Road traffic crash fatalities

An examination of national fatality rates and factors associated with the variation in fatality rates between nations with reference to the World Health Organisation Decade of Action for Road Safety 2011 - 2020

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Abstract

The decade 2011 – 2020 has been declared the Decade of Action for Road safety by the World Health Organisation (WHO). The WHO has published baseline road traffic crash (RTC) fatality data for all member nations. The WHO has also suggested five Pillars of Action, mechanisms that may be instigated at the national level within the decade to halt or reduce the national RTC fatality toll.

This thesis demonstrates that the some of the baseline data published by the WHO and derived from RTC reports compiled by national police forces may not best reflect the number of RTC deaths within each nation. Moreover, this data may not be directly comparable between nations due to definitional and other issues identified. Vital registration (death certificate) data which is directly collated by the WHO may be a better measure for international comparative work.

Contrary to some previous studies, no significant association was found between the level of national economic development (in terms of per capita Gross National Income (GNI)) and health-derived RTC fatality rates for the year 2002.

In multiple regression analysis of factors associated with GNI and presumed causal in the international variation in RTC fatality rates, exposure to risk of crash, percent of the vehicle population which are 2- or 3-wheeled, percent of the population aged 15 – 24 years, per capita alcohol consumption and health spend as a percent of GDP were all significantly associated with RTC fatality rate. No evidence was found to support WHO Pillar 4 in that road user behaviour modification via enactment and enforcement of road safety legislation was not significantly associated with the variation in RTC fatality rate. The demographic and cultural factors identified may not be amenable to modification. This has implications for the globalisation of remedial actions as proposed by the WHO.

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Chapter 1: Introduction and literature review

1.1 Introduction

Road traffic crashes (RTCs) are recognised as a major global health issue. The World Health Organisation (WHO) estimate that over 1.2 million people die on the World's roads annually. Road traffic crashes are socially inequitable in that they are the leading cause of death for those aged 15 – 29 years and over 90% of RTC deaths occur in low- or middle-income nations despite these nations owning only 48% of the world's registered vehicles (WHO, 2011). Moreover, the WHO predicts that, if historic trends continue, RTCs will rise from the ninth leading cause of death worldwide in 2004 to fifth by 2030 (WHO, 2009). It is likely that the burden of these increases will fall on low and middle income nations where RTC death rate has been predicted to increase by up to 85% between 2000 and 2020 (Peden et al., 2004).

The international importance of road traffic crashes (RTCs) as a cause of morbidity and mortality was first recognised by the United Nations in the 1960s. In 1966 the World Health Assembly passed resolution WHA19.36-Prevention of Traffic Accidents. This requested that the World Health Organisation (WHO) play a more active part in the prevention of RTCs and that the WHO should coordinate international research. In 1974 a further resolution (WHA27.59) was passed asking members states to improve driver training and vehicle manufacturers to improve vehicle safety. In 1981 the WHO published a report examining the extent of RTCs in developing nations. However, it was not until 1996 and the publication of the findings of the Global Burden of Disease study (Murray and Lopez, 1996a; Murray and Lopez, 1996b; Murray and Lopez, 1997) that the true level of morbidity and mortality due to RTCs worldwide became apparent. The highlighting of injury, including RTCs, as a major cause of death worldwide led to the establishment of the WHO Department of Violence and Injury Prevention in 2000 and in 2001 the WHO published a five year strategy for road traffic injury prevention (WHO, 2005).

There has been increasing international pressure to address the public health costs of RTCs since that time, and in 2004 the World Health Organisation issued the World Report on Road Traffic Injury Prevention (Peden et al., 2004). This publication detailed the extent of, and trend in, road crash fatality and injury worldwide. It described risk factors associated with higher crash or injury risk and also proposed, and gave evidence to support, a number of remediation schemes that national governments could instigate to address their particular road safety concerns. Since the 2004 report the United Nations Secretary General has issued bi-annual reports charting changes in global road safety (WHO, 2005).

