Issue Brief

SAVING LIVES WITH **SUSTAINABLE TRANSPORT**

Traffic safety impacts of sustainable transport policies

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EXECUTIVE SUMMARY

TRAFFIC SAFETY AND **SUSTAINABLE TRANSPORT**

The funding and evaluation criteria for sustainable transport projects and policies often overlook an important benefit: traffic safety. A growing body of research points to the safety benefits of sustainable transport, defined here as projects and policies that aim to reduce car traffic, increase improved mass transit, and promote cycling and walking in cities.

This issue brief reviews evidence of the safety benefits of sustainable transport, with a particular focus on the applicability of these findings to cities in developing countries. Where the information is available, we also provide estimates of the magnitude of safety benefits that have been recorded for specific projects.

We consider the relationship between traffic volume and safety and present evidence that traffic volumes (measured as vehicle kilometers traveled, or VKT) are a strong predictor of accidents. Drawing on experiences in Europe, Latin America, and India, we show that cities that have restricted car traffic and promoted mass transit have realized measurable safety benefits. In London and Stockholm, charges levied on vehicles traveling through congested city centers reduced traffic volumes and were associated with a drop in accidents causing injuries. In Bogotá, Guadalajara, and Ahmedabad, bus rapid transit (BRT) systems have improved safety on the streets on which they run.

Traffic safety improvements are an often overlooked benefit of sustainable transport projects and policies

Similarly, cities that have invested in infrastructure for cyclists and pedestrians, such as Copenhagen, Minneapolis, and New York City, have reported safety improvements for these vulnerable road users. The evidence in New York City and Copenhagen suggests that these benefits extend to other road users as well.

To be sure, the safety benefits of sustainable transport—both motorized and non-motorized—should be weighed in light of the many other factors that determine road safety. Policies targeting only traffic volumes, for example, do not address hazards related to poor infrastructure design. Similarly, transit service without high-quality infrastructure and safety oversight will not bring any safety benefits. And one should also not overlook that even in the most bike-friendly cities, cyclists remain more vulnerable than motor vehicle occupants. Nevertheless, the evidence presented in this brief shows that well-planned and designed sustainable transport projects and policies can play a significant role in improving road safety.

After setting out the evidence linking sustainable transport and road safety, we draw implications for better integrating safety into transportation planning and policy. We focus specifically on policy implications for cities in the developing world, which are currently dealing with high traffic-fatality rates and increasing motorization.

We conclude by noting areas for future research, including the safety impacts of other transport modes (such as auto-rickshaws) and transit-oriented development policies. Finally, we recognize the need to develop estimates of the expected safety impacts of different types of transit systems so that policymakers can better integrate the safety benefits of transit into cost-benefit analyses for funding decisions.

OVERVIEW

THE POTENTIAL SAFETY BENEFITS OF TRANSIT, WALKING, AND BIKING

In this report, we review evidence of the safety impact of projects ranging from transit improvements to pedestrian action plans and citywide cycling networks

Traffic safety is often the missing piece in the planning and evaluation of sustainable urban transport projects and policies around the world. Initiatives such as new transit routes, transit improvements, or dedicated cycle infrastructure are usually proposed and evaluated based on their impact on travel times, local air quality, accessibility, or greenhouse gas (GHG) emissions. Their impact on traffic safety often goes unnoticed or misunderstood. In this issue brief, we look at the

evidence on the link between sustainable urban transport and traffic safety, with the goal of helping transport professionals and decision makers better understand how different urban transport policies and projects might impact the occurrence of traffic crashes and fatalities.

Although there is no universally accepted definition of "sustainable urban transport," the term generally refers to projects that include some restrictions on private car travel within cities and promote more energy-efficient modes, such as public transport, cycling, and walking. In this brief, we focus on

- policies aimed at reducing car traffic in cities through pricing or other mechanisms (e.g., congestion charges);
- projects and policies aimed at increasing transit[1] patronage and improving transit service in cities; and
- policies aimed at promoting walking and cycling in cities, and improving conditions for pedestrians and cyclists.

Some of these projects, particularly major transit routes, often receive funding from national government agencies, which usually make funding decisions based on cost-benefit analyses. Factors on the benefit side vary by program and country, but they usually focus on the impact on users in terms of travel time and cost, and on the impact on society in terms of GHG emissions, local air quality, and noise.[2] Some national transit investment programs, such as the United Kingdom's Local Major Transport Schemes, include traffic safety in the cost-benefit analysis and provide guidance for how to monetize the value of the impacts.[3] Other programs mention traffic safety as a factor to consider but do not provide specific guidance on how to measure the impacts or factor them into the analysis.[4]

At the project level, the impacts of sustainable urban transport on travel time and costs, as well as the potential benefits in terms of environmental quality, are usually better documented and understood than the impact on safety. The TransMilenio Bus Rapid Transit (BRT) system in Bogotá, for example, is often cited as an exemplary transit reorganization scheme for a city in the developing world. The TransMilenio BRT is the first public transport project to be recognized as a Climate Development Mechanism, reflecting its potential to reduce transport-related GHG emissions. But in addition to its well-documented impacts on emissions and travel times, the first TransMilenio corridor has had equally significant (though less well-known) impacts on traffic crashes. It has contributed to a reduction in traffic fatalities on Avenida Caracas of more than 50 percent, helping avoid an estimated 200 traffic fatalities during its first 9 years of operation.[5]

TransMilenio is not the only BRT system that has helped improve traffic safety. Similar trends have been documented on BRT-type projects in Guadalajara (Mexico), Ahmedabad, and Melbourne.[6]

Similarly, cities that have implemented policies and infrastructure projects to promote citywide cycling have also reported significant safety benefits, from Copenhagen, to New York City, to Minneapolis. In all cases, cycling volumes increased over time, while the rate of injuries and fatalities for cyclists declined during the same period. Moreover, the safety benefits were not limited to bicyclists. A study from New York City found that streets with bike lanes were safer for pedestrians as well.[7] New York City also demonstrates best practices in improving the pedestrian environment, with significant improvements to pedestrian safety as a result.[8]

In the following sections, we look at evidence of the safety impacts of the types of projects and policies listed above. We also suggest avenues for further research where more information is needed. We conclude by offering policy recommendations for maximizing the traffic safety benefits from sustainable transport initiatives. While we study the impacts of the initiatives separately, our recommendations for policymakers focus on an integrated, system-wide approach.

Our objectives are twofold. First, we hope to better integrate safety considerations into the transportation planning process. Second, we aim to highlight for the road safety and public health community the importance of considering sustainable transport as a viable traffic safety policy, in addition to the established areas of work around seatbelts, helmet use, or alcohol limits.

While the impacts of the TransMilenio BRT on GHG emissions, travel times, and passenger capacity are well documented, a less well known fact is that this BRT has contributed to avoiding an estimated 200 traffic fatalities on the 28-kilometer Avenida Caracas corridor in its first nine years of operation

FINDINGS

EVIDENCE OF THE SAFETY IMPACT OF **SUSTAINABLE TRANSPORT**

RELATIONSHIP BETWEEN TRAFFIC VOLUMES AND SAFETY

Vehicle kilometers traveled, or VKT, is a standard measure of performance for sustainable transport projects.[9] California Senate Bill 375 (SB 375) is the first law in the United States aimed at reducing GHG emissions by promoting sustainable transport and urban development.[10] The goal of SB 375 is to reduce VKT through integrated transportation and land use planning. The law sets GHG reduction targets at the regional level, to be achieved from the automobile and light truck sectors. Under SB 375, each metropolitan planning organization in California is expected to prepare a "sustainable community strategy" aimed specifically at reducing VKT in its region.[11]

In practice, cities can achieve VKT reductions in two ways: by promoting compact, mixed-use urban development to reduce trip distances or by shifting travel either to modes with higher passenger occupancy (such as public transit or carpooling) or to non-motorized modes. These policies share the goal of reducing the number of vehicle trips without seeking to affect the number of person trips.

