Assessing discrepancies in estimates of road traffic deaths in Brazil

Kavi Bhalla ,[1] Soames Job,[2] Sudeshna Mitra,[2] James E Harrison,[3] Leah Watetu Mbugua,[2] Kazuyuki Neki,[2] Hialy Gutierrez,[1] Ramshankar Balasubramaniyan,[1] Mercer Winer,[1] Theo Vos,[4] Erin Hamilton[4]

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/ip-2023-044871).

[1]Public Health Sciences, University of Chicago, Chicago, Illinois, USA
[2]World Bank Global Road Safety Facility, World Bank, Washington, DC, USA
[3]Flinders University, Bedford Park, South Australia, Australia
[4]Institute for Health Metrics and Evaluation, Seattle, Washington, USA

Correspondence to
Dr Kavi Bhalla, Public Health Sciences, University of Chicago, Chicago, IL 60637, USA; kavibhalla@gmail.com

Received 6 February 2023
Accepted 30 April 2023
Published Online First 19 May 2023

ABSTRACT

Introduction The First UN Decade of Action for Road Safety (2011–2020) ended with most low/middle-income countries (LMICs) failing to reduce road traffic deaths. In contrast, Brazil reported a strong decline starting in 2012. However, comparisons with global health statistical estimates suggest that official statistics from Brazil under-report traffic deaths and overestimate declines. Therefore, we sought to assess the quality of official reporting in Brazil and explain discrepancies.
Methods We obtained national death registration data and classified deaths to road traffic deaths and partially specified causes that could include traffic deaths. We adjusted data for completeness and reattributed partially specified causes proportionately over specified causes. We compared our estimates with reported statistics and estimates from the Global Burden of Disease (GBD)-2019 study and other sources.
Results We estimate that road traffic deaths in 2019 exceeded the official figure by 31%, similar to traffic insurance claims (27.5%) but less than GBD-2019 estimates (46%). We estimate that traffic deaths have declined by 25% since 2012, close to the decline estimated by official statistics (27%) but much more than estimated by GBD-2019 (10%). We show that GBD-2019 underestimates the extent of recent improvements because GBD models do not track the trends evident in the underlying data.
Conclusion Brazil has made remarkable progress in reducing road traffic deaths in the last decade. A high-level evaluation of what has worked in Brazil could provide important guidance to other LMICs.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ While most low/middle-income countries (LMICs) have made little progress in reducing road traffic deaths, official statistics from Brazil suggest strong improvements since 2012.
⇒ There are substantial discrepancies between official statistics and motor vehicle insurance claims and global health statistical estimates produced by the Global Burden of Disease (GBD) study and WHO's Global Health Estimates.

WHAT THIS STUDY ADDS

⇒ We show that although official statistics underestimate the true road traffic death toll by about 31%, the officially reported reductions in traffic deaths in the last decade are likely real.
⇒ GBD estimates of road traffic deaths do not track the trends evident in the underlying death registration data and underestimate the extent of recent improvements in Brazil.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Brazil presents a rare LMIC road safety success story. A high-level evaluation of the country's road safety programmes can provide important guidance to other countries.
⇒ GBD will need to improve methods for modelling trends in road traffic deaths before it is a reliable source for monitoring progress during the Second Decade of Action for Road Safety 2021–2030.

INTRODUCTION

The first UN Decade of Action for Road Safety, 2011–2020, ended with most low/middle-income countries (LMICs) showing little progress in reducing traffic injuries.[1 2] Brazil was a notable exception, reporting that their road traffic deaths peaked in 2012 (44 812 deaths) and declined by 29% by 2019.[3] While this decline is much less than the 50% reduction that the Decade of Action aimed to achieve,[4] it nevertheless suggests a remarkable performance which may present a model for other countries to emulate.

However, there are several discrepancies that raise questions about the reliability of Brazil's official statistics. Official reporting of road traffic deaths in Brazil is based on death certificates, and derived from the Mortality Information System (SIM) database, of the national health system, *Sistema Único de Saúde*.[3] SIM registered 31 945 road traffic deaths (15.1 per 100 000 population) in Brazil in 2019. However, Seguradora Líder DPVAT, which manages mandatory auto insurance (Law 6, 194/74), reported paying 40 721 traffic fatality claims in 2019, 27.5% more than deaths reported by SIM.[5]

One explanation for the discrepancy is because of fraudulent claims that have received substantial media attention.[6] However, it is extremely unlikely that fraud occurred frequently enough to explain the large discrepancy (in 2019, DPVAT reported only 553 fraudulent claims, 1.4% of fatality claims).[5] Another explanation that has been suggested in our discussion with experts in the country is that insurance claims are reported based

Check for updates

To cite: Bhalla K, Job S, Mitra S, *et al*. *Inj Prev* 2023;**29**:412–417.

