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Who is responsible for global road safety? A cross-cultural comparison of Actor Maps

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ABSTRACT

The traditional three 'E's approach to road safety (engineering, education, enforcement) has had, and will continue to have, a significant impact on road traffic casualty rates worldwide. Nevertheless, with rising motorisation in many countries, global fatality numbers have changed little over the past decade. Following calls for the application of sociotechnical systems thinking to the problem, we widen the road safety discussion with an additional four 'E's; economics, emergency response, enablement, and, the umbrella term for the approach taken, ergonomics. The research presents an application of Rasmussen's Risk Management Framework to the road safety systems of five distinct nations; Bangladesh, China, Kenya, the UK, and Vietnam. Following site visits, reviews of literature, and interviews with subject matter experts in each of the countries, a series of Actor Map models of the countries' road safety systems were developed. These are compared and discussed in terms of the wide variety of interconnecting organisations involved, their influences on road safety outcomes, the differences between nations, and the need to look beyond road users when designing road safety interventions.

1. Introduction

Road transport is central to economic growth and sustainable development worldwide, linking families to schools, workers to jobs, producers to consumers, communities to education and health care facilities. Its importance cannot be overstated; its development is necessarily parallel to that of any given country. Yet it comes at a great cost; in 2015, road traffic incidents claimed the lives of 1.34 million people (WHO, 2017a). Of these fatalities, 90% occurred low- and middle-income countries (LMICs), countries in which only half of the world's registered vehicles are found (WHO, 2015). Globally, it is the 10th leading cause of death; for those aged between 15 and 24 it is the leading cause of death (ibid.). Additional to the fatalities, every year the world sees 78.2 million non-fatal injuries requiring medical attention (GRSF & IHME, 2014).

The 46% increase in fatality numbers that the world has seen over the past twenty years is linked with significant increases in motorisation in the developing world (GRSF & IHME, 2014); however, an increase in road deaths need not be a necessary side effect of increased access to mobility. Between 1986 and 2016 the UK's population increased by 15% and the number of vehicle miles driven by around 50%, yet its fatality rates dropped by 68% (Department for Transport, 2016, 2017a). Similar trends can be found elsewhere, such as in Japan, the US, and Sweden (see GRSF & IHME, 2014). That said, the issue is highly complex; in the UK (a country for which historic traffic and economic data is readily available) there are clear links between economic activity and accident rates, with years of higher economic prosperity linked with higher numbers of fatalities and injuries (Department for Transport, 2017b).

Despite significant progress since the 1980s, the UK has, in recent years, seen road safety efforts plateau in their effectiveness; since 2010 there has been no significant change in the numbers of people killed or seriously injured on its roads (Department for Transport, 2017b). Globally, fatality numbers have seen a consistent rise over the past 40 years (WHO, 2015). Although some reports estimate a levelling off of death rates (WHO, 2015), Global Burden of Disease data suggests otherwise (GRSF & IHME, 2014).

To reduce the burden of road transport worldwide, and to improve matters further in the UK and other (relatively) high-performing countries, we need to look for fresh perspectives from which to view the

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challenge. In this article we argue for a sociotechnical systems approach, using Jens Rasmussen's (1997) Risk Management Framework and the associated Actor Map representation tool (e.g. Svedung and Rasmussen, 2002). This approach structured our analyses of the road transport systems of five geographically dispersed as well as economically and culturally distinct nations; Bangladesh, China, Kenya, Vietnam, and the UK. We also argue for an expansion of the traditional three 'E's approach to road safety; not only should we identify interventions couched in engineering, education, and enforcement (aspects that dominated road safety research and practice in the past), but in economics, emergency response, enablement of research, and beyond.

2. The Many 'E's of Road Safety

Engineering, enforcement, and education represent the 'traditional' approaches to road safety (e.g. Lonero et al. 1994). The terms encompass a wide variety of interventions; under engineering are included vehicle technology as well as road environment design efforts; enforcement covers the development and enforcement of legal standards (in-vehicle and product design, for example) in addition to the use of law to shape driver behaviour; and education includes both the pre- and post-license training of drivers, as well as the education of the wider public. These have been critical in improving road safety outcomes in the past, and will continue to be so into the future. Nevertheless, we need to look beyond these approaches if we are to overcome the challenges faced. We must expand our repertoire of the lenses through which we view road safety. Here we put forward three additional 'E's, namely economics, emergency response, and enablement. To add to the alliteration, all of these 'E's are couched in a seventh, ergonomics; we use this as the umbrella term for the approach taken (i.e., the sociotechnical theoretical framework and methods). This is by no means an exhaustive or definitive list of potentially useful 'E's (or any other letter for that matter), rather it is a starting point for expanding discussions around road safety.

2.1. Economics

In the UK alone, the value of prevention of all reported road casualties was estimated at £15.3 billion for the year 2015; if we include unreported casualties, this estimate rises to £35.55 billion (DfT, 2016). Globally, road traffic injury and death is thought to cause economic losses of around 3% of a country's GDP; in LMICs, the figure rises to 5% of GDP (WHO, 2015). It is clearly an issue of economics; yet despite the huge financial cost, budgetary constraints often dictate just how much can be invested in road safety each year. Indeed, funding is considered the primary barrier to engineering solutions to road safety (Ciaburro and Spencer, 2017).

Where engineering (and educating) will, in the overwhelming majority of circumstances, require expenditure without any expectation of subsequent income generation, economic incentives can be used to both shape driver behaviour and generate income at the same time. In Uganda, for example, income generated through fining drivers caught speeding more than outweighed the economic cost of the police patrols required to catch offenders (Bishai et al. 2008). In the UK, cost-benefit analyses of speed cameras suggest a net financial gain for the economy when considering the benefits from avoided injuries (Gains et al., 2005), despite the assertion that the placement of speed cameras is based on safety considerations and not on financial ones (House of Commons Transport Committee, 2016).