Table 1 Passenger and vehicle throughput on different street and transit corridor configurations

Traffic mix	Configuration per direction	Typical vehicle throughput per hour per direction	Passengers per hour per direction (pphpd)
Mixed traffic with no transit	4 mixed lanes	3,200	4,800–8,000[a]
Mixed traffic including conventional bus service	4 mixed lanes	3,170	7,000 – 10,000[b]
Mixed traffic and a central, single-lane BRT	2 mixed lanes and 1 bus lane [13]	1,660	11,400–19,000[c]
Mixed traffic and a median running light rail transit (LRT)	2 mixed lanes and 1 rail track	1,640	17,500–19,000[d]
Mixed traffic and multilane BRT	2 mixed lanes and 2 bus lanes	1,975	32,000–47,000[e]
Metro line	1 rail track	30	52,500 and higher[f]

Sources:
[a] based on a capacity of a typical urban arterial of 800 vehicles/lane/hour (Dowling 1997) and assuming vehicle occupancy between 1.5 and 2.5;
[b] based on a practical capacity for a conventional bus system of around 3,000 pphpd (Vuchic 2005) and assuming buses operating in mixed traffic in the curbside lane, which would reduce the capacity of the curbside lane for mixed traffic to 400 vehicles/hour;
[c] based on observed peak hour loads on existing BRT systems (Hidalgo and Carrigan 2010) and on a maximum capacity of a single-lane BRT of 15,000 pphpd (Lindau et al. 2011);
[d] based on the practical capacity of a light rail system of around 15,000 pphpd (Vuchic 2005);
[e] based on observed peak hour loads on TransMilenio, Bogotá (Hidalgo, Lleras, and Hernández 2011);
[f] source: Vuchic 2005

Table 1 illustrates how vehicle and passenger throughputs[12] are affected by shifting from a mixed traffic configuration to different transit priority schemes and transit technologies. The scenarios in Table 1 apply to a right-of-way of approximately 30 meters (with the exception of the Metro line), which is fairly typical for a major urban thoroughfare.

Policies promoting VKT reductions usually measure performance through indicators such as GHG emissions, local air pollutant levels, traffic congestion levels, and travel times. However, the sustainable transport community commonly overlooks the strong link between traffic volumes and crash rates. There is, however, a clear consensus in the road safety literature that traffic volumes are a significant predictor of accidents. In fact, it is common practice to develop safety performance functions for roads that aim to estimate crashes solely as a function of traffic volumes.

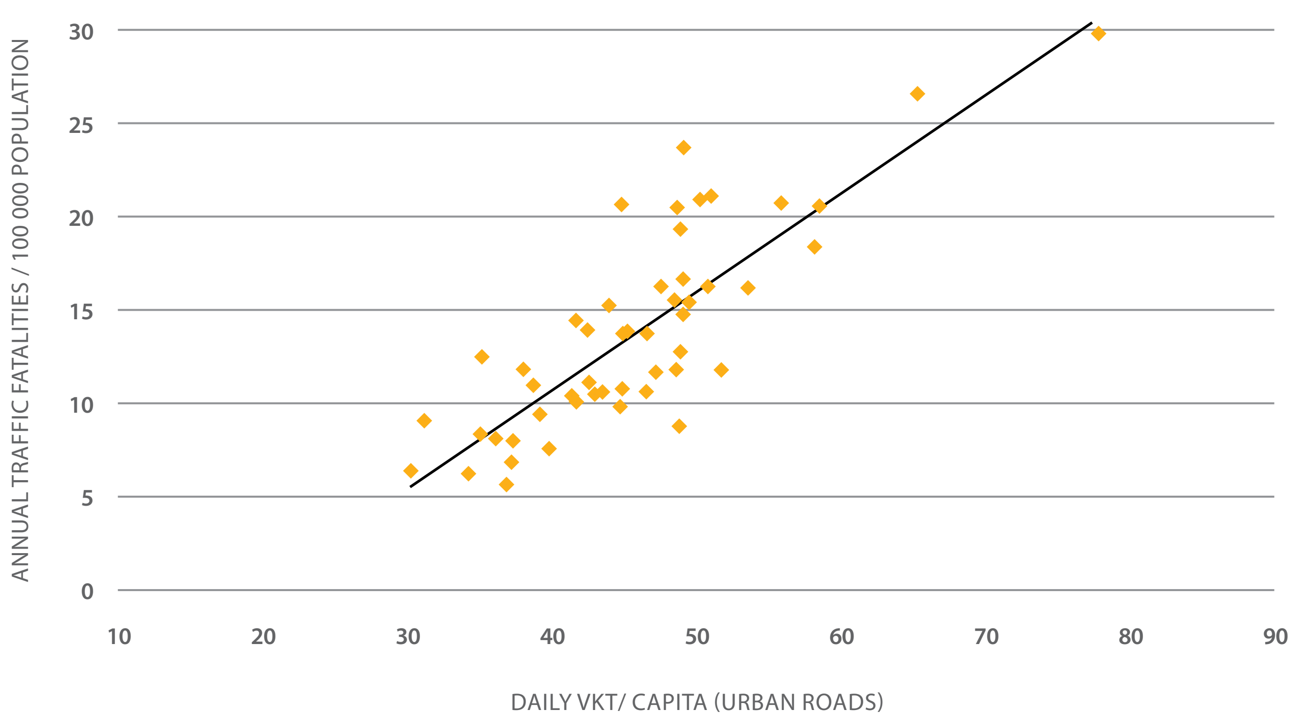
The literature also investigates the relationship between traffic volumes and safety at the neighborhood, city, and regional level. In a study on the influence of the built environment on traffic safety, Dumbaugh and Rae (2009) analyzed the correlation between road traffic fatalities and land use characteristics, street types, and number of intersections for a sample of city neighborhoods in San Antonio, Texas. The study demonstrated that VKT is significantly correlated with crash incidence rates after controlling for income levels, number of intersections, and freeway and arterial miles in each neighborhood.

Using data from 1990 for a sample of 57 world cities, Kenworthy et al. (1997) analyzed the relationship between automobile use—measured as kilometers per year per person—and traffic fatalities per 100,000 people. The authors found a correlation between the two variables: cities with higher travel volumes per capita showed higher fatality rates.

Clark and Cushing (2004) analyzed data provided by the Federal Highway Administration (FHWA) for each US state to estimate the impact of population density, VKT, and the presence of a trauma system on mortality from traffic accidents on urban and rural roads. The authors found that VKT per capita was a strong predictor of traffic fatality rates in both urban and rural areas. Figure 1 illustrates this relationship in US states in 2008 and shows that states with higher daily VKT per capita also have a higher traffic fatality rate.

But while VKT is widely recognized in the literature as a strong predictor of accidents, road safety policies usually do not target VKT reductions. As Clark and Cushing (2004) point out, “it should not be forgotten that VMT is itself a modifiable risk factor. . . . reducing exposure to automobile travel is an undeniable way to reduce traffic fatalities.” Luoma and Sivak (2013) compare travel patterns in the United States and the United

Figure 1 VKT on urban roads and traffic fatality rate, US states, 2008



SOURCE: US Federal Highway Administration (FHWA) Highway Statistics 2008

Table 2 Traffic safety impacts of the London congestion charge (average annual injury accidents)

	Charging zone	Inner Ring Road	Rest of London
Before the congestion charge (2001–2)	1,531	489	17,687
After the charge was implemented (2003–6)	1,054	349	14,265
Percent change	-31%	-28%	-19%

Source: computed from TfL 2008.

The London Congestion Charge has contributed to a reduction in injury accidents within the charging zone. This is one of the few examples of a project aimed at reducing traffic which has also monitored and documented the impacts on traffic safety.

Kingdom and conclude that "the greater distance driven per licensed driver in the U.S. is the main factor affecting the difference in road safety between the two countries." The authors recommend steps for improving safety on US roads, including lowering the blood alcohol content limit, enforcing rear seat seatbelt use, and considering "new strategies to reduce vehicle distance driven."

Because policymakers do not always consider the link between VKT reductions and traffic safety, it is not easy to find examples of policies that have targeted VKT reductions and that have also measured the safety impact. One example, however, is the London Congestion Charge. In February 2003, the city of London instituted a charge for vehicles entering a designated area in the city center, with the aim of reducing traffic congestion. For the next 6 years, the city measured the impacts of this measure on a variety of performance indicators, including the number of injury accidents.

Transport for London's ex post evaluation of impacts (TfL 2008) noted that traffic volumes were reduced in the charging zone as a result of the congestion fee. Traffic accidents decreased citywide in London between 2001 and 2006, but decreased at a faster rate within the charging zone (Table 2). TfL attributed this safety improvement to the reduced traffic volumes. The analysis found that the safety benefits extended to London's Inner Ring Road, which circled the congestion charging area. It is important to note that the reduction in traffic in the charging zone means not that fewer people traveled there but that vehicles across the board, from transit to automobiles, had increased occupancy.

This is not the only example of a congestion-charging scheme yielding safety benefits. The city of Stockholm has implemented a similar scheme and similarly reported reductions in injury accidents. Stockholm evaluated the value of those benefits at USD 18 million. The Handbook of Road Safety Measures, a Norwegian publication that estimates the safety impact of various transport projects and policies through a meta-analysis of existing research, includes a dedicated chapter for road pricing. The authors evaluate the change in number of accidents in four Norwegian cities that implemented various types of pricing, from ring road tolls to local fuel taxes. They found that the different pricing measures resulted in reductions in car traffic of 3 to 10 percent and a corresponding decrease in injury accidents of 5 percent, on average.

