropolitan area and could gain increasing traction in the post-COVID context of heightened aversion to enclosed public spaces and vehicles. Moreover, as shown by the CDR data analysis comparing the prepandemic period with the "new normal" (in October 2021), trips between 1 and 2.5 kilometers still dominate AMBA's mobility, corresponding to trips that could feasibly be made by walking or cycling. Also as suggested by the results of the survey implemented by the study team, the share of the current private motorized mode users willing to switch to cycling for their typical trip if a bicycle lane were available to them is by far the highest (40 percent) among those whose typical trips take place within GBA. However, even among the respondents who typically commute between CABA and GBA, more than 15 percent would consider this mode. Among the current car or motorcycle users, women are much more likely than men to state they would consider biking if a safe bike route were available. Finally, while we have no current comprehensive data on how many rail, subway, or Metrobus stations are physically integrated with NMT modes, a clear untapped opportunity exists for deploying NMT infrastructure to prioritize rail and subway stations as the hubs for trip attraction in GBA. In turn, these hubs would improve public transport ridership. The Metropolitan Transport Agency can play a cross-cutting coordinating role in these efforts.

More selective road infrastructure investment

In order to reduce the incentives for private motorized mobility, to foster multimodal integration, authorities could limit further expansion of the radial access road capacity, while they increase investment in road safety and improve the connectivity between access highways and public transit infrastructure. Additional road space could also be allocated to public transport corridors, perhaps following the example of the segregated corridor set aside for the Metrobus on the 25 de Mayo highway in CABA.

Pricing tools

The decline in public transport ridership over the past two years has further worsened the financial sustainability of the transit system and poses some challenging questions for its future. Even in a context of recovering ridership in 2021 and 2022, the lag in fare increases, combined with recognition of higher public transport service operators' costs, means that the "new normal" for the public transit system in AMBA will be characterized by low cost recovery. The longer-term response of public transport ridership to changes in real fares suggests room certainly exists for increasing fares on most bus and rail routes without jeopardizing ridership. The elasticity of demand with respect to fares is either statistically nonsignificant or marginally significant and low in magnitude on most

of the bus lines (except individual lines mostly concentrated in northern and western AMBA), and there appears to be a small demand response to fare changes on either of the rail lines.

An important aspect for the development of an integrated system is the deepening of the price signals in terms of road pricing, gas taxes, tolls, and licenses for Uber-type ride-share services. An increase in the price of gas, such as through increased taxes, would likely have at least some impacts on mode choices in AMBA, as suggested by the findings of the preference survey implemented by the study team. With a 50 percent increase in the price of gas, approximately 40 percent of the current car or motorcycle users would shift to public transport, and an additional 7 percent would shift to nonmotorized modes. Certainly, such an increase is rather large and also somewhat difficult to interpret in a high-inflation context; increases of such magnitude are much more likely to result from external factors such as logistics bottlenecks and global supply limitations.

Some level of cross-subsidization could be implemented via the city's Metropolitan Transport Agency to support public transport. For example, a small surcharge on road tolls could fund infrastructure to improve the level of service for public transport, following a similar model implemented in 2002, whereby subsidies for public transport were funded through a surcharge on diesel fuel.

Data alliances for mobility planning

The proliferation of mobile devices, the widespread adoption of geolocation technologies, and the increasing digitization of mobility have given rise to new data sources with enormous potential to complement, enrich, or even replace data sources traditionally used for mobility analysis and transport planning. Each of these data sources can provide some, if not complete, insights that will allow AMBA's transport planners to make more demand-responsive and informed decisions.

Many of these new data sources rest in the hands of private entities, heightening interest to explore the establishment of data partnerships from which cities, the private sector, and society as a whole can benefit. We see several opportunities to improve the mobility information available in Buenos Aires through access agreements to nonpublic data and better use of public data, in particular: (1) using cell phone data to periodically update AMBA's origin-destination matrices, perhaps complemented by brief and targeted household travel surveys that can provide more detailed socioeconomic data on the travelers; (2) leveraging SUBE public transport smart card data for a better characterization of public transport demand; (3) making use of Waze for Cities data for transportation planning, beyond just traffic management; and (4) partnering with the providers of different mobility services to help mitigate the existing mobility information gaps, such as on new mobility services (ride sharing, shared mobility) and freight mobility.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Authors:
Sadig Aliyev and Sombath Southivong, **The World Bank**
Corey Wong and Makito Shirahige, **Arup**

Enhancing Green Mobility by Leveraging Data and Innovation in UNESCO Heritage Cities of Cambodia and Lao PDR

Luang Prabang in Lao People's Democratic Republic (PDR) and Siem Reap in the Royal Kingdom of Cambodia are two of Southeast Asia's crown jewels—with the United Nations Educational, Scientific, and Cultural Organization (UNESCO) world heritage sites attracting visitors from around the world and serving as an economic driver through tourism in their respective countries. Both cities, however, are faced with common issues—population growth, urban development, predilection for driving (mainly on two-wheeled vehicles) and an increasing vehicle fleet, road safety issues, along with emissions and congestion.

The World Bank implemented a study, with funding support from the Korean Green Growth Trust Fund (KGGTF), to facilitate green mobility—active mobility (walking and cycling), nonmotorized transport as well as public transport—in both cities by developing an overarching Green Mobility Vision and Investment Plan, buttressed by evidence-based analytical frameworks including a "city-level" green mobility index, a "street-level" green mobility index, and the use of mobile device geolocation data to inform investment planning and public transport planning. The COVID-19 pandemic presented key challenges, which allowed innovation and experimentation to still deliver these three frameworks and the Green Mobility Investment Plan. These lessons learned are applicable to other UNESCO heritage sites experiencing similar "growing pains" and seeking a transition from a vehicle-oriented future to one encompassing more sustainable green mobility modes.

About the Authors

Sadig Aliyev is a Senior Transport Specialist at the World Bank.

Sombath Southivong is a Senior Infrastructure Specialist at the World Bank.

Corey Wong is Associate Director in Transport Consulting at Arup.