These gains are without taking into account the cost benefits of life years saved or deaths averted, though this is a sensitive topic; not only is evidence from cost-effectiveness analyses of road traffic interventions in LMICs mixed (Banstola and Mytton, 2017), but cost benefit analyses of road safety programmes are fraught with ethical quandaries (for example how to value human life; see Viscusi and Aldi, 2003, for a well cited text on the matter). Moreover, although avoiding the costs associated with road traffic injury (e.g. health care expenditure, property damage, productivity loss) can undeniably provide economic benefit to a society, the avoidance of expenditure is not as easily traced as is countable, monetary income. As such, economic considerations rarely figure in road safety discussions.

2.2. Emergency Response

In 2015-16, £2.2 billion was spent on ambulance services in the UK, £1.78 billion of which was on urgent and emergency services (National Audit Office, 2017). In many other countries, no such services exist. The quality of emergency care available has a significant effect on the health outcomes of a particular patient, in terms of both speed of response and quality of care (e.g. Clark et al. 2013; Razzak and Kellermann, 2002; Sánchez-Mangas et al. 2010; Balikuddembe et al. 2017). Indeed, in the UK, the improvement in medical care standards was identified as the primary reason for the fall in casualty rates in the UK from road traffic incidents across the years 1978 to 1998 (Noland and Quddus, 2004). Not only was post-impact care the focus of a recent European Commission report on road safety (European Commission, 2016), but it represents a 'pillar of action' in the UN's Global Plan for the Decade of Action (on road safety; see WHO, 2017b) as well as a key strategy in the World Health Organisation's world report on road traffic injury prevention (Peden et al. 2004).

2.3. Enablement

Perhaps the least immediately obvious of the approaches to road safety thus far introduced, enablement here refers to the activities that make advances in other areas possible. Funding is, of course, part of this, but also of significant importance is the enablement of research through a cultural and societal environment that supports such work, and through the availability of reliable, high quality data to allow the research to be undertaken.

In the UK, police have recorded road traffic accident data since 1926, and have used the same form to record data from all reported incidents since 1979 (the STATS19 form, available from ADRN, 2018). Moreover, the UK is the highest ranked country in terms of the openness of government data (see opendatabaromter.org). As such, access to high quality data is rarely the greatest challenge for road safety researchers in the UK. In many LMICs the situation quite the opposite, with the majority of countries having very limited data systems. Inconsistent and incomplete data collection tools result in inconsistencies in global road safety statistics (e.g., GRSF & IHME, 2014; Al-Madani, 2018), which in turn cloud the true global road safety picture, hindering the development of successful road safety policies (Dimitriou et al. 2018).

Complex problems (such as road safety) require rich, complex data sets to guide solutions (Arzberger et al. 2004), with open access to publicly funded data providing greater returns from public investment (Janssen et al. 2012). This is particularly important for public health research, which relies on large data sets; as Walport and Brest write in The Lancet, "Ensuring data are made widely available to the research community accelerates the pace of discovery and enhances the efficiency of the research enterprise" (Walport and Brest, 2011, p.12). Indeed, that data sharing has positive results for public health and can save lives is, in the words of Pisani et al., "demonstrably true" (Pisani et al. 2016, p. 1). If one accepts that road safety is an international public health issue (a notion we consider manifest), one must accept that data openness is a central part of the path to reduced injury and fatality rates.

3. Ergonomics: A Sociotechnical Approach to Road Safety

The focus on the individual driver as the root cause of accidents, pervasive in the public and academic literature (see Dekker, 2011 and Scott-Parker et al. 2015 for discussions), is beginning to be challenged with increased adoption of Vision Zero and its 'safe systems' approach (e.g., visionzeroinitiative.com; Kristianssen et al. 2018). A central theme of the perspective is that humans are fallible; for example, Bristol City Council's (2015) publication on safe systems states that "roads must be tailored to human limitations" (p.12). The emphasis is on designing a road system that tolerates the errors of the user; it is the human that is the faulty element. Just as with the media found at visionzeroinitiative.com, it is suggested that it is the responsibility of the designer of the road system to design it in such a way that reduces the consequences of these inevitable mistakes.

In the Human Factors and Ergonomics literature, the term 'systems' has slightly different connotations, a much longer history (e.g. Heinrich, 1931), and a broader scope. It considers complex systems (of any type) as multi-levelled assemblies of interconnected actors and organisations, that are more than the sum of their parts. Many systems, including road transport, can be described as 'sociotechnical', insofar as they have social and technical elements that are inextricably intertwined (Walker et al. 2008). When referring to analysis and design approaches, the terms 'systems' and 'sociotechnical' can, and have been, used synonymously in the Ergonomics and Human Factors literature; here we use the term 'sociotechnical' rather than 'systems' in order to more easily distinguish it from the 'safe systems' road safety philosophy.

That humans are fallible is unquestionable (Reason, 1990), and that the road system designer should share some blame is fully in line with the sociotechnical viewpoint. We would argue, however, that the fallibility of drivers should not be a central theme to a road safety philosophy, and that blame should not be apportioned to only the road users and system designers. Multiple actors and organisations are responsible for system outcomes, with the interconnections (or lack thereof) just as important as the actors and organisations themselves (Salmon et al. 2012; Wilson, 2014).

In recent years, there have been growing calls from within the Human Factors and Ergonomics community to apply a sociotechnical approach to the issue (Salmon et al. 2012; Larsson et al. 2010; Lansdown et al. 2015; Salmon and Lenné, 2015; Parnell et al. 2016). Although there have been efforts to use the 'safe systems' approach to guide road safety efforts in LMICs (e.g. Bliss and Breen, 2013), there has been little use of validated sociotechnical methods in those settings. As a response to this gap in the literature, we apply Jens Rasmussen's (1997) Risk Management Framework, and the associated Actor Map representation tool (Svedung and Rasmussen, 2002) to these domains.