The examples cited here, as well as the literature on VKT and traffic safety, make the case that policies aimed at reducing traffic in cities can be expected to have safety benefits. However, it is also possible to “decouple” increased VKT and increases in traffic accidents. Denmark, for example, has achieved significant reductions in traffic fatalities over the past decades, bringing the fatality rate down from a high of 22.6 deaths per 100,000 population in 1973 to 3.1 per 100,000 in 2012, despite a continuous increase in VKT during the same period. Improved infrastructure, better vehicle technology, and stricter enforcement of traffic regulations have driven this decline.

The Danish example highlights the fact that while VKT is a risk factor for traffic safety, it is certainly not the only one and not necessarily the most important one to consider. Dumbaugh and Li (2010) show that, for example, a strip commercial use (i.e., an auto-oriented retail facility with a driveway facing an urban arterial) produces six times more crashes than 1.8 million kilometers of vehicle travel. Infrastructure design and the relationship between street types and land uses are key factors in ensuring traffic safety.

In practice, a policy will not just target VKT reductions but will also seek to shift travel from private vehicles to transit, walking, and cycling. The city of London, for example, implemented its congestion charge while making improvements to transit service. It is important, then, to also understand the relationship between transit service and use, on the one hand, and traffic safety, on the other.

TRANSIT AND TRAFFIC SAFETY

"Transit" is not a uniform category, and not all types of transit service will have a similar impact on traffic safety. In the developed world, all forms of transit (including bus and rail) tend to be the safest transportation options available in cities (ETSC 2003; Elvik and Vaa 2004). Litman (2013) provides an overview of the relative safety of transit compared with other modes. He shows that public transit is the safest mode of urban travel, regardless of how this is measured. For example, urban transit (both rail and bus) has a much lower fatality rate than automobiles, both for vehicle occupants and other road users. Similarly, cities that have a higher number of passenger miles on public transport tend to have fewer traffic fatalities.

Bhalla et al. (2007) studied the relative safety of different modes of travel by developing a risk-based analytical framework for estimating traffic fatalities for a range of transport growth scenarios applicable to cities in the developing world. The results clearly indicate that an increase in motorized travel will inevitably bring about an increase in traffic fatalities. However, depending on how those motorized trips are distributed between transit, private cars, and motorized two-wheelers, the difference in safety outcomes is considerable. The "high bus" case, which assumed that 80 percent of motorized trips would be made by bus, proved to be by far the safest scenario, whereas scenarios with a combined share of cars and motorcycles over 20 percent resulted in considerably more fatalities.

Elvik and Vaa (2004) also considered the relationship between increased motorized travel and increases in injuries, using studies of the safety impacts of fare changes for buses and the Underground in London in the 1980s. The fare changes led to corresponding shifts to and from transit and private vehicles. The studies found that higher transit fares (associated with a decrease in transit patronage) resulted in 4 percent more injury accidents than otherwise expected. The lowering of transit fares, however, was not found to have a significant impact on traffic safety.

There are several other important distinctions. The overall safety performance of a transit system is likely to depend on its location. A transit system on an urban arterial is likely to have a higher incidence of crashes and

The significant safety benefits observed on several BRTs in Latin America and India are due to a combination of improved street geometry and signalization, segregation of buses from mixed traffic, and replacement of competing private bus operators with a single agency.

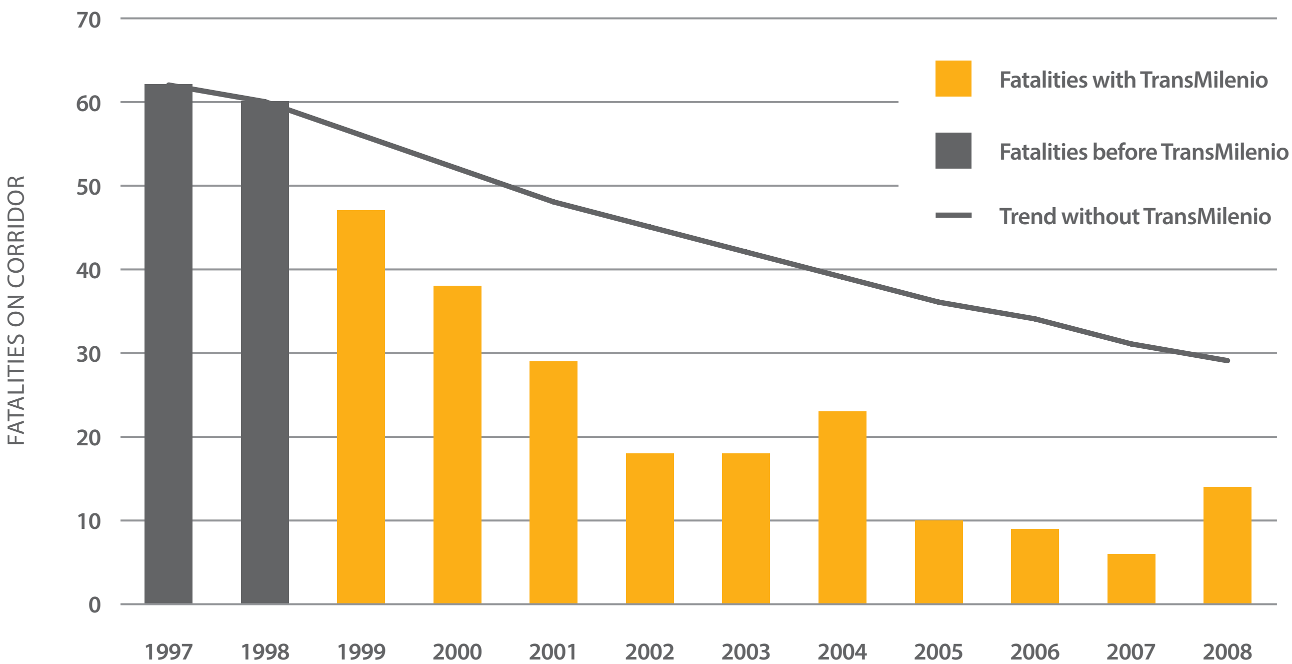
injuries than one operating on an expressway, simply because arterial streets are inherently more dangerous (Dumbaugh and Rae 2009). Several studies have also focused on transit safety in more detail, looking at specific risks on urban tramways in Europe (e.g., Chalanton and Jadoul 2009; Beer and Brenac 2006) and on light rail systems in the United States (e.g., Klaver Pecheux and Saporta 2009; Korve et al. 2001).

All the studies cited above use data from the developed world, predominantly the European Union and the United States. This raises the question of whether their findings, based on cities such as Copenhagen, Amsterdam, and New York, are applicable to cities in developing countries. The predominant transit service in many cities in the developing world is minibuses, which often operate with little oversight from city transport agencies (Restrepo Cadavid 2010).

Duduta et al. (2012) analyze the safety of different types of transit services in developing world cities and find that typical minibus or conventional bus operations have been the most unsafe configuration. For example, the Avenida Caracas busway in Bogotá—a transit corridor typical of many Latin American cities in the 1990s—featured a mix of bus and minibus services. In the 1990s, the busway had as many as 62 reported annual fatalities for a 25-kilometer stretch.

Starting in the late 1990s, Bogotá began implementing TransMilenio, a high-capacity BRT system that replaced the congested busways. TransMilenio has received significant acclaim for its benefits in travel time savings, reduced emissions, and improvements in overall quality of service. Figure 2 analyzes TransMilenio's traffic safety impact. A simple before-and-after comparison shows that annual traffic fatalities on the corridor decreased from an average of 61 before the system was implemented to an average of 21 during the first 9 years of operation. However, before-and-after comparisons can be misleading if they do not account for citywide trends. The city of Bogotá initiated several traffic safety policies in the mid-1990s, and traffic fatalities subsequently decreased citywide at around 8 percent a year. The gray trend line in Figure 2 projects this citywide trend to the Avenida Caracas corridor in order to obtain a more accurate baseline scenario. It projects the expected change in fatalities on the street in a "no project" scenario. Fatalities would have likely decreased on Avenida Caracas even in the absence of TransMilenio, reflecting improved citywide safety. However, actual fatalities were, on average, 52 percent lower than expected under the baseline scenario, indicating clear safety benefits from TransMilenio.