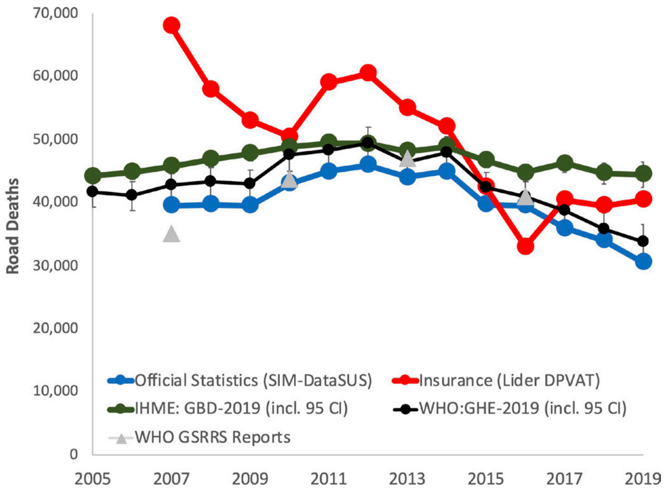


Figure 1 Comparison of official statistics of road traffic deaths in Brazil with insurance claims and estimates by IHME and WHO. DPVAT: Danos Pessoais causados por Veículos Automotores de via Terrestre; GBD, Global Burden of Disease; GHE, Global Health Estimates; GSRRS, Global Status Reports on Road Safety; IHME, Institute for Health Metrics and Evaluation; SIM, Sistema de Informação sobre Mortalidade.

on the year when claims are paid, rather than the year of the event. Nevertheless, such an explanation cannot justify a consistently higher count of insurance claims over many years when trends in deaths have been relatively stable. In fact, over the 13-year period shown in figure 1, there were 25% more insurance claims (130 500 deaths) than officially reported deaths, and insurance claims were higher than official statistics in every year except 2016.

Comparisons of official statistics with estimates developed by international agencies provide further evidence to suggest under-reporting in official statistics. Figure 1 shows road traffic deaths estimated by two major global health studies: (1) the Institute of Health Metrics and Evaluation's Global Burden of Disease (IHME-GBD) study and (2) the WHO's Global Health Estimates (WHO-GHE). GHE are the basis of modelled estimates reported in WHO's Global Status Reports on Road Safety (GSRRS). Note that while official statistics only tabulate deaths registered in SIM with road traffic crash as their listed cause, GHE and GBD aim to provide estimates of the true death toll after adjusting for the quality of reporting by SIM.

Both GBD and GHE estimate more deaths than official statistics over the entire period but GBD's estimates are substantially higher. GBD estimates for 2019 are 46% higher than official statistics and only slightly (10%) higher than insurance claims. Besides the difference in magnitude, the discrepancy in road death trends is noteworthy. GBD estimates show a much slower decline in road traffic deaths. Unlike GHE, which track the trends in official statistics, GBD estimates of road traffic deaths are relatively flat, showing a decline of less than 10% since 2012, much less than the decline reported in official statistics.

Thus, figure 1 raises two important questions that are the focus of this study: (1) Are official statistics of road traffic deaths in Brazil under-reported and by how much? and, (2) Are road traffic deaths declining as rapidly as suggested by official statistics? In this study, we systematically assessed the quality of the Brazilian death registration system, especially the quality of cause coding, and assess how this affects estimates of the magnitude and trend of road traffic deaths.

Table 1 Case definition for road traffic deaths and reattribution strategy for deaths coded to partially specified causes

Category	ICD-10 definition*	Analysis
Deaths specified as road traffic deaths		
Pedestrian	V01–V04, V06, V09	Assigned to road traffic deaths
Bicyclist	V10–V19	
Two/three-wheeler rider	V20–V29, V30–V39	
Car occupant	V40–V49	
Van occupant	V50–V59	
Truck occupant	V60–V69	
Bus occupant	V70–V79	
Other road injury	V80, V82, V83, V84, V85	
Unspecified road injury	V87–V88, V89, Y85.0	
Deaths coded to partially specified causes that may include road traffic deaths		
Unspecified transport deaths	V99, Y85.9	Reattributed† proportionately to 1. road traffic injuries; and 2. transport injuries that are not road traffic injuries
Unspecified unintentional death	X59	Reattributed† proportionately to 1. road traffic injuries; and 2. unintentional injuries that are not road traffic injuries
Unspecified cause of death	Y34, Y87.2, Y89.9	Reattributed† proportionately to 1. road traffic injuries; and 2. injuries that are not road traffic injuries

*10th Revision of the International Statistical Classification of Diseases and Related Health Problems.
†Age, sex pro rata reallocation: deaths coded to each age-group, sex-group of partially specified causes are redistributed proportionately over the specified categories in proportion to the deaths in the specified category. 19 age (<1, 1–4, 5–9, … 80–84 and 85+ years) and two sex (male, female) categories are used.

METHODS

Data source

We extracted death registration data (ie, tabulations of number of deaths for each cause, disaggregated by age and sex) for Brazil from the WHO Mortality Database (WHOMDB, June 2021 revision) for the period 2002–2019.[7]

Map external cause codes

We reclassified all deaths coded to external causes into 48 categories of specified external causes of death, and 21 categories of partially specified external causes as defined by the GBD-2010 Injury expert group.[8] The categories specific to road traffic deaths are shown in table 1.

