Road Safety in Low-Income Countries

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Contents

Executive Summary

This report aims to provide a basis for further in-depth studies in Part 2 of the HVT Applied Research Programme to help improve traffic safety in low-income countries (LICs). To this end, it investigates the state of current knowledge, identifying and targeting the most important problems encountered by these countries, and defines future research directions that help enhance traffic safety effectively, especially given the expected increase in traffic exposure in LICs.

What we have done

This report consists of three main components: (i) analysing and summarising the current state of knowledge through a review of literature considering various topics under the broad heading of traffic safety; (ii) reflections on the outcomes of a survey of a small number of experts in road safety in LICs; and (iii) identifying a number of important existing and emerging issues which could form the future research agenda. The review focused on the following topics: under-reporting; global best practices; vulnerable groups and gender disaggregation; disabilities due to road crashes; economic burden of road crashes; vehicle safety standards and dumping of old vehicles; proactive approaches to road safety; limited data conditions, omitted variables and unobserved heterogeneity; reaching out to other sectors, considering social and behavioural aspects; and capacity limitations of road safety research.

What we have found

Under-reporting of road traffic crashes

Accurate knowledge of road crash rates and causations can help provide robust motives for the investment of appropriate road safety interventions. Police data has been the traditional source of such information, although accuracy of such data is questionable, since all countries suffer from some level of under-reporting. In LICs, this could be due to a lack of knowledge or understanding of the importance of such data for robust future decision making, or a desire to avoid interactions with police and legal systems. A poorly resourced police service could also be a factor, as police officers might only attend or report on major crashes. Relatives and neighbours of crash victims may be deterred from travelling to hospitals due to cost implications. Combining police data with other sources, particularly hospital data, can help provide a better estimate of true crash and injury frequencies, although the results of the literature review have revealed that the number of papers conducting quantitative analyses to

address under-reporting is very low in LICs. However, there are consistencies in methods and results in the four papers identified. Police data tends to account for more fatalities, while injury statistics are likely to be more accurate in hospital records. We also found major limitations in existing methods that are employed to address under-reporting.

Lessons learned from global 'best-practice' and its applicability to LICs

The Sustainable Development Goals (SDG) target 3.6 is to halve road traffic deaths by 2020, and successful cohesive national road safety strategies, campaigns and initiatives in the developed world have been shown to reduce road crashes to a large extent. While some infrastructure and legislative interventions are appropriate for all road networks, there are some challenges and issues involved in improving road safety that are likely to be different in developed countries from those in LICs. Cultural differences may lead to variations in road user behaviour in different jurisdictions, which might affect the magnitude of effectiveness of an intervention, but it would not deter the effect of such interventions entirely. Therefore, lessons can be learnt from successful interventions in developed countries, while understanding that local variations need to be considered.

The Global Plan for the Decade of Action for Road Safety (2011-2020) aims to improve road safety through enforcement of revised legislation particularly in the five key risk factors of speed, drink driving, misuse of motorcycle helmets, seat belts, and child restraints in cars. There is some evidence of a multi-sectoral approach (e.g. in Ethiopia) where improvements in these areas have been achieved. However, as the decade comes to an end, such areas-wide initiatives are limited, and any progress has not occurred at a pace fast enough to compensate for the rising population and rapid motorisation of transport taking place in many parts of the world, suggesting that the SDG target 3.6 will not be met.

Vulnerable groups and gender disaggregation

Travel behaviour and the injury profile of road crashes in LICs differs from that of the developed world, with pedestrians, cyclists and public transport users at particular risk when using dangerous and inappropriate shared road space. However, vulnerable road users often tend to be ignored in urban road design. In LICs, compared to the developed world, there are much larger differences in journey patterns adopted by men and women, affecting their exposure to risk of involvement in road crashes disproportionately. Men tend to have priority access to private vehicles, while women tend to walk or use slower modes of transport, exposing themselves to different levels of injury risk.

Disabilities due to road crashes

Disability due to road crashes is a significant burden in LICs, where medical care and rehabilitation systems are usually insufficient. Unfortunately, accurate data on the number of people who survive road crashes but live with disabilities are almost non-existent, and where such data does exist, there are uncertainties related to methods and definitions, which need to be considered. Various tools and metrics exist to help assess disabilities, but none provide details of the underlying causes of disability, nor estimates of disabilities caused by road crashes. A surprising gap in previous traffic safety research conducted in LICs relates to the lack of studies that aim at analysing and understanding differing injury-severity levels properly.

Economic burden of road crashes

Road crash cost estimates are difficult to obtain, and there are few studies that specifically focus on road crash costing in LICs. Information about the social costs of road crashes is important for evidence-based policy making, providing insight into the consequences of crashes for the economy and social welfare, and informing decision-makers when prioritising investments and selecting the most effective interventions. Tangible costs such as lost productivity (indirect cost) and medical costs (direct costs) can be estimated in economic terms more easily than intangible costs such as pain and suffering. Of the three main approaches used in estimating the cost of road crashes, the “human capital” approach, in which mainly tangible injury costs to individuals are aggregated at societal, regional and national levels is the most common approach used in LMICs. The “willingness-to-pay” approach derives a value of pain and suffering based on the preferred amounts that people would be prepared to pay to live in a world where risks are reduced. The “general equilibrium” approach uses simulation models to estimate costs from a broader macroeconomic perspective, although is as yet untested for injury cost modelling.

Vehicle safety standards and dumping of old vehicles

An emerging problem for road safety in LICs is understanding how modern vehicle safety and technologies such as air bags or crash avoidance systems might affect road user behaviour. Road users may become less vigilant about road safety due to innovations that are designed to improve safety, due to risk compensation. For example, drivers may trade off improved safety for speedier trips. Such effects may be alleviated through awareness raising publicity campaigns to educate and train drivers at the very beginning steps of moving towards advanced vehicle safety features in LICs.

The environmental aspect of dumping old vehicles in LICs has been the focus of a small number of studies. Poor safety standards associated with the older vehicle fleet in LICs increases the propensity and severity of crashes, potentially exacerbated by vehicle modification, poor maintenance standards, inappropriate use (e.g. overloading) and lack of safety enforcement. To our knowledge, scientific studies that investigate safety implications of exporting old vehicles to LICs are non-existent. Policies may be needed to prevent developed countries from dumping vehicles of certain age or category to LICs and to encourage scrappage in LICs (e.g. cash for clunkers).

Proactive approaches to road safety

Traditional methods that help detect, prioritise and treat high crash-risk sites have been based solely on prior crash data, which tends to be of poor quality in LICs, at limited numbers of sites, and with high rates of under-reporting. Additionally, manual data collection is time consuming and costly. New forms of data collection techniques may help overcome these constraints. Data storage and manipulation techniques involving 'big data', derived from remote sensors or video data could allow for a proactive road safety approach that can address safety deficiencies before crashes occur, especially if complemented by traditional, reactive methods. However, applying such approaches in LICs may not be straightforward, due to cost and resource constraints.

Limited data conditions, omitted variables problem, and unobserved heterogeneity

When a crash data set is not large enough, the maximum likelihood estimation is prone to bias; and therefore, the model estimates maybe misleading. This problem can be addressed employing Bayesian methods in which prior knowledge can be included in the analysis in the form of the prior distribution, leading to enhanced statistical inferences. With respect to the omission of risk factors, when important variables that have significant explanatory power are missing from the data, road safety inferences could be biased.

Unobserved heterogeneity is related to the omitted variables problem and leads to spurious road safety inferences. Several risk factors that affect road safety at a site (intersection, road segment, neighbourhood, etc.) are often missing (being unknown or unmeasured) in crash databases causing the unobserved heterogeneity problem. Statistical techniques can be applied to help obtain reliable estimates, but most studies that address the abovementioned issues are conducted in the developed world. Advanced statistical methods can mitigate unobserved heterogeneity and omitted variables problems, and such methods should be applicable to data sets in LICs, but their use in such contexts has so far been limited.

Reaching out to other sectors – social and behavioural aspects

Traditional road safety education and awareness campaigns in high-income settings aim to change attitudes and behaviour, but such an approach may not work across all cultural contexts. Culture is a significant factor in this regard, where religious, mystical, and fatalistic beliefs might affect road user behaviour and disregard for safety measures.

Road transport is a highly complex sociotechnical system, and road safety is not the domain of one actor or group of actors alone, but it is the concern of many entities, at many levels of the system, from the end user to the policy maker. The end user carries the weight of the road traffic injury and fatality burden, but it is generally not the end user that makes safety intervention decisions. Change is beginning to be seen in some high-income countries with acceptance of the ‘safe system’ or ‘vision zero’ philosophy, acknowledging that the end user is fallible, and that the system should be designed in a way to reduce the likelihood of crashes, and reduce the consequences of crashes that happen.

Current capacity for research and practice

Capacity for research and practice in the field of road safety is one of the key recurring issues impeding progress in this area in the context of LICs. Capacity is needed for research as well as planning and implementation of appropriate safety improvement programmes, and any work being done in such settings ought to embed capacity development into it as well as consider how to overcome institutional barriers. Some initiatives have aimed to reduce the burden of road crashes in developing countries by identifying and promoting effective, evidenced-based interventions and supporting research capacity building in road safety research in LMICs. Building on the experience gained from such initiatives, there is a need to develop formal training programs that are readily accessible by individuals residing in LMICs.

Expert survey

Road safety experts were asked to identify topics which were most important to consider for future research in LICs, and two main themes emerged as the most important issues: i) data collection and management techniques, and ii) governance and legislation. Respondents agreed that the complexities of road safety implementation meant that there are unlikely to be any ‘quick wins’, although investigating how governance could be improved and held more accountable could initiate action to improve the impact of road safety interventions in the short term. Further responses suggested that the effective use of increased resources and awareness of global best practice could help provide rapid insight into the priority issues, particularly in respect to the safety of vulnerable road users and the expected growth of traffic in developing countries. Additionally, reviewing current practices could help inform government and other stakeholders of the key issues in their specific location, and highlight where current governance mechanisms can be improved, with the aim of achieving greater political and funding commitments from decision-makers, resulting in better legislation and enforcement.

What we recommend

A number of topics emerge from our analysis of the State of Knowledge review above combined with discussions with experts and stakeholders, which can help form a future research agenda. These topics relate to both empirical and methodological frontiers; and therefore, they will lead to noteworthy improvements in the way road safety research will be conducted in the context of LICs.

Under-reporting of crashes

As a major issue in LICs, research is needed to better understand the causes of under-reporting, and to develop methodological approaches that can better address the issue. Capture-recapture has been shown to be a useful and cost-effective tool to estimate the levels of under-reporting in LICs, and as such could be used by authorities to derive a more reliable measure of road traffic crash rates in their country. However, there are limitations with the capture-recapture approach. We suggest:

- Alternative statistical methods should be examined and/or developed.
- A review of police and hospital data availability in LICs and LMICs should be undertaken in order to understand data availability.

- Development of a general ‘toolkit’ offering guidance and methodologies for the analysis of under-reporting in LICs and LMICs. Such guidance could incorporate minimum data requirements, software tools and reporting templates in order to standardise such reporting in all LICs and LMICs in the future.

Traffic injuries sustained in the crash

Roads safety policies and interventions could be improved given a better understanding of the causes, severities, long term implications and costs to society of disabilities resulting from road crashes. There are inconsistencies in the metrics and methods used to assess injury severities. We suggest:

- Assess the most appropriate metrics for LICs to use in analyses of disabilities (derived in part from the review of road safety and healthcare data suggested above)
- Develop new methodologies for road safety and healthcare practitioners in LICs to understand the trends, societal and economic impacts associated with disabilities resulting from road crashes.
- It may be appropriate to focus such future research on vulnerable groups.

There is a lack of LIC-based research providing greater understanding of differing injury-severity levels properly (i.e. how different factors increase or decrease the likelihood of varying injury-severity levels). We suggest:

- Further research in LICs is needed to understand differing injury-severity levels once a crash occurs. Such studies will help identify factors that increase or decrease injury likelihoods.

Road crash costing

There are limitations in the methods used to apply cost estimates to road crashes in LMICs and in LICs in particular. We suggest:

- Further research should focus on identifying relevant methods of road crash cost estimations or cost-benefit analyses of road safety interventions which would be applicable to provide evidence for investments in LICs.

Characterisations of the vehicle fleet

The introduction of new technologies and safety features could have implications for risk compensation. We suggest:

- Further research is needed to better understand risk compensation issues in LICs to be able to take advantage of emerging safety innovations more fully.
- Explore issues surrounding the second hand vehicle market and how countries that are heavily reliant on imported second hand vehicles can regulate more appropriately.
- Scientific research is needed to quantify road safety implications of dumping old vehicles in LICs.

Challenges of data collection and analysis

Many of the issues pertinent to this study relate to the challenges of data collection, management and analysis. While it may be possible to draw on experiences of global good practice, it may also be relevant to develop specific methods and analysis techniques that apply in the LIC-context. The following four sections discuss these issues in greater detail.

Expected increase in traffic volume and its implications

As traffic volume (and consequently exposure) increases, road safety deteriorates, but this relationship is not linear and varies from one jurisdiction to another. It is important to quantify the rate of deterioration in road safety as traffic exposure increases; and consequently, investigate how we can reduce this rate. We suggest:

- Using advanced statistical methods with limited data to better understand the deterioration rate in road safety as traffic exposure increases.
- Further research is needed to understand the relationship between road safety and traffic exposure in LICs, enabled by developing a series of safety performance functions for different road infrastructures in LICs. These functions are used to quantify road safety, to understand factors affecting safety, and to identify hazardous locations that should then be prioritised for safety improvement programs.

Accounting for data-related limitations and unobserved heterogeneity

Crash data in LICs tends to be lacking or when it exists, it is often limited, whether in form of limited sample size and/or risk factors available in the data. The number of road safety studies conducted in LICs is limited, and rarely do those studies employ rigorous road safety and statistical techniques to address the aforementioned issues properly. We suggest:

- Build on research work in this area, and develop statistical methods, especially those applicable to LIC-contexts, and help provide more robust analysis of road safety data.

Feasibility of proactive approaches to road safety in LICs

Building on the successful experience of developed countries in implementing successful road safety interventions and programmes (while considering resource and cost constraints applicable to LIC-contexts), it would be possible to adapt proactive methods in LICs to optimise their benefits with a minimum cost. We suggest:

- Develop a range of feasibility studies to extend the knowledge base to LICs.
- Initially focus on monitoring a limited number of road infrastructures, which extend the knowledge base and allow for designing tailored safety improvements transferable to other similar locations within each jurisdiction.

Alternative low-cost approaches to obtain data

A valuable and cost-effective solution to limited data issues (especially given the expected increase in traffic exposure) could be based on using street imagery. It is possible to estimate travel patterns and/or traffic exposure by different modes of transport and/or road user through non-traditional data collection techniques. We suggest:

- Investigate how these methods could be employed to collect relevant data and improve safety in LICs.

Social and behavioural approaches to road safety

The majority of road safety research is performed in high-income countries; hence, the majority of methods are biased towards these settings. Cultural, attitudinal and behavioural differences mean that such approaches may not be appropriate in low-income contexts. As such, there is a strong requirement for research methods and assessment of interventions developed in low income settings. We suggest:

- More in-depth research on the social and behavioural factors that influence road safety in low-income settings.
- Embed sociotechnical systems thinking in crash analyses, and in road transport policy, planning, and construction. The design of road safety interventions should be done

based on a good understanding of the context of application and a consideration of all the factors that influence outcomes.

How to build sustainable capacity effectively and timely?

Two of the future road safety challenges identified by the World Health Organization are 'Building Capacity' and 'Strengthening Data Collection', and effective training programmes could help improve both of these aspects of road safety. We suggest:

- Encourage capacity building by systematically identifying and/or defining the most cost-effective and sustainable strategies that can be in place in a timely fashion.

1. Introduction

Road safety is a major global health issue since large proportions of unintentional injuries are caused by traffic-related crashes. According to the Global Health Observatory, 1.35 million fatalities occur on the world's roads each year (World Health Organization 2018). In general, in both high-income countries (HICs) and low- and lower-middle income countries (LMICs), although traffic-related injuries and fatalities have seen a slowly decreasing trend during the past two decades, this reduction has not been as significant as expected (Mannering *et al.* 2016). This is despite several improvements in motor vehicle safety standards and features, road safety policies, and road design (Mannering *et al.* 2016). In fact, road transport still poses a substantial risk to human health in many regions around the world.

The problem is especially critical in low-income countries (LICs), due to several persisting shortcomings in road safety standards, vehicle safety and maintenance, and in the design and implementation of policies and safe transportation infrastructure. Figure 1 displays national wealth versus road death rate based on the data provided by the WHO (World Health Organization 2018). Research is thus needed to better understand the underlying mechanisms of road safety in LICs. This will help guide road safety policies and strategies, with the aim of reducing traffic-related injuries and fatalities. Note that we refer to LMICs to indicate low- and lower-middle income countries, while LICs refer specifically to low-income countries, as shown in Figure 1.

In most countries including developed ones, a significant decreasing trend is not observed despite several improvements in motor vehicle safety standards/features, traffic safety policies, and road design (Mannering *et al.* 2016). The problem is critical (very high rate of traffic related fatalities and injuries) in the low-income context due to several persisting shortcomings in traffic safety standards (e.g., vehicle safety) and in the design and implementation of policies and safe transportation infrastructure. Research is thus needed to better understand the underlying mechanisms of traffic safety, especially in LICs. This will help guide traffic safety policies and strategies, with the aim of reducing traffic-related injuries and fatalities.