Figure 2 Reported traffic fatalities on Avenida Caracas (first TransMilenio BRT corridor) in Bogotá, before and after the implementation of the BRT



SOURCE: EMBARQ Analysis, based on data provided by TRANSMILENIO S.A.

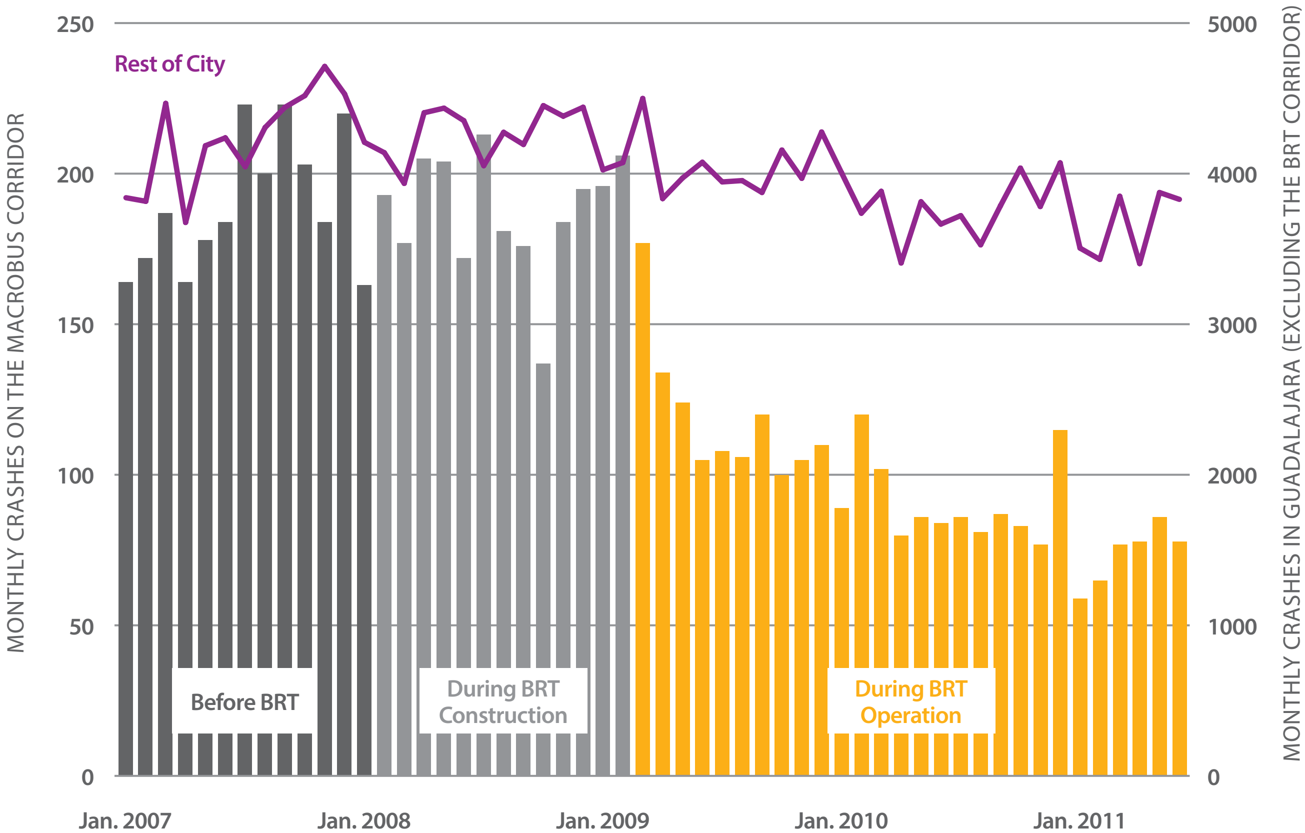
The changes introduced by TransMilenio went beyond the geometry of the street. The different private operators competing for passengers were replaced with a single operating agency. TransMilenio also features an operations control center that monitors bus operations in real time and a safety unit which collects and analyzes crash data and performs audits and inspections to address safety issues.

In Guadalajara (Mexico), the Macrobús BRT replaced conventional buses with a segregated transit infrastructure and a single operating agency. Crashes remained relatively constant citywide, with a slight decrease of around 8 percent over a 5-year period. In contrast, crashes on the corridor fell by 46 percent after the implementation of Macrobús, and the accident rate continued to decrease slightly throughout the first 2 years of operation (Figure 3).

The Janmarg system in Ahmedabad is another example of a BRT that reported safety improvements after its implementation. According to data provided by the Center for Environmental Planning and Technology (CEPT) in Ahmedabad, average annual traffic fatalities have decreased by 55 percent and injuries by 33 percent on the streets where BRT runs.

Goh et al. (2013) evaluate the safety impacts of BRT priority measures in Melbourne. The authors use a more sophisticated technique than a simple before-and-after comparison; instead, they estimate the safety impact of the BRT by using the Empirical Bayes (EB) method. EB involves averaging the actual crash counts on the BRT corridor before BRT implementation with an estimate of expected crashes. The estimate is developed via a safety performance function, which aims to predict accidents based on traffic volumes, using data from similar streets in Melbourne. This technique can help avoid two common problems with fatality data—regression to the mean and general randomness, both

Figure 3 Crashes before and after the implementation of the Macrobús BRT in Guadalajara



SOURCE: EMBARQ Analysis, based on data provided by the Jalisco State Secretariat for Roadways and Transport

of which can be problematic in the case of small sample sizes. By applying the EB method, the authors estimate that the Melbourne BRT contributed to an 18 percent reduction in accidents on its corridors.

The examples cited above provide evidence that transit priority schemes such as BRT can improve safety on the streets where they are implemented. But it should not be assumed that every BRT will have a positive impact. Duduta et al. (2012) analyze the safety performance of different types of BRT and busway design configurations and identify the infrastructure characteristics most likely to influence accident frequencies (Table 3).

As Table 3 shows, while the presence of the BRT is correlated with a reduction in crashes, this reduction is not statistically significant. Rather, the results suggest that the safety benefits accrue primarily from the changes in street geometry associated with the introduction of a center-lane BRT system. Street geometry changes include reducing the number of legs at certain intersections by extending the median along the BRT corridor ($p<0.001$), reducing the total number of lanes on a street to accommodate the station infrastructure ($p<0.001$), restricting left turns ($p<0.001$), and shortening pedestrian crossings with a central median ($p<0.05$). It should be noted that this cross-sectional study does not account for some of the organizational changes that occur when private minibus operators are replaced by a centralized agency, as discussed in the TransMilenio example. Table 3 also illustrates a common problem in analyzing safety in a developing world context - lack of

Table 3 Negative binomial model predicting crash frequencies on major bus corridors in Mexico City

Traffic mix	Vehicle collision model coef.	Pedestrian crash model coef.
Constant	-1.518***	-1.857***
Number of legs	0.374***	0.252***
Number of lanes per leg	0.374***	0.341***
Left turns per approach	1.705***	1.268**
Market area	-	0.664***
Maximum pedestrian crossing distance (m)	-	0.026**
Pedestrian overpass	-	-0.147
Center-lane BRT (Metrobus Line 1)	-0.029	-0.299
Counterflow bus lane	0.554***	0.389**
Curbside bus lane	-0.176	-0.087
Number of observations	216	216
Log likelihood	-618.475	-518.539
LR chi2	139.99	104.88
Prob > chi2	0.000	0.000
chibar2(01)	367.14	231.39
Prob >=chibar2	0.000	0.000

*** p<=0.001, ** p<=0.05, * p<=0.1, - variable not included in the model

Source: Duduta et al. 2012.

high quality data. Traffic volumes are always a key predictor of crash rates and they are an important variable to include in crash frequency models. However, there was not enough traffic volume data available for analysis in this case. While there are precedents in the literature for developing crash frequency models without traffic volume data (e.g. Viola et al. 2010), this is an important limitation of the model.

The evidence in the literature suggests that it would be inaccurate to claim that all forms of transit have similar safety benefits, especially in the developing world. A more accurate claim is that transit systems can have significant benefits. In order to achieve these benefits, their design must incorporate safety elements such as segregated lanes or tracks, pedestrian refuge islands, and improved intersection geometry. The organizational structure of these systems must eliminate competition for passengers and instead promote best practices in driver training and vehicle maintenance.