Assess completeness

We assessed completeness of the registration system by calculating the ratio of registered deaths and independent estimates of all-cause deaths in the country. There are two global agencies that estimate all-cause deaths: (1) IHME, whose estimates are used to adjust for completeness in GBD[9] and (2) United Nations Population Division's (UNPD) World Population Prospects estimates,[10] which are used by WHO to adjust for completeness in GHE. The two sources produce estimates that can differ substantially for some countries.[11 12] These differences affect road traffic death estimates because cause-specific mortality estimates are scaled-up to ensure their aggregate is consistent with all-cause death totals.

Reapportion partially specified causes of death and adjust for completeness

We estimated national road traffic injury deaths using an algebraic process of redistribution of partially specified causes of death that we have described previously.[13] Briefly, this method for reattribution involves a series of steps, where the deaths in each of the partially specified categories are redistributed over the set of well-specified categories to which they could possibly belong, in proportion to the numbers of deaths in those categories before redistribution. The redistribution is done within age-group and sex-group. This method is similar to that used in WHO's estimates (GHE) and was used in GBD until it was replaced by a new method[14] that is more complex and less transparent to external researchers. Finally, we scaled up the age-specific and sex-specific road traffic death estimates to adjust for under-registration (ie, completeness).

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

The proportion of deaths from all causes that are registered by SIM has risen steadily over the last two decades and the system is nearly complete now. In 2019, completeness was 95.5% based on comparison with IHME's estimate of all-cause deaths, and slightly higher (98.2%) based on UNPD's estimate (see online supplemental figure A1).

Figure 2 shows the relative magnitude of deaths coded to those partially specified causes that affect estimates of road traffic deaths. The proportion of deaths coded to transport that are unknown (ie, unknown if they are road traffic or another mode of transport) has steadily increased but the proportions are small. In 2019, these amounted to less than 3% of transport deaths. The proportion of unintentional injury deaths that are unknown (ie, unknown if they are road traffic or other types of unintentional injury) has declined and was only 2.6% of all unintentional injury deaths in 2019. The proportion of injuries that are not further specified (ie, unknown if they are road traffic or other types of intentional or unintentional injury) shows an

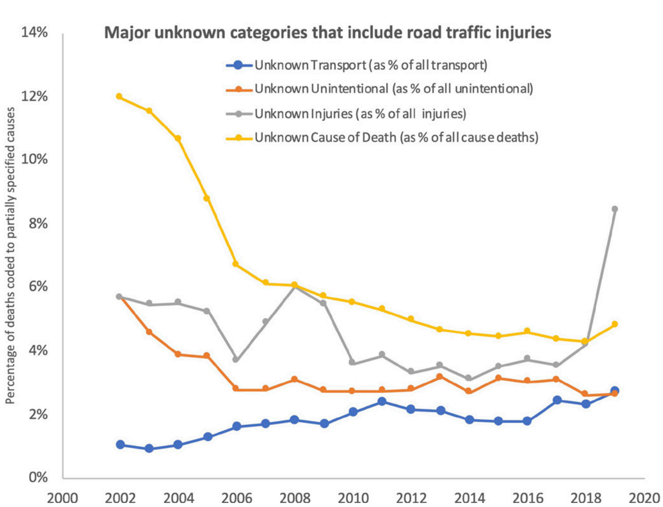


Figure 2 Percentage of deaths coded to partially specified cause categories relevant to estimates of road traffic deaths.

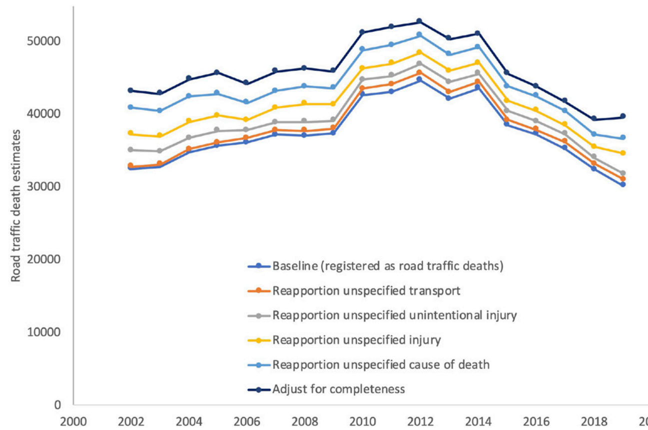


Figure 3 Effect of reapportionment of partially specified causes of death that may include road traffic deaths.

unusual pattern with elevated values in 2008 (6% of all injuries) and a spike (8.4%) in 2019. Almost all the deaths (98%, 11 822 deaths in 2019) coded to this partially specified cause group were coded to ICD-10:Y34 (*Unspecified Event, Undetermined Intent*). Finally, the proportion of deaths coded to the broadest group of unspecified causes (unknown cause of death) has declined from 12% in 2002 to less than 5% in 2019.