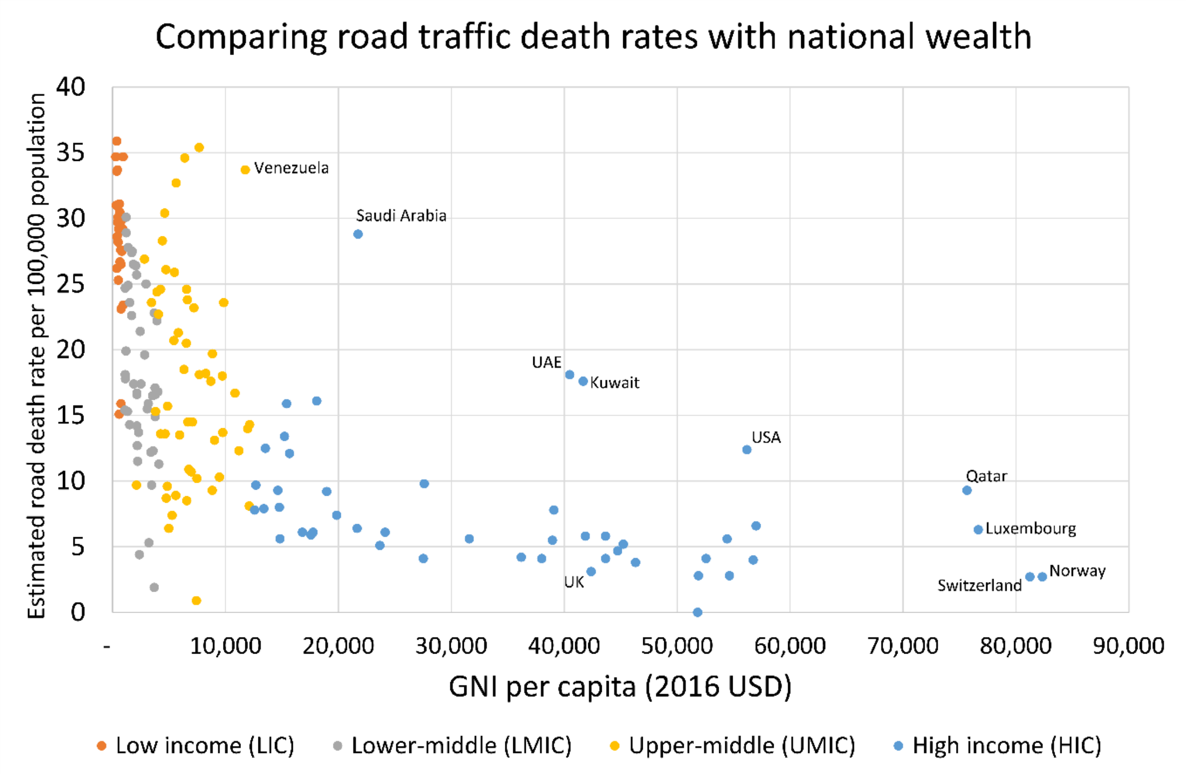

Figure 1: Comparing road traffic death rates with national wealth (World Health Organization 2018 Table A2)

There are global initiatives that have sought to address such issues, many of which are coordinated through the Global Plan for the Decade of Action for Road Safety 2011-2020 (World Health Organization 2011), developed by the United Nations Road Safety Collaboration (UNRSC). Examples include the Global Road Safety Partnership (GRSP) (Global Road Safety Partnership 2016), the World Bank's Global Road Safety Facility (World Bank 2018), the Bloomberg Philanthropies Initiative for Global Road Safety (Bloomberg Philanthropies 2019), and the Road Safety in 10 Countries Project (Hyder *et al.* 2013). These global efforts have generally focused on the practical implementation of policies and standards to improve road safety in the developing world (Hyder *et al.* 2017). Little attention, however, has been applied to the evidence-base and research knowledge upon which future directions of road safety research can be established.

The current project – road safety in LICs – is part of the applied research programme in high volume transport (HVT), complementing three existing on-going projects at the University of Southampton (UoS): Metamorphosis EU, the Global Road Safety Research Centre's STARS (Socio-Economic Assessment of Road Safety), and Metamorphosis Global. The Metamorphosis EU project (www.metamorphosis-project.eu) focuses on transforming the urban street environment in a child-friendly way, through innovations in development, design, governance and planning procedures. The aim is to promote behavioural change among all road users, while promoting mobility of vulnerable road users, particularly children (Metamorphosis Consortium 2017). The STARS project is demonstrating how socio-technical approaches can also improve road safety in Low/Middle-Income Countries (L/MICs) (Plant *et al.* 2018), taking a collaborative approach between a consortium of four LMICs (Bangladesh, China, Kenya and Vietnam) and UoS. Building on the traditional '3 Es' approach – Engineering, Enforcement and Education – the STARS project aims to tackle road safety from a '7 Es' perspective, with the inclusion of Economics, Emergency response, Enablement, and the overarching 'E' of Ergonomics, i.e. applying contemporary socio-technical systems methods to develop systemic solutions to the seemingly intractable problem of road safety.

The Metamorphosis Global project (metamorphosis-global.org) builds on the work of Metamorphosis EU and STARS, as a collaboration between the UoS and Bangladesh University of Engineering and Technology (BUET). It is part of the High Volume Transport (HVT) Applied Research Programme in Transport – Technology Research Innovation for International Development (T-TRIID). This collaboration will produce an online toolkit that will assist L/MICs in redesigning urban environments, particularly around schools. This toolkit will incorporate a series of case study initiatives which could potentially be applied in Bangladesh, including a locally 'worked example' (or examples) to be undertaken as part of the project, as well as further practical guidance on how to design child-friendly streets and neighbourhoods as taken from existing 'best practice' in other countries. The toolkit and associated measures suggested by Metamorphosis Global are designed to provide local health and other associated benefits by reducing road crashes, improving the urban environment, stimulating local economic development and enhancing social inclusion, whilst protecting the most vulnerable.

While the aforementioned ongoing projects at UoS mainly focus on specific areas of research within the context of road safety, our study complements these projects by taking a holistic approach that investigates different lines of research under the broad topic of traffic safety. Despite the on-going projects, our study is centred exclusively on traffic safety issues in LICs. Moreover, there is a focus on understanding of engineering issues since this is emphasized in the Request for Proposal. The general objective of our research is to help improve road safety in LICs, identifying and targeting the most important problems encountered by these countries and defining future research directions that help enhance safety effectively given the expected increase in traffic exposure in LICs. To this end, the current study is mainly centred on areas not covered by the on-going projects although some level of overlapping is inevitable.

Our study takes a holistic approach, investigating different lines of research under the broad topic of road safety in LICs with the aim of (i) analysing and summarising the current state of knowledge; and (ii) identifying a number of future research directions. There is a focus on understanding of road safety engineering issues while reaching out other sectors. The review identified studies related to ten focus areas: (i) under-reporting of road crashes in LICs; (ii) lessons learned from global best practices; (iii) vulnerable groups and gender disaggregation; (iv) disabilities due to road crashes; (v) economic burden of road crashes; (vi) vehicle safety standards and dumping of old vehicles; (vii) proactive approaches to road safety; (viii) limited data conditions, omitted variables and unobserved heterogeneity; (ix) reaching out to other sectors, considering social and behavioural aspects; and (x) capacity limitations of road safety research.

The report is structured as follows: Section 2 discusses our methodology. Section 3 is centred on an overview of current (available) research focusing on the main road safety issues in LICs. In Section 4, we report on the results of a survey of experts in road safety in LICs. Section 5 introduces and discusses future directions, where there are several opportunities for improvements, both empirically and methodologically. We conclude with a summary in Section 6.

2. Methods

This paper explores the state of knowledge of road safety in LICs, based largely on a review of literature, in combination with informal consultation with experts and stakeholders. For the review, while there was no search restriction on the publication date, articles published before 1990 were only considered for inclusion if the number of relevant results was particularly low. The search strategy (see Section 3.1.1. for 'Under-reporting', Appendix 1 otherwise) aimed to limit the search to LICs by combining search results from a list of names of LICs with other relevant keywords applicable to other search topics such as vehicles and crashes, road safety measures, vehicle safety measures or vulnerable road user groups. Articles had to be peer-reviewed and published in English. Articles were screened by title and abstract for relevance, and appropriate bibliographies were also scanned for further relevant articles or reports. The search resulted in over 7,000 potential articles to be screened across all the topics under consideration.

Further relevant documents published in peer-reviewed and non-peer-reviewed formats (mostly journal article and reports published by international organisations) were identified through online searches using appropriate keywords for each of the topics, and from discussions with experts and stakeholders. Many of the experts were informally consulted during the review, while a smaller number of experts were approached to respond to a survey to assess the important topics of road safety research in LICs. The outcomes from the survey and other discussions also provided context for topics for which literature is unlikely to be available, but which helps provide the background to the future research agenda set out in Section 5.

3. State of knowledge

3.1 Under-reporting of road crashes in LICs

There are many reasons why it is important to quantify traffic safety accurately in a country or region. As detailed in 'Reporting on serious road traffic casualties' (IRTAD 2011), knowledge and understanding of road crash rates and causations can help to develop and support robust arguments for the adoption of road safety interventions, especially when there are limited funds available in LICs for implementing countermeasures that aim at reducing crash frequencies and injuries. Where such funds are available, it is important to be able to deploy interventions where they are likely to have the greatest benefit, targeting particular road user groups, area types (i.e. rural/urban) or road types.

Traditionally, police road crash data has been the primary source of road safety analysis in both developed nations and low- and middle-income countries. However, it is acknowledged that road traffic crashes and injuries are commonly under-reported in official records. This is especially true in lower income countries but is also common in higher income countries. The WHO provide estimates of the numbers of fatalities in each country, using negative binomial modelling based on the actual number of reported fatalities (World Health Organization 2018). According to their estimates, the average number of road fatalities correctly reported to official sources is likely to be higher for higher income countries, with an average of 88% of road fatalities correctly reported in high income countries (HICs) and 77% in middle-income countries (MICs). However, this reporting accuracy is significantly lower in LMICs (52%) and LICs (17%).

Many studies have investigated these issues and offered insight into alternative approaches to road crash investigation, such as linking road traffic crash data from police databases with hospital records of patients admitted as a result of road crashes. For example, Emanuelle Amoros and her colleagues have developed a series of papers aiming to understand how the French road crash recording system can be improved (Amoros *et al.* 2006, 2007, 2008, 2018). There are examples of similar studies undertaken through the developed world elsewhere in Europe (Bauer *et al.* 2018; Broughton *et al.* 2010; Chini *et al.* 2009; Ferrando *et al.* 1999; Reurings & Stipdonk 2011; Ward *et al.* 2006; Yannis *et al.* 2014), the United States (Conderino *et al.* 2017; Sciortino *et al.* 2005), Australia and New Zealand (Alsop & Langley 2001; Cercarelli *et al.* 1996; Lujic *et al.* 2008; Meuleners *et al.* 2006; Rosman 2001; Watson *et al.* 2015), and China and Japan (Ma *et al.* 2012; Nakahara & Wakai 2001). A limited number of studies have also been undertaken in low- and middle-income countries, which is the focus of the subsequent sections.

The under-reporting of road crashes has important implications for policy makers, who often rely on crash data to provide an overview and insight into road safety related issues. In order to estimate the magnitude of under-reporting evident in traffic police and hospital registries in LICs, we carried out a literature review of relevant papers.

3.1.1 Search strategy and results

The following section gives the outcomes of the literature search undertaken using a range of bibliographic databases including Scopus, Web of Science, TRID, PUBMED, BMC, SafetyLit, EMBASE, and Lilac. Quantitative results were specifically sought for under-reporting, and the literature search for that topic was carried out in February 2019. These searches resulted in a number of academic peer-reviewed journal papers, which were subsequently assessed for relevance according to PRISMA guidelines (Moher *et al.* 2015; Shamseer *et al.* 2015). Further appropriate documentation has been revealed through searches undertaken using Google Scholar, and by reviewing reference lists within relevant papers and reports. Further to this, documents, databases and reports published in non-peer reviewed formats were identified, providing other useful data and information on the topics particularly relevant for LICs.

Eligibility Criteria

The primary criteria for article consideration was qualitative evaluation of under-reporting in LICs (according to the World Health Organization). To be included, articles had to be related to an assessment of under-reporting using either capture-recapture or other methodologies. As the number of eligible papers was relatively few, there was no restriction on whether the assessment was for injury/fatality counts, nor any restriction on date. Articles had to be peer-reviewed and published in English.

Search terms and results

The following is an example of the typical search string used to generate search results: ((underreport* OR under-report* OR capture-recapture) AND (low-income OR road accident OR traffic accident OR road crash OR traffic crash)).

Through the database search, 936 articles were initially identified which yielded 4 final articles that fit the inclusion/exclusion criteria, as shown in the PRISMA[1] flow diagram (Figure 2). The four studies were all from LICs in Africa (Ethiopia, Uganda, Malawi and Mali), and each carried out a quantitative assessment of the level of under-reporting comparing police data with those of hospital records.

[1] PRISMA (www.prisma-statement.org) - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

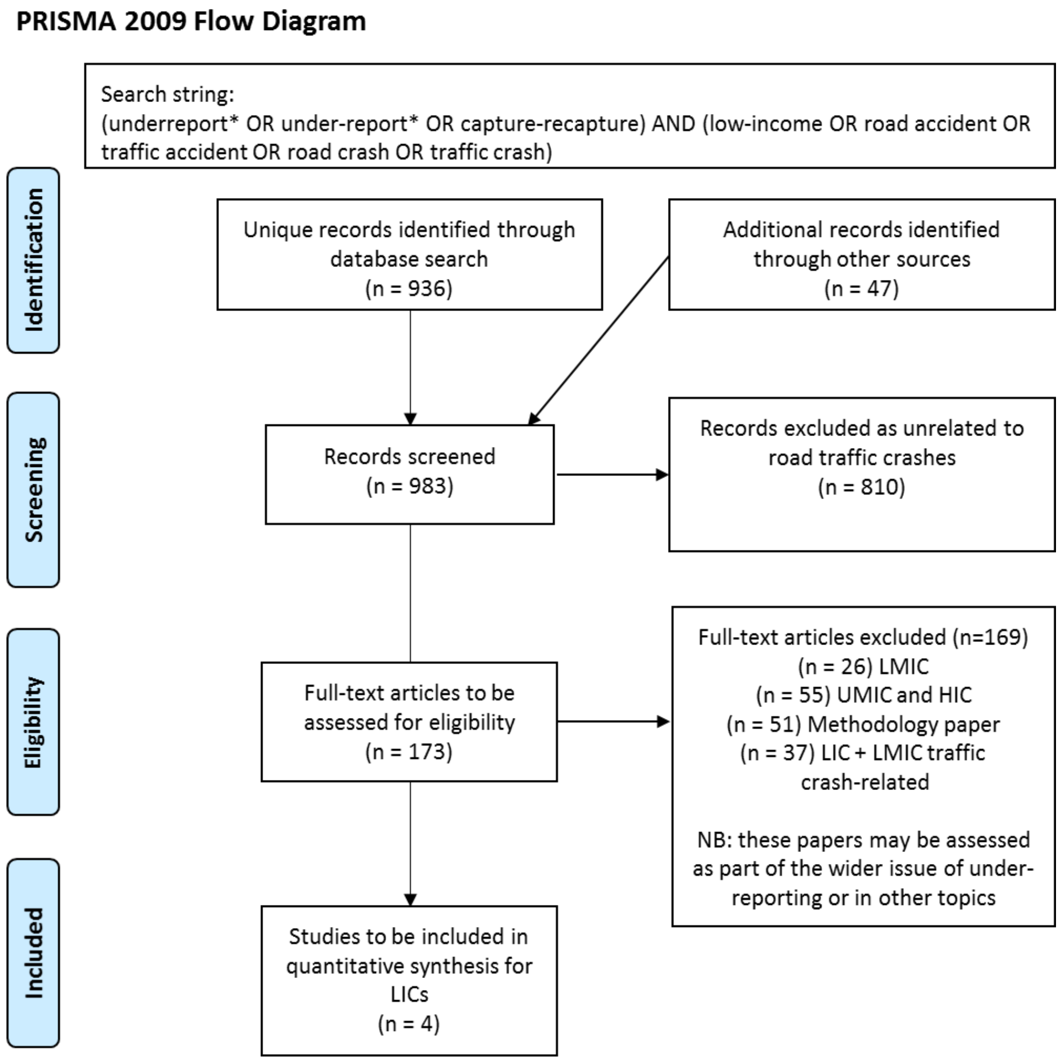

Figure 2: PRISMA flow diagram for Under-reporting literature search

Table 1 gives a summary of the selected papers, showing location, study period, methodologies and metrics used. Note that two of the studies assessed road crashes over a year, while the others assessed a shorter time period; therefore, seasonal variability may affect reporting and road crash prevalence in these studies.

The study in Ethiopia (Abegaz *et al.* 2014b) is the only one which directly relates to High Volume Transport. The data collection focuses on a 264 km stretch of two-way, two-lane road, with traffic volumes varying from an average 17,000-20,000 vehicles per day travelling on the 64 km stretch near Addis Ababa, with the remaining 200 km averaging around 3,000-3,500 vehicles per day as the road approaches Hawassa. The other studies focus on regional areas (adopting a zone- or macro-level approach), considering the records at police offices and hospitals within a certain region.

Table 1: Summary characteristics of selected studies

Author	Location	Study period	Method used	Metric used
Abegaz et al. (2014b)	Ethiopia 264km major highway	Jun 2013 – May 2014 (12 months)	Capture-recapture – two-source	Fatalities/injuries per billion vehicle km
Magoola et al. (2018)	Uganda Jinja municipality	Mar 2014 – Apr 2014 (2 months)	Capture-recapture – two-source	Number of road traffic injuries (RTIs)
Samuel et al. (2012)	Malawi Lilongwe district	Jul 2008 – Jun 2009 (12 months)	Capture-recapture – two-source	Number of fatalities Mortality incidence (fatalities/1000 person-years)
Sango et al. (2016)	Mali Bamako district	Jan 2012 – Apr 2012 (4 months)	Capture-recapture – two-source	Number of fatalities; Number of records; Incidence per 100,000 people

3.1.2 Capture-recapture method

The four LIC papers under review all use the capture-recapture two-source method to help determine a more accurate estimate of the true number of road crashes and injuries. 'Capture-recapture' is possibly the most widely used method to rectify inaccuracies in road crash reporting (Ahmed *et al.* 2017), but was originally developed for use in estimating the biometrics of animal populations and has subsequently been applied to human populations and the injury field (as discussed for example in Morrison & Stone 2000). The method involves estimating the number of cases in a defined population using multiple sources of information (e.g. linked databases), assuming that each source alone may under-count the population.