In 2009 the World Health Organisation issued a further comprehensive review of road safety, the Global Status Report on Road Safety (WHO, 2009). For the first time the 2009 report attempted to draw together comparable data from all 178 contributing nations. National road safety experts from health, transport and road safety enforcement fields were asked to rate the existence and enforcement of road safety legislation regarding mandatory seat belt, helmet and child restraint use, speed limit and driver alcohol consumption. Data was also presented for numbers of fatalities, registered vehicles and whether there was a national universal access telephone number for emergency services and formal publicly available pre hospital casualty care (WHO, 2009).

In March 2010 the United Nations General Assembly proclaimed the period 2011-2020 as the Decade of Action for Road Safety. The goal of the Decade is to stabilize and then reduce the forecast level of road traffic deaths around the world (WHO, 2011). The 2009 WHO publication will serve as a baseline against which future progress will be monitored; the WHO also claim that the 2009 Status Report will indicate potential deficiencies in individual nation's road safety policies and activities and thereby inform future road safety work (WHO, 2011).

Key to the Decade of Action the WHO has identified five Pillars of Action, mechanisms which may be instigated to reduce the RTC fatality rate. The Pillars of Action are proposed by the WHO as factors operating at the national level and which are directly associated with (and by implication are causal) in the variation in the number of road traffic crashes and fatalities arising from those crashes.

Pillar 1 concerns national-level road safety management and asks that nations develop the systems to fund, monitor, evaluate and instigate road safety strategies. Pillar 2 concerns the safety of the road network and asks that the network is designed, constructed and operated with consideration for the safety of all road users, especially the most vulnerable pedestrians, cyclists and two- and three-wheeled motor vehicle users. Pillar 3 recognises that vehicles design and maintenance may be important in preventing RTCs (for example, anti-lock brake and electronic stability control systems, so-called primary safety systems) and in protecting vehicle occupants from injury in the event of a crash (for example, side-impact protection and air-bags, so-called secondary safety features). Seat belts and other basic safety devices should be fitted as standard to all new vehicles and the globalisation of the more advanced technologies is to be encouraged. Moreover, vehicle users should be made aware of the safety performance of vehicles on offer with the expectation that this creates a demand for vehicles with a higher safety specification.

Pillar 4 concentrates on road user behaviour and recognises that safer road use behaviour may require both public education and a degree of coercion in that appropriate road safety legislation is enacted and its enforcement is seen to take place. Behavioural modification includes an increase in seat belt, helmet and child safety seat use and a reduction in drink-driving and speeding. Nations are asked to implement graduated licences for novice drivers whereby the least experienced drivers and riders are limited in their exposure to the more demanding road environments (for example, limiting night driving or the use of the faster, busier roads). Nations are also encouraged to reduce work-related RTCs. Pillar 5 recognises that death and disability may be reduced by a timely appropriate and effective post-crash response from health services. To this end nations are advised to implement a single nationwide emergency telephone number, pre-hospital care for casualties and appropriate immediate and longer-term care for crash victims and the bereaved. Use of funds from insurance schemes is advocated to fund this work.

While the WHO Decade of Action for Road Safety Initiative has admirable aims it does suggest that a number of fundamental questions be asked. The World Health Organisation Pillar 1 advocates monitoring national RTC numbers over time. Such data will define the extent of RTC fatalities within each nation; the WHO also proposes that this data will identify risk factors for RTC and fatality and will allow intervention strategies to be formulated and evaluated (WHO, 2011). To be of use these statistics should accurately reflect the true number of crashes, deaths and injuries in the nation; reporting mechanisms and definitions should be consistent over time and, ideally in the context of the Decade of Action for Road Safety, the measures should be directly comparable between nations.

This thesis starts with a consideration of the currently available databases detailing the number of RTC fatalities at the national level. It critiques the most commonly quoted data source, that compiled from police crash reports by the International Road Federation (IRF). Police-derived RTC fatality rates per 100,000 population are the predominant data quoted in the 2009 WHO Global Status Report on Road Safety. The WHO also propose continued monitoring of police-derived RTC data during the Decade of Action (WHO, 2011). However, it is shown that RTC fatality rates using health-service derived data (and collated by the WHO) are more closely associated with the national-level factors presumed causal in RTCs. IRF data may suffer from definitional issues regarding who may be categorised as an RTC victim. For example, some locations or type of crash may be excluded. In some nations only deaths that occur at the time of the crash enter the IRF database whilst in others the death may occur up to 30 days following the incident. Health data suffers no such definitional issues in that all contributing nations adopt a standard system for coding deaths (the International Code for Deaths 10th revision, ICD-10). The International Classification of Diseases is the standard tool used in epidemiology and health management to monitor the incidence and prevalence of diseases or other health problems (WHO, 2012).