Makito Shirahige is a Transport Planner at Arup.

Background

Heritage context and global relevance

Cities around the world are facing ever-increasing issues with scattered and unplanned development and growth, increasing motorization and congestion, emissions and environmental issues associated with motorized vehicle use as well as vehicular and road-based access and mobility strategies. These combined threats are especially acute in Southeast Asian cities, where growth has accelerated quickly over the past few decades, and multiple forms of motorized modes are typically preferred for their convenience and "status" over walking, cycling, nonmotorized transport (NMT), and public transport or other forms of green mobility.

This nexus of issues is facing both Luang Prabang in the Lao People's Democratic Republic (PDR) and Siem Reap in the Royal Kingdom of Cambodia—host to world-renowned sites designated as UNESCO world heritage attractions (see **figure 1**).

- **Luang Prabang** is the ancient royal capital located in the northern part of Lao PDR. Luang Prabang is famous for its temples and monasteries, many of them with elaborate decoration and beautiful gold overlays. There are 34 historic temples within the city, a large number of which are located on the peninsula between the Mekong and Nam Kham rivers. The peninsula and surrounding areas comprise a "living heritage district" and are designated as a world heritage zone. Visitors come to Luang Prabang to explore this heritage district and observe or partake in the morning alms-giving ceremonies.

- **Siem Reap** is the closest city to Angkor, one of the world's most iconic landmarks with an extensive area of ruins from the Khmer Empire, including the iconic sites of Angkor Wat and Angkor Thom. The World Heritage Area (WHA) includes three areas, managed as archaeological parks: Angkor, Roluos, and Banteay Srei. Siem Reap is host to the hotels and other tourism-related services and sectors that thrive from the millions of visitors coming each year to the city and its heritage attractions.

Figure 1. World Heritage Sites around Siem Reap and in Luang Prabang

a. Siem Reap

b. Luang Prabang

Source: Image of Angkor Wat temple in Siam Reap found on the Asia Society website; image of one of the 34 world heritage site temples in Luang Prabang found in the Forbes online image library.

Socioeconomic and tourism context

Siem Reap has a population of 245,000 in the city and over 1 million residents in the province, with Angkor attracting some 2.5 million visitors in 2017 (Angkor Enterprise 2017). Luang Prabang is smaller and more compact, with a population of 66,800 in the urbanized area and 463,000 in the province, and some 860,000 visitors in 2019—accounting for about 20 percent of all tourist arrivals to the country (MICT 2019).

Both cities are expected to see significant increases in population and tourists. Siem Reap is expanding around the world heritage attractions, particularly to the east with a new airport and new city—by 2035 the population is expected to grow to 440,000 (or about 5 percent annually). The 2035 Siem Reap Tourism Development Master Plan forecasts some 10.9 million domestic and 7.5 million international tourists respectively. Luang Prabang is forecasted to experience slower growth to around 115,000 residents by 2035 (or about 4.5 percent annually), though growth in tourism is expected to be substantial given the recent opening of the Lao–China Railway in late 2021 (with some 335,000 visitors coming to Luang Prabang by train from January to October 2022) (Bangkok Post 2022).

Tourism is the major lifeblood in both cities, which serve as major contributors to national-level gross domestic product (GDP) in both countries (about 12 percent of the national GDP in both countries is due to tourism). It is estimated that in Siem Reap (Firn 2021), tourism generates US$1.2 billion in annual revenues, creating some 248,000 jobs, with over 230 hotels and 310 guesthouses and thousands employed in the sector (National Institute of Statistics 2021). Similarly, Luang Prabang contributes a large portion of tourism revenues to the national coffers, hosting nearly 100 hotels, 400 guesthouses, and thousands employed by accommodation providers, as tour guides and as taxi or tuk-tuk drivers.

Transport context

Two and three-wheel motorized vehicles (such as motorbikes or tuk-tuks) represent the predominant travel mode in both cities. Motorbikes dominate local resident trips, comprising 60 to 70 percent of motorized trips, while tuk-tuks dominate tourist travel, followed by tourist coaches and minivans. These motorized means of transport create congestion, emission, and road safety issues—impacting health of residents, active mobility comfort, and attractiveness of the city. The added local and visitor demand might place greater strains on the existing transport system and further exacerbate highlighted issues.

Two and three-wheel motorized vehicles represent the predominant travel mode in both cities.

A key question is how to handle this future growth and development, even though two- and three-wheel vehicles dominate, while at the same time preserving each city's unique heritage that attracts visitors and is the lifeblood for the cities (not to mention a major economic contributor due to their global tourist appeal).

Green mobility and relevance to the cities

Global experience indicates that continuing to deal with urban mobility using a vehicle or road-based approach is impractical and undesirable. Cities are increasingly adopting green mobility as a tool to address these challenges along with strategic land use and other policy and strategy measures. Green mobility seeks to reduce impacts of mobility in terms of greenhouse gas (GHG) emissions, air pollution, and noise through active mobility (such as walking and cycling), public transport, and emobility infrastructure and services.

Adopting green mobility offers a chance to shift the tide and build green mobility "sentiment" among the public to encourage greater use of active mobility and public transport. At the same time, the government has an important choice to make whether to keep developing a vehicle-based growth strategy or to prioritize green mobility options—a choice that can initiate "sentiment" toward green mobility to build momentum for this transition.

Against this backdrop, the World Bank implemented a study to enhance green mobility in the two cities through a targeted investment plan as well as concerted efforts at creating an enabling institutional and regulatory framework for green mobility. The study team faced several key challenges necessitating innovation, which could also be adopted in similar studies or contexts to develop evidence-based green mobility policies and plans, to both accommodate future growth and at the same time protect and preserve UNESCO heritage attractions.