3.1. The Risk Management Framework

Over the past 20 years there has been increasing recognition of the role that each of the various levels of a complex sociotechnical system plays on system performance; not only are workers and their equipment of importance, but also management structures, regulatory systems, social norms, and legal and political frameworks (e.g. Leveson, 2004). Though there currently exist a wide variety of sociotechnical systems models and analysis techniques (see, for example, Stanton et al. 2013), it is Jens Rasmussen's (1997) Risk Management Framework (RMF) that has received the most recent attention in the road safety domain (e.g. Salmon et al., 2013; Newnam and Goode, 2015; Scott-Parker et al., 2015; Young and Salmon, 2015; Parnell et al., 2017). The original framework contained six levels, from the equipment at the bottom of the hierarchy up to national government at the top. This has subsequently been expanded upon to include two additional levels above government; national and international committees (Fig. 1; Parnell et al. 2017).

The framework considers accidents as emergent properties that arise from the interplay of technology, individuals, and organisations at various levels of system abstraction. It is this hierarchical description of a sociotechnical system on which the Accimap accident analysis method is based. Accimaps are graphical representations of accidents, serving to identify relevant decision makers and decision points, and to capture the 'normal', causal flow of activities within which an accident is embedded. First described in detail by Svedung and Rasmussen (2002), the aim is not to ascribe blame, but to support the analysis and design of better systems, its goal being to support the identification of system-based interventions that reduce the potential for future accidents.

Part of the Accimap process is the development of the Actor Map, a representation that aims to display a system's relevant causal actors in such a way as to give structure to the list of parties involved. This aids the analysts in their identification of the objects, actors, and organisations that affect whether or not an accident occurs, from the specific equipment used up to the abstract legal frameworks that shape the environment within which accidents occur. Although Svedung and Rasmussen (2002) discussed the Actor Map as something that follows creation of the Accimap, it is common to see the Actor Map developed first (e.g. Parnell et al. 2017; Scott-Parker et al. 2015; Young and Salmon, 2015). Used in this way, the Actor Map gives a picture not of one specific accident, but of the system as a whole; it graphically describes the entities that influence system outcomes, and their organisation across the RMF levels of abstraction. It is in this way that we have used the diagram; to map out the system under analysis, and provide an information audit of sorts, detailing what actors and organisations influence system performance. From the Actor Map, it is possible to identify potential contributions (both positive and negative) to system events, at all levels.

4. Aims

The main aim of this article is to put forward a sociotechnical perspective of global road safety through use of the Actor Map representation, part of the Accimap approach to accident and systems analysis (Svedung and Rasmussen, 2002). The expansion of the three traditional 'E's to include additional lenses through which current and potential road safety interventions might be viewed or considered (as described above) is done in conjunction with this. As well as adding to the growing body of literature applying sociotechnical systems methods to the road safety domain, and the first, to our knowledge, to do so in LMIC settings, the research presented herein thereby sheds light on the complexity of the road transport domain. Although it is widely known that no single agency or organisation has full responsibility for road safety, the true complexity of a given road safety system is rarely appreciated. A second aim of the paper is to identify the interested parties in each of the road safety systems of the countries we have taken as our research contexts, such that policy makers and road safety intervention designers can better appreciate the variety of relevant organisations that need to be considered. Finally, a third aim of the research is to show the ways in which the road safety systems of distinct countries differ, and the ways in which they are similar.

5. Modelling Road Safety Systems

The analyses presented herein represent the first major output of a multi-partner project involving researchers in five universities in five different countries, namely Bangladesh, China, Kenya, Vietnam, and the UK (see NIHR (2017) for more details on the project). These countries differ in a wide variety of ways; Table 1 gives some example statistics regarding population, economics, motorisation, and road traffic casualty rates.

Following World Health Organisation (WHO) estimates of the five countries under investigation (rather than reported figures, argued to be highly inaccurate for many countries; WHO, 2015), Kenya sees the highest fatality rates per 100,000 population. In this measure, Bangladesh is second to the UK in terms of safety; however, Bangladesh has a significantly lower level of motorisation, and therefore lower exposure. Measuring by fatalities per 10,000 registered vehicles, Bangladesh has