Overall, the proportions of deaths coded to each partially specified cause are small compared with the threshold that is typically used to assess the quality of death registration systems.[15] Nevertheless, they have a relatively large cumulative effect on road traffic deaths estimates. Figure 3 shows the incremental effects of the adjustments to account for deaths coded to partially specified causes and completeness of reporting. The effect of reapportioning unspecified transport deaths and unspecified unintentional injuries is relatively small, especially in recent years. The effects of reapportioning the broader partially specified categories, and the adjustment for completeness of death registration, are a bit larger. In total, these adjustments result in an estimate that is 31% higher than deaths specified as road traffic (baseline).

The cumulative effect of these adjustments has not changed significantly over the last two decades. As a result, the fully adjusted estimates have a time trend that is similar to the official statistics (ie, the baseline in figure 3). For instance, official statistics suggest that between 2012 and 2018 road traffic deaths declined by 27%, while our fully adjusted estimate suggests they declined by 25%.

Figure 4 shows that the adjustments bridge much of the gap between official statistics and GBD estimates. Furthermore, our estimates are similar to the deaths reported by insurance claims. However, while our fully adjusted estimates are lower than GBD for the last 5 years (2015–2019), they were higher than GBD for the previous 5 years (2010–2014). Thus, our fully adjusted estimates suggest a sharper decline in traffic deaths in recent years than that estimated by GBD. Figure 5 helps explains this difference in trends predicted by GBD and our estimates. Figure 5 compares how well the GBD-2019 corrected mortality estimates (in red) fit the input death registration (yellow circles). The input data have already been adjusted to account for deaths coded to partially specified deaths and corrected for completeness (ie, the input data shown are equivalent to our fully adjusted estimate). It is evident that the GBD-2019 estimates do not track the rapidly increasing deaths in the underlying data during the late 2000s and the rapidly declining trends in the last decade.

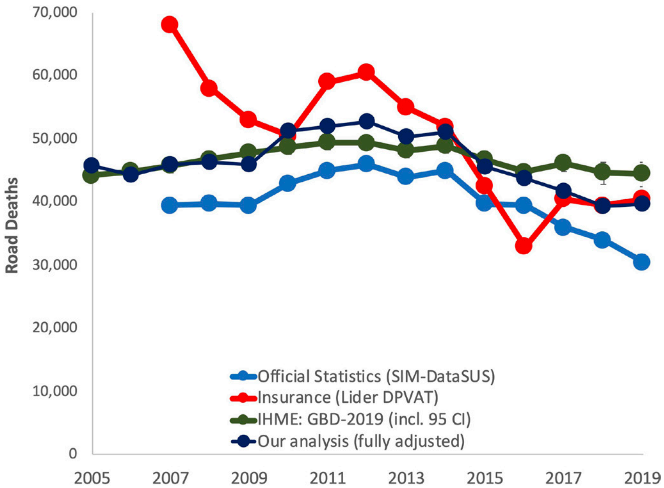


Figure 4 Comparison of our fully adjusted estimate with official statistics, insurance claims and GBD estimates. DPVAT: Danos Pessoais causados por Veículos Automotores de via terrestre; GBD, Global Burden of Disease; IHME, Institute for health metrics and evaluation; SIM, Sistema de Informação sobre Mortalidade.

DISCUSSION

Quality of road traffic injury surveillance in Brazil

Brazil is among the few countries that use vital registration as the source for official road traffic death statistics. This is a serious shortcoming because death registers are poorly suited to provide the information needed for effective road safety management—that is, for identifying risk factors, developing a safety strategy, implementing targeted interventions and evaluating outcomes. In countries with mature road safety programmes, crash-scene investigations by police provide detailed information about crash circumstances, vehicles involved, road environment and behavioural risk factors. However, police-based surveillance in Brazil is highly fragmented with no single database that covers the entire country. Expanding the coverage of the Federal Highway Police database, as recommended by the 2015 National Road Safety Capacity Review by the World Bank,[16] could be an effective solution to a comprehensive and complete national road traffic database.

Until a comprehensive traffic safety surveillance system is established, the national death register (SIM) is an important data source for estimating the scale of the road safety problem and for tracking progress in reducing deaths. Our analysis shows that SIM contains a large number of deaths classified to partially specified causes. Reattributing these deaths results in an estimate that is similar to insurance claims and 31% higher than registered road traffic deaths.

Our analysis assumes that every cause of death is equally likely to be assigned to partially specified causes. We have previously shown[17] that our approach of age, sex-reapportionment is likely the best approach for reattribution if age and sex are the only other information available about these deaths. However, cause of death information may not be missing at random. For instance, Soares Filho[18] suggests that in Brazil deaths in hospitals are often coded to unspecified causes because doctors do not have the prerogative to determine legal causes if a police report is unavailable. Therefore, it is important that future work on improving road traffic injury estimates should include empirical studies that assess the biases in deaths coded to partially specified causes. For instance, Mandacaru *et al*[19] used probabilistic record linkage to link death certificates to police records and hospital records in five cities. They reported that the proportion of traffic deaths missed by SIM varied considerably by city, ranging from 4.2% in Curitiba to 33.5% in Teresina, which is broadly consistent with our estimates, and confirms that under-reporting in official statistics is a significant problem. Extending such work to a nationally representative sample of deaths could provide more insights into under-reporting and the true death toll. Finally, our analysis was conducted with data aggregated at the national level because data at sub-national level were not available to us. However, we expect that there are large differences in quality of coding across provinces, and that replicating our analysis at the province-level will provide more accurate results.