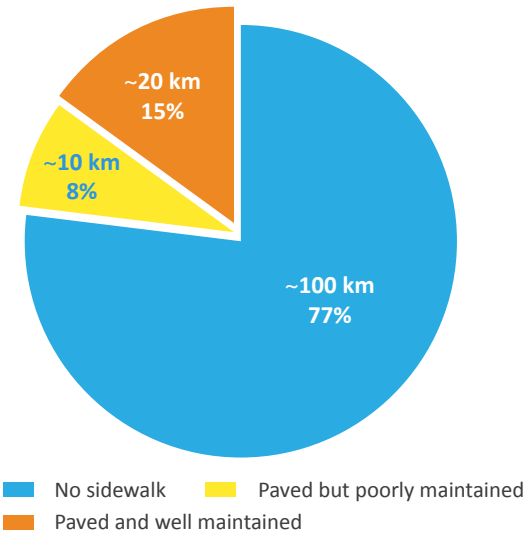
Increasing Mobility Challenges

How residents and visitors move in the city is a key issue. As noted, two-wheelers dominate—generating congestion, emissions, and safety issues within the cities and the heritage areas—and impacting the daily lives of residents and the visitor experience/appeal. Both cities face similar issues, but they also have unique issues owing to their particular land use and development patterns.

Common issues for both cities pertaining to mobility:

- **Limited mobility options encourage motorcycles and driving**—Motorcycles are the principal means of travel for most residents, where they comprise over 60 to 70 percent of motorized trips in both cities. Both cities lack alternate mobility options, which encourage motorcycles and driving. New bike lanes have been built in Siem Reap, while a short segment is planned in Luang Prabang. No public transport operates in either city.

Figure 2. Luang Prabang Sidewalk Pavement Condition along 130 Kilometers of Roads



Source: Original figure produced for this publication.

- **Current infrastructure less friendly for green mobility**—Existing infrastructure is built for vehicles. The walking environment is perceived as insufficient, unsafe, and uncomfortable due to limited provision of paved and segregated sidewalks as well as discontinuities in the walking path network. Of some 130 kilometers of roadways in Luang Prabang, only 15 percent of these were paved and in "well-maintained" conditions, with nearly three-quarters of the roads lacking any sidewalk (**figure 2**).

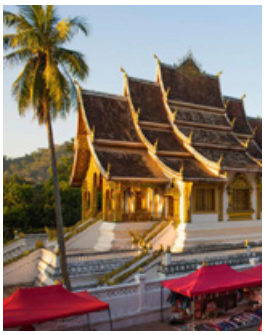
- **Limited access-for-all amenities**—Many sidewalks have obstructions such as illegal on-street parking. Only 13 junctions are signalized in Siem Reap, while there are no signalized junctions in Luang Prabang. Both cities lack safe access-for-all amenities, including drop ramps at junctions as well as tactile paving, thus crossing the street and walking is perceived as difficult, inconvenient, and dangerous for all types of users.

- **Mobility and congestion issues around key locations and heritage sites**—Congestion is a key issue along major corridors, busy tourist areas (such as Pub Street in Siem Reap and the Night Market in Luang Prabang), and around heritage sites themselves. Illegal parking on sidewalks and streets is a key issue, impacting congestion, safety, and the visitor experience.

Distinct issues in Siem Reap:

- **Emissions and air quality issues impact monuments**—Angkor and related sites are located outside Siem Reap, but emissions and air quality issues from transport do not respect boundaries. Authorities cite acid rain as a threat to the monuments.

- **Significant population and tourism growth expected, translating into higher demand for travel and strains on the transport system**—Current mobility issues could be magnified due to planned growth and development if current travel patterns persist. A significant increase in population and jobs is forecast. A new airport and city are planned to the east. Declines in tourism experienced in 2018 and 2019 are expected to be reserved, with significant increases in tourism forecast due to targeted tourism and infrastructure development.



Distinct issues in Luang Prabang:

- **Juxtaposition of living heritage district preservation and accommodating future tourism growth**—Residents of Luang Prabang live and work within the historic zone, interspersed with heritage sites and attractions, and is the primary tourist zone with plentiful cafes, restaurants, tourist stalls, and accommodations. Residents and tourists alike use the same roads, walk the same sidewalks, and eat at the same places in Luang Prabang's heritage area. Within the heritage area, development and changes to the roads are highly restricted, which can limit road and vehicular expansion that would enable the areas to accommodate larger tourist volumes.

- **Emissions and air quality issues from transport**—In 2014, transport accounted for more than 60 percent of the total greenhouse gas emissions in Lao PDR. The transport contribution is largely from two-wheelers, which make up nearly 85 percent of the total fleet, growing annually at around 8 percent.

- **Significant population and tourism growth expected, translating into higher demand for travel and strains on the transport system**—Luang Prabang's population is expected to grow by 25 percent by 2035, mainly to the northeast toward the airport. In addition, new development areas to the southeast and across the Mekong River could place additional strains on the transport system. Visitors are expected to increase due to popularity of heritage sites, the new Lao–China Railway, and a planned regional expressway from the capital, Vientiane, to China.

Green Mobility Vision

Both cities have recently initiated a transition toward a greener and more sustainable transport system by investing in extensive transport network improvements. For instance, Siem Reap has implemented investments to create cycle, walk, and all-weather road networks across the city through several ongoing projects, including a US$150 million, 38-road improvement project during COVID-19 as well as the Siem Reap River Rehabilitation and a new dedicated bike trail leading to and around the world heritage site (known as the Angkor Bike Trail). Luang Prabang is improving roads and facilities under a Cities Development Initiative for Asia (CDIA) initiative, by creating more conducive and attractive walk environments with new streetlights, paving, and placement of utilities underground in the heritage area, among other enhancements.

"Accessible, Comfortable, Inclusive, and Resilient Green Mobility System, Focusing on People Movement, Enhancing the Environment, and Accentuating Heritage, and Supported by an Enabling Framework."

Therefore, this World Bank study builds upon these initiatives and seeks to create synergies by laying the strategy, vision, and actions to accelerate the shift toward green mobility, while preserving each city's unique and intrinsic heritage that attracts visitors. Thus, the noted green mobility issues guided the development of a Green Mobility Vision, which comprises goals, objectives, and strategies. Given the similarity of issues faced by Siem Reap and Luang Prabang, the vision is defined as follows in **table 1**, supported by four overarching goals.