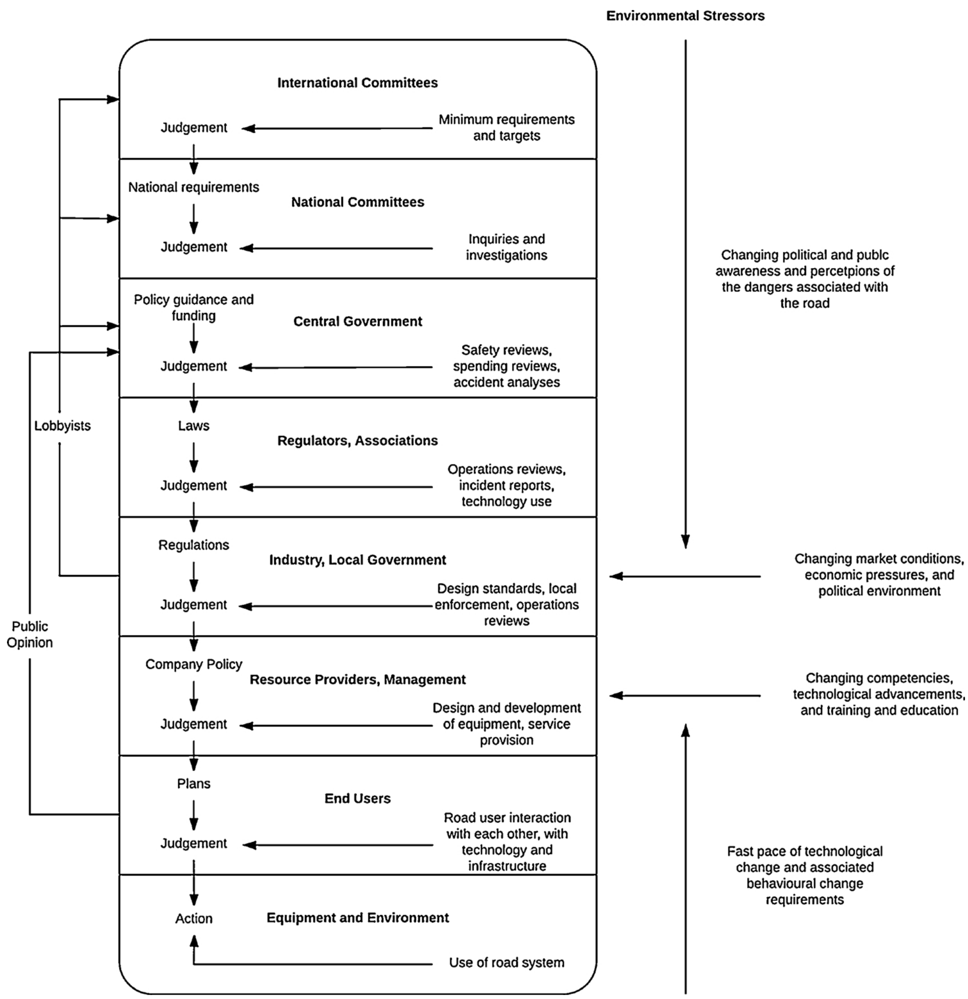

Fig. 1. Rasmussen's Risk Management Framework (RMF), expanded upon by Parnell et al. (2017). Labels have been edited in line with a road transport perspective.

(statistically speaking) a significantly more dangerous road transport system (though it must be noted that it is difficult to estimate the number of unregistered vehicles on Bangladesh's roads; Hossain et al. 2009). Vietnam is characterised by a very high level of motorcycle use, hence has a large number of registered vehicles for its population size. As such, the fatality rate per 10,000 vehicles is relatively low; per 100,000 population, however, its roads appear far more dangerous, with only Kenya showing higher fatality rates. Measured by either fatalities per 10,000 vehicles or by fatalities per 100,000 population, China's fatality statistics are in the middle of the five countries under analysis.

The first Actor Map to be constructed was that of the UK road transport system. To do so recourse was first made to relevant existing academic literature. Work from Salmon et al. (2013), Scott-Parker et al. (2015), Newnam and Goode (2015), Young and Salmon (2015) and Parnell et al. (2017) provided the starting point. Although this literature provides Actor Maps of the road transport system, each article focuses on a particular aspect of the system (i.e., road-rail intersections, young drivers, road freight, distraction). It was necessary therefore to expand the document review beyond the academic literature.

Government and local council documents and statistical releases, as well as industry, charity, and other non-governmental organisation websites represented the primary information sources, alongside the UK's parliament website (parliament.uk). Consultations with other members of the University of Southampton's Transportation Research Group served to supplement the model, and further additions and

Table 1
Example statistics for the five countries investigated. All data from, and additional explanations found in WHO (2015).

	Bangladesh	China	Kenya	United Kingdom	Vietnam
Population	156,594,962	1,385,566,537	44,353,691	63,136,265	91,679,733
Gross National Income per capita in USD	1,010	6,560	1,160	41,680	1,740
Income level	low	middle	low	high	middle
Number of registered vehicles	2,088,566	250,138,212	2,011,972	35,582,650	40,790,841
Vehicles per 1,000 population	13.3	180.5	45.4	563.6	444.0
Reported number of road traffic deaths	3,296	62,945	3,191	1,770	9,845
WHO estimated number of road deaths	21,316	261,367	12,891	1,827	22,419
Estimated road traffic death rate per 10,000 vehicles	102.1	10.4	64.1	0.51	5.5
Estimated road traffic death rate per 100,000 population	13.6	18.8	29.1	2.9	24.5

Note: All data and WHO estimations are for the year 2013, except registered vehicle numbers in Bangladesh (2014) and in the UK (2012).

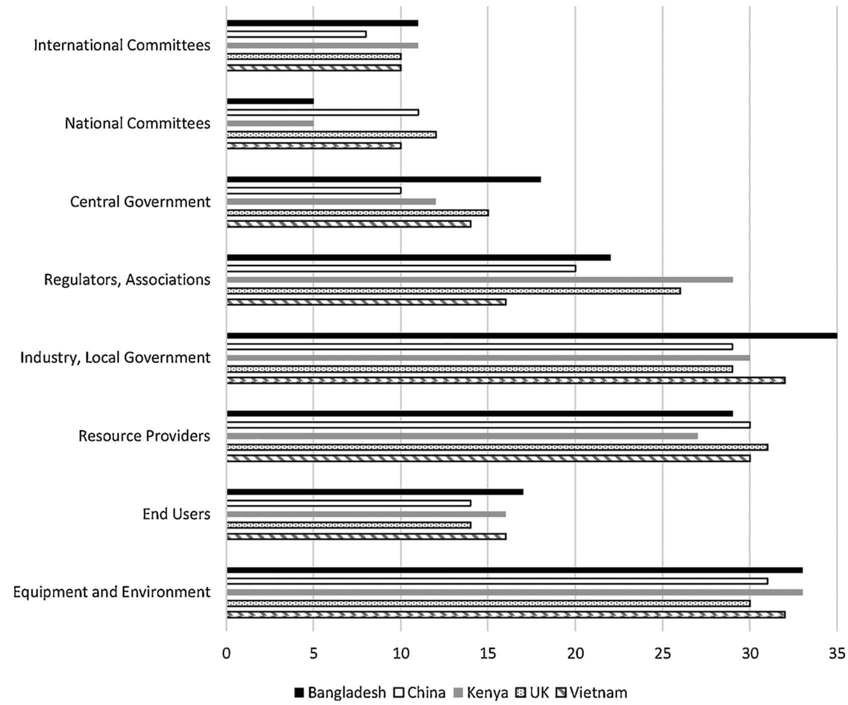

Fig. 2. Numbers of actors identified at each level of the system for each country analysed.

alterations were made following conversations with subject matter experts in the motor industry, public health, emergency medical response, and emergency police response domains. In particular, three individuals (a professor of public health, a surgeon and founder of a regional air ambulance service, and a senior police data analyst) assisted with the various iterations of the Actor Map model, reviewing and commenting where appropriate.