Implications for global road safety efforts

Notably, our analysis confirms that road traffic deaths in Brazil have declined by 25% since 2012, which is close to the decline estimated by official statistics but much more than GBD-2019 estimates. These declines have been driven by strong declines in pedestrian deaths and motor-vehicle occupant deaths (see online supplemental figure A3). This is a remarkable achievement because most LMICs have failed to show meaningful progress during the last decade despite extensive global advocacy.[2 4]

Although assessing what has driven these declines in road traffic injuries was beyond the scope of this study, there are a number of recent and ongoing road safety initiatives that may be resulting in improving road safety in Brazil. Before–after evaluation of the Federal Highway Police's *Rodovida* campaign, which included an enforcement and promotion campaign on federal roads, shows beneficial effects on the risk of serious crashes.[16] Efforts to enforce drink-driving laws in some states have benefited from legislative change that allows police to use behavioural evidence of intoxication for drivers who refuse to take a breath test.[16] There is also increasing attention to improvements to the safety of road infrastructure and the urban built environment, with the state of Bahia committing to a minimum 3-star iRAP safety rating for new and rebuilt roads.[20] Evaluations of the Bloomberg Philanthropies Global Road Safety Programme's activities in Brazil, report improved safety of infrastructure[21] and reduced speeding in Sao Paulo and Fortaleza.[22 23] A high-level evaluation of the effect of these and other interventions on the national and province-level road traffic injury toll can explain what has worked in Brazil and provide guidance to other LMICs.

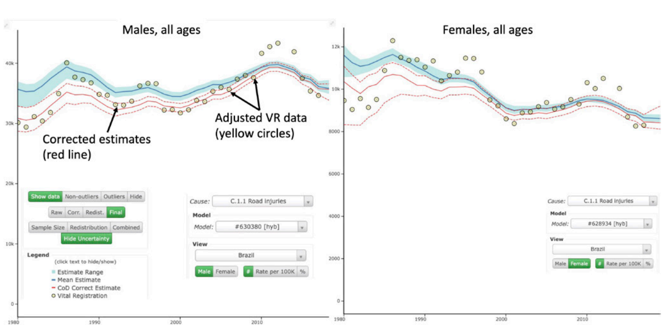


Figure 5 Comparison of the GBD-2019 estimates for Brazil with the adjusted vital registration data used as GBD-2019 model inputs. (These are annotated screenshots of the GBD causes of death visualisation tool, CODVIZ: https://vizhub.healthdata.org/cod/). CoD, causes of death; GBD, Global Burden of Disease; VR, vital registration.

Implications for global modelling efforts

Although the discrepancy between GBD and GHE estimates of traffic deaths in Brazil was not the focus of this study, it is surprising and problematic. In 2019, GBD estimates were 31.5% higher than GHE estimates and the two estimates had non-overlapping uncertainty ranges. Discrepancies between GBD and GHE estimates are understandable in information poor contexts (eg, many parts of sub-Saharan Africa), or when one of the projects incorporates data sources that are not used by the other project. However, both studies use the same underlying data source (national death registration data) for Brazil and conceptually similar methods for estimating road traffic mortality. Furthermore, Brazil's death registration data are considered to be of high quality. IHME rates the quality of Brazil's death registration data at 4 (out of 5) stars, the same rating it gives many Western European countries.[9] Thus, the discrepancy between GBD and GHE in Brazil illustrates that even in countries that have arguably the best health sector data, global health statistical projects (like GBD and GHE) disagree substantially on their point estimates and predicted trends.

Relatedly, our findings raise concerns about GBD's ability to correctly estimate trends in road traffic deaths and monitor progress towards Sustainable Development Goal (SDG) 3.6. While our analysis confirms the declines in national road traffic deaths since 2012 reported in official statistics, GBD estimates are much flatter. We show that the discrepancy arises not from adjustments for completeness and reattribution of partially specified causes, but because GBD's final modelled estimates do not closely track the trends apparent in the (adjusted) underlying data (figure 5). For this step, GBD uses a tool called CODEm (Cause Of Death Ensemble model) that runs a large number of different models (including different statistical approaches, different units of analysis and different choices of covariates) and uses an ensemble of models that perform best in out-of-sample prediction tests.[24 25] CODEm ensures consistency across all cause-specific models by scaling their final total to match all-cause deaths in each age, sex, country and year. While ensemble models have been shown to outperform the best component models for diseases and a range of other fields,[24] we show that in the particular case of road traffic deaths in Brazil, current GBD models do not track the underlying data. We suggest that IHME should invest additional effort to improve the modelling of road traffic deaths, including a focus on better modelling of trends so that GBD estimates can be used to track progress towards the SDGs related to road traffic during the second decade of action for road safety.

Acknowledgements We thank our project advisory group for feedback on preliminary results.