Table 1. Four Key Goals in Green Mobility Vision

#	Goal	Description
1	People	Creating a people-centric, integrated green mobility system that moves all people safely, securely, and effectively.
2	Environment	Reducing emissions and improving air quality by facilitating the transition to green mobility by building sentiment and changing behaviour, while also responding to climate change.
3	Heritage and tourism	Preserving and respecting heritage, while accentuating heritage and broadening tourism through green mobility.
4	Institutional	Creating an enabling framework to facilitate and encourage green mobility.

Source: Original data produced for this publication.

From the Green Mobility Vision and the key gaps, a Green Mobility Investment Plan was to be developed, then undergo financial analysis, with specific capacity building and institutional enhancements recommended. To inform the Green Mobility Investment Plan, an evidence-based approach was needed to facilitate decision making and prioritization.

Evidence-Based Tools and Analyses to Underpin the Green Mobility Investment Plan

Summary of key tools and challenges posed by COVID-19

Several tools and analyses were proposed to inform the Green Mobility Investment Plan and provide an evidence-based framework for decision making; however, the COVID-19 pandemic presented the study team with several key challenges:

- **Restrictions on field investigations due to COVID-19**—The study started in the middle of 2020 when travel restrictions were imposed due to the COVID-19 pandemic. In effect, the study team was unable to investigate existing conditions on the streets to deliver the street-level index and portions of the city-level index. Furthermore, direct interviews with key stakeholders were not possible in person.

- **Changes in visitor and local travel behavior due to COVID-19**—The pandemic changed travel behavior significantly. Firstly, international visitors declined precipitously due to travel restrictions. In addition, local restrictions further limited local trips. Under this context, utilization of current trip-making behavior (modes and origin-destinations, among others) would not be representative of the context prior to the COVID-19 context—leading to a green mobility plan that could significantly underestimate demand or identify nonoptimal locations for improvements.

These challenges, however, provided room for ingenuity, experimentation, and innovation as described below for the three key analytical tools and approaches informing the Green Mobility Investment Plan.

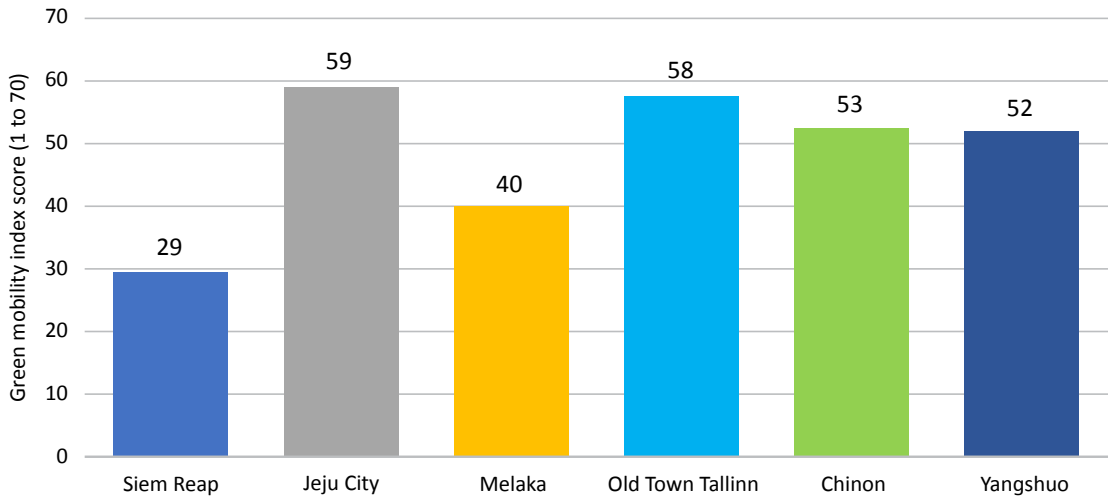
City-level Index: Benchmarking cities and identifying infrastructure, policy, and institutional elements for enhancement

A city-level index was developed to benchmark green mobility "friendliness" and supportiveness of the two cities versus other comparable UNESCO heritage cities around the world to identify areas for improvement. The city-level index combines both quantitative and qualitative elements to assess green mobility in each city. Seven metrics were assessed as part of the benchmarking exercise: (1) accessibility (including street density, public transport network, average street length, and other factors); (2) health and well-being; (3) green mobility sentiment (such as a positive or negative attitude toward green mobility by the government and populace); (4) equal access (or access for all); (5) safety and security; (6) resilience; and (7) convergence (commitment and coordination among governments and institutional or regulatory structure to adopt green mobility). Each subscore is ranked on a 1 to 3 basis, with each pillar score normalized with a maximum of 10 points—thus the maximum possible score is 70.

Since travel was restricted, the team relied on a variety of data sources, including publicly available databases, city, and sociodemographic statistics as well as geospatial characteristics via geographic information systems (GIS) or OpenStreetMap to generate the data across cites and provide a holistic or composite score.