Following completion of the identification of the relevant actors, i.e., creation of the Actor Map, each of those in the upper six levels was assigned one or more of the six 'E' categories listed above, indicating through which avenues each actor has an influence on potential road safety outcomes. The bottom two levels were not categorised as only the organisational factors are of interest in this type of analysis. To assign 'E' categorisations, the functions (with regard to road safety) of each identified actor had to first be identified. This was done primarily through reference to the official website of each actor (where possible).

Note that the assignation of categories does not necessarily indicate the full gamut of activities performed by each specific actor, rather only those specifically related to road safety. Just as with the identification of actors, the assignation of 'E' categories was discussed with other road transport researchers and subject matter experts in public health, emergency response, and economics.

To develop Actor Maps for the LMIC partner countries, the UK Actor Map acted as a base from which the other models were developed. As with UK Actor Map development, online literature, much of it governmental, aided and supported discussions. As part of a separate project, a number of site visits were made to accident blackspots identified by researchers in each country (via discussions with traffic police officers and local traffic authorities, namely the National Road Safety Council (NRSC) in Bangladesh, the National Transport Safety Authority (NTSA) in Kenya, and the National Traffic Safety Committee (NTSC) in Vietnam). Although the aim of the current research was not to model any particular area or road environment, these site visits allowed the researchers access to local road users. Discussions with local shop owners, security guards, traffic police, and other members of the public (most often pedestrians) were made on an informal basis where possible. At each site photos and video recordings were taken (and later reviewed).

Just as with the UK model, assignation of the six 'E' categories followed completion of actor identification. Any changes made to one document were considered in terms of the other countries' road transport systems, and edits made to other models if appropriate. In all countries, subject matter experts were consulted, for both the identification of actors, and the assignation of 'E' categorisations. The process for doing so varied across countries, with some discussions happening more informally than others. For example, in Kenya, site visits were made with an ex-police officer, and the Actor Map discussed with him. In China, researchers met with traffic police at particular site. In Vietnam and Bangladesh, local Transport Engineers accompanied researchers on site visits. For each Actor Map model, the process was iterative, with each iteration discussed with local subject matter experts, and between researchers in the different countries.

From the initial identification of actors with document searches, to the validation with subject matter experts, the use of the 'E' coding system, and the subsequent iterations following further consultations with subject matter experts, the process of developing the UK Actor Map lasted approximately four months. In the LMIC partner countries, using the UK Actor Map as a starting point, and discussing all changes made in one country's model in terms of the potential for changes to be made in the others, the process took approximately two months.

6. Results

The final Actor Maps for all five countries' road transport systems are too large to be displayed in their graphical format here; the reader is referred to the online supplementary materials for the complete diagrams with colour-coding to show the 'E' categorisations. Fig. 2 displays the number of actors identified at each level of the system for each country, and Fig. 3 displays the number of actors assigned to each of the six 'E's for each country.

Looking at the Actor Maps (presented online for each of the five countries investigated) and at Figs. 2 and 3, it can be seen that, generally speaking, the road safety systems of the countries under analysis have more similarities than differences. In terms of the number of actors at each level, in Fig. 2 it can be seen that Bangladesh and Kenya have significantly fewer actors at the National Committees level (with five

Fig. 3. Numbers of actors, in each country analysed, that have been assigned each of the six 'E' categorisations.

each) than China (11), the UK (12), or Vietnam (10). The UK and China differ from the other three countries insofar as the actors at the National Committees level outnumber those at the International Committees level. This may reflect the developmental states of the countries; the higher income the country, the less they are influenced by, or rely on external organisations. In Kenya and Bangladesh, actors at the International Committees level outnumber those at the National Committees level; in these two countries foreign governments, non-governmental organisations, and multilateral development banks have stronger influences on the road systems. Vietnam sits in the middle in terms of development and economy size; in their system the same number of actors have been identified at the International Committees level as at the National Committees level. More actors were identified at the Central and Local Government levels in Bangladesh than in any other country, and there were more actors identified at the Regulators and Associations level in the Kenya and the UK than in the other countries.

In terms of the six 'E' perspectives (Fig. 3) the weighting towards economics across the whole system can be appreciated for all countries, including China (though to a less pronounced extent). This is perhaps reflective of the fact the we live in a largely capitalistic world (even in China and Vietnam, ostensibly communist countries); economic constraints influence the system at every level, from the Organisation of Petroleum Exporting Countries at the International Committees level influencing the price of fuel (and therefore the amount and style in which people drive; e.g. Goodwin et al. 2004), to the regional public transport operators at the Resource Providers level using pricing to encourage patronage (e.g. Redman et al. 2013).

Other actors motivated by economics have a less direct role in road safety, yet nonetheless affect it. For example Protective Personal Equipment (PPE) vendors, also represented at the Resource Providers level, are those simply trying to sell equipment to customers; the need to meet financial targets can outweigh the risks of selling 'fake' (i.e., below legal standard) helmets (e.g. Hill et al. 2009). Regarding enablement, it can be seen that the UK and Bangladesh have noticeably more actors involved in this approach than do the other countries. The same pattern is also true for education; more actors in the UK and Bangladesh road safety systems have been assigned this category than in the China, Kenya, or Vietnam systems.

7. Comparisons and Discussion

7.1. International Committees

At the top level of Parnell et al.'s (2017) modified Risk Management Framework (RMF) are the committees that exist at an international level, influencing law, policy, and directives. The Actor Map models, presented online, show that many of the International Committees identified are the same across all five countries, including such actors as the World Health Organisation, Multilateral Development Banks, the Organisation of Petroleum Exporting Countries, the International Organisation for Standardisation, etc. The only deviations from this are where specific regional organisations are concerned (i.e., the European Union, African Union, Association of South East Asian Nations, etc.), where foreign governments have notable influence on certain countries' system (Bangladesh, Kenya, and Vietnam) and not others (China and the UK), and in the use of certain international standards in particular countries (i.e., the UK's and Bangladesh's use of European Committee for Standardisation guidelines).