In addition, it is possible that a number of RTCs are not reported to the police. In the context of the Decade of Action for Road safety, it is proposed that health service derived (ICD-10) data may be a better monitoring tool especially since this data is already collated by the World Health Organisation. This area is discussed in chapter 2.

The basis of the WHO Decade of Action is that road traffic fatalities can be prevented. A number of nations, mainly high-income nations, have made significant reductions in RTC death rates over the last few decades (WHO, 2011).

This thesis goes on to consider some of the factors operating at the national level which are proposed as causal in the variation in international RTC fatality rates seen. Some of these are promulgated as the WHO Pillars of Action. WHO Director-General Margaret Chan described the Pillars as *"...well defined measures. Evidence tells us that these measures work and can save millions of lives" (WHO, 2011).* This thesis goes on to examine whether there is evidence to support this claim and whether the proposed Pillars of Action are associated with the variation in international RTC fatality rates seen. Indeed the WHO literature concerning the Decade of Action for Road Safety gives very little evidence of the benefits of the proposed actions. For example, the introduction of a nationwide ambulance service and emergency phone number in Ghana has resulted in an increase in cases handled by the ambulance service and a reduction in ambulance response time. However, no details are given regarding any change in RTC fatalities associated with this (WHO, 2011).

Chapter 3 initially examines the relationship between national economic development in terms of per capita Gross National Income (GNI) since the predicted increase in global RTC fatalities is commonly based on the presumed relationship between national wealth, motorisation (level of road usage) and RTC fatality. Regression analysis is then used to explore the relationship between a number of factors associated with economic development, and suggested by the literature as causal in the variation in RTC fatality rate, with national-level RTC fatality rates for the year 2002.

1.2 Literature review

1.2.1 Why research international road traffic fatality rates

Since the WHO propose the globalisation of remedial actions for road safety it is important to determine whether the proposed pillars of action are associated with the variation in RTC fatality seen between nations. Indeed, Kopits and Cropper (2008) proposed that the examination of the variation in RTC fatalities from a number of nations was vital in determining the effect of factors such as vehicle use per capita, composition of the vehicle fleet, demographics particularly the proportion of the population in the higher risk age categories and of the availability and quality of medical services available for RTC victims on RTC fatality. The variation of each factor over time in one nation would be too small to determine the true effect of the remedial action and would be subject to a large number of confounders.

In comparative studies it is usual to express road fatalities as a rate term, either fatalities per 100,000 population, fatalities per 10,000 registered vehicles or fatalities per billion vehicle-kilometres travelled (International Road Traffic and Accident Database (IRTAD), 2010). IRTAD (2010) suggest that all three measures should be examined when comparing national-level road safety.

Fatalities per unit of population allows comparison with other causes of death and the denominator data is most readily available. However, IRTAD (IRTAD, 2010) caution against use when comparing road fatality risk between nations with differing levels of motorisation.

Vehicle ownership denominator information is the next most readily available data. However, this measure makes no account of kilometres travelled per annum; it takes no account of the different types of vehicles registered; it may not include two-wheeled motor vehicles and may be inaccurate in nations where a proportion of the national fleet are unregistered or where no account is made for vehicles removed from the fleet (Jacobs et al., 2000).

Vehicle kilometres travelled per annum data is available for the fewest nations (Quddus, 2008). Annual vehicle kilometres may be determined by a number of methods including roadside surveys, vehicle odometer readings taken at annual compulsory vehicle safety checks (Leduc, 2008), vehicle-user survey (Leduc, 2008) or may be extrapolated from fuel use (for example in Fridstrøm and Ingebrigtsen, 1991; Fridstrøm et al. (1995); Bishai et al., 2006). It may also be extrapolated from the number of vehicles registered (UK Department for Transport, 2001). Kopits and Cropper (2005) and Law et al. (2011) analysed registered vehicles as a proxy for kilometres travelled but that assumes that all vehicles travel an approximately similar distance per annum. This may not be accurate at the international level and may be influenced by a number of factors including the degree of urbanisation and the distance between urban centres or employment locations within each nation, for example. No studies were found which explored this proxy for exposure to risk of RTC.