Contributors SM and KB contributed to the study design and jointly led all aspects of the study. SJ and SM initiated the research into the issue. KN, LWM, HG, MW, and RB searched for data sources, reviewed literature and conducted data analysis. KB wrote the first draft of the article. All authors contributed to the discussion and interpretation of the results and to the writing of the manuscript. All authors have read and approved the final manuscript. KB is the guarantor of the manuscript.

Funding This investigation was conducted by researchers from the University of Chicago and the World Bank Global Road Safety Facility and supported by funding from UKAID (Award/Grant Number: 7197082).

Disclaimer UKAID had no role in data analysis, data interpretation or writing of the article. The corresponding author had full access to all the data in the study and had the final responsibility for the decision to submit for publication.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. WHO Mortality Database is available to researchers from https://www.who.int/data/data-collection-tools/who-mortality-database.

ORCID iD

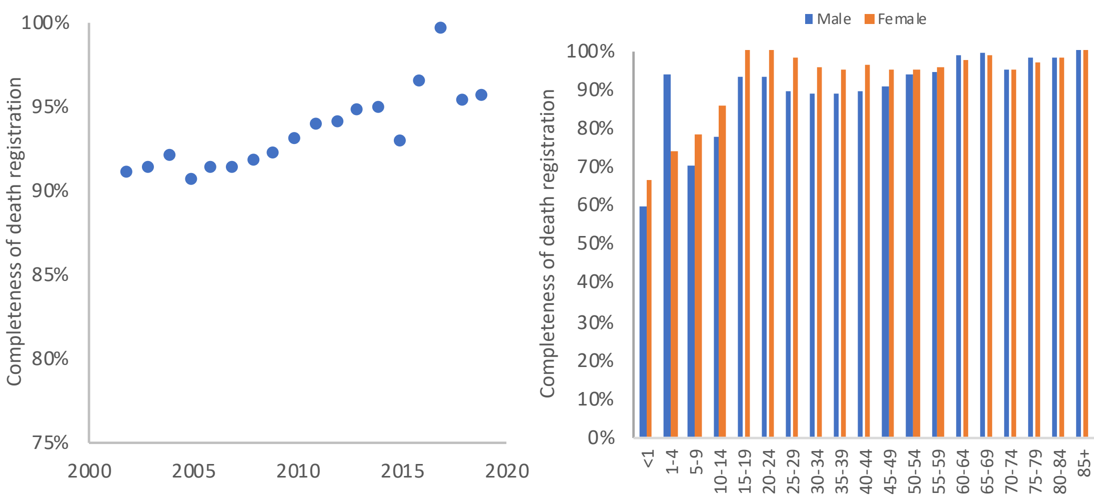
Kavi Bhalla http://orcid.org/0000-0002-6679-7820

REFERENCES

1 Third Global Ministerial Conference on Road Safety. Stockholm declaration: achieving global goals 2030. 2020. Available: https://www.roadsafetysweden.com/about-the-conference/stockholm-declaration/ [Accessed 20 Mar 2021].
2 World Health Organization. *Global plan: decade of action for road safety 2021-2030*. Geneva, Switzerland: World Health Organization, 2021.
3 Brasil Ministério da Saúde. DATASUS-Sistema de Informações Sobre Mortalidade (SIM). DATASUS Tecnologia DA Informação a Serviço do SUS. 2022. Available: http://tabnet.datasus.gov.br/cgi/tabcgi.exe?sim/cnv/ext10uf.def [Accessed 22 Mar 2022].
4 United Nations Road Safety Collaboration. *Global plan for the decade of action for road safety 2011-2020*. Geneva: World Health Organization, 2011. Available: http://www.who.int/roadsafety/decade_of_action/plan/plan_english.pdf
5 Seguradora Lider. Relatorio anual - 2020. 2021. Available: https://www.seguradoralider.com.br/Centro-de-Dados-e-Estatisticas/Relatorio-Anual
6 Baria S. *Shareholders exit Brazil's Líder amid fraud concerns – Folha*. S&P Global Market Intelligence, 2020: 2.
7 World Health Organization. WHO mortality database. 2021. Available: https://www.who.int/data/data-collection-tools/who-mortality-database
8 Bhalla K, Shahraz S, Abraham J, *et al*. *Road injuries in 18 countries*. Cambridge, MA: Department of Global Health and Population, Harvard School of Public Health, 2011.
9 Institute for Health Metrics and Evaluation. Global burden of disease results tool, GBD-2019 revision. n.d. Available: https://vizhub.healthdata.org/gbd-results/
10 United Nations Population Division. World population prospects: the 2021 revision. 2021. Available: https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html
11 Mathers C. Deaths of older children: what do the data tell us? *Lancet Glob Health* 2015;3:e579–80.
12 Mathers CD. History of global burden of disease assessment at the World Health Organization. *Arch Public Health* 2020;78:77.
13 Bhalla K, Harrison JE. GBD-2010 overestimates deaths from road injuries in OECD countries: new methods perform poorly. *Int J Epidemiol* 2015;44:1648–56.
14 Naghavi M, Makela S, Foreman K, *et al*. Algorithms for enhancing public health utility of national causes-of-death data. *Popul Health Metr* 2010;8:9.
15 Bhalla K, Harrison JE, Shahraz S, *et al*. Availability and quality of cause-of-death data for estimating the global burden of injuries. *Bull World Health Organ* 2010;88:831–838C.
16 Job R, Lancelot E, Gauthier G, *et al*. *Federative Republic of Brazil: national road safety capacity review*. Washington D.C: World Bank Global Road Safety Facility, 2015. Available: https://openknowledge.worldbank.org/handle/10986/23811?show=full&locale-attribute=fr
17 Bhalla K, Shahraz S, Naghavi M, *et al*. Estimating the distribution of external causes in hospital data from injury diagnosis. *Accid Anal Prev* 2008;40:1822–9.
18 Soares Filho AM, Bermudez XP, Merchan-Hamann E. Frequency and factors associated with recording deaths due to unspecified external causes in Brazil: a cross-sectional study, 2017. *Epidemiol Serv Saude* 2021;30:e2020452.
19 Mandacaru PMP, Andrade AL, Rocha MS, *et al*. Qualifying information on deaths and serious injuries caused by road traffic in five Brazilian capitals using record linkage. *Accid Anal Prev* 2017;106:392–8.
20 Job R, Lancelot E, Gauthier G. *Brazil State of Bahia road safety management capacity review & multisectorial plan for road safety investments*. Washington D.C: World Bank Global Road Safety Facility, 2015. Available: https://openknowledge.worldbank.org/handle/10986/23811?show=full&locale-attribute=fr
21 Hendrie D, Lyle G, Cameron M. Lives saved in Low- and middle-income countries by road safety initiatives funded by Bloomberg philanthropies and implemented by their partners between 2007–2018. *Int J Environ Res Public Health* 2021;18:11185.