Another notable difference is where the same actor influences road safety in different ways depending on the country in which it acts. For example, in the UK, the World Bank (a Multilateral Development Bank; MDB) influences road safety via enablement alone, through its collection, analysis, and dissemination of road traffic data. They typically do not fund projects in the UK. This is quite the contrary in low- and middle-income countries, where the World Bank and other MDBs are highly influential in road safety, not only through providing economic support for projects, but through ensuring certain design standards are met; hence in these countries, MDBs have also been assigned to the economics and engineering categories. For example, in Vietnam, the Asian Development Bank and the Japan Bank for International Cooperation have had significant influence in a number of road building projects, which they not only fund, but to which they apply their own engineering standards, rather than using those of the country in which they operate (e.g. ADB, 2017; JICA & NTSA, 2009).

7.2. National Committees, Central Government, Regulators and Associations

From the National Committees level, where national law and policy is overseen, down to the Regulators and Associations level, where legislation is interpreted and implemented, are where most of the differences between the countries' road safety systems are found (again, the reader is referred to the online supplementary materials for the full Actor Map models). It is at the National Committees and Central Government levels that government structures are represented, and each country has its own approach to governance. At the National Committees level, for example, the UK has a cross-party committee that sits above each government department or ministry, providing oversight and monitoring functions. In China and Vietnam, the National Committees more directly influence the running of the country. China is the only country that does not have a dedicated transport committee, though the role of the UK's Transport Select Committee is simply to scrutinise the Department for Transport, it is not an organisation aimed at improving road safety (as are those in Bangladesh, Kenya, and Vietnam).

As an indication of the centrality of road transport to modern society, the large majority of each country's existing governmental departments and ministries are represented at the Central Government level. All have some level of influence on road safety, through one or more of the six 'E's listed above, be that through influencing built environment policy, national and international trade, environmental guidelines and restrictions, fuel prices, road and vehicle laws, education, construction practices, or any other of the myriad ways in which safety on the roads might be impacted.

In terms of the Regulators and Associations level, China's road safety system differs insofar as none of the associations identified has influence through more than two of the 'E' perspectives; each has a relatively narrow focus. Moreover, seven actors have been assigned only the Enablement category; they provide a supporting role, through encouraging research or collecting and disseminating data. In the other countries, the actors listed at this level have more direct roles, reflecting the authorities, industrial associations, and organisations that interpret legislation and design specific implementation strategies. Again, this is a reflection of the differences in the way the countries are governed.

It can be seen from the Actor Maps (online) that the Regulators and Associations level is the highest level that contains actors that have not been assigned an 'E' category. In all countries there is an organisation that is involved in the provision of rail services, both passenger and freight. Additionally, in Bangladesh there exists an Inland Water Transport Authority, also influential in the movement of people and goods (given Bangladesh's topography). These organisations (as well as their subordinate actors in lower levels) influence road safety through their effect on traffic levels; the higher proportion of people and goods transported by rail or water, the lower the proportion will be transported on the roads. This can have complex effects on a country's road safety system not necessarily captured by our six 'E's categorisation, and is discussed in more detail in Section 7.6.

7.3. Industry, Local Government

The Industry and Local Government level includes actors that have a more narrowly defined remit than the Regulators and Associations that sit directly above them; they put into action the implementation plans passed down, acting in a more localised context. This level includes a large number of actor groups as well as specifically named organisations, for example Driver Training Centres, Insurance Companies, and Research Centres (of which there are many examples of each in all the road safety systems considered). Of the 64 distinct actors identified at this level, 14 are active across all five countries; however, not all operate through the same 'E' perspectives in each county, as the colour coding of the online Actor Map models shows.

For example, Haulage and Delivery Companies have been assigned the Economics category for all countries; delivery pricing, economic targets, and financial pressures will affect their use (over other haulage methods such as water, air, or rail transport) and the standards of practice they can achieve. In Bangladesh, this is the only 'E' category applied. In Kenya, the companies are also expected to impose working practices (for example maximum hours; enforcement) and to train their drivers (education). In China, the UK, and Vietnam, Haulage and Delivery Companies also perform an enforcement function, but they typically do not train the drivers. In China and the UK, that function is performed by dedicated driver training centres. In Vietnam, responsibility for truck driver training falls to the National Traffic Safety Committee (NTSC) who are represented at the National Committees level (though even this is not a legal requirement, see, e.g., Viet Nam News, 2017)

Many other Actros have similar functions across countries, but differ in terms of governance, organisation, or funding. For example, the UK's air ambulance service performs largely the same function as those of Bangladesh and Kenya; however, very few people in Bangladesh or Kenya are able to pay for these private services. In the UK, the service is a public one that is free at the point of use (its funding coming from a mixture of sources, including National Health Service contributions, corporate sponsorship, and charitable donation).

Other notable differences between the road safety systems analysed include, for example, the influence of Used Vehicle Importers in Bangladesh, Kenya, and Vietnam (an actor not significantly influential in China or the UK), and the lack of an emergency call centre in Kenya, as well as the separation of Ambulance Emergency Call Centre and Fire and Rescue Emergency Call Centre in Vietnam (where the other countries have combined systems).

7.4. Resource Providers

The specific functions and services of the actors displayed at the Industry, Local Government level are typically implemented by those in the level below, the Resource Providers (e.g. Traffic Police, Emergency Service Workers, Driving Instructors). Even more so than the level above, the road safety systems of the different countries analysed here share many similarities, having many of the same kinds of actors present. Again, there are some examples of where the same actor influences road safety in different ways depending on the country. Moreover, there are instances where the same actor can be involved in road safety via one of the 'E' perspectives without its superordinate organisation also doing so. For example, higher level taxi companies in Kenya and Bangladesh play no role in emergency services or responding; however, individual taxi operators are often those that are required to take people to hospital following an incident on the roads (e.g. Botchey et al. 2016). Although transport to hospital in a taxi is certainly not unheard of in the UK, it is far from typical, hence UK taxi operators have not been assigned that category.