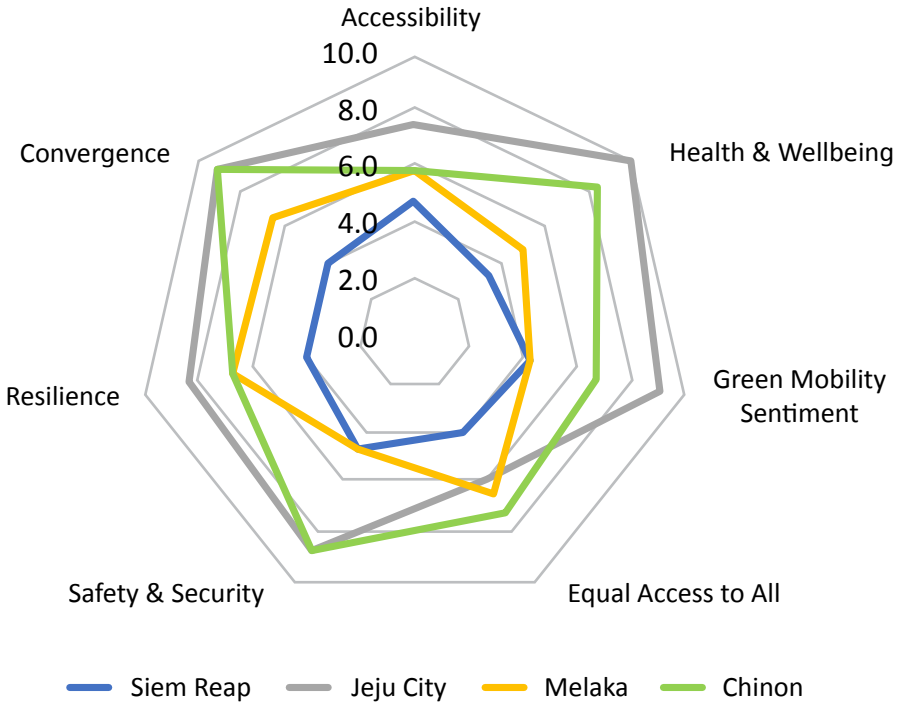
Figure 3 presents the results for Siem Reap versus five other UNESCO heritage cities chosen for the benchmarking. While Siem Reap received a score of 29 and Luang Prabang a score of 31, both of which are relatively low compared to comparator cities, they nonetheless show the opportunity for further growth in the cities through targeted investments, institutional enhancements, and capacity building to catch up with their peers. **Figure 4** shows the metric-level scores by city with Siem Reap shown in blue. Both cities performed relatively low in accessibility (due to lack of public transport and alternate transport choices), street density (an impediment to more extensive walk or cycle networks), integration of active mobility into policy and design standards, and the lack of coordinated heritage and green mobility plans.

Figure 3. City-Level Green Mobility Index Scores, Siem Reap vs. Comparators



Source: Original figure produced for this publication.

Figure 4. City-Level Green Mobility Index Score by Pillar, Siem Reap vs. Comparators



Source: Original figure produced for this publication.

Street-level analysis: Delving into details to identify particular streets or corridors for active mobility enhancements

The street-level index, compared to the city-level index, includes more detailed quantitative analysis to understand specific street conditions based on various factors, including sidewalk provision and continuity, crossing safety and facility, shading walkways, wheelchair and disabled facilities, along with other factors—all of which indicate the relative attractiveness, convenience, and usability of a corridor from **the perspective of active transport users and those of all mobility abilities**.

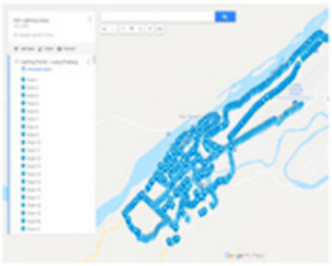
The street-level index (**figure 5**) assesses specific street blocks—thus it represents a very localized and "micro" snapshot of conditions and the user experience. A composite score for each block is then generated based on more than a dozen metrics, which allows a transparent comparison of performance vis-à-vis walking and cycling—and thus green mobility. Metrics focus on pavement and sidewalk condition and continuity, sidewalk safety, crossing safety and provision of amenities to facilitate crossing for all users, disability friendly, and public amenities—including street furniture, sidewalk shading, along with other metrics. Blocks found to be more "green mobility friendly" are shaded in green, with those performing moderately in yellow, and those performing poorly in orange/red (as shown in **panel f**).

Due to COVID-19 travel prohibitions, the study team leveraged online and video tools to develop the database, using street imagery from videos or Google Street View. Key attributes were then geocoded into Google My Maps by block or location (that is, the width, condition or presence of pavement, presence of lighting or trees, among attributes). This was then translated into GIS and then scored in Excel to generate a composite map for each metric. This process is shown in **figure 5**.

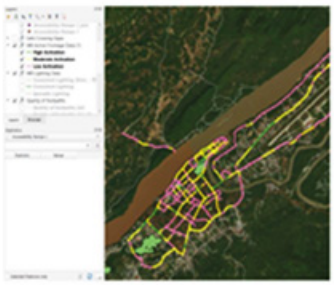
Figure 5. Six-Step Street-Level Assessment

a. Step 1: Split streets into link

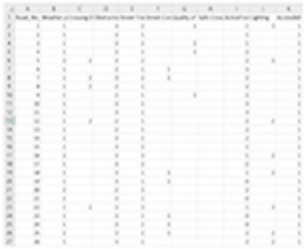
b. Step 2: Assess conditions with Google Street View and videos



c. Step 3: Pinpoint attributes using Google My Maps



d. Step 4: Google My Maps Geodata imported into GIS



e. Step 5: Street links scored in Excel, by attribute

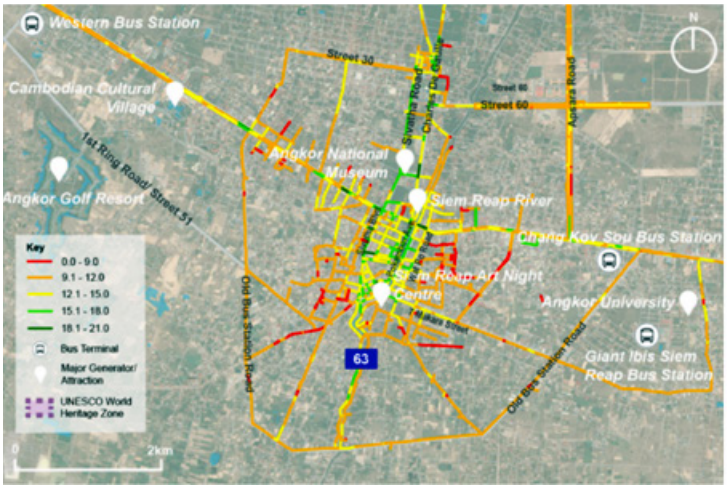
f. Step 6: Maps generated for individual metrics and for the cumulative street-level score

Source: Original figure produced for this publication.