Magoola et al. (2018) note that using the two-source method "could improve data quality and accuracy, and reduce under-reporting of RTIs" (road traffic injuries). While it is a useful (and relatively low-cost) tool for road crash investigators, especially in lower-income countries where under-reporting may be more prevalent, there are certain caveats to understand regarding its use. As discussed in van Hest et al. (2011), there is a strong possibility of violating some of the underlying assumptions. For instance, when linking data from police and hospital records, there may be insufficient reliable identifiers for perfect record linkage. As shown in Table 2, the identifiers used in the four relevant papers were not consistent:

- Abegaz et al. used four key identifier variables; name of the victim, gender, place and date of the road crashes, and they assumed a match had been found when three of these identifiers were identical.
- Magoola et al. adopted a two-tier matching approach, 'low restrictive' which used date, place, time, day, type of crash and road user type; and the 'high restrictive' (more specific) matching standard with date, place, time and type of crash, road user type and sex of the injured party. Casualties were considered matched if they included all selected variables in both datasets.
- Samuel et al. considered a match to have been made when gender, age (within five years), injury mechanism, location, and time (within three hours) matched, with one missing variable allowed as long as the other parameters were met.
- Sango et al used an automated probabilistic matching process, attributing scores corresponding to the weighted variables of locational and personal data

There is no consistent method used to determine matching records, but this may be due to the availability of records and methods used to collect the data. Other potential problems revolve around the populations in the study. Capture-recapture techniques require closed populations (i.e. no migration), which is unlikely to be the case for a district or region, and there is an assumption that the likelihood of an individual being included in any particular source should be equal, which is again unlikely in road traffic crashes where more young men are involved than other person types.

Data sources should also be independent. However, dependence can result from co-operation between the agencies that keep the different registrations, exchange of information or referral of patients. In two-source capture-recapture analysis, this assumption is crucial because it is difficult to check independence mathematically and researchers must make the judgement intuitively (van Hest *et al.* 2011).

Table 2: Criteria for data linkage in selected studies

Author	Variables used for data linkage matching	Matching requirements
Abegaz et al. (2014b)	Name; gender; date; location	Three of four variables constituted a match:
Magoola et al. (2018)	Low restrictive: Date; location; time; day; crash type; road user type High restrictive: Date; location; time; crash type; road user type; gender	All variables must match
Samuel et al. (2012)	Gender; age (+/- 5 yrs); injury mechanism; location; time (+/- 3 hrs)	Four out of five variables constituted a match
Sango et al. (2016)	Date; time; age; gender; name; place of discharge; district; road user type	Automated probabilistic matching process

All the studies aim to address the bias introduced by this lack of independence by using a stratified capture-recapture technique to identify those factors that were associated with dependency of the data sources. There are other statistical techniques which may also apply to these data, such as multi-variate regression analyses, which avoid such biases, as discussed below.

3.1.3 Quantitative results

The four papers selected for review were the only ones that specifically provided quantitative results on the estimated accuracy of the police and hospital records in LICs. Since the metrics used were not consistent across the papers, the following analysis considers how accurate (in percentage terms) both the police and hospital records are. The accuracy rate is obtained by considering the main metric used in a particular study (e.g. number of fatalities, or injuries per 100,000 vehicle km), and comparing police and hospital results with those generated by the capture-recapture method. The results are shown in Table 3, which also shows the limits of confidence intervals as an indication of the uncertainties involved using the capture-recapture method.

Table 3: Accuracy rates of police and hospital records compared with capture-recapture estimates for LICs (with associated 95% confidence intervals)

	Police	**Hospital**	**Police**	**Hospital**	**Police**	**Hospital**
	Fatalities		**Injuries**		**Crashes**	
Ethiopia	59.2% (57.4-60.9)	32.5% (31.5-33.4)	23.7% (23.5-23.9)	55.6% (55.2-56.0)	n/a	n/a
Uganda	n/a	n/a	14.4% (13.1-16.5)	60.4% (55.1-65.2)	n/a	n/a
Malawi	37.6% (30.9-48.0)	25.5% (21.0-32.6)	n/a	n/a	n/a	n/a
Mali	57.6% (50.4-67.9)	54.5% (47.8-64.2)	n/a	n/a	16.8% (15.9-17.8)	42.1% (39.9-44.6)

As these figures show, there are some patterns evident in these results. Police records tend to account for more fatalities than hospital records, while hospitals tend to have more complete records of injuries caused by road crashes. However, neither set of records has a complete record of the numbers of fatalities or injuries. The results from Ethiopia and Mali indicate that the police records contain around 60% of the total fatalities, and hospital records seem to account for between 40 and 60% of injuries or road crash numbers.

Several reasons are offered to explain the under-reporting evident from these results. There is a lack of knowledge and understanding among those involved regarding the usefulness and benefit to society of complete and accurate road crash records (Magoola *et al.* 2018), and the importance therefore of ensuring police are aware of all road crashes to enable further investigation. For non-fatal pedestrian crashes (especially if the pedestrian is among the poorer socio-economic group), this is exacerbated by a perception that if a road crash is not serious, police and subsequent legal involvement is something to be avoided (Magoola *et al.* 2018), so there are likely to be negotiations with the driver rather than reporting to official sources (Abegaz *et al.* 2014b; Dandona *et al.* 2008). Also, where non-fatal road crashes occur in built-up areas, victims are likely to be taken to a nearby hospital by relatives or bystanders before any police officers can attend the crash scene (Abegaz *et al.* 2014b; Bhatti *et al.* 2011; Magoola *et al.* 2018), especially given the limited capacity of the police to be able to provide sufficient regional coverage for road crash attendance.

This lack of capacity of the police may also result in fewer road crashes being recorded, as they are likely to focus on those crashes that involve more injuries, fatalities or property damage (Bhatti *et al.* 2011; Magoola *et al.* 2018; Samuel *et al.* 2012). Also, police do not record details of all non-fatal crashes partly because the legal requirement to report road crashes to the police varies from country to country (Bonnet *et al.* 2017). There are further limitations due to the reliance on paper records, rather than electronic recording systems in place in higher income countries (Bonnet *et al.* 2017), especially if such original paperwork is required for subsequent judicial hearings (Patel *et al.* 2016).

The lack of reporting of fatal road crashes to hospitals could be explained by poor community awareness on the importance of medical evidence, particularly when the road crash occurred in rural areas (Abegaz *et al.* 2014b). Another challenge may be the transportation cost of the body to and from a health facility, especially if the crash happened on rural road and if the victims were pedestrians (Abegaz *et al.* 2014b). Also, there are differences between police and hospital data collection in terms of when a fatality becomes recorded as a result of a road traffic crash. Some hospitals only record such if the death occurs within seven days of arrival, while others (in Vietnam, for instance) could do so up to 30 days after treatment (Duc *et al.* 2011). To be able to make LMICs more comparable and allow them to learn lessons from each other, it is imperative to move towards a unified system that will be beneficial to all countries.

The authors of the abovementioned four papers all recognise the capture-recapture technique as a useful method of revealing the true number road crashes and injuries. They suggest using the method further, although with an acknowledgement that current reporting systems for both police and hospitals should be strengthened to provide more robust databases in the future. Also, additional sources of information could be utilised, including mortuary and insurance data where applicable.

As discussed above, there are limitations to the capture-recapture method that may lead to biased statistical inferences. Ahmed et al. (Ahmed *et al.* 2017) carried out a review of techniques used to estimate the errors in reporting and recording of road traffic crashes. In their study, two of the twelve papers identified using capture-recapture were in LICs, and are covered in detail above. Other techniques identified, which are linked with the capture-recapture methodology, include comparison with health service data, probabilistic linkage of matched records and cross-sectional population-based surveys.

3.1.4 Using regression analysis in the assessment of under-reporting

Given the limitations associated with capture-recapture methods, other studies have used multi-variate regression analyses in order to estimate the levels of under-reporting. This technique is useful if the two-source approach used in capture-recapture is not appropriate or feasible. For instance, the World Health Organization's estimates of road crash numbers (World Health Organization 2018) are modelled using negative binomial regression, depending on the quality of the original death registration data and population size.

Regression analysis has been used to model under-reporting of road crashes in a number of studies, but none are related to LICs. For instance, in New Zealand, Alsop and Langley (2001) define a "reporting rate" as the number of linked hospital records divided by the total number of hospital records, and use a multivariate stepwise logistic regression to examine differences in reporting rates between groups within factors (such as road user type, age, third party involvement, region, month), while simultaneously controlling for all other factors.

Amoros et al. (2006) apply a modified Poisson regression to estimate the probabilities of road crashes being reported to the police in France. The model variables include injury severity, age, gender, road user type, third party involvement, light conditions, road type, crash environment, police force area and calendar year. Similar approaches have been used in India (Dandona *et al.* 2008), the United States (Sciortino *et al.* 2005) and Australia (Watson *et al.* 2015). While previous studies employing regression provide useful insight, they are limited due to the use of simplistic regression models. More advanced regression techniques are shown to be able to draw a fuller picture, revealing the underlying structure of crash data more adequately compared to conventional regression methods. Thus, other statistical techniques such as Bayesian methods should also be examined in order to provide the best estimates of under-reporting (and their associated uncertainties) in LICs, given the potentially limited data available. Note that the Bayesian approach is known for its ability to properly estimate uncertainties and to obtain reliable estimates under limited data conditions. However, its use has been very limited or non-existent in the context of under-reporting in road safety research. We therefore recommend investigating Bayesian methods in addressing under-reporting issues.

3.2 Lessons learned from global 'best practice' and its applicability to LICs

The study aims to draw on the experience of successful road safety campaigns around the world while taking into account social aspects associated with successful campaigns. With respect to successful road safety campaigns, for example, Wegman (2017) identifies Spain in particular as an exemplar of success in road safety practice, as the number of fatalities there has decreased by over 70% between 2000 and 2013, with neighbours Portugal close behind.

According to the Spanish Government's Traffic Directorate report on their road safety strategy (Traffic General Directorate 2010), Spain's improved safety level in the 2000's stemmed from their adoption of the European Road Safety Strategy in 2000, followed by the increased use of in-car safety systems, the increased use of helmets (from 73% to 99%), the increased use of seat belts (from 70% to 91%), and reduced risks from slower average speeds (reduced by 2km/h) and a downward trend in drink-driving (the percentage of drivers who died when over the limit of 0.3g/l fell from 35% to 29%).

The change in road user behaviour is coupled with improved infrastructures and vehicle technologies and safety features. The Spanish Road Safety Strategy 2011-2020 aimed to increase the scope of road safety work and to continue working to coordinate actions and governance of road safety. As the figures for 2010 to 2015 indicate, there has been continued progress, although there may be an upsurge in traffic crashes in 2018 (see for example https://www.thelocal.es/20180905/spanish-roads-see-surge-in-traffic-fatalities-on-spanish-this-summer), possibly partly due to more incidences of driver distraction due to mobile phone use while at the wheel.

The Spanish experience is one example of how a cohesive national road safety strategy may result in significant reductions in road crashes. However, as a developed country, the challenges and issues involved in improving road safety are likely to be different from those in LICs (Wang *et al.* 2013). Nevertheless, road user behaviour, infrastructure improvements and appropriate legislation are to a relatively large extent common themes appropriate to all road networks. This is why one should take into account that cultural differences may lead to variation in road user behaviour in different jurisdictions. For example, the same engineering intervention may result in unequal traffic safety improvements even if all other factors such as traffic exposure and roadway characteristics are similar. However, we speculate that, while such variation in road user behaviour would affect the magnitude of effectiveness, it would not deter the effect of such engineering interventions entirely. Therefore, lessons can be learnt from successful interventions in developed countries. For example, the Safer Africa project (Safer Africa 2019) aims to utilise knowledge and expertise from successful European road safety projects to implement effective road safety and traffic management in African countries.

In order to attempt to affect road safety positively in LICs and LMICs, 2011-2020 has been designated the World Health Organization's (WHO) 'Decade of Action for Road Safety', seeking to save millions of lives by building road safety management capacity, improving the safety of road infrastructure, further developing the safety of vehicles, enhancing the behaviour of road users and improving post-crash response. A number of previous studies have carried out reviews of road safety interventions in LICs and LMICs, some of which are shown in Table 4 and discussed in more detail below.

Table 4: A sample of papers related to road safety initiatives and interventions in LICs and LMICs

Main themes	Location	
General review of interventions	Africa	Bonnet et al. (2018)
	LICs &LMICs	Gupta et al. (2016)
	LICs & LMICs	Staton et al. (2016)
	LMICs	Esperato et al. (2012)
Legislation change	Ethiopia	Abegaz et al. (2014a)
Road safety education	Pakistan	Ahmad et al. (2018)
	LICs & LMICs	Li et al. (2016)
	Tanzania	Zimmerman et al. (2015)
	Ethiopia	Salmon and Eckersley (2010)
	LICs & LMICs	Bradbury and Quimby (2008)
	Ghana	Blantari et al. (2005)
Enforcement	Kenya	Bachani et al. (2017a) – Helmet use
	Cambodia	Bachani et al. (2017c) – Drink driving
	Nigeria & Vietnam	Stewart et al. (2013) – Drink driving
	Kenya	Bachani et al. (2013) – Speeding
	Malawi	Kraemer et al. (2012) – Helmet use
	LICs & LMICs	Johnson (2012) – Drink driving
Roundabout design	Ethiopia	Tulu et al. (2015)

Gupta et al. (2016) focused on regulatory and road engineering interventions for preventing road traffic injuries and fatalities among non-motorised and motorised two-wheel (i.e. vulnerable) road users. Of the twenty-five studies in their review, only two were LIC-based. Esperato et al (2012) aimed to evaluate the cost and health impacts of road safety interventions in LMICs, identifying thirteen studies which met their criteria, none of which were based in LICs. Staton et al.'s focus (2016) was to determine quantitative impacts of road safety interventions including legislation, enforcement and education campaigns. Of the eighteen studies identified, three were in LICs. Bonnet et al. (2018) identified twenty-three articles relating to road safety interventions in Africa, eight were set in LICs. These studies highlight the relative dearth in quantity and quality of research output that relate specifically to the impact of road safety interventions in LICs.

With respect to best practices in LICs, the experience of Ethiopia could be mentioned, where media campaigns coupled with targeted research studies have provided a more complete picture of the impact of road safety legislation (Abegaz *et al.* 2014a; Bloomberg Philanthropies 2019; John Hopkins International Injury Research Unit 2019; Tulu *et al.* 2015). A summary of these and other research into policy interventions in LMICs is given below under the broad themes of education, enforcement and engineering.

3.2.1 Education

Educating the populace, and children in particular, about road safety and good road user behaviour can help to reduce the number and severity of crashes, particularly when used as part of a wider package of interventions (Bonnet *et al.* 2018; Li *et al.* 2016; Salmon & Eckersley 2010). For example, storybook narratives have been used in Pakistan to improve children's knowledge and attitudes towards road safety, and the relatively low-cost storybooks provided an effective and early strategy towards promoting behavioural change, particularly how to behave at the road side and when crossing. For instance, results indicated that while questions regarding where it is safe to cross were answered correctly by just over 50% of the children, this increased to over 90% correctly answering two months after the initial intervention. However, it was acknowledged that there may be a need for regular road safety education to further ensure that students retain traffic safety messages in the longer term (Ahmad *et al.*

2018), and for any impact to be effective, such measures ought to be coupled with legislative and enforcement measures (Staton *et al.* 2016).

Communities and families also have considerable potential to influence the young and road safety programmes need to be developed in support of formal school programmes (Bradbury & Quimby 2008). In the wider community, research has focused on the impact of televised road safety messaging (Blantari *et al.* 2005), which was found to be largely effective at promoting lower alcohol consumption when driving, although the language used in the messages was considered a potential barrier in a country with multiple languages spoken. In Tanzania, an education programme was developed based on an assessment of local road crashes, including targeting motorcyclists (Zimmerman *et al.* 2015).

The transferral of road safety education practices from developed to developing countries can be difficult due to variations in education systems, teaching methods, traffic regulations and exposure to risk. Road safety education and awareness have been identified as the interventions which are most adapted to LICs (Bonnet *et al.* 2018). Thus, road safety practitioners should aim to research and develop bespoke teaching methods and materials in the country in which they will be used (Bradbury & Quimby 2008).

3.2.2 Enforcement

Improving road safety through enforcement of revised legislation can also help promote road safety, particularly in the five key risk factors identified in Global Plan for the Decade of Action for Road Safety (speed, drink driving, not wearing motorcycle helmets, not wearing seat belts, and not using child restraints in cars) (World Health Organization 2011), and manuals for each have been published by WHO (UNRSC 2019). The drink-driving manual has been further developed into an assessment framework to help understand how LICs and LMICs can better adopt the guidelines (Johnson 2012). Further examples of research in this area include a study in Addis Ababa in Ethiopia, where joint media and enforcement campaigns have reduced drink driving by 50% (John Hopkins International Injury Research Unit 2019). In terms of legislation, Addis Ababa has developed its first ever road safety strategy and implementation plan, and established an inter-agency road safety council chaired by the Deputy Mayor and is considering setting up a road safety fund (Bloomberg Philanthropies 2019). Wider road safety policy interventions in Ethiopia were investigated using interrupted time series (Abegaz *et al.*

2014a), indicating that the revised road safety policy aimed at banning the use of mobile phones while driving, the obligation to use a helmet, to use a seat belt and increased levels of enforcement of excessive speeding, drunk driving and carrying dangerous loads had helped in reducing motor vehicle crashes by around 19% and associated fatalities by 12% in the year following the intervention, but the overall crash rate was still very high.

Helmet use, for both bicycle and motorcycle, is low throughout LICs. A study in Malawi observed zero bicyclists wearing a helmet over a four-day study period (Kraemer *et al.* 2012). In Kenya, the low prevalence of motorcycle helmet use remained unchanged with around 30% of motorcycle riders correctly using helmets following the introduction of a traffic amendment bill in 2012, highlighting the need for a multi-faceted strategy that includes media campaigns and widespread enforcement in addition to legislative change for improving helmet use (Bachani *et al.* 2017a). The authors reached a similar conclusion after studying the prevalence and attitudes towards drink driving in Cambodia, as Bachani et al. (2017c) concluded that a multi-pronged and coordinated approach would be needed to effectively address this issue, including social marketing and public education campaigns, and enhanced enforcement measures.

Wismans et al. (2016) provide a summary of the WHO report (World Health Organization 2013) focusing on Asian countries, highlighting that while the interventions suggested have been adopted in many countries, LICs (notably Afghanistan and Nepal) tend to be lacking in such interventions.