NON-MOTORIZED TRANSPORT AND TRAFFIC SAFETY

The safety impact of projects and policies related to walking and cycling is more complex than that of transit. On the one hand, pedestrians and cyclists are among the most vulnerable road users and tend to be at a higher risk of accidents than transit or car users (Jorgenesen 1996; ETSC 2003). It would be fair to assume then that a person who switches from a motorized mode

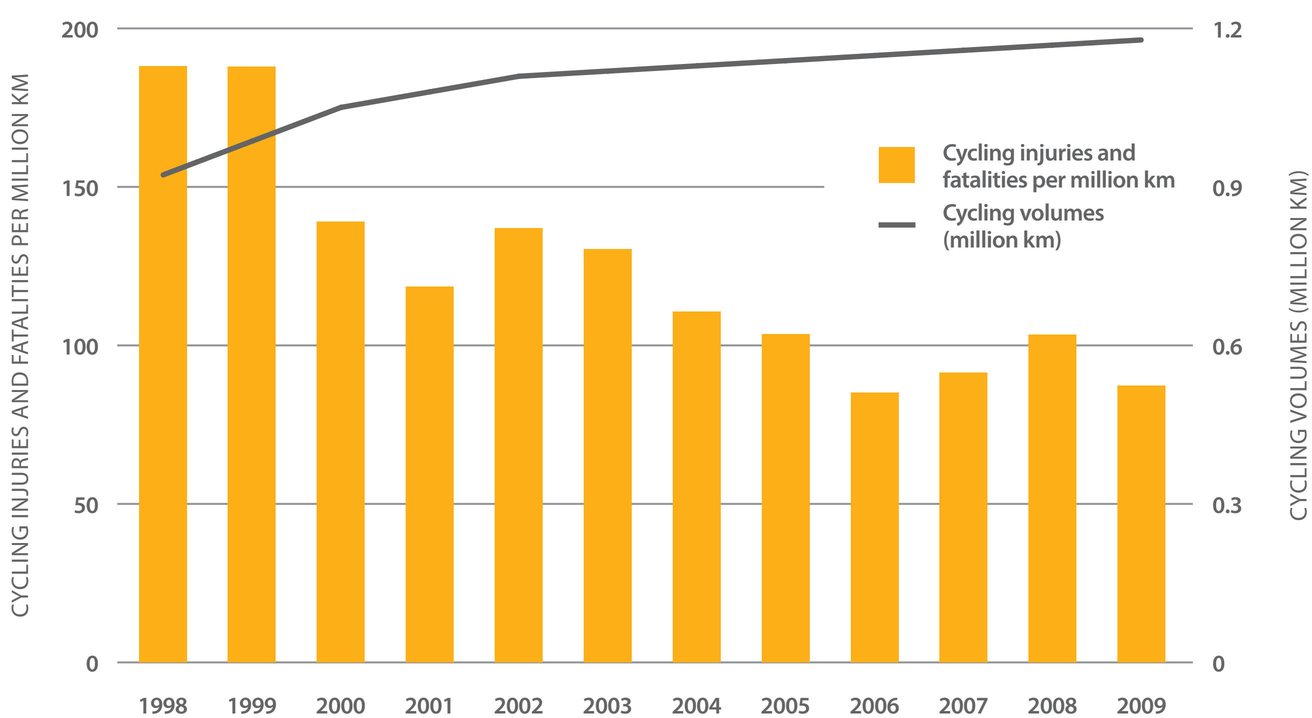
to walking or cycling is at a higher risk of being injured or killed in a crash. On the other hand, there is increasing evidence that when this mode shift occurs on a larger scale, safety tends to improve considerably, and not just for non-motorized modes.

The city of Copenhagen, for example, has invested massively in improving infrastructure for cyclists. Over the past decade, cycling volumes in the city (measured as millions of kilometers cycled) have more than doubled, while the rate of injuries and fatalities for cyclists per kilometer ridden has decreased sharply (Figure 4). Similarly, New York City added cycling infrastructure during the same period, and the number of people who commute by bicycle has quadrupled since 2000. As in Copenhagen, the relative risk of cycling in New York City (i.e., the ratio of cycling injuries to people cycling) has decreased significantly (Figure 5). The city of Minneapolis has witnessed a similar trend (Figure 6).

The safety improvements are due at least in part to safer cycling infrastructure. The increase in cycling volumes in the three cities has been accompanied—and to some extent driven—by improved cycling infrastructure, particularly more cycle lanes and paths. New York City, for example, built over 320 kilometers of bike lanes between 2006 and 2009 (Viola, Roe, and Shin 2010).

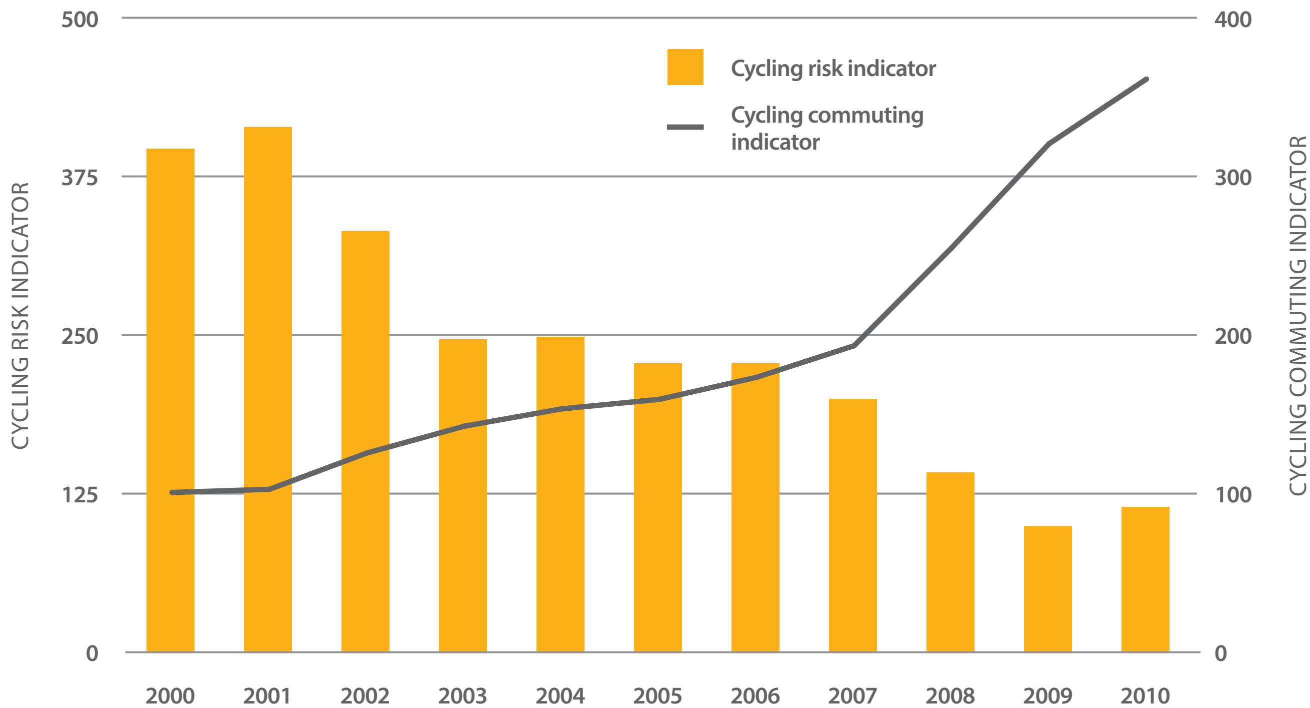
Elvik and Vaa (2004) found that across a number of studies around the world, cycle lanes are linked to small but statistically significant reductions in injury accidents. A study in New York City (Viola, Roe, and Shin 2010) found that the presence of bike lanes on a street improved safety for not just cyclists but also pedestrians. According to the study, pedestrian crashes on streets that featured

Figure 4 Cycling volumes and cycling risk in Copenhagen, 1998–2009



SOURCE: Computed from data provided by Consia Consultants, Copenhagen

Figure 5 Comparison of cycling commuting indicator and cycling risk in New York City *



SOURCE: New York City Department of Transportation (NYC DOT)

* The cycling commuting indicator is a measure of the change in cycling commuter volumes, using 2000 as a base year (i.e., the indicator is equal to 100 in the year 2000). The cycling risk indicator is a ratio of cycling injuries to cyclist commuters. Both indicators were developed by NYC DOT.