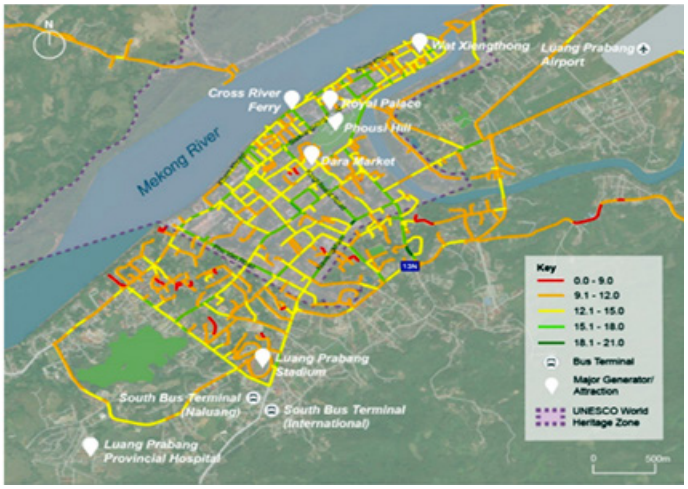
Figure 6 illustrates the street-level index in each city—highlighting key gaps in the current network for green mobility. While the central area around Pub Street in Siem Reap (**panel a**) and the peninsula in Luang Prabang (**panel b**) perform relatively well (as demonstrated by green or yellow shading), outside of these areas score more poorly. These findings were then used to identify potential locations or street blocks for targeted enhancements to make walking and cycling more continuous, safer, secure, more comfortable.

Figure 6. Composite Street-Level Index Score in Urbanized Areas

a. Siem Reap



b. Luang Prabang



Source: Original figure produced for this publication.

Mobile data: Leveraging anonymous geolocation data to identify trip patterns prior to COVID-19 and inform bus route planning and active mobility investments

The Green Mobility Investment Plan covers a variety of modes including walking, cycling and public transport. For the latter especially, understanding where people travel to and from, the chaining of trips, and the length of trips is important to planning routes and the schedule to be competitive versus vehicles. Typically, interview surveys of a sample population would be undertaken to understand predominant origin-destination (OD) patterns and primary travel periods. However, the COVID-19 pandemic made such surveys meaningless as visitor numbers fell precipitously, meaning this group of potential public transport passengers could not be accounted for nor surveyed. Secondly, local trip patterns may have drastically changed with the predilection for social distancing and individual travel. Thus, any surveys during the COVID-19 period would not be representative of the high tourism season (or even the daily commute).

Anonymized mobile device location data offered one potential solution—that could "go back in time" to provide trip-making data/information prior to COVID-19. The study team obtained from Veraset anonymized geolocation data from mobile devices for January to April 2019 for the Siem Reap and Luang Prabang areas. Geolocation information per detected device included time, location, and trajectory of each trip linked with a unique identification number, allowing trips to be tracked (both spatially and temporally. Data also included the native country code to differentiate between local residents and

visitors. This data was used to identify key ODs for public transport as well as key corridors for potential walk/cycle improvements to handle short- and medium-distance trips and identify potential routes segmented by target passenger, such as resident or visitor.

The data were then used to: (1) develop the framework for the public transport route network; (2) provide insights on the operating plan for public transport (including intensity of service and service span); and (3) provide insights on where pedestrian improvements should be made. Four key insights from mobile data analytics included the following:

- **Trip length**—Trips longer than 100 meters are distributed by trip length to demonstrate a movement of a device within a one-hour period.

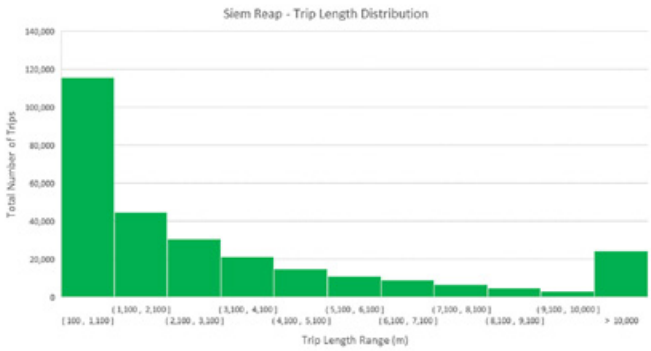
- **OD and trip chaining insight**—Trips between key areas are generated by combining two or more pings from the same device within one hour to identify common origins and destinations. These trips are grouped by trip length, with short-distance trips (1.0 kilometer or less) mainly observed in the city center, medium-distance trips (1.0 to 5.0 kilometers) connecting to/from the city center, and all trips (regardless of distance) representing all trips detected to/from specific locations around the city center and heritage sites.

- **District activity insights**—The device pings detected within the morning (6:00 a.m. to 11:00 a.m.) and the evening (6:00 p.m. to 11:00 p.m.) around the city center (Pub Street in Siem Reap and the Peninsula in Luang Prabang) show the level of pedestrian activity—dense detections on streets as indicated by a cluster of device pings suggest high pedestrian activity.

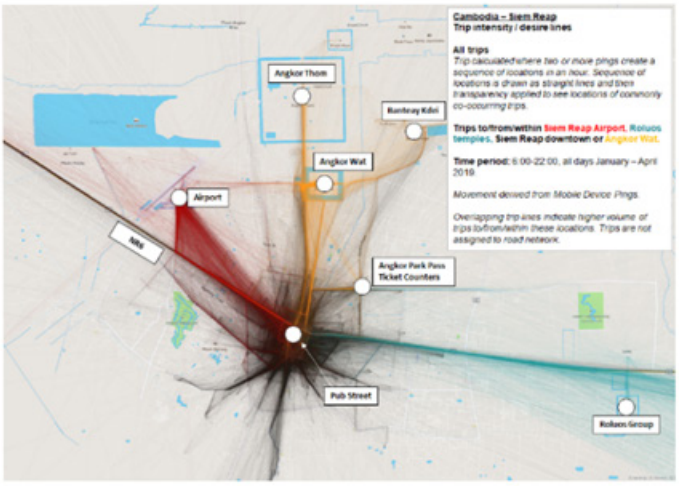
- **Temporal insights**—Volume of detections by arrival hour at sites around the city and heritage sites are recorded for both visitors and local residents. These arrival pattern snapshots provide insight on potential operations for a public transport system, including service span—such as operating hours—and peak vehicles.