3.2.3 Engineering

There is a lack of studies specifically assessing the impact of engineering interventions in LMICs (Gupta *et al.* 2016), and those that are available have mixed results. Gupta et al. (2016) report that the results of the three before-and-after engineering-based studies included in their review show that while fatalities declined, the number of casualties more than doubled. Other more recent research in Ethiopia has focused on reducing traffic-related pedestrian injuries at roundabouts by modelling the effects of different features of the approaches, such as presence of guard railing and location of pedestrian crossings. The results which emerged from a crash prediction model and development of safety performance functions suggested that the number of crashes involving pedestrians was 50% higher near public transport terminals, where the spatial intensity of pedestrian-vehicle conflicts is high. A change in gradient of the approach of 1% could result in 12% increase in pedestrian crashes, as visibility is reduced and speeds are affected. However, there is less risk of pedestrian crashes where appropriate crossing facilities are provided. For instance, roundabout approaches with central refuges had 44% fewer pedestrian crashes than those without such facilities (Tulu *et al.* 2015). However, provision of pedestrian facilities does not imply compliant use. In Ghana, 65% of pedestrians using a zebra crossing displayed some aspect of risky behaviour such as talking, eating or drinking, using telephones, and wearing headphones (Ojo *et al.* 2019).

The WHO annual 'Global Status Report on Road Safety' provides an overview of progress that has been achieved in important areas such as legislation, vehicle standards and improving access to post-crash care. The 2018 report (World Health Organization 2018) notes that progress has not, however, occurred at a pace fast enough to compensate for the rising population and rapid motorisation of transport taking place in many parts of the world. At this rate, they note, the Sustainable Development Goals (SDG) target 3.6 to halve road traffic deaths by 2020 will not be met.

3.3 Vulnerable groups and gender disaggregation

The travel behaviour of vulnerable groups, such as the disabled, women and children can be adversely affected by road safety issues, particularly in LICs. The injury profile of road traffic crashes in LICs differs in important ways from the profile seen in developed countries. Pedestrians, cyclists and passengers on multi-passenger transport (buses, trucks and minibuses) are at particular risk of injury. For instance, Nantulya and Reich (2002, 2003) note that pedestrians, cyclists and passengers in buses and trucks account for around 90% of the casualties in countries in low- and middle-income regions, as opposed to high income regions where drivers constitute the majority of victims. This large proportion of vulnerable road users in road crash statistics in LICs may be explained by a traffic mix of incompatible users, where pedestrians, cyclists and motorbikes are forced to share road space with cars, and trucks, especially where communities live within the vicinity of roads or the lack of pavement along large urban streets (Lagarde 2007), and where children are particularly vulnerable to increasing levels of motorisation (Towner & Towner 2009).

Despite the prominence of vulnerable road users in LICs, they are still largely ignored in the planning, design and operation of roads (World Health Organization 2018). Around three quarters of the casualties and fatalities in LICs are men (Odero *et al.* 1997; Peden *et al.* 2013), and this may reflect gender disparities in access to economic opportunities and in exposure to road traffic injury risks as drivers and passengers (Nantulya & Reich 2003). Unfortunately, the published summary data of injury numbers is seldom disaggregated to look at patterns in factors such as gender (Turner & Fletcher 2007). However, as more countries are conducting household surveys, in addition to regular population censuses, more countries can now produce data disaggregated by sex for basic indicators on population, families, health, education and work (UN DESA 2015). Nevertheless, even when such information is collected, it is often not tabulated and disseminated to allow for meaningful gender analysis (UN DESA 2015).

Men and women typically adopt different journey patterns, which will differentially change their exposure to risk of involvement in road crashes (Damsere-Derry *et al.* 2017; Turner & Fletcher 2007). Uteng (2012) suggests that there are a number of factors influencing women's mobility in the developing world, including social and cultural norms in a patriarchal system and transport infrastructure planning and design. Typically women are less likely to make long journeys or use slower modes, and may not use busy roads as frequently as men, thus crash statistics for men and women will tend to show different patterns (Uteng 2012). The predominant mode of transport for women in rural Africa, for instance, is walking (Remacle *et al.* 2018), while men get access and priority for the use of private vehicles (Uteng 2012). When women use motorised transport, it is likely to be public transport and they are often subject to other risks while travelling (Remacle *et al.* 2018). While these gender differences in use of transport is greatest in rural settings (Venter *et al.* 2007), in urban areas women have less access to either individual or public means of transport than men, due to both economic and social reasons, and are hence dependent on walking or using undesirable and potentially unsafe forms of public transport (Peters 2013).

In their review of 73 studies of road traffic injuries in developing countries, Odero et al. (1997) note that "no study in this review attempted to investigate specific potential factors that would explain the observed gender differences. Such a study is desirable and would need to assess and correct for levels of exposure by gender." Thus, the available literature on gender disaggregation in road crashes specifically relating to LICs is sparse, indicating a clear gap in the knowledge base, and this is a topic which could merit the use of social research mechanisms such as behavioural and attitudinal surveys of these vulnerable groups, especially focussing on countries which have recently improved frequency of and access to household survey data. Car-centric transport policies coupled with increased urbanisation could lead to greater inequity in mobility (Uteng 2012), and further study needs to be made on how such policies affect mobility from a gender-based perspective.

3.4 Disabilities due to road crashes

Disability due to road traffic crashes and injuries is a significant proportion of the burden in low income settings, where appropriate and timely medical care is not usually available for victims. Rehabilitation care systems are sorely lacking in LICs (Hyder & Razzak 2013; Üzümcüoğlu *et al.* 2016). It is estimated that for every road traffic death, there are an additional 20-50 more people who are injured, and often face disability (Peden 2004). According to the World Health Organization (Peden 2004), around 85% of all global road deaths, 90% of the disability-adjusted life years (DALYs) lost due to crashes, and 96% of all children killed worldwide as a result of road traffic injuries occur in low-income and middle-income countries. However, definite data on the number of people who survive road crashes but live with disabilities are almost non-existent (Bachani *et al.* 2017b).

Some indicative data is available as highlighted in the WHO's report on Global Road Safety 2018 (World Health Organization 2018). There is data available for 29 of the 175 countries listed in Table A3 of that report, giving details of post-crash response, which provides an estimated value for the percentage of road traffic crash victims with permanent disability. Of these 29 countries, four are classified as LICs and four as LMICs. The range of estimates for the four LICs is quite wide, with an estimated 47% of road crash victims having permanent disabilities in Togo and 40% in the Democratic Republic of Congo, while estimates for Zimbabwe (7%) and Uganda (3%) are much lower. The range is less stark for the LMICs, with an estimate of 19% of road crash victims in Sudan, and 15% in Cambodia suffering from permanent disabilities, compared with 2.4% in Bangladesh and 1% in Palestine (West Bank and Gaza). Of the upper-middle and high-income countries for which data is provided, this metric is highest in Brazil (24%) and Romania (21%), lowest in Qatar and France (both 1%). There are no reasons offered within that report on why these data should be so disparate, and there is no obvious pattern linking the health care availability and these disability rates.

Zafar et al. (2018) carried out secondary analysis of the results of four nationally representative cluster randomized surveys in LICs (Nepal and Uganda in 2014, Rwanda in 2011 and Sierra Leone in 2012) as part of the Surgeons Overseas Assessment of Surgical Needs, which collected information regarding demographics, injury characteristics, anatomic location of injury, healthcare seeking behaviour, and disability from injury. The authors found that among the four LICs, involvement in a road crash was reported by 1.8%–2.6% of the population. These accounted for about 12.9% of all injuries. ‘Major disability’ was reported by an average of 38.5% of those suffering an injury as a result of a road crash. Respondents from Sierra Leone (49.3%) and Uganda (46%) were most likely to report a disability, whereas those from Rwanda (32.8%) and Nepal (21.1%) were less likely. Patterns of injury varied between countries; however, head and extremity injuries remained the most common.

One potential problem comparing the studies above is that of inconsistent definitions. For instance, the international road safety community has not yet settled on a precise definition of ‘serious’ injury resulting from a road traffic crash (Polinder *et al.* 2015). Injury severity in some developed countries has been assessed by means of the maximum abbreviated injury scale (MAIS), i.e., the maximum score of a six-point scale ranging from 1 (minor injury) to 6 (fatal injury) (Petrucelli *et al.* 1981). However, there is no agreement on which of the central MAIS levels should be used to define serious road injuries as a policy indicator. In the Netherlands, for instance, MAIS 2+ is used to indicate a serious road crash (Polinder *et al.* 2015), while the International Road Traffic and Accident Database (IRTAD), proposes an injury score of MAIS 3+ to define a seriously injured road casualty (IRTAD 2011).

The metric of disability-adjusted life years (DALYs) (World Health Organization 2019) is used to integrate the fatal and non-fatal consequences of diseases, a summary measure of population health that combines the effects of mortality, morbidity and disability into a single measure (Polinder *et al.* 2015), calculated by summing ‘Years of Life Lost’ (YLL), based on the age of the fatality compared to average life span, and ‘Years Lived with Disability’ (YLD), which uses a weight factor to reflect the severity of the disease or injury. An alternative method which provides an opportunity to understand how population health is affected by non-fatal injuries is the ‘Health-Related Quality of Life’ (HRQOL) (see for example Alghnam *et al.* 2015; Kenardy *et al.* 2017; Landolt *et al.* 2009), a method which relies on self-reporting by patients.

A tool to assess the consequences of disability on activity limitations has been developed as a practical, generic assessment instrument that can measure health and disability at population level or in clinical practice (Ustun *et al.* 2010). WHODAS 2.0 captures the level of functioning in six domains: cognition, mobility, self-care, getting along (i.e. interacting with others), life activities (i.e. domestic responsibilities, leisure, work, school) and participation (joining in community activities). However, there is no assessment made of the underlying condition or cause that led to the disability.

These metrics and tools described above do not give an explicit estimate of the levels of disability resulting from road traffic crashes. However, there has been some research into the impact of road crashes on disability severity. For instance, Alemany et al. (Alemany *et al.* 2013) used data from a Spanish survey related to severities and causes of disabilities, and found that of those disabled as a result of road crashes, 52% had major difficulties walking or moving outside their home unaided, 44% faced problems using public transport unaided, 43% had difficulties changing their body posture unaided, while 33% faced problems when driving a vehicle.

Rissanen et al. (Rissanen *et al.* 2017) identified 30 studies which appraise quality of life as a result of road traffic injuries, although none are in LICs. Their review identified that the overall quality of life was significantly reduced after a road traffic injury compared to the general population norms. Persons who are older, of female gender, lower socioeconomic status, diagnosed with post-traumatic stress disorder, or with more severe injuries or injuries to the lower limbs are more vulnerable to the loss of quality of life than other groups.

In Uganda, Bachani et al. (Bachani *et al.* 2014) used a modified census-style questionnaire to estimate the prevalence and types of physical disability in residents of a region of 12,000 households. Information was collected on over 57,000 individuals aged over five (out of 66,000 residents), of which 9.4% said they had some form of disability (10.6% of females, 8.2% males). The questionnaire was designed to be brief and simple to complete, so no indication was gained about the causes of the disabilities. Subsequent research in the region (Bachani *et al.* 2016) used the WHODAS 2.0 tool to assess the limitations of 1,500 adults previously identified as having a disability, and found that in general, individuals with disabilities had the most trouble on getting around, life activities and participation in society.

Palmera-Suarez et al. (Palmera-Suárez *et al.* 2016) suggest that in Spain, disability caused by road traffic crashes is generally of a mild nature, but one in two thousand people suffers from moderate, severe or complete disability, affecting such individuals' work capacity and giving rise to an increased demand for technical aids and personal assistance, as well as a greater need of family support. Risk of disability is higher among women, middle-aged and older persons, those with a lower educational level and illegal drug users (Palmera-Suárez *et al.* 2018).

These studies provide means to monitor the prevalence of disabilities among populations, but it should be noted that improved health care and vehicle safety does not necessarily imply that there will be fewer disabled people as a result of road traffic crashes. If healthcare and acute care services improve in LICs and in-vehicle protection devices (e.g. airbags) become more prevalent, there are likely to be fewer fatalities resulting from road crashes. However, the implication is that more people will survive with non-fatal but extensive injuries, resulting in higher numbers of disabled people (Lund & Bjerkedal 2001), implying a greater need in the future for long term care and rehabilitation facilities for those who survive road crashes, but are permanently disabled. There are obvious cost implications associated with this (Alemany *et al.* 2013).

Understanding the causes, severities, long term implications and costs to society of disabilities resulting from road crashes could help refine road safety policies in LICs, and improve impact analysis of road safety interventions (Alemany *et al.* 2013). There are inconsistencies in the metrics and methods used to assess injury severities, and further work could seek to build on any review of road safety and healthcare data recording systems suggested in 3.1 (under-reporting), and aim to assess the most appropriate metrics for LICs to use in analyses of disabilities. Further research could help to develop methodologies for road safety and healthcare practitioners in LICs to understand not only the trends associated with disabilities resulting from road crashes but also their short- and long-term impacts on society and the economy. This topic of road crash costing is discussed further in the next section.

A surprising gap in previous traffic safety research conducted in LICs relates to the lack of studies that aim at understanding differing injury-severity levels properly. While most previous studies in the context of LICs focus on crash and injury/fatality frequencies, it is noteworthy to identify and understand factors that increase or decrease injury likelihoods. Such analyses are common in the developed world and help draw a complete picture, allowing decision makers to design cost-effective countermeasures to reduce injuries once a crash occurs. Therefore, there is a need to conduct research in this area.

3.5 Economic burden of road crashes

Since road crash cost estimates are difficult to obtain, there are few studies that specifically focus on road crash costing or cost-effectiveness of interventions in LICs (Banstola & Mytton 2017). A recent summary of the economic costs of RTIs included in the Disease Control Priorities project suggests that these costs could range between 1-2% of a country's GNP (Bachani *et al.* 2017b). Delays in implementing road safety measures could also impact severely on a nation's wealth and its population's wellbeing (Martin *et al.* 2018). While estimates on the total costs of RTIs vary based on methodological approaches used, one large 21-country study estimated the global cost of RTIs at US$518 billion (Bachani *et al.* 2017b; Jacobs *et al.* 2000). Another recent analysis of the economic impact of road traffic injuries led by the World Bank's Global Road Safety Facility found that if countries were able to halve mortality and morbidity due to road traffic injuries and sustain that over 24 years, they could realize significant increases in their GDP – between 7-22% (World Bank 2017).

In addition to the above costs, it is important to note that RTIs result in a significant societal burden as well, information about which is important for evidence-based policy making. However, there is a paucity in information in the global literature about the societal costs of RTIs, especially in LMICs, and more studies are needed. This information would provide insight into the consequences of crashes for the economy and social welfare. In fact, road crash costs can be used as a comparator with other policy areas, to help decision-makers prioritise investments. While epidemiological data for crash-related disability from LICs is scarce, the costs of prolonged care, loss of income and consequences for injured parents and their dependents impose financial pressures on families, threatening sustainable livelihoods (Ameratunga *et al.* 2006). Also, the burden of care for long-term illness and disability may fall disproportionately on women and girls (Aeron-Thomas *et al.* 2004). That said, the tangible costs such as lost productivity (indirect cost) and medical costs (direct costs) can be estimated in economic terms more easily compared to the intangible costs such as pain and suffering (Bishai & Bachani 2012). However, regardless of difficulties in estimating road crash costs, accounting for economic costs of crashes is necessary to inform policy makers in prioritising and choosing the most effective countermeasures. Three main approaches used in estimating the cost of road crashes (Bishai & Bachani 2012) are (i) the human capital approach, in which mainly tangible injury costs to individuals are aggregated at societal, regional and national levels; (ii) the willingness-to-pay approach, which derives a value of pain and suffering based on the preferred amounts that people would be prepared to pay to live in a world where risks are reduced; and (iii) the general equilibrium approach, which uses simulation models to estimate costs from a broader macroeconomic perspective, although is as yet untested for injury cost modelling (Bachani *et al.* 2017b). The human capital approach has been the most common approach used in LMICs, due to the relative simplicity and structured approach (Bishai & Bachani 2012).

3.6 Vehicle safety standards and dumping of old vehicles

An emerging problem for road safety in LICs is the issue of vehicle safety and technologies. While there is a dearth of literature focusing on this issue in LICs, as part of this project, we have been working to liaise with stakeholders and lessons learnt from the developed world in this area to understand this issue further. These stakeholders include experts from the Global New Car Assessment Programme (NCAP), and regional car assessment programs.

With respect to emerging vehicle safety features in LICs (e.g., air bags, crash avoidance systems, etc.), one should take into account risk compensation issues. A number of studies have investigated risk compensation issues mostly in the developed world (Garbacz 1991; Lv *et al.* 2015; Nicita & Benedettini 2012; Winston *et al.* 2006). As discussed by Winston et al. (2006) road users may become less vigilant about road safety due to innovations that are designed to improve safety. For example, drivers may trade off improved safety for speedier trips (Winston *et al.* 2006). With the expected change in vehicle fleet (and their safety features) in LICs, it is important to understand how the experience of developed countries in this regard could lend itself to LICs. This also highlights the importance of publicity campaigns to raise awareness among road users in LICs with respect to vehicle safety features. This is particularly necessary to educate and train drivers at the very beginning steps of moving towards advanced vehicle safety features in LICs.

With respect to dumping old vehicles in LICs, the issue has been raised by a number of organisations and research studies, which mostly focus on environmental impact of dumping old vehicles in LICs (Health Effects Institute 2018). The mainly old vehicle fleet in LICs does not meet some of the basic safety standards set in developed countries, increasing the propensity of crashes. This may be exacerbated by vehicle modification, poor maintenance standards, inappropriate use (e.g. overloading) and lack of safety enforcement. In addition, when a crash occurs, drivers and passengers would sustain more severe injuries, for example, due to lack of airbags. To our knowledge, scientific studies that investigate safety implications of exporting old vehicles to LICs are non-existent. Policies may be needed to prevent developed countries from dumping vehicles of certain age or category to LICs and to encourage scrappage in LICs (e.g. cash for clunkers).

3.7 Proactive approaches to road safety

Traditional methods that help detect, prioritise and treat high crash-risk sites have been based solely on prior crash history (Sayed *et al.* 2010). However, crash data quality in LICs tends to be poor, at limited numbers of sites, and with high rates of under-reporting. Studies of observed unsafe road user behaviour in LMICs do exist (e.g. Uzondu *et al.* 2018, 2019), but manual data collection is time consuming and costly. To overcome these constraints, it may be possible to use new forms of data collection techniques such as video data or remote sensors, and storage and manipulation techniques involving 'big data' to allow for a proactive road safety approach that can address safety deficiencies before crashes occur (Chang *et al.* 2017). For instance, assessing global databases could help identify country-specific determinants of road safety (Dhibi 2019). More locally, it is possible to monitor and analyse road users' trajectories and identify conflicts and near misses (St-Aubin *et al.* 2015). A proactive approach to road safety should ideally complement traditional, reactive methods (de Leur & Sayed 2003), allowing us to design improvement programs (publicity campaigns, engineering interventions, etc.) before crashes happen. However, applying such approaches in LICs may not be straightforward, due to cost and resource constraints.