Consideration of fatalities per vehicle kilometre travelled has other disadvantages; it makes no account for exposure to risk on the roads for pedestrians, pedal cyclists and those using mass transport. Even when flow data is available this is unlikely to be disaggregated by road type and the risk of fatality is not the same throughout the road network (Elvik et al., 2009). As a first approximation the fatality rate per vehicle kilometre travelled would be expected to be lowest for motorway type roads (UK Department for Transport, 2001). These are roads where opposing traffic streams are physically separate, more vulnerable road users including pedestrians and cyclists are excluded, junctions are few and road design is to the highest standards.

This thesis examines RTC fatality rates per 100,000 population. This allows consideration of data from the largest number of nations and from nations with a range of social, economic and geographic conditions. It is also appropriate given that the Pillars of Action for Road Safety are proposed by the World Health Organisation, an organisation primarily dealing with health data and where consideration of fatalities per unit of population would be the standard. Analysis is restricted to consideration of fatalities for the number of individuals killed on the roads is known more accurately than the number injured (Farchi, et al., 2006; Garg and Hyder, 2006, Amoros et al., 2006). Many injuries, particularly the less serious, may never become known to the authorities, or may not be included as part of national reporting systems (Derriks and Maks, 2007). For fatalities the likelihood of the event becoming recorded is much higher and it is national road traffic fatality rates, and the factors associated with the variation in those rates, which is examined in this thesis.

1.2.2 Sources of international road traffic fatality data

Given that to be able to evaluate contributory factors for variations in levels of road safety between nations some measure of road fatality rate is required, this must be comparable and of sufficient quality for all nations studied. However, data availability and reliability have been recognised as significant issues from the earliest studies of RTCs. Smeed (1949) noted that there were difficulties in obtaining accurate and directly comparable international RTC data, and Bangdiwala et al. (1985, pg 420) stated that “The reliability of accident (crash) data is a basic problem that must be considered by health planners”. Racioppi et al. (2004) advised caution in comparing and interpreting international RTC fatality rates because of data quality issues.

A number of aggregate national RTC fatality data sources exist. Availability varies and is best for the most economically developed nations. An overview of the existing datasets is given by Luoma and Sivak (2007).

The United Nations Economic Commission for Europe (UNECE) publishes annual Statistics of Road Traffic Accidents in Europe and North America. This gives aggregate crash and casualty statistics for 56 nations. However, some of this is data is assembled from the Community Database on Accidents on the Roads in Europe (CARE) database. CARE reports aggregate national RTC casualties for 27 EU nation. Records commence with 1991 data at the earliest and detail casualty numbers by user type, gender, age and month and year of crash.

However for internationally comparable data, only two sources are available, that produced by national health authorities and collated by the WHO (for example, examined by van Beeck et al., 2000) and police crash reports maintained by transport authorities and published by the IRF (as analysed by, for example, Eksler, 2007). While both health and transport data has been used in several comparative and descriptive studies, there has been little work in determining the accuracy or completeness of these datasets (Dharmaratne and Ameratunga, 2004).

Both the WHO and IRF report information for a large number of nations, and are described in more detail below.

1.2.2.1 World Health Organisation: Global Burden of Disease Project data

Preceding the 2004 and 2009 WHO reports numbers of RTC deaths per nation were estimated by the World Health Organisation for their Global Burden of Disease project (Murray and Lopez, 1996a; Murray et al., 2001). The WHO Department of Measurement and Health Information publish estimates of deaths per 100,000 population by cause for each member nation and it was this information, where available, which was used to produce the Global Burden of Disease estimates. The data details deaths by cause from official death notifications (vital registration) where the death of each individual in the nation is recorded. Information for 103 causes of death, including RTCs, is available for 2002 (WHO, 2004a) and it was this data which was analysed in this thesis.