Figure 7 illustrates examples of the anonymized mobile data and how trips could be created and used to develop the ensuring green mobility improvement.

Figure 7. Examples of Mobile Data Analysis in Siem Reap

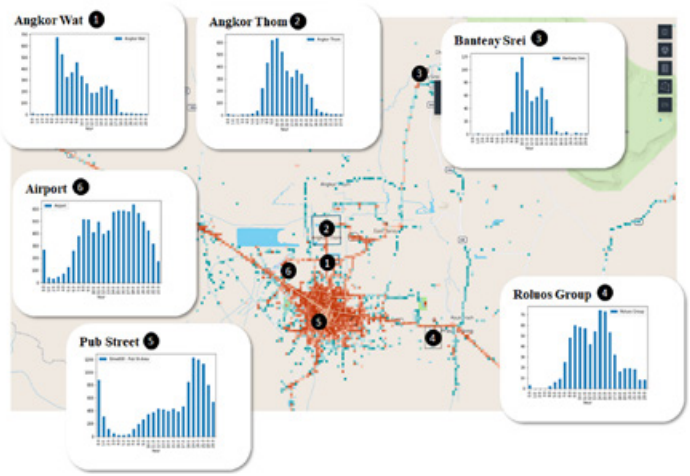


a. Trip length distribution



b. Mobile data used to develop origin-destination and trip chaining, essential for public transport planning

c. User pings vs. street-level index to assess need for walk improvements, by district



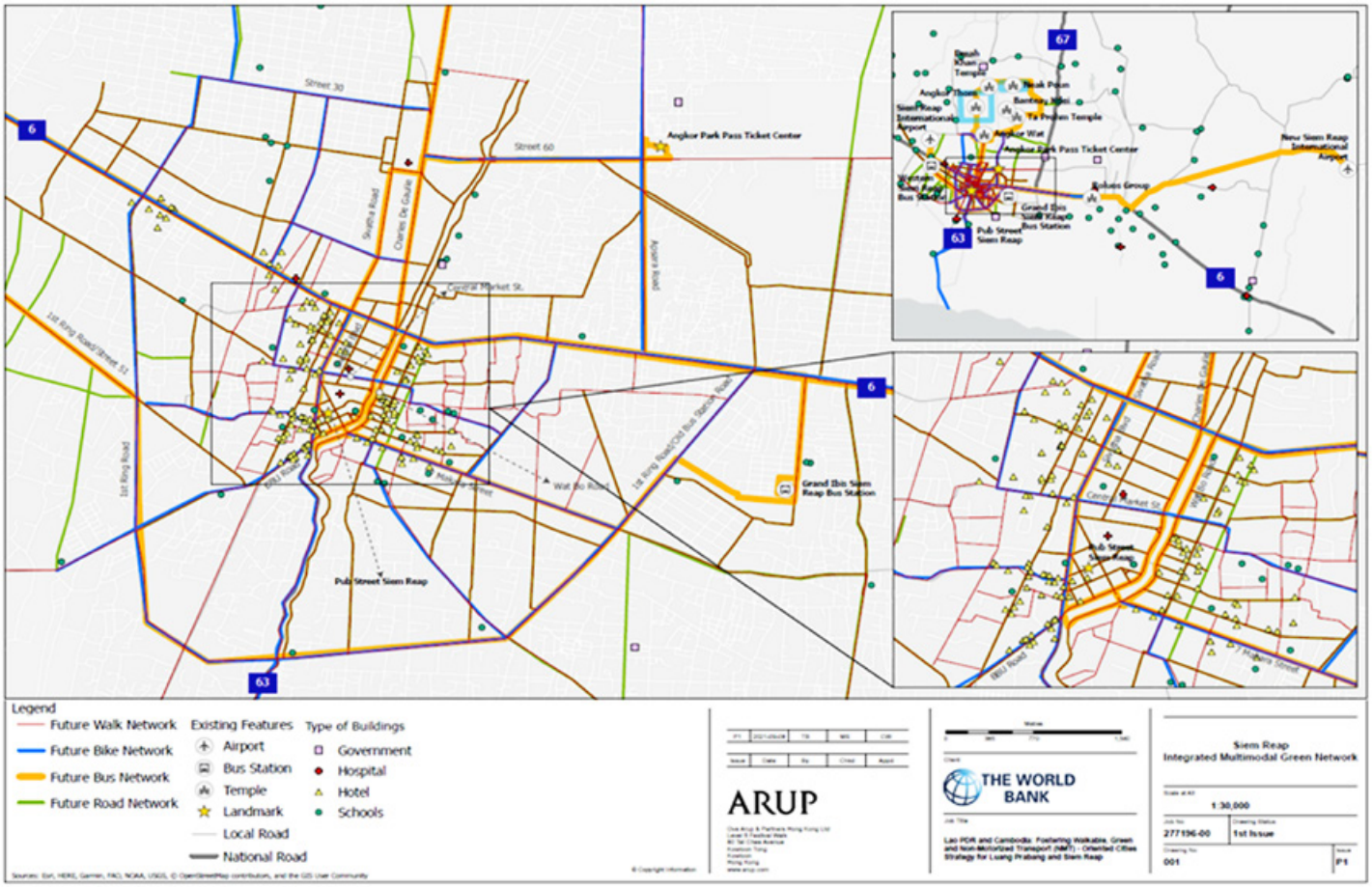
d. Volume of detections by arrival times at various locations for planning public transport services

Source: Original figure produced for this publication.