3.8 Limited data conditions, omitted variables, and unobserved heterogeneity

A series of well-known issues often encountered in road safety analysis are related to data limitations of various types. Crash data may be limited in terms of sample size or the number of risk (contributing) factors available in the data resulting in limited data conditions, omitted variables problem, and unobserved heterogeneity (Heydari *et al.* 2014; Mannering & Bhat 2014; Mitra & Washington 2012). Note that risk factors are needed to explain safety of a site (highway segment, jurisdiction, etc.).

When a crash data set is not large enough, the maximum likelihood estimation is prone to bias; and therefore, the model estimates are biased. This problem can be addressed employing Bayesian methods in which prior knowledge can be included in the analysis in the form of the prior distribution, leading to enhanced statistical inferences. In this regard, for instance, Heydari et al. (2014) showed how it is possible to obtain reliable statistical models for crash data characterised by a sample size. With respect to the omission of risk factors, road safety literature discusses that, when important variables that have significant explanatory power are missing from the data, road safety inferences could be misleading (Mitra & Washington 2012).

Unobserved heterogeneity is related to the omitted variables problem and leads to spurious road safety inferences as indicated in the crash literature (Mannering *et al.* 2016). Several risk factors that affect road safety at a site (intersection, road segment, neighbourhood, etc.) are often missing (being unknown or unmeasured) in crash databases causing the unobserved heterogeneity problem. A large body of literature discusses how to overcome this problem in order to obtain reliable estimates (Heydari 2018; Mannering *et al.* 2016). However, most studies that address the abovementioned issues are conducted in the developed world. Advanced statistical methods can mitigate unobserved heterogeneity and omitted variables problems (Mannering & Bhat 2014), and such methods should be applicable to data sets in LICs, but their use in such contexts has so far been limited.

3.9 Reaching out to other sectors – social and behavioural aspects

In reaching out other sectors, we mainly focus on social and behavioural aspects. We discuss this section under six major headings emphasizing the need for (1) methods, (2) country-specific understanding, (3) change the approach, (4), understanding the wider system, (5) understanding culture, and (6) targeted research and action.

The need for methods

The tools used in social, cognitive, and behavioural research are, in the vast majority of cases, developed in high-income settings, where academic research has a well-developed and long-standing history. Data from the author's own survey-based research (Hasanat-E-Rabbi et al. in preparation; McIlroy et al. in press) suggests that some of these measures may not always be suitable for application in low-income settings. McIlroy et al (in press) used distributed a pedestrian behaviour questionnaire across a variety of country settings, finding that the original structure could not be used across all countries in which it was applied. Although the authors did not change the composition of the factors they used, only three of the five original factors were sufficiently reliable in each setting.

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Looking in more detail at results from Bangladesh, Hasanat-E-Rabbi et al. (in preparation) found the factor structure of the pedestrian behaviour questionnaire to be quite different in some respects. They argued that the scale could not be applied as it was described in the original literature (see Deb *et al.* 2017; Granié *et al.* 2013). Questions that dealt with cycle paths, or with light-controlled pedestrian crossings, suitable in France or North America (the contexts in which the questionnaire was developed), were not at all suitable in Bangladesh. Moreover, positive behaviours, relating to what European or North American respondents might consider as ‘polite’ behaviours, were simply not relevant. The culture is quite different, hence its social norms, to which ‘politeness’ is closely tied, are quite different. There is, therefore, a strong need to develop research tools in the settings in which they are to be used. This is a fundamental necessity for research in LICs.

The need for country-specific understanding

The full pedestrian behaviour questionnaire used by McIlroy et al. (in press) was not able to capture the intended range of behaviours across all country contexts. Nevertheless, the authors were able to look at the relationships between attitudes to road safety and three behavioural factors; intentional rule violations, aggressive behaviours, and unintentional errors of memory or judgement. Previous research had suggested the link between attitudes and behaviours (in a road safety context) to be weaker in Sub-Saharan African countries than in high-income, European countries (Nordfjærn *et al.* 2011, e.g. 2014). Although McIlroy et al.'s results showed significant links between attitudes and behaviours in all countries analysed (i.e., Bangladesh, China, Kenya, Thailand, the UK, and Vietnam), the difference in strengths of the relationships were broadly as hypothesised. In Kenya, road safety attitudes predicted self-reported pedestrian behaviours to a significantly lesser extent than in the UK. That said, the pattern of relationship strengths did not follow the pattern of national income or road safety statistics. The UK has the safest road system (measured in fatalities relative to population or motorisation levels) and the highest income of all countries included in the study, yet it was not the country in which attitudes predicted behaviour to the greatest extent. Indeed, no patterns were found in this respect. This strongly points to the need to conduct preliminary research in the country of interest before applying road safety interventions. Every setting has unique characteristics, and interventions should be designed with this in mind. Going forward, more detailed work on the attitudes of road users in low-income settings is sorely needed.

The need to understand culture

It is not sufficient to assume, based on research performed in other countries, that an educational campaign (for example) that appeals to road safety attitudes will be as effective (or ineffective) in one country as it will in another. Equally, just because in some Sub-Saharan African countries the attitudes-behaviour link has been shown to be weak does not mean that other low-income countries will follow this pattern. Culture is a significant factor, and is independent of income level. This has been explored by a variety of researchers with regards to traffic safety, with mixed results.

In one of the first studies to explore the relationships between underlying belief systems and traffic safety, Kouabenan (1998) examined religious, mystical, and fatalistic beliefs and how they affected West African taxi drivers' explanations of road crashes. Road crashes were attributed more to external factors (such as poor road maintenance and the absence of pedestrian infrastructure) than to driver behaviours (such as the breaking of road laws or carelessness). Additionally, such beliefs were linked with a disregard for safety measures. A strong belief in luck, fate, or destiny, was linked with a perceived lack of need for things such as helmets or seatbelts. This result was also reported by Dixey (1999) in a study conducted in Nigeria. As one interviewee stated that as he had consulted the Babalawo (the traditional priest of the Yaruba people) he felt no need to wear a motorcycle helmet. He simply knew he was not in danger that day. Similar findings have since been reported by Peltzer (2003), Omari and Baron-Epel (2013), and Maghsoudi et al. (2018) in relation to car driving behaviours. Stronger beliefs in fate or destiny are related to lower engagement in self-protective behaviours.

Such beliefs are linked not only with an avoidance of protective behaviour, but an active engagement in risky behaviours. Results to this effect have been found in a variety of settings, including South Africa (Peltzer & Renner 2003), Turkey and Iran (Nordfjærn *et al.* 2012; Şimşekoğlu *et al.* 2013), and Cameroon (Ngueutsa & Kouabenan 2017). These kinds of findings appeal to a common-sense perspective. For example, one can imagine the Bangladeshi minibus driver behaving in a more reckless manner given his belief in the protective qualities of the passage of the Quran written on the vehicle. Such assumptions may not, however, be valid, despite research in some countries suggesting them to be so. In a study in Turkey, Yıldırım (2007) found religiosity to have a positive effect on self-reported traffic behaviours. Those reporting stronger religious beliefs also reported making *fewer* risk taking behaviours. This was explained in terms of the rule-following orientation of those following Islam in its Turkish cultural interpretation.

A similar explanation can also explain results described in McIlroy et al. (in preparation), in their exploration of fatalistic beliefs, road safety attitudes and self-reported pedestrian behaviours. Here, the authors found stronger beliefs in divine control (a belief in the influence of God over one's life) to be generally related to riskier pedestrian behaviours and less safe road safety attitudes in China, Thailand, the UK, and Vietnam. The opposite was true, however, in Bangladesh, and (to a lesser extent) in Kenya. In these settings, a stronger belief in the guiding influence of God was associated with safer attitudes to traffic behaviours, and safer self-reported pedestrian behaviours.

Of the countries investigated, Bangladesh and Kenya showed the highest levels of 'traditional' monotheistic religion (i.e., Islam and Christianity, respectively), whereas many in China, Vietnam and Thailand hold more to varying interpretations of Buddhism, a non-theistic religion. In the UK, most reported having no religion. It is therefore apparent that not only are beliefs, attitudes, and behaviours, different across cultures, but the relationships between those factors differ depending on the context of study. Taking results from McIlroy et al. (in preparation) alone, it is tempting to suggest that in monotheistic cultures religion serve a protective purpose in risk behaviours, while in more non-theistic or atheistic settings religiosity has a negative effect. This would not, however, explain the aforementioned findings from Turkey and Iran (Nordfjærn *et al.* 2012; Şimşekoğlu *et al.* 2013).

What is clear from all of these findings is that one cannot assume, based on knowledge developed in one setting, that available research tools or established road safety interventions will work in different countries or cultural contexts. Preliminary research must be conducted in the setting in which an intervention is to be implemented. Additionally, researchers should not focus only on the driver or pedestrian (or rickshaw or minibus passenger), but must also look at the transport system as a whole.

The need to understand the wider system

Road transport is a highly complex sociotechnical system, with influence from a wide variety of individuals and organisations at varying levels of system abstraction. From the concrete physical objects that make up the road environment, to the governance and organisational entities, there exist myriad influences on road safety. Intervention designers should therefore take into account not only the end drivers, cyclists, pedestrians, passengers, etc., but also those that work at different levels of that system. For example driving instructors, parking attendants, traffic and police officers, teachers, community and business leaders, civil servants, politicians, and so on, all have an effect on outcomes. All those involved have some influence over the system, and the interconnections between system components are equally important as the components themselves.

Although it is the end user that carries the weight of the road traffic injury and fatality burden, it is generally not the end user that makes safety intervention decisions. This is left to actors higher up in the system. Across countries, however, not all systems are the same, and they do not all reside within the same social and cultural backdrop. This means that despite politicians' (for example) good intent, an intervention that worked well in one country may not work to the same extent in another. When an engineering intervention seemingly fails, the likely reason is that the footbridges were not designed or placed with the behaviours of end users in mind. For example, the presence of foot bridges over high speed, multiple-lane roads does not always result in their use. In these cases, the interconnections in the system are failing. Perhaps the foot bridges are in the wrong place, perhaps the steps are too steep for certain road users, perhaps they become places were unhygienic use is common and therefore dissuade potential users. Although the approach is gaining traction in the Europe, North America, and Australia, there is as yet a complete lack of systems-level research in low-income settings.

The footbridge example above is commonly seen across low- and middle-income countries (e.g. Räsänen *et al.* 2007), the result being wasted money and resources, and little or no improvement in pedestrian safety. Other examples of ill-conceived investment can, however, have even more serious consequences. In 2005, the World Bank provided funding for the paving of Bangladesh's 39-kilometre N2 highway, turning a dirt road into what was termed the 'world's most dangerous road' (Anam 2014; Kelly 2012). The project gave no forethought to local traffic culture and behavioural tendencies. It therefore did not consider the potential knock-on effects of laying the N2 with tarmac. Potential vehicle speeds, initially restricted by the uneven road surface, pot holes, and cracks, were dramatically increased. Although this achieved the intended large reduction in travel time between Dhaka and Sylhet, it did so without considering local road use patterns, and without considering any other system factors. No consideration was paid to speed enforcement capabilities, attitudes to overtaking and other risky driving behaviours, registration and licensing compliance, or the characteristics of the environments through which the road travelled.

The need to change the approach

The focus on economics and, relatedly, reducing travel times, has been dominant in traffic safety thinking across low- and middle-income countries (Vasconcellos 2001). There is also a strong culture of blame, something also seen in high-income countries. Both of these issues stem from a lack of appreciation for the complexity of the road transport sociotechnical system. Its components are highly inter-related, and its properties emergent (i.e., that system failures emerge from the complex interplay of many factors). Blame is of particular significance here. The focus on assigning culpability is often at the expense of resources assigned to the true goal of road crash investigation and safety intervention, i.e., the reduction of the likelihood of similar crashes occurring in the future.

This blame culture is rife across road transport systems around the world. A strong example of this comes from Kenya. The National Transport and Safety Authority (NTSA) (see www.ntsa.go.ke) was tasked with collating road crash data, and were given additional traffic safety and control powers that were previously the responsibility of the police. The police, responsible for recording data at road crash sites, did not respond positively to this transfer of power. Fatality statistics then began to rise. The NTSA were therefore stripped of their increased level of power, with control handed back to the police. This was despite recognition of corruption in the traffic police system (e.g. Kimanthi 2018). The NTSA placed the blame on the driver, the police placed the blame on the NTSA, and prominent MPs placed blame on both the NTSA and the police (Dibondo 2018). None of parties involved accepted any amount of blame, and none recognised the idea that responsibility for road safety should be shared.

This is not unique to low- and middle-income countries; however, change is beginning to be seen in some high-income countries with acceptance of the ‘safe system’ or ‘vision zero’ philosophy. The approach is becoming relatively well-known in the European traffic safety domain, having been around since their inception in the 1990s in Sweden (see Johansson 2009). Its primary central tenet is the idea that the end user is fallible, and that the system should be designed in a way to reduce the likelihood of crashes, and reduce the consequences of crashes that happen. Crucially, blame is not placed solely on the end user, rather it is shared among system actors. Although the road safety systems of different countries have unique characteristics, they also have many shared characteristics, with this notion of shared responsibility being perhaps the most significant. To reiterate the aforementioned sociotechnical perspective of the issue, road safety is not the domain of one actor or group of actors alone, but it is the concern of many entities, at many levels of the system, from the end user to the policy maker (McIlroy *et al.* 2019).

The need for targeted research and action

As aforementioned, there is a strong requirement for research methods developed in low income settings. The majority of research is performed in high-income countries; hence, the majority of methods are biased towards these settings. This can also be said for road safety interventions. Often, what has worked in Europe or America is assumed to be applicable to other countries. Given differences in cultures, attitudes, and behaviour constraints, this may well not be the case. As such, interventions should be designed based on research conducted in the country in which the intervention is to be implemented. A programme of work that addresses these issues would be highly beneficial to road safety in LICs. One success story of such an approach being applied comes from Bangladesh, from the same aforementioned highway once described as the world’s most deadly. Using an integrated approach that included community engagement, education, and small-scale infrastructure change, three sections of the highway were dramatically improved (van der Horst *et al.* 2017). An estimated 605 reduction in fatalities was achieved, at relatively little expense.

3.10 Current capacity for research and practice

Capacity for research and practice in the field of road safety is one of the key issues impeding progress in this area in the context of LICs. This is a recurrent theme in all global and regional reports published to date on road safety (Bachani *et al.* 2017b; Hyder *et al.* 2017; Peden 2004; World Health Organization 2018). Capacity is needed for research as well as planning and implementation of appropriate safety improvement programmes, and any work being done in such settings ought to embed capacity development into it (Bhalla & Shotten 2019; Perel *et al.* 2007) as well as consider how to overcome institutional barriers (Khademi & Choupani 2018).

Initiatives such as the Road Traffic Injuries Research Network (Hyder *et al.* 2016) and the UNECE programmes in developing countries, in partnership with ECLAC (Latin America and Caribbean region) and ESCAP (Asia and the Pacific region) (UNECE 2014) have aimed to reduce the burden of road crashes in developing countries by identifying and promoting effective, evidenced-based interventions and supporting research capacity building in road safety research in LMICs. Building on the experience gained from such initiatives, there is a need to develop formal training programs that are readily accessible by individuals residing in LMICs. Based on the literature review and through liaising with experts and stakeholders, we have identified two main areas where improving capacity is mostly needed.

1. Limited trained human resources: Many LICs around the world lack adequate human resources in the various areas necessary for effective action on road safety – research, program planning and implementation, as well as monitoring and evaluation (Bachani *et al.* 2017b; UNECE 2014). One main reason for this is the lack of formal training programs in these settings that are specifically targeted towards the skills necessary for effective and appropriate action on an issue as complex and multi-sectoral as road safety (World Health Organization 2008). This limits the amount and type of research conducted locally. For example, road safety studies that focus on data derived from LICs are extremely under-represented in peer-reviewed publications (Perel *et al.* 2007), and when they exist, they are often far away from advanced methodological techniques adopted in studies conducted in the developed world. To this end, it is important to train practitioners and researchers residing in LICs in the different areas necessary to effect programmatic change, such as road safety management, research on risk factors for road safety, evaluation of interventions, etc. Incorporating some of these capacity building activities in ongoing engagements and initiatives in LMICs will also have the

added benefit of enhancing collaboration between HIC and LMIC researchers and practitioners.

2. Lack of data: As set out in Sections 3.1, 3.3, and 3.4, another gap identified in LICs is the limited amount of disaggregated data available for understanding the safety condition and monitoring safety improvement programs when implemented. Capacity development efforts for road safety in LMICs ought to focus on improving data systems such that there is valid, reliable, and timely data available to not only assess the safety condition, but also serve as a basis for assessing the effectiveness of programs or interventions implemented.

4. Expert survey

A number of road safety experts were approached to provide insight into those topics which were most important to consider for future research in LICs, and two main themes emerged as the most important issues: i) data collection and management techniques, and ii) governance and legislation. The range of sub-topics is shown in Table 5.

Respondents agreed that the complexities of road safety implementation meant that there are unlikely to be any 'quick wins', although investigating how governance could be improved and held more accountable could initiate action to improve the impact of road safety interventions in the short term. Further responses suggested that the effective use of increased resources and awareness of global best practice could help provide rapid insight into the priority issues, particularly in respect to the safety of vulnerable road users and the expected growth of traffic in developing countries. Additionally, reviewing current practices could help inform government and other stakeholders of the key issues in their specific location, and highlight where current governance mechanisms can be improved, with the aim of achieving greater political and funding commitments from decision-makers, resulting in better legislation and enforcement.