Fatality definition is standardised in the WHO datasets since all contributing nations adopt the International Classification of Diseases (ICD) system for recording deaths in national returns to the WHO. Most nations use the 10th revision in which those injured in road transport accidents are coded V01-V89. For example, V40.5 specifies that the individual concerned was the driver of a car or minibus. This coding would identify that individual as the victim of an RTC regardless of the country where the incident occurred or the period elapsed between the incident and the individual's death. Thus the vital registration returns made to the WHO should be directly comparable between nations.

However, the WHO acknowledges that the data reported may have deficiencies. The 2009 WHO Global Road Safety Report identifies 73 of the 178 nations presenting data as supplying accurate and timely vital registration (death certificate) data. Accuracy was determined by the WHO from the low percentage of reported deaths ascribed to non-specific descriptors while timeliness was determined from the currency of the latest available data.

While the majority of nations supply vital registration data of variable quality, two (India and China) rely on survey data where deaths occurring in a representative cohort are extrapolated to the whole nation. This method relies on the chosen cohort being truly representative of the nation.

In the least economically developed nations, predominantly in Sub-Saharan Africa and South East Asia, universal vital registration systems do not exist. For these nations (referred to as Level Four nations by the WHO) deaths-by-cause are estimated through mathematical modelling (Salomon and Murray, 2000; Murray et al., 2001). For the year 2002 modelling to determine RTC fatality rate in WHO level four nations is a three-stage process and the technique may lead to RTC fatality rates of questionable validity. Total all-cause adult mortality in these nations is not known accurately but is inferred from child mortality. Total adult fatalities are then divided among three cause-of-death groups using a vector-based compositional model developed by Katz and King (1999). This process involves using the total adult mortality rate together with per capita income to predict the proportion of all deaths attributed to communicable, maternal, perinatal and nutritional diseases (Group I), non-communicable (Group II) and injury (Group III) causes. The two predictors enable allowance to be made for the epidemiologic transition. A low income, high mortality rate nation has a different pattern of causes of death to a high income, low mortality rate nation. Total deaths for Groups I, II and III are then disaggregated to individual causes using life tables of numbers of deaths-by-cause obtained from a reference country in the same geographic region which collects vital registration data. For Group III (injury, including RTC) deaths the WHO suggest a +/-25% error rate (Mathers, 2005).

The technique used by the WHO assumes that the modelled nations have similar demographics and proportions of deaths-by-cause as the reference nation. In the case of RTC fatalities this assumption is questionable. For Sub-Saharan Africa the reference country is South Africa. Würtheim et al. (2001) point out that Sub-Saharan Africa is a very diverse region, both economically and demographically. South Africa is both wealthier and has more vehicles per unit of population than other nations in the region. Moreover, the South African vital registration system accounted for fewer than 50% of all deaths in the 1990s and was only around 90% complete when the 2002 data was collected (Bradshaw et al., 2003). Cardiovascular disease mortality estimates for Sub-Saharan Africa, obtained using the same method, have been criticised for overestimating true levels given the low incidence of risk factors in these nations (Cooper et al., 1998).

Similar problems can occur elsewhere. Nations with good cause-of-death data will generally be more economically developed than the nations they provide reference data for and their higher levels of development will be associated with higher levels of motorisation. Hence, the 2002 WHO RTC fatality rates for level four nations are most likely considerably less reliable than RTC fatality rates for other nations, with the likelihood that the method used overestimates the true RTC fatality rate.