Green Mobility Investment Plan

Findings from these analyses were crucial in developing the overarching Green Mobility Investment Plan as shown in **figure 8** (for Siem Reap). The integrated multimodal network envisions creating public transport as the principal medium- and long-distance mode, followed by cycling as a potential medium-distance alternative to motorcycles, and then supported by an extensive and connected walk network that includes both formal curbed sidewalks and shared streets. Other key initiatives include traffic improvements, parking improvements as well as capacity building and institutional or regulatory elements—in total, the proposed investment plan includes over US$125 million in potential initiatives for Siem Reap and about US$40 million for Luang Prabang in the initial five-year phase.

Figure 8. Integrated Multimodal Green Network in Siem Reap



Source: Original figure produced for this publication.

Empowering and building capacity: Giving green mobility a foothold and traction

Current knowledge on green mobility within the government in both cities is limited. There is, however, enthusiasm to learn about planning, design, and operation of green mobility. To fill such knowledge gaps, the study team conducted workshops and training sessions to improve understanding of green mobility, and disseminate new and innovative analytical techniques applicable to the planning and design of green mobility (focusing on walking, cycling, NMT, and public transport). These sessions also sought to inspire and encourage sentiment toward facilitating green mobility and encouraging careers with a focus on green mobility. Activities included the following:

- **Technical workshops for decision makers**—Technical workshops helped to set the stage to showcase the benefits of green mobility to key stakeholders, while identifying their priorities and needs to finalize the Green Mobility Strategy and accompanying investment plans. Both national and subnational agencies attended the workshops to discuss institutional gaps, capacity building, and funding/financing options.

Current knowledge on green mobility within the government in both cities is limited.

- **Knowledge sharing workshops for students**—A unique element of this World Bank study was not only capacity building of stakeholders and agency participants, but also the trainees, youth, and students in the two cities and countries that can benefit the most from spearheading a transition to green mobility now and in the future. Civil engineering and transport students attended online courses, including students from Cambodia (from the Techo Sen Institute of Public Works and Transport, a training institute of the Ministry of Public Works and Transport) as well as the Institute of Technology of Cambodia (ITC) and from Lao PDR (from the Ministry of Public Works and Transport, Public Works and Transport Training Institute (PTTI), the National University of Laos (NUOL), and the Souphanouvong University (SU) in Luang Prabang). In total, around 70 participants attended these knowledge sharing workshops.

- **Study visit to Korea**—A study visit to Korea was organized for officials from Cambodia and Lao PDR representing various ministries (transport, finance, and city administrations). The study visit provided a practical opportunity for government counterparts in both countries to learn about developing a sustainable and green transportation system based on experience from Korea, including Jeju City, which has similar urban development elements and UNESCO heritage sites as the two cities.

Commitment to empowering and building capacity is paramount to developing and nurturing "green sentiment" at the grassroots, facilitating greater awareness and interest in green mobility, and encouraging careers and a focus on green mobility for tomorrow's decision makers.

Legacy and significance

The green mobility studies undertaken by the World Bank in Luang Prabang and Siem Reap are a steppingstone to allowing both cities to better accommodate future growth and development, but at the same time preserve and retain the very heritage and attractions that drive the economies and provide for many livelihoods in both of these UNECSO heritage areas and cities. While development of a Green Mobility Vision and Investment Plan may not be novel in itself, the adoption of three evidence-based tools and analytical approaches is unique—namely, the city-level index, the street-level index, and the utilization of mobile device data to inform decision making and prioritization of potential investments. Furthermore, key challenges laid down by the COVID-19 pandemic allowed the study team to develop innovative approaches to collect and analyze data using a variety of digital and publicly available information, which was used to plan the investments, identify where the investments should be located, and also develop a bus operation and system plan. For other UNESCO and heritage cities facing similar challenges of growth, congestion, and emissions, along with other issues that threaten the core of the attractions, this approach and evidence-based methodology could also be applied to help these cities develop their own plans to transition toward more sustainable and green mobility.

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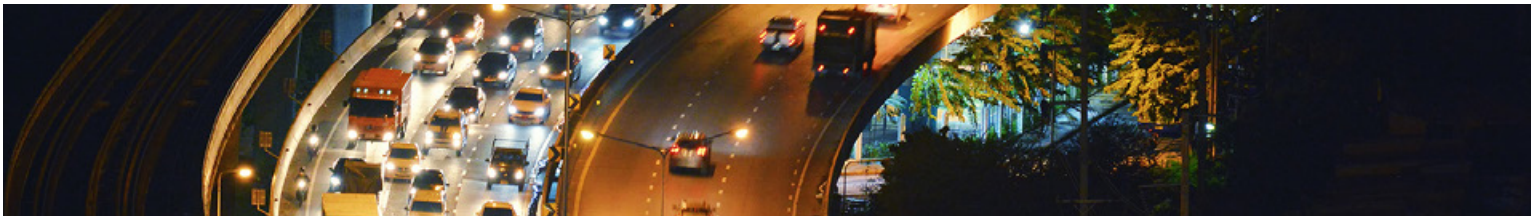

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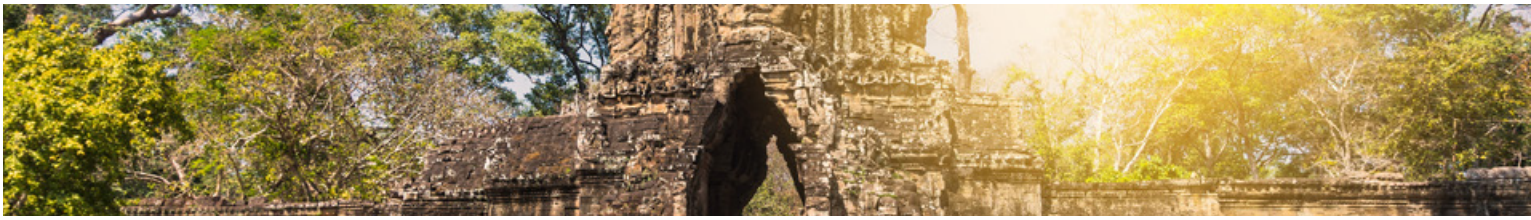

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