22 Andreuccetti G, Leyton V, Carvalho HB, *et al*. Drink driving and speeding in Sao Paulo, Brazil: empirical cross-sectional study (2015-2018). *BMJ Open* 2019;9:e030294.
23 Global Designing Cities Initiative. Streets for life in Brazil: speed reduction initiatives in Recife and Salvador. 2021. Available: https://globaldesigningcities.org/2021/08/26/brazil-speed-reduction/ [Accessed 17 Jul 2022].
24 Foreman KJ, Lozano R, Lopez AD, *et al*. Modeling causes of death: an integrated approach using codem. *Popul Health Metr* 2012;10:1.
25 James SL, Lucchesi LR, Bisignano C, *et al*. Morbidity and mortality from road injuries: results from the Global Burden of Disease Study 2017. *Inj Prev* 2020;26:i46–56.

Supplementary Appendix



(a) (b)

Figure A1: Proportion of estimated all-cause deaths that are registered (“completeness” of death registration) in Brazil over time, (a), and by age and sex groups in 2019, (b).

Figure A1 shows the completeness of death registration data in Brazil based on IHME’s estimates of all-cause deaths. The estimates suggest that completeness has increased over the last two decades to 95.5% in 2019. Note that this is lower than WHO’s estimate of completeness (98.2% in 2019). The completeness estimates vary substantially by sex and age. In general, completeness is lower among males (except among 1-4 year olds), and children under 15.