The WHO acknowledge that in some nations RTC fatalities may not appear in vital registration, and hence the WHO records. This may occur if casualties die at the scene (approximately 60% of all deaths in less motorised nations (Montazeri, 2004)), on the way to hospital, or after receiving non-formal health care, a widespread practice in rural areas of sub-Saharan Africa (Moshiro et al*.,* 2001). Because the fatality is dealt with directly by family or friends and does not enter the formal health system their deaths are not documented. The degree of under-reporting can be considerable; Abdalla and Shaheen (2007) found that only 4.4% of deaths in Sudan in 2002 were formally recorded. In a mortuary study in Ghana, 80% of deaths due to injury occurred outside hospital and would not have appeared in hospital statistics. 88% of these deaths were RTC victims (London et al., 2002). The WHO publishes estimates of the completeness of national vital registration data (WHO, 2008). Completeness varied from less than 50% (Zimbabwe, Haiti and Malaysia) to 100% (all level one and 48 of 84 level two nations). The WHO stress that reported deaths may not be typical of all deaths in the nation (for example, reported deaths may have an urban bias or record deaths in a particular region only) (WHO, 2008). Thus it would be unwise to extrapolate from the reported RTC deaths to produce an estimate for the whole nation. The WHO Global Status Report on Road Safety (WHO, 2009) also discusses the significance of underreporting. Indeed it suggests that reported deaths in 2007 may only have reflected around 55% of the World total.

1.2.2.2 International Road Federation data

The most commonly used database is World Road Statistics published annually by the International Road Federation (IRF). Fatalities are aggregated by gender, age, road user type and by year and month. This information is supplied by national statistics or transport administrations and reports data originating from police RTC records. The data originates from predominantly Organisation for Economic Cooperation and Development (OECD) and economically developed nations. The 2006 edition includes RTC fatality estimates for the year 2002 for 81 nations (International Road Federation, 2006). The IRF also supplies information regarding vehicle ownership, annual kilometres travelled, road length by class of road and crashes and casualties by age, gender and severity[1]. Data has been collected annually from 1965, though the number of contributing nations has increased over time.

However, issues of data comparability and under-reporting are acknowledged to occur with the IRF data source (Bishai et al., 2006; WHO, 2009 pg ix). Comparability issues occur because national police forces and transport authorities may adopt different time periods for the casualties death to occur. In most of Western Europe and North America the Vienna Convention (The United Nations Convention of Road Traffic, Vienna, 1968) is adopted and road traffic deaths are those occurring at the time, or within 30 days of the crash, and as a result of the crash. In many of the former Soviet states road deaths must occur within seven days of the crash. In other nations, regardless of the stated time period, in practice only deaths occurring at the time of the crash or very shortly afterwards will enter the national RTC fatality database (Jacobs et al., 2000).

Under-reporting may be a significant issue in some returns to the IRF and will include incidents not reported to the authorities or those falling outside the police remit. For example, Derriks and Maks (2007) found that only 92% of road fatalities were notified to the police in the Netherlands. Fatalities will only appear in the national database if the police are advised that the crash has occurred. Razzak and Luby (1998) found that only 56% of RTC fatalities had been reported to the police in Karachi, Pakistan, and Jacobs et al. (2000) suggested even higher non-report rates for some nations. The health service in the Philippines reported five times the number of road deaths as the police. In a study of RTC fatality in Yemen, Ameen and Naji (2001) found that some deaths were omitted because those admitted to hospital with serious injuries were not always followed up after admission. Furthermore, some fatalities were not recorded by the police if the parties involved in the crash resolved the matter between themselves.

A number of incidents will go unrecorded if they do not meet the official criteria of RTC. Authorities in Mexico only record crashes occurring on national highways (Jacobs et al., 2000). In most EU nations the incident must involve at least one moving vehicle. However, in Portugal and the UK the

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[1] Crashes and casualties are usually graded fatal, where one or more individual are killed, serious, where the most badly injured casualty requires hospital treatment and slight, where the most badly injured casualty requires medical attention but does not require in-patient treatment at hospital.

vehicle(s) involved can be stationary (European Commission Directorate General Energy and Transport, 2006).

Jacobs et al. (2000) give a full description of the problems inherent in IRF data and offer a solution by way of mathematical adjustment to correct for both differences in fatality definition and for under-reporting. Jacobs et al. (2000), and others, used the adjustment factors for different time limits for RTC fatalities suggested by the European Council of Ministers of Transport (ECMT, now known as the International Transport Forum). Using these factors, the number of RTC fatalities in a nation adopting a within-7-days of the crash time limit for road deaths would be multiplied by 1.08 to allow comparison with data from nations adhering to the within 30 day rule.