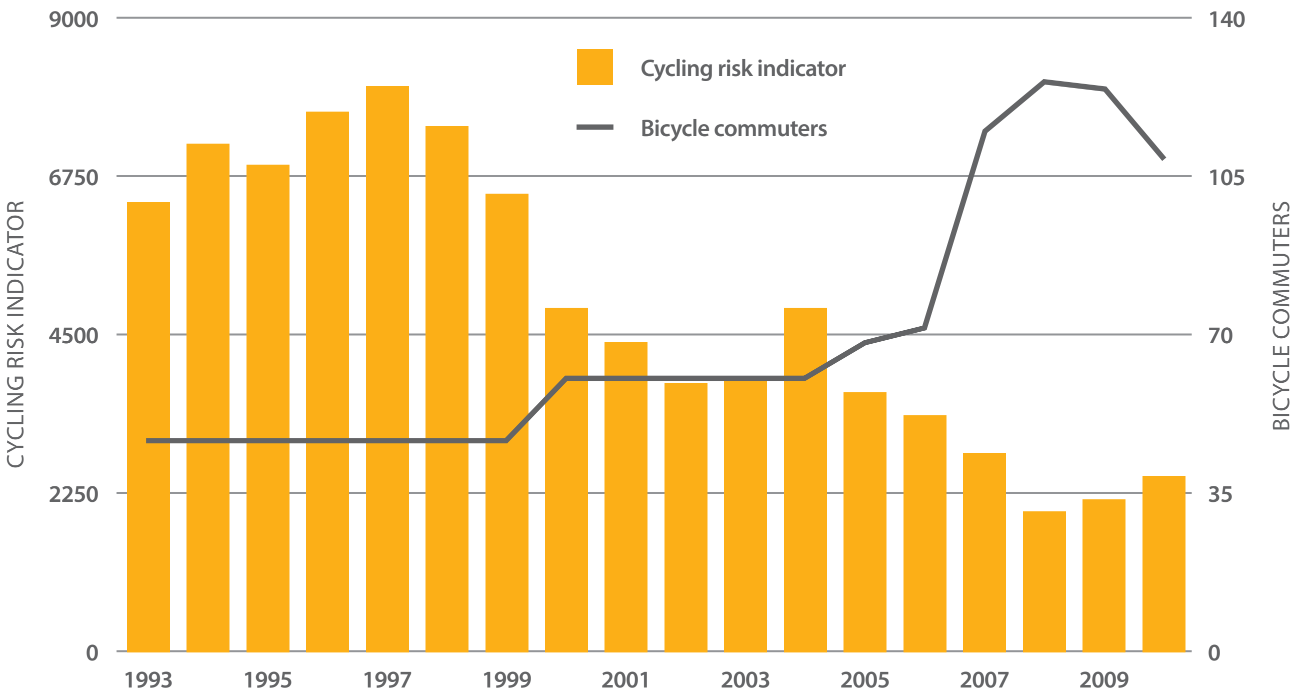
bike lanes were 40 percent less deadly than crashes on any other streets. According to the New York City Department of Transportation (NYC DOT), most of the bike lanes in the city were made by narrowing the motor vehicle portion of the roadway. The narrower road space for vehicles may calm traffic, which could explain the difference in crash severity.

The Urban Bikeway Design Guide (NACTO 2011) surveys best practices in the design and signalization of urban cycling facilities. It also provides an extensive list of references on the safety aspects of various types of cycling infrastructure.

Minikel (2012) discusses the safety impact of placing bike lanes on different types of streets and concludes that side streets are safer than busier arterials. These findings suggest opting for a hierarchy of streets, in which some prioritize motorized travel, while others are designed to encourage bicycle traffic. Lusk et al. (2011) compare the injury risk for cyclists on cycle tracks versus in the street, and find that cyclists using tracks have a lower risk of being involved in a crash than those riding in the street.

The question of how to accommodate cycling turning movements at intersections has received little attention in the literature. Bike boxes are a common solution. They allow left-turning cyclists to move in front of stopped vehicles when arriving at a red light. Dill, Monsere, and McNeil (2010) evaluate bike boxes

Figure 6 Bicycle commuters and cycling risk in Minneapolis *



SOURCE: Computed from data provided by the Minneapolis Public Works Department

* The cycling risk indicator is calculated as a ratio of reported bicyclist crashes to bicyclist commuters.

in Portland and note that fewer conflicts are observed between cyclists and motor vehicles where bike boxes are present. Other studies have looked at how to manage conflicts between right-turning vehicles and cyclists continuing through an intersection (Hunter 2000) and how to mitigate the risk of bicycle–motor vehicle collisions by using raised crossings (Aultman-Hall and Adams 1998).

Another common intersection treatment is to paint the cycle lanes a different color than the pavement within the intersection area, thus making them more visible. Copenhagen followed this approach and painted its bike lanes blue inside junctions. Jensen (2008) evaluated their safety impact in Copenhagen and found mixed results, with some blue markings improving safety and others leading to an increase in crashes and injuries.

The studies cited above all provide evidence of how specific infrastructure provisions can affect cycling safety. However, research also shows that the likelihood of a cyclist being struck by a motorist varies inversely with the number of cyclists on the road, an effect known as “safety in numbers” (Jacobsen 2003). This effect assumes that a cyclist’s likelihood of being struck by a car depends to a great extent on the behavior of the motorist; as more cyclists use the road, motorists adjust their behavior accordingly. It is most likely that both the infrastructure improvements and the increase in cycling volumes contribute to the increased safety of cyclists

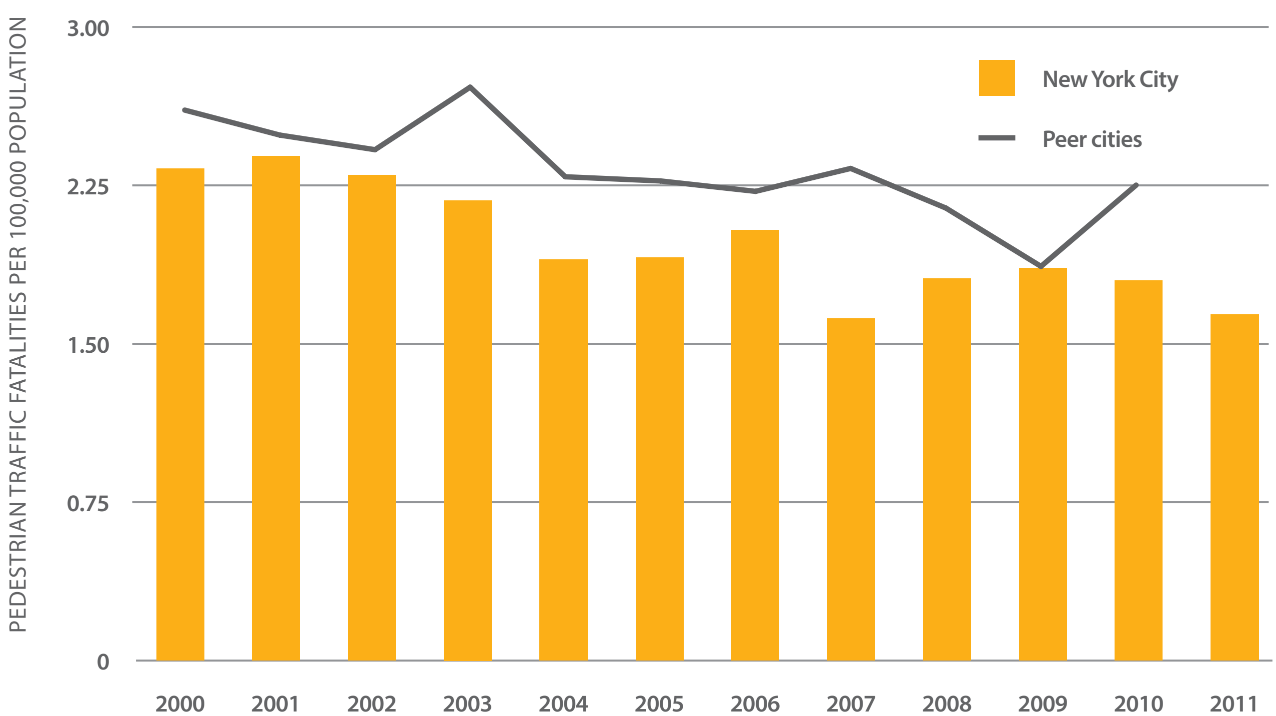
observed in New York City, Copenhagen, and Minneapolis.

Despite the overall improvements in cycling safety, cyclists remain vulnerable road users and are more likely than motorists to be injured or killed if involved in a crash. Therefore, even in a context of high cycling volumes, it is important to pay careful consideration to safety provisions for cyclists.

Many of the findings related to the safety of cycling apply to pedestrians as well. Similarly to cyclists, pedestrians are vulnerable road users and are generally at a higher risk of being injured or killed in a crash than motorized transport users, with the notable exception of motorcyclists (ETSC 2003). Yet pedestrians also appear to benefit from the "safety in numbers" effect—their crash and injury risk is inversely correlated with pedestrian volumes (Jacobsen 2003).