7.5. End Users, Equipment and Environment

In both the End Users level and the Equipment and Environment level there are again far more similarities than there are differences across the five countries. Although different in characteristics, the fundamental objects that make up the physical road system are largely the same regardless of the setting. The same is true for road users. The main differences are where specific vehicle types are seen on one country's roads but not another, for example the proliferation of cycle rickshaws in Bangladesh (particularly Dhaka), or the use of hand carts in Kenya. Other differences include the common use of sound level monitors and speed governors in Nairobi, the use of fixed megaphones for public information and safety messages in Vietnam, and the appearance of unregistered, highly non-standard motorised vehicles in Bangladesh. As aforementioned, actors in these levels were not assigned 'E' categories.

7.6. Going Beyond the Actor Map and the Six 'E's

The colour coded Actor Maps (presented in full as supplementary materials, available online), and the discussion of the various 'E's of road safety, are by no means meant as complete descriptions or analyses of the road safety systems of the countries investigated. Their aim is to provide a starting point for future research and intervention design through identifying the relevant organisations and actors that would need to be considered and/or involved. That no single agency or organisation has full responsibility over road safety outcomes is by no means a learning outcome of this research; this was already well-known. We would argue, however, that there have been few attempts to model any road system in its entirety. The current research presents, to our knowledge, the first attempt at an information audit of the complex sociotechnical system that is road safety; however, it is necessary to go beyond what is explicitly outlined in the Actor Map representations. The next step is to delve deeper into the functions of the various organisations involved.

Something not explicitly captured in the Actor Maps is the extent to which a road safety perspective is followed through, or successful. For example, although all countries have emergency services, not all operate at the same level of quality. Ambulance services differ enormously, from free for all at the point of use (in the UK) to operating more like a taxi service, with minimum fares and metres (for example in Beijing; e.g. BBC, 2016). In Kenya, most road traffic injury casualties arrived to a hospital by car, taxi, or minivan (Botchey et al. 2016).

In terms of enforcement, although all countries have judicial systems, lawyers, magistrates, and police to enforce laws and punish transgressions, this extent to which this is done varies greatly between systems. For example, Botchey et al. (2016) found that only 7.2% of passenger casualties reported wearing a seatbelt prior to the accident, despite the fact that both drivers and passengers of cars are legally required to wear one. Matheka et al. (2015) reported a similar lack of protective equipment use in motorcycle accident casualties, despite helmet use being a legal requirement. The reasons for this are varied; in Vietnam, for example, it has been suggested that there simply are not enough traffic police officers for the quantity of offending road users (La et al. 2017). Moreover, despite a concerted effort to increase the rate of helmet use in Vietnam (underpinned by economic disincentive and stronger enforcement), a proliferation of sub-standard helmets limited the programme's benefits (Olson et al. 2016). Given that non-standard motorcycle helmets are an issue across LMICs (Ackaah et al. 2013), engineering standards must be considered alongside economic and enforcement strategies when designing road safety interventions.

Such low use of protective equipment has also been explained by ineffective campaigning (Odhiambo et al. 2016); however, when mixed interventions are used, results can be positive (Abdella et a. 2016). Education is key; to go back to Metheka et al. (2015), it was found that the chance of injury was 1.3 times higher for those who had not received road safety education. Again, if a road safety intervention is to be maximally successful, it should act on more than one part of the system, and any potential effects should be considered in terms of more than one road safety perspective.

The extent to which the system actors identified in our analyses adhere to the varying engineering standards in each country varies greatly. For example, despite the World Bank's history of road improvement programmes (World Bank, 2016, GRSF, 2017; WRI India, 2017), in 2005 it played a central role in creating what has been described as the world's deadliest road, namely Bangladesh's N2 highway (Anam, 2014; Kelly, 2012). By laying the road with tarmac, possible vehicle speeds, previously restricted by the many pot holes and surface undulations, were dramatically increased. This significantly reduced travel times between Dhaka to Sylhet; however, it did so without considering any other system factors. The envisaged economic benefit came at an extremely high human cost; if upper estimates are to be believed, as many as two people die every day on the N2 (Kelly, 2012).

Decisions taken purely in terms of the benefits afforded to the motorised road vehicle, driven by economics and engineering, had severe consequences for many of the N2's users. Unfortunately, this has been the case in much of the thinking around transportation in LMICs (Vasconcellos, 2001). Bangladesh is one of the least motorised large countries in the world, and there are many more non-motorised vehicles (including bicycles, rickshaws, hand carts, and animal carts) than motorised vehicles (Hoque and Salehin, 2013). Pedestrians and users of these vehicles account for as many as 80% of the country's on-road fatalities (Hoque et al. 2007; Hoque et al. 2008), with children representing a particularly vulnerable group (Baset et al. 2016). To focus solely using engineering methods to realise the economic gains of allowing the rapid movement of motorised vehicles between cities is to completely overlook the majority of the actors involved in the system, and the other possible perspectives through which road safety could be viewed.

As described in Section 7.2, above, there are actors present in the majority of countries that have not been assigned one of the 'E' categories, the typical example being train operators and organisations. The rail system has a clear, direct effect on road safety where the two systems meet (e.g. Salmon et al. 2013). What is not captured, however, is where non-road transport can affect road safety through its ability to reduce traffic volumes, one of the factors most affecting on-road fatality rates (e.g. Ahangari et al. 2017; Aldred et al. 2018). This is true not only for the movement of people, but also goods. The more freight that is moved by rail or (particularly in Bangladesh) by waterway, the fewer heavy goods vehicles need to be on the roads. Given that in Bangladesh locally modified and overloaded trucks are involved in a disproportionately high number of fatal incidents (e.g. Sufian et al. 2016), it would be highly beneficial to reduce the volume of such road traffic.