Table 5: Expert elicitation results showing important topics for future road safety

Topic	Potential solutions
Data:	
Inconsistent data collection and management techniques (including under-reporting)	- Improved training and resources for police and hospital staff - Dedicated specialists in crash data reporting - Use of modern technology to ensure accuracy of reporting and efficiency of data storage - Use of multiple data sources - Public awareness raising of importance of accurate data

Under-use of road crash cost estimates	- Establish specialised team to promote road safety reduction, and ensure cost implications are explicitly considered in road safety interventions - Disseminate cost evaluation results to reveal shortcomings in current approach
Governance:	
Lack of integrated approach to road safety issues	- Develop and apply integrated multi-sectoral, multi-governance framework, possibly using a systems-based approach, include feedback mechanisms and knowledge exchange - Consider how to integrate research into vulnerable road users into policy and education
Lack of accountability of leadership	- Review and re-evaluate current governance mechanisms to improve transparency and avoid redundancy and overlapping of responsibilities - Vision Zero approach - Implement Lead Road Safety Agency to coordinate and champion road safety activities at national, municipal and local levels
Poor legislation	- Apply best practice techniques from developed world
Poorly resourced sector	- Increased levels of trained personnel, equipment and knowledge base - Consider use of outsourcing to private sector for certain aspects of road traffic management

5. Future directions

A number of topics emerge from our analysis of the State of Knowledge review above combined with discussions with experts and stakeholders, which can help form a future research agenda. These topics relate to both empirical and methodological frontiers; and therefore, they will lead to noteworthy improvements in the way road safety research will be conducted in the context of LICs. Note that topics discussed below are inter-related; nevertheless, their theoretical and empirical weights vary from one topic to another.

5.1 Under-reporting of crashes

This is a major issue in LICs; and therefore, research is needed not only to understand causes of under-reporting but also to develop methodological approaches that can better address the issue. The use of capture-recapture techniques has been shown to be a useful tool to estimate the levels of under-reporting in low-income countries, and as such could be used when authorities wish to understand the true nature of road traffic crash rates in their country. To address limitations of the capture-recapture approach, alternative statistical methods should be examined and/or developed in order to address under-reporting properly. It is also advisable to carry out a review of police and hospital data availability in LICs and LMICs, in order to understand better the nature of the types of data generally available. Following such a review, a general ‘toolkit’ could be developed offering guidance and methodologies for the analysis of under-reporting in LICs and LMICs. Such guidance could incorporate minimum data requirements, software tools and reporting templates in order to standardise such reporting in all LICs and LMICs in the future.

5.2 Traffic injuries sustained in the crash

Understanding the causes, severities, long term implications and costs to society of disabilities resulting from road crashes could help refine road safety policies in LICs and improve impact analysis of road safety interventions. There are inconsistencies in the metrics and methods used to assess injury severities, and further work could seek to build on any review of road safety and healthcare data recording systems suggested in 5.1 (under-reporting), and aim to assess the most appropriate metrics for LICs to use in analyses of disabilities. Further research could help to develop methodologies for road safety and healthcare practitioners in LICs to understand not only the trends associated with disabilities resulting from road crashes but also their impact on society and the economy. It may be appropriate to focus such future research on vulnerable groups. Also, a surprising gap in previous road safety research conducted in LICs relates to the lack of studies that aim at analysing and understanding differing injury-severity levels properly. That is, how different factors increase or decrease the likelihood of varying injury-severity levels. Further research in LICs is needed to understand differing injury-severity levels once a crash occurs. Such studies will help identify factors that increase or decrease injury likelihoods. Such analyses are common in the developed world and help draw a complete picture, allowing decision makers to design cost-effective countermeasures to reduce injuries once a crash occurs.

5.3 Road crash costing

There are limitations in the methods used to apply cost estimates to road crashes in LMICs (Wijnen & Stipdonk 2016) and in LICs in particular. Wesson et al. (2013) carried out a review of economic evaluations in LMICs founding only three studies that assessed the costs of road safety interventions, and six studies that were cost-effectiveness analyses. Only one of these papers referred specifically to LICs (Bishai *et al.* 2003). Similarly, Banstola and Mytton (2017) only found five studies assessing cost-effectiveness in LMICs, with only two interventions showing moderate evidence of being cost-effective. More recently, Mukama et al. (2019) assessed the costs of unintentional injuries to children in a Ugandan slum, noting that costs associated with road traffic crashes are higher than those for incidents occurring at a school, due to the severe nature of most road traffic injuries requiring specialised care and hence higher treatment costs. This lack of LIC-based research indicates that further research is needed to identify relevant methods of road crash cost estimations or cost-benefit analyses of road safety interventions which would be applicable to provide evidence for investments in LICs.

5.4 Characterisations of the vehicle fleet

With respect to vehicle safety features and risk compensation concerns discussed in Section 3.6, further research is needed to better understand risk compensation issues in LICs to be able to take advantage of emerging safety innovations more fully. Also, it is important to explore issues surrounding the second hand vehicle market and how countries that are heavily reliant on imported second hand vehicles can regulate more appropriately, as well as vehicle technologies. In this regard, scientific research is needed to quantify road safety implications of dumping old vehicles in LICs.

5.5 Challenges of data collection and analysis

As set out in Section 3, and identified by the expert survey, many of the issues pertinent to this study relate to the challenges of data collection, management and analysis. While it may be possible to draw on experiences of global good practice, it may also be relevant to develop specific methods and analysis techniques that apply in the LIC-context. The following sections discuss these issues in greater detail.

5.5.1 Expected increase in traffic volume and its implications

Previous research indicates that as a country's economy grows and traffic volume (and consequently exposure) increases, road safety deteriorates. However, the relationship is not linear and varies from one jurisdiction to another (Hauer 1997; Wiebe *et al.* 2016). It is important to quantify the rate of deterioration in road safety as traffic exposure increases; and consequently, investigate how we can reduce this rate. For example, using advanced statistical methods, a study conducted by Heydari et al. (2018) shows how with the same set of variables available in the data one can understand the deterioration rate in road safety as traffic exposure increases. Understanding the deterioration rate is important since an increase in traffic volume in LICs seems inevitable in the near future. Further research is thus needed to understand the relationship between road safety and traffic exposure in LICs. To this end, a series of safety performance functions should be developed for different road infrastructures in LICs, similar to those developed in the Highway Safety Manual 2010 (AASHTO 2010). Note that safety performance functions are the main ingredient for the six-step safety management process described in the Highway Safety Manual (AASHTO 2010). They are used to quantify road safety, to understand factors affecting safety, and to identify hazardous locations that should then be prioritised for safety improvement programs.

5.5.2 Accounting for data-related limitations and unobserved heterogeneity

As previously discussed, in LICs crash data tends to be lacking or when it exists, it is often limited, whether in form of limited sample size and/or risk factors available in the data. Therefore, issues discussed in Section 3.8 are often more prevalent and frequent in LICs compared to the developed world. The number of road safety studies conducted in LICs is limited, and rarely do those studies employ rigorous road safety and statistical techniques to address the aforementioned issues properly. One aspect of future research should be to continue work in this area, and develop statistical methods, especially those applicable to LIC-contexts, and help provide more robust analysis of road safety data.

5.5.3 Feasibility of proactive approaches to road safety in LICs

Although we recognise challenges for implementing proactive road safety approaches in LICs, it is important to investigate how this could help mitigate crash risk propensities in LICs. Building on the successful experience of developed countries in implementing such approaches, while considering resource and cost constraints applicable to LIC-contexts, it would be possible to adapt proactive methods in LICs to optimise their benefits with a minimum cost. Initially this could be treated as a range of feasibility studies to extend the knowledge base to LICs. Perhaps, it would be possible to focus on monitoring a limited number of road infrastructures and based on that provide valuable insights, which in turn allow for designing tailored safety improvements transferable to other similar locations within each jurisdiction. To summarise, proactive safety approaches should be considered in the future if a major improvement in road safety in LICs is expected to be achieved.

5.5.4 Alternative low-cost approaches to obtain data

With respect to data issues and limitations encountered by LICs, which also relates to limited capacity in these countries, a valuable and cost-effective approach could be based on using street imagery, for example, available in Google street view or shared on social networks.

Previous research has successfully took advantage of street imagery, for example, to identify travel patterns (Goel *et al*. 2018). Estimating travel patterns and/or traffic exposure by different modes of transport and/or road user could be promising when such information is not collected through traditional data collection techniques. This is in particular important given the expected increase in traffic exposure in LICs since traffic exposure is known as a major determinant of road safety. Therefore, it would be interesting to investigate how this could be employed to collect relevant data and improve safety in LICs.

5.6 Social and behavioural approaches to road safety

As described in Section 3.2, the majority of road safety research is performed in high-income countries; hence, the majority of methods are biased towards these settings. As such, there is a strong requirement for research methods developed in low income settings. This can also be said for road safety interventions. Given differences in cultures, attitudes, and behaviour constraints, it may not be the case that what has worked in Europe or America will also work in low-income countries. As such, interventions should be designed based on research conducted in the country in which the intervention is to be implemented. Therefore, there is a clear need for more in-depth research on the social and behavioural factors that influence road safety in low-income settings. There is also a strong need to embed sociotechnical systems thinking in crash analyses, and in road transport policy, planning, and construction. This is beginning to happen in high-income countries; however, LICs are being left behind in this respect. As such, a concerted effort to apply contemporary sociotechnical systems methods to the analysis of road transport in low-income countries is needed. The design of road safety interventions should be done based on a good understanding of the context of application and a consideration of all the factors that influence outcomes. Neither of these points are typically addressed in LICs; as such, they represent important topics for research.

5.7 How to build sustainable capacity effectively and timely?

Two of the future road safety challenges identified by the WHO (World Health Organization 2018) are 'Building Capacity' and 'Strengthening Data Collection', and effective training programmes could help improve both of these aspects of road safety. As discussed in Section 3.10, limited trained human resources and lack of data are two areas where capacity building is most warranted. Although some previous studies have investigated related issues in LICs, there is a need to continue work in this area in order to systematically identify and/or define the most cost-effective and sustainable strategies that can be in place in a timely fashion.

6. Summary

Road safety is inherently a multi-sectoral issue, where interventions will need to involve multiple strategies and stakeholders. The most successful programmes globally have been those that have integrated systems of legislation, regulation and enforcement, combining robust road safety data collection and management systems, economic evalution systems to inform investment decisions, significant technical and enforcement capacity, and a substantial knowledge base of the social, medical and behavioural implications of road safety interventions. Our study reveals where some of the major knowledge gaps exist for those topics that have been part of the research arena for some time. To this end, not only have we conducted a literature review, but we have also liaised with international organisations, local authorities, experts and professionals, particularly where the body of literature does not exist. Thus, we have identified some of the most critical road safety concerns in LICs; and consequently, suggest some areas of future research which could be considered to inform an agenda for future action.

Given the poor resources and lack of capacity for data management available in LICs, improving the quality of data in these countries would be one of the initial steps to make any improvements, either through investing in capacity for analysis and research, or through development of modern techniques of data collection. We also suggest investigations into data analysis techniques considering both the statistical foundations upon which such analyses are built, and use of proactive measures to prioritise investments, all carried out with a focus on existing cost and resource limitations in LICs, and using evidence-based techniques to promote effective changes. Combining expert insights and experiences with research from LICs, LMICs, and developed countries should provide the basis for a robust approach and future research agenda that will help improve road safety in LICs.

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REFERENCES

AASHTO. (2010). *Highway Safety Manual*. (American Association of State Highway and Transportation Officials, Ed.), Washington DC, USA.

Abegaz, T., Berhane, Y., Worku, A., & Assrat, A. (2014a). Effectiveness of an improved road safety policy in Ethiopia: an interrupted time series study. *BMC Public Health*, **14**(1), 539.

Abegaz, T., Berhane, Y., Worku, A., Assrat, A., & Assefa, A. (2014b). Road traffic deaths and injuries are under-reported in Ethiopia: a capture-recapture method. *PLOS ONE*, **9**(7), e103001.

Aeron-Thomas, A., Jacobs, G. D., Sexton, B. F., Gururaj, G., & Rahman, F. (2004). *The involvement and impact of road crashes on the poor: Bangladesh and India case studies*. (TRL Limited, Ed.).

Ahmad, H., Naeem, R., Feroze, A., … Mian, A. I. (2018). Teaching children road safety through storybooks: An approach to child health literacy in Pakistan. *BMC Pediatrics*, **18**(1), 1–8.

Ahmed, A., Sadullah, A. F. M., & Yahya, A. S. (2017). Errors in accident data, its types, causes and methods of rectification-analysis of the literature. *Accident Analysis & Prevention*. doi:https://doi.org/10.1016/j.aap.2017.07.018

Alemany, R., Ayuso, M., & Guillén, M. (2013). Impact of road traffic injuries on disability rates and long-term care costs in Spain. *Accident Analysis & Prevention*, **60**, 95–102.

Alghnam, S., Wegener, S. T., Bhalla, K., Colantuoni, E., & Castillo, R. (2015). Long-term outcomes of individuals injured in motor vehicle crashes: A population-based study. *Injury*, **46**(8), 1503–1508.

Alsop, J., & Langley, J. (2001). Under-reporting of motor vehicle traffic crash victims in New Zealand. *Accident Analysis & Prevention*, **33**(3), 353–359.

Ameratunga, S., Hijar, M., & Norton, R. (2006). Road-traffic injuries: confronting disparities to address a global-health problem. *The Lancet*, **367**(9521), 1533–1540.

Amoros, E., Martin, J.-L., Lafont, S., & Laumon, B. (2008). Actual incidences of road casualties, and their injury severity, modelled from police and hospital data, France. *European Journal of Public Health*, **18**(4), 360–365.

Amoros, E., Martin, J.-L., & Laumon, B. (2006). Under-reporting of road crash casualties in France. *Accident Analysis & Prevention*, **38**(4), 627–635.

Amoros, E., Martin, J.-L., & Laumon, B. (2007). Estimating non-fatal road casualties in a large French county, using the capture–recapture method. *Accident Analysis & Prevention*,

39(3), 483–490.

Amoros, E., Soler, G., Pascal, L., Ndaiye, A., Gadegbeku, B., & Martin, J.-L. (2018). Estimation of the number of seriously injured road users in France, 2006–2015. *Revue d'Épidémiologie et de Santé Publique*, **66**(Supplement 5). doi:https://doi.org/10.1016/j.respe.2018.05.258

Anam, T. (2014). Bangladesh's travelling pain. Retrieved March 1, 2019, from https://www.nytimes.com/2014/09/03/opinion/tahmima-anam-bangladeshs-traveling-pain.html

Bachani, A. M., Galiwango, E., Kadobera, D., … Hyder, A. A. (2014). A new screening instrument for disability in low-income and middle-income settings: application at the Iganga-Mayuge Demographic Surveillance System (IM-DSS), Uganda. *BMJ Open*, **4**(12), e005795.

Bachani, A. M., Galiwango, E., Kadobera, D., … Hyder, A. A. (2016). Characterizing disability at the Iganga-Mayuge Demographic Surveillance System (IM-DSS), Uganda. *Disability and Rehabilitation*, **38**(13), 1291–1299.

Bachani, A. M., Hung, Y. W., Mogere, S., … Hyder, A. A. (2013). Prevalence, knowledge, attitude and practice of speeding in two districts in Kenya: Thika and Naivasha. *Injury*, **44**(SUPPL. 4), S24–S30.

Bachani, A. M., Mogere, S., Hyder, A. A., Hung, Y. W., Nyamari, J., & Akunga, D. (2017a). Helmet wearing in Kenya: prevalence, knowledge, attitude, practice and implications. *Public Health*, **144**(410), S23–S31.

Bachani, A. M., Peden, M., Gururaj, G., Norton, R., & Hyder, A. A. (2017b). Road traffic injuries. In C. N. Mock, R. Nugent, O. Kobusingye, & K. R. Smith, eds., *Injury Prevention and Environmental Health. Disease Control Priorities Volume 7*.

Bachani, A. M., Risko, C. B., Gnim, C., Coelho, S., & Hyder, A. A. (2017c). Knowledge, attitudes, and practices around drinking and driving in Cambodia: 2010–2012. *Public Health*, **144**, S32–S38.

Banstola, A., & Mytton, J. (2017). Cost-effectiveness of interventions to prevent road traffic injuries in low- and middle-income countries: A literature review. *Traffic Injury Prevention*, **18**(4), 357–362.

Bauer, R., Steiner, M., Khnelt-Leddihn, A., Rogmans, W., & Kisser, R. (2018). Under-reporting of vulnerable road users in official EU road accident statistics - implications for road safety and added value of EU IDB hospital data. *Injury Prevention*, **24**(Suppl 2), A266–A266.

Bhalla, K., & Shotten, M. (2019). Building road safety institutions in low- and middle-income countries: the case of Argentina. *Health Systems & Reform*, 1–13.

Bhatti, J. A., Razzak, J. A., Lagarde, E., & Salmi, L. R. (2011). Differences in police, ambulance, and emergency department reporting of traffic injuries on Karachi-Hala road, Pakistan. *BMC Research Notes*, **4**, 75.

Bishai, D., & Bachani, A. M. (2012). Injury costing frameworks. In G. Li & S. P. Baker, eds., *Injury Research: Theories, Methods and Approaches*, Springer US.

Bishai, D., Hyder, A. A., Ghaffar, A., Morrow, R. H., & Kobusingye, O. (2003). Rates of public investment for road safety in developing countries: case studies of Uganda and Pakistan. *Health Policy and Planning*, **18**(2), 232–235.

Blantari, J., Asiamah, G., Appiah, N., & Mock, C. (2005). An evaluation of the effectiveness of televised road safety messages in Ghana. *International Journal of Injury Control and Safety Promotion*, **12**(1), 23–29.

Bloomberg Philanthropies. (2019). Road Safety. Retrieved April 24, 2019, from https://www.bloomberg.org/program/public-health/road-safety/

Bonnet, E., Lechat, L., & Ridde, V. (2018). What interventions are required to reduce road traffic injuries in Africa? A scoping review of the literature. *PLOS ONE*, **13**(11), e0208195.

Bonnet, E., Nikiéma, A., Traoré, Z., Sidbega, S., & Ridde, V. (2017). Technological solutions for an effective health surveillance system for road traffic crashes in Burkina Faso. *Global Health Action*, **10**(1). doi:10.1080/16549716.2017.1295698

Bradbury, A., & Quimby, A. (2008). Community road safety education: an international perspective. *Proceedings of the Institution of Civil Engineers - Municipal Engineer*. doi:10.1680/muen.2008.161.2.137

Broughton, J., Keigan, M., Yannis, G., … Tecl, J. (2010). Estimation of the real number of road casualties in Europe. *Safety Science*, **48**(3), 365–371.

Cercarelli, L. R., Rosman, D. L., & Ryan, G. A. (1996). Comparison of accident and emergency with police road injury data. *Journal of Trauma*, **40**(5), 805–809.

Chang, A., Saunier, N., & Laureshyn, A. (2017). *Proactive methods for road safety analysis*.

Chini, F., Farchi, S., Camilloni, L., … Rossi, P. (2009). Road traffic injuries in one local health unit in the Lazio region: results of a surveillance system integrating police and health data. *International Journal of Health Geographics*, **8**(1), 21.