There is an extensive body of literature on pedestrian safety. Recent studies have examined the crossing behavior of pedestrians at signalized intersections (Bai et al. 2013), the impact of the built environment on pedestrian crash frequency (Ukkusuri et al. 2011), pedestrian safety at rail crossings (Metaxatos and Sriraj 2013), and specific risks to pedestrians on different types of light-rail (LRT) and BRT systems (Currie, Scott, and Tivendale 2011; Duduta et al. 2012; Goh et al. 2013).

Figure 7 Pedestrian traffic fatality rate per 100,000 inhabitants in New York City and selected peer cities *



SOURCE: Computed from data provided by NYC DOT

* New York City's US peer cities are cities with populations greater than 500,000, population densities greater than 5,000 per square mile, and/or a rate of nonautomotive commuting of over 20 percent. This indicator was created by NYC DOT.

New York City provides an example of best practices for addressing pedestrian safety. The city passed a law in 2008 mandating a study of pedestrian fatalities and severe injuries, and the development of a strategy and schedule for improving pedestrian safety. The city's Department of Transportation studied pedestrian safety in the city, developing crash frequency and severity models and identifying black spots and key areas for safety interventions (Viola, Roe, and Shin 2010). Based on this study, the DOT developed key safety recommendations informed by the data analysis, targeting high-crash corridors and intersections as well as key risk factors.

As Figure 7 shows, between 2000 and 2010, the pedestrian safety improvements kept New York City's pedestrian fatality rate lower on average than that of peer cities selected by the NYC DOT for comparison. The pedestrian fatality rate has also declined in New York City over the past decade.

Overall, the evidence from New York City, Copenhagen, and Minneapolis shows that policies aimed at improving the infrastructure for pedestrians and cyclists can achieve significant safety benefits, and that these benefits can extend to all traffic modes in the city.

CONCLUSIONS AND POLICY IMPLICATIONS

BETTER INTEGRATING SAFETY INTO TRANSPORTATION PLANNING AND POLICY

The findings presented in this paper suggest a number of policy options for developing world cities that are currently facing high levels of traffic injuries and fatalities and increasing motorization. These include curbing VKT growth, but also working to improve infrastructure and technology. On the institutional side, the key is setting clear goals for fatality reductions and collecting data to monitor progress towards those goals.

This issue brief has brought together the different pieces of evidence currently available on the traffic safety impact of sustainable transport initiatives, including transit improvements, better infrastructure for walking and biking, and restrictions on car traffic in city centers. While some of the evidence is anecdotal (not all cities consistently document the safety impact of sustainable transport), the data and research suggest that sustainable transport can have significant traffic safety benefits. It is important for policymakers and transport professionals to understand this

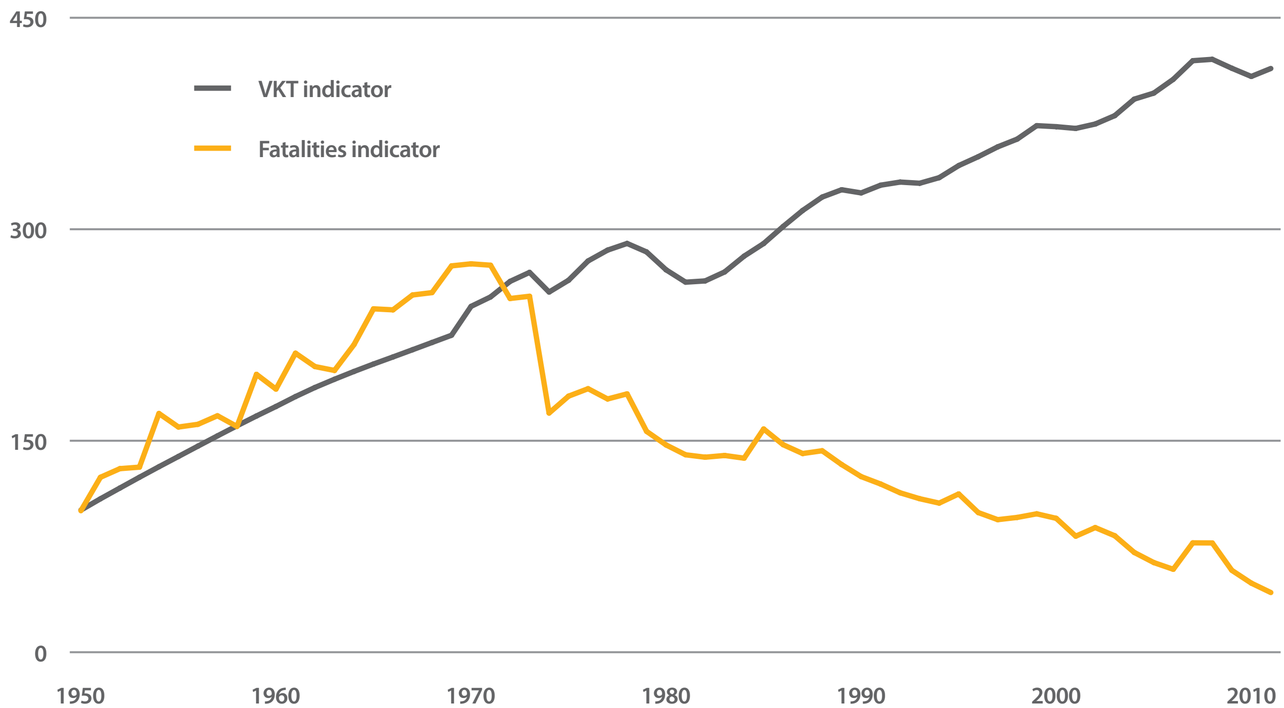
link and, following the example of cities such as Copenhagen and New York, better promote and document the safety aspect of sustainable transport.

This is particularly important for cities in developing countries. Traffic accidents already claim over 1.2 million lives every year. The majority of these fatalities occur in low- and middle-income countries, and their numbers are expected to rise; traffic accidents are expected to become the fifth-leading cause of premature death worldwide by 2030 (WHO 2009). The United Nations has declared 2011 to 2020 the Decade of Action on Road Safety, with the aim of raising awareness of traffic safety issues and encouraging local and national governments to focus on reducing traffic crashes and fatalities.

By 2030, China, India, and Brazil are expected to be in the top four markets for car sales worldwide, with a combined expected sales volume of over 60 million units per year across the three countries. A World Bank study noted that as countries develop, death rates among the population usually fall, especially for diseases that affect the young and result in substantial life-years lost (Kopits and Cropper 2003). However, the study notes that traffic fatalities are a notable exception to this rule, as the growth in motor vehicles usually associated with economic development also brings about an increase in traffic deaths.

We noted earlier the Danish example of “decoupling” VKT and traffic fatalities. As shown in Figure 8, VKT and fatalities in Denmark were closely correlated between 1950 and 1970. From 1970 until the present day, Denmark has been at the forefront of innovation