Encouraging rail (and waterway) use are not the only means to reduce traffic volume; encouraging bus use over use of the private car can also help. In the UK, bus passengers are one of the lowest represented groups in terms of injuries or fatalities per billion vehicle kilometres (Department for Transport, 2017b); however, care should be taken when imposing interventions across other countries. In Bangladesh, for example, buses continue to be involved in an excessively high number of fatal incidents (e.g. Barua and Tay, 2010), while the Kenyan 'matatus', colourfully decorated minivans or small buses, are involved in near-daily fatal accidents (Kuo, 2015). In Vietnam, bus-related crashes have been linked with drink-driving, poor bus company policy, a lack of supervision of drivers, low enforcement of existing legislation, physical road environment issues, and bus company financial targets and the low payment of workers; i.e., a wide variety of system factors (La et al. 2013; 2017). Importantly, the encouragement of public transport use should be made in conjunction with other system interventions, rather than considered in isolation.

The effect of reducing road traffic on injury rates is not the only way the human health is affected; although largely outside the scope of this article, obesity and air quality are two issues that merit a brief discussion here. The first is a rising health concern around the globe; no country has ever been successful in reversing an obesity epidemic once it has begun (Ford et al. 2017), and strong links have been shown to exist between physical inactivity and obesity (Myers et al. 2017). Regarding the second, global estimates suggest that 184,000 deaths each year are caused by the emissions of motorised road transport (GRSF & IHME, 2014), 88% of which occur in LMICs (WHO, 2014). Indeed, one could suggest Environment as an additional 'E', or Exercise as another, and design interventions that view the challenge through these perspectives. Again, however, this focus should not be done at the expense of also considering other road safety perspectives, system actors, or the connections and links between those actors; interventions in one area of the system can give rise to emergent properties in other parts of that system.

8. Limitations

It is important to note that the six different road safety perspectives we have used in the analyses presented above, namely engineering, education, enforcement, economics, emergency response, and enablement, are not always easily delineated, and certain actors are more easily assigned to categories than others. For example, Ambulance Providers affect road safety outcomes through only the emergency response perspective. Others are more ambiguous, such as Road Marshalls in Kenya (those who direct traffic at junctions and roundabouts). These individuals *could* assist with the emergency response to an accident, helping emergency response vehicles through heavy traffic; however, they typically do not, hence they have not been categorised as such. In this way, the categorisation we have used is open to discussion; however, it is not our aim to be prescriptive, rather it is to highlight the high level of complexity inherent to the road transport system.

Additionally, our categorisation system is not able to display the weighting towards a particular 'E' perspective any given organisation has. For example, our coding shows that the UK's National Health Service influences road safety, to a lesser or greater extent, through Education, Emergency Response, and Education; the coding does not show that the majority of its activities are focussed on Emergency Response. An understanding of weighting requires a more detailed consideration of each individual system actor, something that is outside the scope of the current analysis.

The method we have used to construct the five system models has its limitations. Due to the unique characteristics of each country, and the different challenges of working in those countries, access to neither the same types of information nor the same classes or numbers of subject matter experts could be guaranteed. Different levels of detail exist in the available information, and different levels of access were achieved in the different countries; some are simply more open than others (see, for example, opendatabarometer.org).

Given the input of additional or different experts or researchers, it is possible that the resulting Actor Map models would have been different to those presented above. It is also possible that visiting different road environments would have resulted in additional, or indeed fewer identified actors. Again, however, our aim is not to provide a definitive description of each country's road safety system, rather it is to provide an indication of the complexity involved, through an initial attempt to graphically represent the parties that have an interest in, or influence over road safety in each country. We offer a starting point for discussions that go beyond traditional, end-user focussed perspectives.

9. Conclusions

The road transport picture is highly complex when taken as a whole, as we have attempted to do here. Of course, with increasing breadth one must sacrifice depth; there exist whole bodies of literature devoted to single components of the models developed as part of this research, and to each of the aforementioned six 'E's, not to mention to the acceptance of road safety as a public health issue. And it does not stop there. Private road transport plays a significant role in climate change, which has been linked to 150,000 deaths across the globe each year (Patz et al. 2005). The majority of these occur in developing nations; however, there are many uncertainties in the data, hence such figures are unlikely to have much influence on, for example, a local council's decision-making on public transport policy. That does not mean that the link is not of importance. The complexity of road safety is such that no deterministic approach can consider all its facets (Salmon et al. 2016); it truly is a system of systems. Treating one aspect in isolation can certainly have an effect; however, it leaves other factors unaddressed, therefore limiting any potential system benefits.

It also is important to bear in mind that successful strategies or interventions could not only provide benefit in one domain, but across a whole raft of them. The challenge is great, but the opportunity equally so. Although there have been a number calls for the sociotechnical approach to be applied to the road safety domain, with some convincing theoretical arguments, there is as yet little by way of practical research. In LMIC settings, we know of no such research. Although there are some allusions to the 'safe systems' approach in LMICs (Bliss and Breen, 2013, Ogombe, 2017), these are very limited in their treatment of the philosophy. Moreover, they do not apply current sociotechnical systems analysis methods to the challenge, rather simply speak of the need to consider more than just the driver (which, though important, is not sufficient).

The Actor Map is just a starting point. It provides a consistent framework for describing road safety systems across countries, and offers a supporting tool that aids development of Accimap analyses, analyses that delve deeper into the actions and influences of, and relationships between each individual system actor. What is important is that we consider *all* possible actors; blaming individual human actors at the lower levels represents a missed opportunity to learn lessons about the overall safety of the system, hindering the design of effective road safety interventions. To focus only on one aspect is to do so to the detriment of others. As Salmon et al. (2012) argued, we have to move beyond the 'hunt for the broken component' mentality, a hinderance to road safety progress (Dekker, 2011), to a 'hunt for the interacting system components' at all sociotechnical levels.

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Appendix A. Supplementary data

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