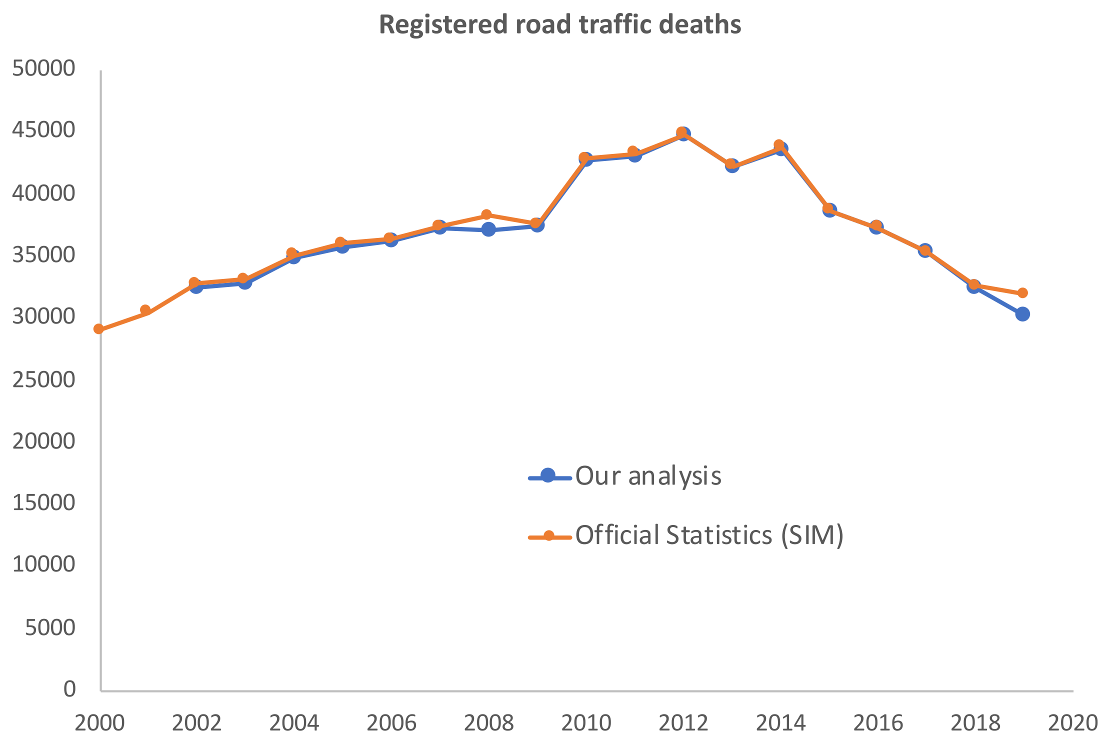


Figure A2: Deaths coded to our case definition (Table 1) of road traffic deaths in the WHOMDB compared with official statistics

Figure A2 illustrates our ability to reconstruct official statistics from the WHOMDB. The figure shows a close correspondence between deaths coded to the fully specified ICD-10 codes for road traffic deaths in the WHOMDB, and the official statistics reported by SIM. Notably, the 2018 GSRRS reported that the official death toll in Brazil for the year 2015 reported was 38,651 deaths, which is the same number that we extracted from SIM. However, our analysis of the WHOMDB found 38,553 deaths that met our case definition. While this discrepancy (0.2%) is negligibly small, we note that Figure 3 shows a larger discrepancy for the years 2008 and 2019, whose source is unclear to us. To some extent, such discrepancies may be attributed to differences in the case definition. For instance, the case definition used in SIM includes deaths due to rail (ICD10:V05, V87). However, the number of cases coded to these ICD10 codes in the WHOMDB was too small to explain the difference.

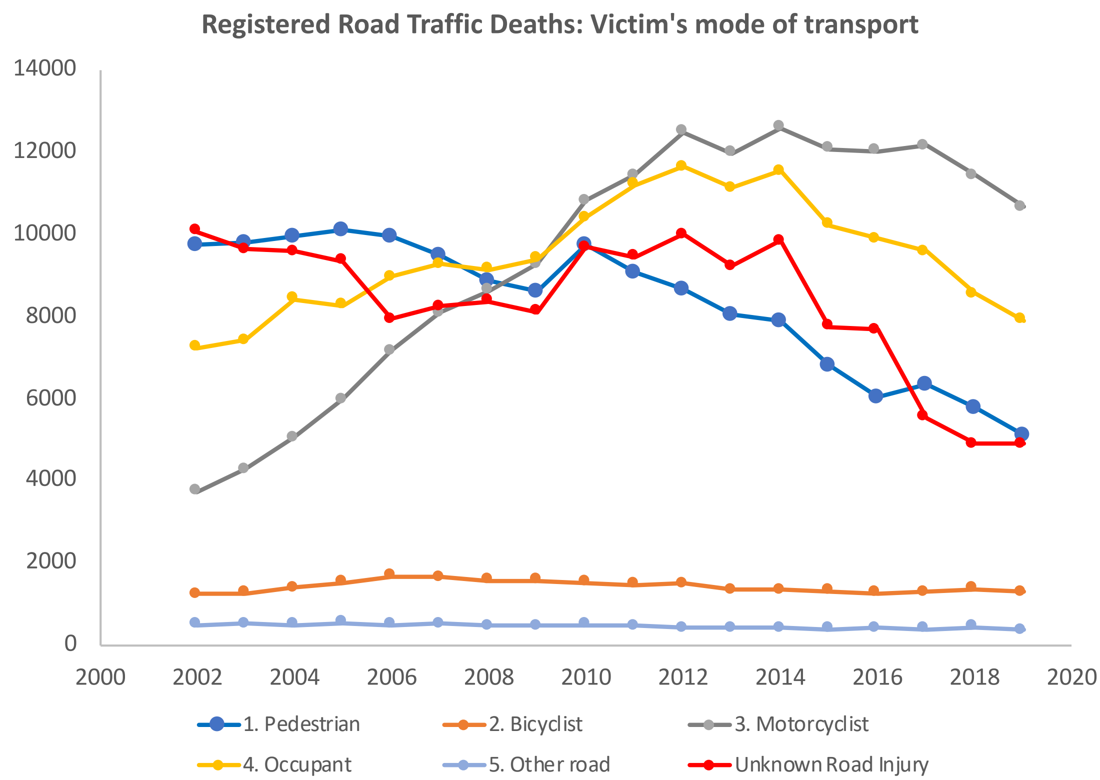


Figure A3: Deaths coded to our case definitions for various road-user categories

Figure A3 shows trends in deaths among different types of road users. These trends (notably, rising motorcyclist deaths and declining pedestrian deaths) are broadly consistent with the reported literature.[16–19] Notably, deaths coded to road traffic injuries where the victim's mode of transport is unknown have been declining starting in 2014. While these accounted for 31% of deaths coded to road traffic in 2002, they only accounted for 16% of such deaths in 2019. Although this is a fairly large proportion of the deaths registered as due to road traffic, these deaths are specified as road traffic deaths, and thus counted in official statistics as road traffic deaths.