Conderino, S., Fung, L., Sedlar, S., & Norton, J. M. (2017). Linkage of traffic crash and hospitalization records with limited identifiers for enhanced public health surveillance.

Accident Analysis & Prevention, **101**, 117–123.

Damsere-Derry, J., Palk, G., & King, M. (2017). Road accident fatality risks for "vulnerable" versus "protected" road users in northern Ghana. *Traffic Injury Prevention*, **18**(7), 736–743.

Dandona, R., Kumar, G. A., Ameer, M. A., Reddy, G. B., & Dandona, L. (2008). Under-reporting of road traffic injuries to the police: results from two data sources in urban India. *Injury Prevention*, **14**(6), 360–365.

de Leur, P., & Sayed, T. (2003). A framework to proactively consider road safety within the road planning process. *Canadian Journal of Civil Engineering*, **30**(4), 711–719.

Deb, S., Strawderman, L., DuBien, J., Smith, B., Carruth, D. W., & Garrison, T. M. (2017). Evaluating pedestrian behavior at crosswalks: Validation of a pedestrian behavior questionnaire for the U.S. population. *Accident Analysis & Prevention*, **106**, 191–201.

Dhibi, M. (2019). Road safety determinants in low and middle income countries. *International Journal of Injury Control and Safety Promotion*, **26**(1), 99–107.

Dibondo, D. (2018). MP blames NTSA, police to blame for increasing road carnage. Retrieved March 2, 2019, from https://www.the-star.co.ke/news/2018/01/01/mp-blames-ntsa-police-to-blame-for-increasing-road-carnage_c1691176

Dixey, R. A. (1999). "Fatalism", accident causation and prevention: issues for health promotion from an exploratory study in a Yoruba town, Nigeria. *Health Education Research*, **14**(2), 197–208.

Duc, N. H., Hoa, D. T. M., Huong, N. T., & Bao, N. N. (2011). Study on Vietnam traffic accident situation via data of health sector. *Journal of the Eastern Asia Society for Transportation Studies*, **9**, 2011–2021.

Esperato, A., Bishai, D., & Hyder, A. A. (2012). Projecting the health and economic impact of road safety initiatives: A case study of a multi-country project. *Traffic Injury Prevention*, **13**(SUPPL. 1), 82–89.

Ferrando, J., Plasencia, A., Ricart, I., Oros, M., & Borrell, C. (1999). The contribution of independent health and police sources of information to the ascertainment of traffic deaths in a European urban setting. In *Proceedings of the 43rd Annual Conference of the Association for the Advancement of Automotive Medicine*, Barcelona (Sitges), Spain.

Garbacz, C. (1991). Impact of the New Zealand seat belt law. *Economic Inquiry*, **29**(2), 310–316.

Global Road Safety Partnership. (2016). *Road Map: Strategic Plan 2015-2020*, Geneva, Switzerland.

Goel, R., Garcia, L. M. T., Goodman, A., … Woodcock, J. (2018). Estimating city-level travel patterns using street imagery: A case study of using Google Street View in Britain. *PLOS ONE*, **13**(5), e0196521.

Granié, M. A., Pannetier, M., & Guého, L. (2013). Developing a self-reporting method to measure pedestrian behaviors at all ages. *Accident Analysis & Prevention*, **50**, 830–839.

Gupta, M., Menon, G. R., Devkar, G., & Thomson, H. (2016). *Regulatory and road engineering interventions for preventing road traffic injuries and fatalities among vulnerable (non-motorised and motorised two-wheel) road users in low- and middle-income countries*, London, UK.

Hasanat-E-Rabbi, S., Hoque, M. S., McIlroy, R. C., & Stanton, N. . (n.d.). Exploring pedestrian behaviour through attitudes towards traffic safety and demographic characteristics in the context of a low-income country. *In Preparation*.

Hauer, E. (1997). *Observational before/after studies in road safety. Estimating the effect of highway and traffic engineering measures on road safety*, Bingley, UK: Emerald Group Publishing.

Health Effects Institute. (2018). *State of Global Air 2018. A special report on global exposure to air pollution and its disease burden*, Boston, MA.

Heydari, S. (2018). A flexible discrete density random parameters model for count data: Embracing unobserved heterogeneity in highway safety analysis. *Analytic Methods in Accident Research*, **20**, 68–80.

Heydari, S., Fu, L., Thakali, L., & Joseph, L. (2018). Benchmarking regions using a heteroskedastic grouped random parameters model with heterogeneity in mean and variance: Applications to grade crossing safety analysis. *Analytic Methods in Accident Research*, **19**, 33–48.

Heydari, S., Miranda-Moreno, L. F., Lord, D., & Fu, L. (2014). Bayesian methodology to estimate and update safety performance functions under limited data conditions: A sensitivity analysis. *Accident Analysis & Prevention*, **64**, 41–51.

Hyder, A. A., Allen, K. A., Peters, D. H., Chandran, A., & Bishai, D. (2013). Large-scale road safety programmes in low- and middle-income countries: An opportunity to generate evidence. *Global Public Health*, **8**(5), 504–518.

Hyder, A. A., Norton, R., Pérez-Núñez, R., … Road Traffic Injuries Research Network's Group. (2016). The Road Traffic Injuries Research Network: a decade of research capacity strengthening in low- and middle-income countries. *Health Research Policy and Systems*, **14**(1), 14.

Hyder, A. A., Paichadze, N., Toroyan, T., & Peden, M. M. (2017). Monitoring the Decade of Action for Global Road Safety 2011–2020: an update. *Global Public Health*, **12**(12), 1492–1505.

Hyder, A. A., & Razzak, J. A. (2013). The challenges of injuries and trauma in Pakistan: An opportunity for concerted action. *Public Health*, **127**(8), 699–703.

IRTAD. (2011). Reporting on Serious Road Traffic Casualties. *International Traffic Safety Data and Analysis Group*, 107.

Jacobs, G., Aeron-Thomas, A., & Astrop, A. (2000). *Estimating global road fatalities. TRL Report 445*, Crowthorne, UK: Transport Research Laboratory.

Johansson, R. (2009). Vision Zero – Implementing a policy for traffic safety. *Safety Science*, **47**(6), 826–831.

John Hopkins International Injury Research Unit. (2019). *Risky road behaviors in Addis Ababa*.

Johnson, M. (2012). Assessing a country's drink driving situation: An overview of the method used in 6 low- and middle-income countries. *Traffic Injury Prevention*, **13**(2), 96–100.

Kelly, A. (2012). The world's deadliest road. Retrieved March 1, 2019, from https://www.theguardian.com/global-development/2012/dec/09/world-most-lethal-road-bangladesh

Kenardy, J., Heron-Delaney, M., Hendrikz, J., Warren, J., Edmed, S. L., & Brown, E. (2017). Recovery trajectories for long-term health-related quality of life following a road traffic crash injury: Results from the UQ SuPPORT study. *Journal of Affective Disorders*, **214**, 8–14.

Khademi, N., & Choupani, A.-A. (2018). Investigating the road safety management capacity: Toward a lead agency reform. *IATSS Research*, **42**(3), 105–120.

Kimanthi, K. (2018). Police back on the roads with gusto as NTSA men leave. Retrieved March 1, 2019, from https://www.nation.co.ke/news/Police-back-on-the-roads-as-NTSA-men-leave-/1056-4259144-40j5gmz/index.html

Kouabenan, D. R. (1998). Beliefs and the perception of risks and accidents. *Risk Analysis*, **18**(3), 243–252.

Kraemer, J. D., Honermann, B. J., & Roffenbender, J. S. (2012). Cyclists' helmet usage and characteristics in central and southern Malawi: a cross-sectional study. *International Journal of Injury Control and Safety Promotion*, **19**(4), 373–377.

Lagarde, E. (2007). Road traffic injury is an escalating burden in Africa and deserves proportionate research efforts. *PLOS Medicine*, **4**(6), 170.

Landolt, M. A., Vollrath, M. E., Gnehm, H. E., & Sennhauser, F. H. (2009). Post-traumatic stress impacts on quality of life in children after road traffic accidents: Prospective study. *Australian & New Zealand Journal of Psychiatry*, **43**(8), 746–753.

Li, Q., Alonge, O., & Hyder, A. A. (2016). Children and road traffic injuries: Can't the world do better? *Archives of Disease in Childhood*, **101**(11), 1063–1070.

Lujic, S., Finch, C., Boufous, S., Hayen, A., & Dunsmuir, W. (2008). How comparable are road traffic crash cases in hospital admissions data and police records? An examination of data linkage rates. *Australian and New Zealand Journal of Public Health*, **32**(1), 28–33.

Lund, J., & Bjerkedal, T. (2001). Permanent impairments, disabilities and disability pensions related to accidents in Norway. *Accident Analysis & Prevention*, **33**(1), 19–30.

Lv, J., Lord, D., Zhang, Y., & Chen, Z. (2015). Investigating Peltzman effects in adopting mandatory seat belt laws in the US: Evidence from non-occupant fatalities. *Transport Policy*, **44**, 58–64.

Ma, S., Li, Q., Zhou, M., Duan, L., & Bishai, D. (2012). Road traffic injury in China: a review of national data sources. *Traffic Injury Prevention*, **13**(sup1), 57–63.

Maghsoudi, A., Boostani, D., & Rafeiee, M. (2018). Investigation of the reasons for not using helmet among motorcyclists in Kerman, Iran. *International Journal of Injury Control and Safety Promotion*, **25**(1), 58–64.

Magoola, J., Kobusingye, O., Bachani, A. M., Tumwesigye, N. M., Kimuli, D., & Paichadze, N. (2018). Estimating road traffic injuries in Jinja district, Uganda, using the capture-recapture method. *International Journal of Injury Control and Safety Promotion*, **25**(4), 341–346.

Mannering, F. L., & Bhat, C. R. (2014). Analytic methods in accident research: methodological frontier and future directions. *Analytic Methods in Accident Research*, **1**, 1–22.

Mannering, F. L., Shankar, V., & Bhat, C. R. (2016). Unobserved heterogeneity and the statistical analysis of highway accident data. *Analytic Methods in Accident Research*, **11**, 1–16.

Martin, A., Lagarde, E., & Salmi, L. R. (2018). Burden of road traffic injuries related to delays in implementing safety belt laws in low- and lower-middle-income countries. *Traffic Injury Prevention*, **19**(sup1), S1–S6.

McIlroy, R. C., Nam, V. H., Bunyasi, B., … Stanton, N. A. (n.d.). Vulnerable road users in low-, middle-, and high-income countries: Examining the relationships between pedestrian behaviours and attitudes towards traffic safety. *Accident Analysis & Prevention*.

McIlroy, R. C., Plant, K. A., Hoque, M. S., … Stanton, N. A. (2019). Who is responsible for global road safety? A cross-cultural comparison of Actor Maps. *Accident Analysis & Prevention*, **122**, 8–18.

Metamorphosis Consortium. (2017). *General analysis report: transformation of neighbourhoods in a child-friendly way to increase the quality of life for all citizens*.

Meuleners, L. B., Lee, A. H., Cercarelli, L. R., & Legge, M. (2006). Estimating crashes involving heavy vehicles in Western Australia, 1999–2000: a capture–recapture method. *Accident Analysis & Prevention*, **38**(1), 170–174.

Mitra, S., & Washington, S. (2012). On the significance of omitted variables in intersection crash modeling. *Accident Analysis & Prevention*, **49**, 439–448.

Moher, D., Shamseer, L., Clarke, M., … Group, P.-P. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, **4**(1), 1.

Morrison, A., & Stone, D. H. (2000). Capture-recapture: a useful methodological tool for counting traffic related injuries? *Injury Prevention*, **6**(4), 299–304.

Mukama, T., Ssemugabo, C., Ali Halage, A., … Kobusingye, O. (2019). Costs of unintentional injuries among children in an urban slum community in Kampala city, Uganda. *International Journal of Injury Control and Safety Promotion*, **26**(2), 129–136.

Nakahara, S., & Wakai, S. (2001). Underreporting of traffic injuries involving children in Japan. *Injury Prevention*, **7**(3), 242–244.

Nantulya, V. M., & Reich, M. R. (2002). The neglected epidemic: Road traffic injuries in developing countries, **324**(May 2002), 1139–1141.

Nantulya, V. M., & Reich, M. R. (2003). Equity dimensions of road traffic injuries in low- and middle-income countries. *Injury Control and Safety Promotion*, **10**(1–2), 13–20.

Ngueutsa, R., & Kouabenan, D. R. (2017). Fatalistic beliefs, risk perception and traffic safe behaviors. *Revue Européenne de Psychologie Appliquée*, **67**(6), 307–316.

Nicita, A., & Benedettini, S. (2012). *The costs of avoiding accidents: selective compliance and the "Peltzman Effect" in Italy*.

Nordfjærn, T., Jørgensen, S., & Rundmo, T. (2012). Cultural and socio-demographic predictors of car accident involvement in Norway, Ghana, Tanzania and Uganda. *Safety Science*, **50**(9), 1862–1872.

Nordfjærn, T., Jrgensen, S., & Rundmo, T. (2011). A cross-cultural comparison of road traffic risk perceptions, attitudes towards traffic safety and driver behaviour. *Journal of Risk Research*, **14**(6), 657–684.

Nordfjærn, T., Şimşekoğlu, Ö., & Rundmo, T. (2014). Culture related to road traffic safety: A comparison of eight countries using two conceptualizations of culture. *Accident Analysis & Prevention*, **62**, 319–328.

Odero, W., Garner, P., & Zwi, A. (1997). Road traffic injuries in developing countries: a comprehensive review of epidemiological studies. *Tropical Medicine & International Health*, **2**(5), 445–460.

Ojo, T., Adetona, C. O., Agyemang, W., & Afukaar, F. K. (2019). Pedestrian risky behavior and safety at zebra crossings in a Ghanaian metropolitan area. *Traffic Injury Prevention*, **20**(2), 216–219.

Omari, K., & Baron-Epel, O. (2013). Low rates of child restraint system use in cars may be due to fatalistic beliefs and other factors. *Transportation Research Part F: Traffic Psychology and Behaviour*, **16**, 53–59.

Palmera-Suárez, R., López-Cuadrado, T., Brockhaus, S., Fernández-Cuenca, R., Alcalde-Cabero, E., & Galán, I. (2016). Severity of disability related to road traffic crashes in the Spanish adult population. *Accident Analysis & Prevention*, **91**, 36–42.

Palmera-Suárez, R., López-Cuadrado, T., Fernández-Cuenca, R., Alcalde-Cabero, E., & Galán, I. (2018). Inequalities in the risk of disability due to traffic injuries in the Spanish adult population, 2009–2010. *Injury*, **49**(3), 549–555.

Patel, A., Krebs, E., Andrade, L., Rulisa, S., Vissoci, J. R. N., & Staton, C. A. (2016). The epidemiology of road traffic injury hotspots in Kigali, Rwanda from police data. *BMC Public Health*, **16**(1), 697.

Peden, M. (2004). *World report on road traffic injury prevention*, Geneva, Switzerland.

Peden, M., Kobusingye, O., & Monono, M. E. (2013). Africa's roads - the deadliest in the world. *SAMJ: South African Medical Journal*, **103**, 228–229.

Peltzer, K. (2003). Seatbelt use and belief in destiny in a sample of South African black and white drivers. *Psychological Reports*, **93**(3), 732–734.

Peltzer, K., & Renner, W. (2003). Superstition, risk-taking and risk perception of accidents among South African taxi drivers. *Accident Analysis & Prevention*, **35**(4), 619–623.

Perel, P., Ker, K., Ivers, R., & Blackhall, K. (2007). Road safety in low- and middle-income countries: a neglected research area. *Injury Prevention*, **13**(4), 227–227.

Peters, D. (2013). *Gender and sustainable urban mobility*.

Petrucelli, E., States, J. D., & Hames, L. N. (1981). The abbreviated injury scale: Evolution, usage and future adaptability. *Accident Analysis & Prevention*, **13**(1), 29–35.

Plant, K. A., McIlroy, R. C., & Stanton, N. A. (2018). Taking a "7 E's" approach to road safety in the UK and beyond. In R. Charles & J. Wilkinson, eds., *Contemporary Ergonomics and Human Factors 2018*, Birmingham, UK: CIEHF.

Polinder, S., Haagsma, J., Bos, N., … van Beeck, E. (2015). Burden of road traffic injuries: Disability-adjusted life years in relation to hospitalization and the maximum abbreviated injury scale. *Accident Analysis & Prevention*, **80**, 193–200.

Räsänen, M., Lajunen, T., Alticafarbay, F., & Aydin, C. (2007). Pedestrian self-reports of factors influencing the use of pedestrian bridges. *Accident Analysis & Prevention*, **39**(5), 969–973.

Remacle, E., Sanon, C., & Aketch, S. (2018). *Safer Africa: Thematic fact sheet on gender*.

Reurings, M. C. B., & Stipdonk, H. L. (2011). Estimating the number of serious road injuries in the Netherlands. *Annals of Epidemiology*, **21**(9), 648–653.

Rissanen, R., Berg, H.-Y., & Hasselberg, M. (2017). Quality of life following road traffic injury: A systematic literature review. *Accident Analysis & Prevention*, **108**, 308–320.

Rosman, D. L. (2001). The Western Australian Road Injury Database (1987–1996): ten years of linked police, hospital and death records of road crashes and injuries. *Accident Analysis & Prevention*, **33**(1), 81–88.

Safer Africa. (2019). SaferAfrica project. Retrieved June 7, 2019, from http://www.saferafrica.eu/

Salmon, R., & Eckersley, W. (2010). Where there's no green man: child road-safety education in Ethiopia. *Development in Practice*, **20**(6), 726–733.

Samuel, J. C., Sankhulani, E., Qureshi, J. S., … Charles, A. G. (2012). Under-reporting of road traffic mortality in developing countries: application of a capture-recapture statistical model to refine mortality estimates. *PLOS ONE*, **7**(2), e31091.

Sango, H. A., Testa, J., Meda, N., … Lagarde, E. (2016). Mortality and morbidity of urban road traffic crashes in Africa: capture-recapture estimates in Bamako, Mali, 2012. *PLOS ONE*, **11**(2), e0149070.

Sayed, T., Saunier, N., Lovegrove, G., & de Leur, P. (2010). Advances in proactive road safety planning. In *Proceedings of the 20th Canadian Multidisciplinary Road Safety Conference*, Ontario, Canada.