Figure 8 Relationship between VKT and traffic fatalities in Denmark, 1950–2010 *

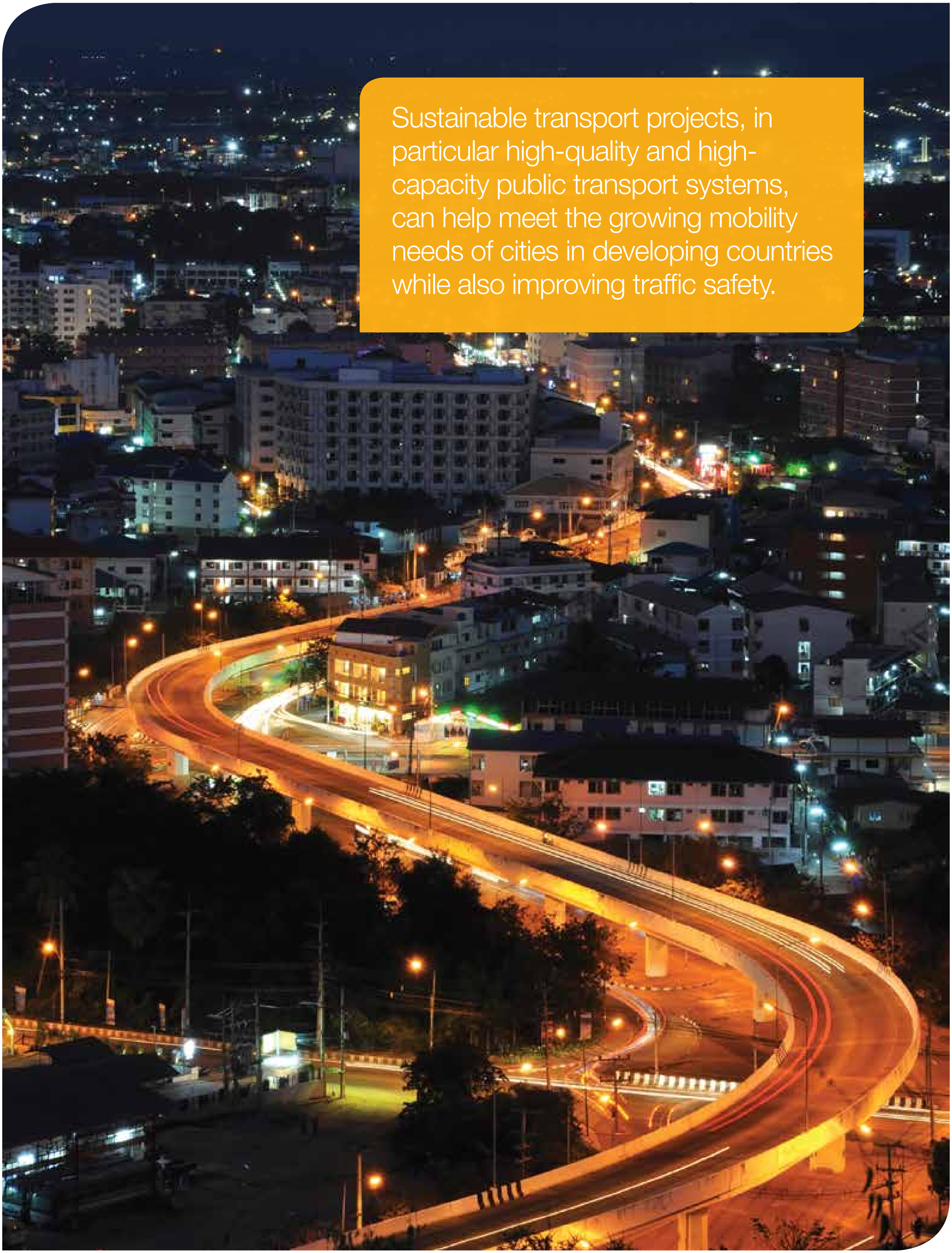


* The VKT indicator is a measure of the change in VKT per capita over time, using 1950 as a base year (i.e., the indicator is equal to 100 in the year 1950). Similarly, the fatalities indicator is a measure of the change in the fatality rate per 100,000 inhabitants over time, also using 1950 as a base year. Both indicators are based on data provided by the Danish Road Safety Council and Consia Consultants, Copenhagen.

in road safety policies and research, setting ambitious targets for fatality reductions, analyzing data to identify key areas for interventions, and implementing a multitude of initiatives to address specific risks and crash types.

Denmark shows that it is possible to achieve significant safety benefits even in a context of continued VKT growth. And while sustainable transport can have significant safety benefits, many other highly effective safety policies can be explored, including improved enforcement of seatbelt and helmet use, blood alcohol limits, and street infrastructure and vehicle technology improvements.

Developed countries can provide useful examples of policies for improving safety, including improved infrastructure and technology, as well as better enforcement and laws. As shown here, sustainable transport projects, in particular high-quality and high-capacity public transport systems, can help meet the growing mobility needs of cities in developing countries while also improving traffic safety. For these benefits to be realizable, transport systems must meet certain quality standards. Cities must ensure that vehicle operators are well trained and that road users respect transit facilities such as dedicated bus lanes, which implies a high level of enforcement. Local and national authorities need to develop their institutional and technical capacities to design, build, and operate systems safely. As New York City demonstrates, it is equally important to set clear, ambitious targets for injury and fatality reductions, and to pursue integrated strategies to achieve those targets.



Sustainable transport projects, in particular high-quality and high-capacity public transport systems, can help meet the growing mobility needs of cities in developing countries while also improving traffic safety.

NEXT STEPS

AVENUES FOR FURTHER **RESEARCH**

This issue brief does not cover all the projects and policies that might qualify as sustainable transport. Instead, it focuses on several specific policies and interventions. Further research could expand on this topic and explore the safety impacts of other modes or initiatives, such as car-sharing, electric bikes, auto-rickshaws, and transit-oriented development. Future studies could also examine in detail the relative safety of different types of transit infrastructure (e.g., curbside versus center alignment for BRT and light rail) or provide more robust estimates of the expected safety impacts of different transport initiatives. Some studies have already addressed these issues. In this section, we summarize those studies and highlight questions for future research.

While the relationship between VKT and traffic safety is well documented, not enough is known about how potential VKT-reducing initiatives such as transit-oriented development or car-sharing might impact traffic safety. Two issues warrant further research: the magnitude of crash reductions from different types of policies or initiatives, and the elements that contribute to this reduction. Dumbaugh and Rae (2009) explore these issues, looking at variables such as pedestrian-oriented retail versus arterial-oriented retail and density of intersections by type. Marshall and Garrick (2011) also look at intersection density and street connectivity and how they relate to crash severity.

As for the link between transit and traffic safety, most of the literature focuses on two themes: the relative safety of transit compared with other modes at the citywide or regional level, and how different geometric designs for transit facilities perform in terms of safety. More research is needed to develop estimates of the expected safety impacts of different types of transit systems. In other words, what is the magnitude in crash reductions that should be expected from implementing, for example, a median LRT corridor on an urban arterial or from increasing transit mode share in a city by 10 percent? With robust estimates, the safety benefits of transit could be better integrated into a cost-benefit analysis for allocating infrastructure funding.

In section 2, we provided evidence of safety impacts from the implementation of several BRT in Latin America and India. In our dataset, corridor-level reductions in fatalities ranged from 10 percent to 68 percent, with an average of 50 percent across five BRT corridors. Goh et al. (2013) propose increasing the robustness of such estimates by using the Empirical Bayes method to account for regression to the mean and the general randomness of fatality data. They estimate that a BRT system in Melbourne has reduced crashes on the streets where it was implemented by 18 percent. The next steps are not just to collect more data but also to expand this analysis beyond BRT and into other surface transportation systems, including different types of bus priority schemes, tramways, and LRT systems.

As we noted above, it is also important to look at the safety impacts of other modes that can be considered sustainable transport, such as auto-rickshaws. Mani, Pai, and Aggarwal (2012) make the case for the auto-rickshaw sector as an integral part of sustainable transport in Indian cities, and they provide initial evidence of the relative safety of auto-rickshaws compared with other modes. The authors also caution, however, that while rickshaws are less dangerous to pedestrians in Indian cities than larger vehicles, the injury patterns to rickshaw occupants in collisions with larger motor vehicles are similar to those of vulnerable road users. Schmucker et al. (2011) delve deeper into this issue and suggest rickshaw design improvements to address occupant safety.

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Endnotes

1. We use the term transit here to refer to all forms of mass transportation involving bus, minibus, or rail vehicles. Some of the studies we cite from Europe and the United States use the terms public transport or public transit. Those terms, however, would be inaccurate in some Latin American cities, where most transit services involve private operators. We therefore consider that transit better fits all the systems described in this paper.
2. Owen, Carrigan, and Hidalgo 2012, table 3, 26.
3. DfT 2013.
4. Owen, Carrigan, and Hidalgo 2012.
5. Duduta et al. 2012.
6. Goh et al. 2013; Duduta et al. 2012.
7. Viola, Roe, and Shin 2010.
8. Ibid.
9. VKT is defined as the total number of kilometers traveled by all vehicles within a jurisdiction and within a given period of time. Daily VKT and annual VKT are the most commonly used metrics.
10. Duduta and Bishins 2010.
11. California Office of the Governor 2010.
12. The vehicle or passenger throughput is the number of vehicles (or passengers) that move through a roadway during a defined period of time.
13. This scenario is based on the assumption that the BRT infrastructure would eliminate two mixed-traffic lanes per direction. It is important to note that a median running BRT requires space not only for the bus lanes but also for the stations and, where applicable, passing lanes
14. Hauer et al. 2001; Srinivasan and Carter 2010 ; Goh et al. 2013.
15. Since the study was based on US data, it used vehicle miles traveled (VMT) instead of VKT.
16. Pike 2010.
17. Elvik and Vaa 2004.
18. Danish Road Safety Council, Consia Consultants, Copenhagen.
19. EMBARQ 2009.
20. Computed from data provided by the Colombian Ministry of Transport.
21. For more details on the institutional structure of BRT agencies, see Wright and Hook 2007, vol.2, section 15, “Business and Institutional Structure.”
22. Viola et al. 2010.
23. New York City Pedestrian Safety Act (Local Law 11 of 2008).
24. United Nations Road Safety Collaboration 2013.
25. Booz and Co..

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