Sciortino, S., Vassar, M., Radetsky, M., & Knudson, M. M. (2005). San Francisco pedestrian injury surveillance: mapping, under-reporting, and injury severity in police and hospital records. *Accident Analysis & Prevention*, **37**(6), 1102–1113.

Shamseer, L., Moher, D., Clarke, M., … Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ : British Medical Journal*, **349**, g7647.

Şimşekoğlu, Ö., Nordfjærn, T., Zavareh, M. F., Hezaveh, A. M., Mamdoohi, A. R., & Rundmo, T. (2013). Risk perceptions, fatalism and driver behaviors in Turkey and Iran. *Safety Science*, **59**, 187–192.

St-Aubin, P., Saunier, N., & Miranda-Moreno, L. (2015). Large-scale automated proactive road safety analysis using video data. *Transportation Research Part C: Emerging Technologies*, **58**, 363–379.

Staton, C., Vissoci, J., Gong, E. Y., … Hocker, M. (2016). Road traffic injury prevention initiatives: a systematic review and metasummary of effectiveness in low and middle income countries. *PLOS ONE*, **11**(1). doi:10.1371/journal.pone.0144971

Stewart, K., Bivans, B., Nguyen, L. H., & Onigbogi, L. (2013). Drink driving prevention initiatives in low- and middle-income countries: challenges and progress in Nigeria and Vietnam. *20th International Conference on Alcohol, Drugs and Traffic Safety Conference*, (Grsp), 1–7.

Towner, E., & Towner, J. (2009). Child injury in a changing world. *Global Public Health*, **4**(4), 402–413.

Traffic General Directorate. (2010). *Spanish road safety strategy 2011-2020*, Madrid, Spain.

Tulu, G. S., Haque, M. M., Washington, S., & King, M. J. (2015). Investigating pedestrian injury crashes on modern roundabouts in Addis Ababa, Ethiopia. *Transportation Research Record: Journal of the Transportation Research Board*, **2512**(July 2016), 1–10.

Turner, J., & Fletcher, J. (2007). *TI-UP Enquiry: Gender and road safety*.

UN DESA. (2015). *The World's Women 2015: trends and statistics*. (UN Department of Economic and Social Affairs, Ed.), New York, USA.

UNECE. (2014). *Strengthening the national road safety management capacities of selected developing countries and countries with economies in transition*.

UNRSC. (2019). United Nations Road Safety Collaboration Publications. Retrieved June 6, 2019, from https://www.who.int/roadsafety/publications/en/

Ustun, T. B., Kostanjsek, N., Chatterji, S., & Rehm, J. (2010). *Measuring health and disability: manual for WHO Disability Assessment Schedule (WHODAS 2.0)*, Geneva, switzerland.

Uteng, T. P. (2012). *Gender and mobility in the developing world*, Washington, DC: World Bank.

Uzondu, C., Jamson, S., & Lai, F. (2018). Exploratory study involving observation of traffic behaviour and conflicts in Nigeria using the Traffic Conflict Technique. *Safety Science*, **110**, 273–284.

Uzondu, C., Jamson, S., & Lai, F. (2019). Investigating unsafe behaviours in traffic conflict situations: An observational study in Nigeria. *Journal of Traffic and Transportation Engineering (English Edition)*. doi:10.1016/j.jtte.2018.06.002

Üzümcüoğlu, Y., Özkan, T., Lajunen, T., … Chliaoutakis, J. (2016). Life quality and rehabilitation after a road traffic crash: A literature review. *Transportation Research Part F: Traffic Psychology and Behaviour*, **40**, 1–13.

van der Horst, A. R. A., Thierry, M. C., Vet, J. M., & Rahman, A. K. M. F. (2017). An evaluation of speed management measures in Bangladesh based upon alternative accident recording, speed measurements, and DOCTOR traffic conflict observations. *Transportation Research Part F: Traffic Psychology and Behaviour*, **46**, 390–403.

van Hest, R., Grant, A., & Abubakar, I. (2011). Quality assessment of capture–recapture studies in resource-limited countries. *Tropical Medicine & International Health*, **16**(8), 1019–1041.

Vasconcellos, E. A. de. (2001). *Urban transport, environment, and equity : the case for developing countries*, Earthscan.

Venter, C., Vokolkova, V., & Michalek, J. (2007). Gender, residential location, and household travel: empirical findings from low-income urban settlements in Durban, South Africa. *Transport Reviews*, **27**(6), 653–677.

Wang, C., Quddus, M. A., & Ison, S. G. (2013). The effect of traffic and road characteristics on road safety: A review and future research direction. *Safety Science*, **57**, 264–275.

Ward, H., Lyons, R., & Thoreau, R. (2006). *Under-reporting of road casualties - Phase 1*, London, UK.

Watson, A., Watson, B., & Vallmuur, K. (2015). Estimating under-reporting of road crash injuries to police using multiple linked data collections. *Accident Analysis & Prevention*, **83**, 18–25.

Wegman, F. (2017). The future of road safety: a worldwide perspective. *IATSS Research*, **40**(2), 66–71.

Wesson, H. K. H., Boikhutso, N., Bachani, A. M., Hofman, K. J., & Hyder, A. A. (2013, September 1). The cost of injury and trauma care in low-and middle-income countries: A review of economic evidence. *Health Policy and Planning*, pp. 795–808.

Wiebe, D. J., Ray, S., Maswabi, T., Kgathi, C., & Branas, C. C. (2016). Economic development and road traffic fatalities in two neighbouring African nations. *African Journal of Emergency Medicine*, **6**(2), 80–86.

Wijnen, W., & Stipdonk, H. (2016). Social costs of road crashes: an international analysis.

Accident Analysis & Prevention, **94**, 97–106.

Winston, C., Maheshri, V., & Mannering, F. (2006). An exploration of the offset hypothesis using disaggregate data: The case of airbags and antilock brakes. *Journal of Risk and Uncertainty*, **32**(2), 83–99.

Wismans, J., Skogsmo, I., Nilsson-Ehle, A., Lie, A., Thynell, M., & Lindberg, G. (2016). Commentary: status of road safety in Asia. *Traffic Injury Prevention*, **17**(3), 217–225.

World Bank. (2017). *The high toll of traffic injuries: unacceptable and preventable*, World Bank.

World Bank. (2018). *Global Road Safety Facility Annual Report 2018*, Washington, D.C., USA.

World Health Organization. (2008). *Capacity building for preventing injuries and violence: Strategic plan 2009-2013*.

World Health Organization. (2011). *Global Plan for the Decade of Action for Road Safety 2011-2020*, Geneva, Switzerland.

World Health Organization. (2013). *Global status report on road safety 2013*, Geneva, Switzerland.

World Health Organization. (2018). *Global status report on road safety 2018*, Geneva, Switzerland: World Health Organization.

World Health Organization. (2019). Metrics: Disability-Adjusted Life Year (DALY). Retrieved April 10, 2019, from https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

Yannis, G., Papadimitriou, E., Chaziris, A., & Broughton, J. (2014). Modeling road accident injury under-reporting in Europe. *European Transport Research Review*, **6**(4), 425–438.

Yildirim, Z. (2007). *Religiousness, conservatism and their relationship with traffic behaviour*, Middle East Technical University.

Zafar, S. N., Canner, J. K., Nagarajan, N., … Kushner, A. L. (2018). Road traffic injuries: cross-sectional cluster randomized countrywide population data from 4 low-income countries. *International Journal of Surgery*, **52**, 237–242.

Zimmerman, K., Jinadasa, D., Maegga, B., & Guerrero, A. (2015). Road traffic injury on rural roads in Tanzania: Measuring the effectiveness of a road safety program. *Traffic Injury Prevention*, **16**(5), 456–460.

Appendix 1 - Search terms developed for the literature review

The following tables give examples of the search strategy developed for this study, used for Scopus, EMBASE and PUBMED. The strategy aims to limit the search to LICs (see Scopus #1), and then limit the search according to the desired topics of vehicles and crashes (e.g. Scopus #2), road safety measures (e.g. Scopus #3), vehicle safety measures (e.g. Scopus #4), or vulnerable road user groups (e.g. Scopus #5)

Scopus Search Strategy

Set #	Search string	Results
#1 **Low-income countries**	TITLE-ABS-KEY(“developing country” OR “developing countries” OR Afghanistan OR Benin OR "Burkina Faso" OR Burundi OR "Central African Republic" OR Chad OR Comoros OR Congo OR Eritrea OR Ethiopia OR Gambia OR Guinea OR “Guinea-Bissau” OR Haiti OR “North Korea” OR Liberia Madagascar OR Malawi OR Mali OR Mozambique OR Nepal OR Niger OR Rwanda OR Senegal OR “Sierra Leone” OR Somalia OR Sudan OR Tanzania OR Togo OR Uganda OR Zimbabwe OR "low resource" OR "under-resourced" OR "resource poor" OR "under-developed" OR "underdeveloped" OR "developing world" OR “third world” OR LIC OR (low AND income))	**69,448**
#2 **Vehicles and accidents or crashes**	TITLE-ABS-KEY((("Motor Vehicles" OR Automobiles OR Motorcycles OR traffic OR vehicle OR vehicular OR car OR cars OR automobile OR motorcycle OR taxi OR cab OR road OR pedestrian OR pedestrians) AND (accident OR accidents OR crash OR crashes OR injury OR injuries)))	**151,221**
#3 **Road safety measures**	TITLE-ABS-KEY(“road safety” OR “road safety interventions” OR speeding OR “drink driving” OR helmet OR “motorcycle helmet” OR “seat belt” OR “seatbelt” OR “child restraint” OR “distracted driving” OR “drug driving” OR “traffic calming”)	**49,812**
#4 **Vehicle safety measures**	TITLE-ABS-KEY(“vehicle safety” OR “vehicle safety standards” OR “advanced braking” OR “anti-lock braking” OR “electronic stability control” OR NCAP)	**6,559**

#5 **Vulnerable road user groups**	TITLE-ABS-KEY("vulnerable road user" OR "disability" OR "disabled" OR "gender disaggregation" OR "gender")	**956,942**
#6 **Crashes in LICs**	#1 AND #2	**454**
#7 **Road safety measures in LICs**	#1 AND #3	**147**
#8 **Vehicle safety measures in LICs**	#1 AND #4	**5**
#9 **VRU crashes in LICs**	#1 AND #2 AND #5	**103**

These search terms do not guarantee that the papers identified will be appropriate for this review. For instance, of the five papers identified in search #8 'Vehicle safety measures in LICs', which applied country names and vehicle safety measures as the search string, none were specifically associated with LICs:

Citation	Location of study
1 Behnood, H.R. (2018) Best practice analysis of action for road safety in Iran amongst the leading developing countries using an optimized success indicator. Transport Policy, 66, pp. 76-84.	Iran (UMIC)
2. Kurmi, Y., Chaurasia, V., Sharma, J., Singh, S. (2018) Safety box on vehicle's front for striking object. International Conference on Recent Innovations in Signal Processing and Embedded Systems, RISE 2017, 2018-January, pp. 218-222.	Not country specific
3. Oviedo-Trespalacios, O., Scott-Parker, B. (2018) Young drivers and their cars: Safe and sound or the perfect storm? Accident Analysis and Prevention, 110, pp. 18-28.	Colombia (UMIC)
4. Pattanarattanamolee, R., Lertsinudom, S., Nakahara, S., Sakamoto, T. (2017) Ambulance crash in a rural area of Thailand. Journal of Emergency Medicine, 53 (5), pp. 730-734.	Thailand (UMIC)
5. Nordberg, E. (2000) Injuries as a public health problem in sub-Saharan Africa: Epidemiology and prospects for control. East African Medical Journal, 77 (12 SUPPL.), pp. S1-S41.	Not specifically road traffic crashes

Nevertheless, some of the issues raised in the UMIC-based papers may be applicable to this study.

EMBASE Search strategy

Set #	Search string	Results
#1 **Low-income countries**	('Afghanistan' or 'Benin' or 'Burkina Faso' or 'Burundi' or 'Central African Republic' or 'Chad' or 'Comoros' or 'Congo' or 'Eritrea' or 'Ethiopia' or 'Gambia' or 'Guinea' or 'Guinea-Bissau' or 'Haiti' or 'Korea' or 'Liberia' or 'Madagascar' or 'Malawi' or 'Mali' or 'Mozambique' or 'Nepal' or 'Niger' or 'Rwanda' or 'Senegal' or 'Sierra Leone' or 'Somalia' or 'Sudan' or 'Tanzania' or 'Togo' or 'Uganda' or 'Zimbabwe' or 'low resource' or 'under resourced' or 'resource poor' or 'under developed' or 'underdeveloped' or 'developing country' or 'developing countries' or 'developing world' or 'third world' or 'lic' or (low and income)).mp.	**565,528**
#2 **Vehicles and crashes**	('Motor Vehicles' or 'Automobiles' or 'Motorcycles' or 'traffic' or 'vehicle' or 'vehicular' or 'car' or 'cars' or 'automobile' or 'motorcycle' or 'taxi' or 'cab' or 'road' or 'pedestrian' or 'pedestrians').mp. and ('accident' or 'accidents' or 'crash' or 'crashes' 'injury' or 'injuries').ab,ti.	**66,544**
#3 **Road safety measures**	('road safety' or 'road safety interventions' or 'speeding' or 'drink driving' or 'helmet' or 'motorcycle helmet' or 'seat belt' or 'seatbelt' or 'child restraint' or 'distracted driving' or 'drug driving' or 'traffic calming').ab,ti.	**13,619**
#4 **Vehicle safety measures**	('vehicle safety' or 'vehicle safety standards' or 'advanced braking' or 'anti-lock braking' or 'electronic stability control' or 'NCAP').ab,ti.	**612**
#5 **Vulnerable road user groups**	('vulnerable road user' or 'disability' or 'disabled' or 'gender disaggregation' or 'gender').ab,ti.	**650,286**
#6 **Crashes in LICs**	#1 AND #2	**2,162**
#7 **Road safety measures in LICs**	#1 AND #3	**513**
#8 **Vehicle safety measures in LICs**	#1 AND #4	**16**
#9 **VRU crashes in LICs**	#1 AND #2 AND #5	**346**

PUBMED Search strategy

Set #	Search string	Results
#1 **Low-income countries**	"Developing Countries"[Mesh] OR "Afghanistan"[Mesh] OR "Benin"[Mesh] OR "Burkina Faso"[Mesh] OR "Burundi"[Mesh] OR "Central African Republic"[Mesh] OR "Chad"[Mesh] OR "Comoros"[Mesh] OR "Congo"[Mesh] OR "Eritrea"[Mesh] OR "Ethiopia"[Mesh] OR "Gambia"[Mesh] OR "Guinea"[Mesh] OR "Guinea-Bissau"[Mesh] OR "Korea"[Mesh] OR "Liberia"[Mesh] OR "Madagascar"[Mesh] OR "Malawi"[Mesh] OR "Mali"[Mesh] OR "Mozambique"[Mesh] OR "Nepal"[Mesh] OR "Niger"[Mesh] OR "Rwanda"[Mesh] OR "Senegal"[Mesh] OR "Sierra Leone"[Mesh] OR "Somalia"[Mesh] OR "Sudan"[Mesh] OR "Tanzania"[Mesh] OR "Togo"[Mesh] OR "Uganda"[Mesh] OR "Zimbabwe"[Mesh] OR "Developing Countries"[tiab] OR "Afghanistan"[tiab] OR "Benin"[tiab] OR "Burkina Faso"[tiab] OR "Burundi"[tiab] OR "Central African Republic"[tiab] OR "Chad"[tiab] OR "Comoros"[tiab] OR "Congo"[tiab] OR "Eritrea"[tiab] OR "Ethiopia"[tiab] OR "Gambia"[tiab] OR "Guinea"[tiab] OR "Guinea-Bissau"[tiab] OR "Korea"[tiab] OR "Liberia"[tiab] OR "Madagascar"[tiab] OR "Malawi"[tiab] OR "Mali"[tiab] OR "Mozambique"[tiab] OR "Nepal"[tiab] OR "Niger"[tiab] OR "Rwanda"[tiab] OR "Senegal"[tiab] OR "Sierra Leone"[tiab] OR "Somalia"[tiab] OR "Sudan"[tiab] OR "Tanzania"[tiab] OR "Togo"[tiab] OR "Uganda"[tiab] OR "Zimbabwe"[tiab] OR "low resource"[tiab] OR "under-resourced"[tiab] OR "resource poor"[tiab] OR "under-developed"[tiab] OR "underdeveloped"[tiab] OR "developing country"[tiab] OR "developing countries"[tiab] OR "developing world"[tiab] OR "third world"[tiab] OR lic[tiab] OR (low[tiab] AND income[tiab])	**463,699**
#2 **Vehicles and crashes**	"Accidents, Traffic"[Mesh] OR (("Motor Vehicles"[Mesh:NoExp] OR "Automobiles"[Mesh] OR "Motorcycles"[Mesh]	**70,881**

	OR traffic[tiab] OR vehicle[tiab] OR vehicular[tiab] OR car[tiab] OR cars[tiab] OR automobile[tiab] OR automobiles[tiab] OR motorcycle[tiab] OR motorcycles[tiab] OR taxi[tiab] OR cab[tiab] OR road[tiab] OR pedestrian[tiab] OR pedestrians[tiab]) AND (accident[tiab] OR accidents[tiab] OR injury[tiab] OR injuries[tiab] OR "Wounds and Injuries"[Mesh] OR "injuries" [Subheading]))	
#3 **Road safety measures**	"road safety"[tiab]' OR "road safety interventions"[tiab] or "speeding"[tiab] or "drink driving"[tiab] or "helmet"[tiab] or "motorcycle helmet"[tiab] or "seat belt"[tiab] or "seatbelt"[tiab] or "child restraint"[tiab] or "distracted driving"[tiab] or "drug driving"[tiab] or "traffic calming"[tiab]	**10,288**
#4 **Vehicle safety measures**	"vehicle safety"[tiab] or "vehicle safety standards"[tiab] or "advanced braking"[tiab] or "anti-lock braking"[tiab] or "electronic stability control"[tiab] or "NCAP"[tiab]	**537**
#5 **Vulnerable road user groups**	"vulnerable road user"[tiab] or "disability"[tiab] or "disabled"[tiab] or "gender disaggregation"[tiab] or "gender"[tiab]	**434,540**
#6 **Crashes in LICs**	#1 AND #2	**1,971**
#7 **Road safety measures in LICs**	#1 AND #3	**310**
#8 **Vehicle safety measures in LICs**	#1 AND #4	**15**
#9 **VRU crashes in LICs**	#1 AND #2 AND #5	**306**