Under-reporting may also be present for some high-income nations. While Derriks and Mak (2007) found a non-report rate of less than 5% in nations such as Spain, Australia and Germany, Jacobs et al. (2000) suggested an RTC fatality under-report rate of 26% in Italy. This was based on the discrepancy between police and health records although the reasons for the difference were not explored.

Jacobs et al. (2000) also give examples of administrative factors which can affect the reliability of the IRF RTC fatality estimates. UK local police authorities have six months to provide RTC fatality information to the national database, whilst in France all data for the preceding year must be received by the end of January, with the potential that some fatalities occurring in the latter months of each year do not enter the national records.

Traditionally, transport studies analyse police-reported RTC fatality data though these are acknowledged to often be lower than health-derived data (Jacobs et al., 2000). Since the IRF database presents a long time-series and has been used frequently in the past, there is some merit in its continued use in international studies.

1.2.2.3 World Health Organisation Global Status Report on Road Safety

Since road traffic fatalities can be enumerated from both health service or police and transport sources for most countries, which should be used for comparative purposes? The World Health Organisation Global Status Report on Road Safety (WHO, 2009) presents road safety data for 178 nations. The aim was to produce benchmark data by which nations could assess their road safety record with respect to other nations. Participating nations were asked to identify the national reporting authority and supply the total number of RTC fatalities recorded by that authority. It is noteworthy that the reporting authority was identified as the police or transport authorities for over 60% of nations. Only 14% reported fatality data collated by the health service, the data source hitherto used by the WHO.

The WHO document gives unadjusted RTC fatalities for one group of 75 countries and estimated numbers of fatalities for the remaining countries. The first group were nations whose vital registrations were considered at least 85% complete and where fewer than 30% of deaths due to external causes are coded as being from an undetermined cause. The unstated assumption being that nations producing reliable vital registration data also provide accurate police-derived RTC data. Reported data from the nations judged to be accurate was used as the basis of a statistical model to estimate RTC fatalities for the remaining nations, the majority (70%) of which are level four nations, as classified by WHO (2004a). Predictors of RTC fatality, selected from a literature review and included in a regression model were national population and income together with measures of vehicle ownership, road density, alcohol consumption, hospital beds available and presence of road safety policies and legislation.

Although WHO (2009) employs a revised method to estimate fatalities for nations with unreliable statistics, this approach is limited in that it assumes modelled relationships derived for nations where suitable quality data is available will accurately predict fatalities in other, less developed, nations. A further limitation is that the outputs of such modelling exercises are essentially synthetic estimates that are based on empirical relationships with the predictor variables used in the model. Hence they are of no use in studies which aim to identify the specific characteristics of less developed countries that may be driving their higher fatality rates.

The WHO (2009) report thus presents a mixture of road traffic fatality numbers from police and health service sources, as received from individual countries, with a large proportion of estimated values.

1.2.3 Relationship between national economic development and RTC fatality rate

Road traffic crashes (RTCs) have been referred to as a disease of affluence, with road use and road deaths increasing with the economic development of a nation (van Beeck et al., 2000). There is some evidence that the association is, however, non-linear, with an inverted U-shaped relationship between economic development and RTC fatalities (Söderlund and Zwi, 1995; van Beeck et al., 2000; Kopits and Cropper, 2003; Kopits and Cropper, 2005; Bishai et al., 2006; Paulozzi et al., 2007; Kopits and Cropper, 2008). The observed relationship suggests that at the lowest levels of economic development, as the wealth of a nation increases, the per-capita rate of road traffic crash fatalities increases rapidly. A turning point was reached in the 1970s for many Organisation for Economic Cooperation and Development (OECD) nations after which increased economic development was associated with a decreasing RTC fatality rate (Kopits and Cropper, 2005). At the highest levels of income it has been suggested that RTC fatality rates may no longer decline but may level off to some 'natural' value (van Beeck et al., 2000; Paulozzi et al., 2007).

However, the studies described above have analysed IRF data from predominantly highly motorised nations and this has dated from the 1990s. Moreover, Nasrullah et al. (2008) analysed WHO-derived data for 1996 – 97 and found that the relationship between Gross Domestic Product (GDP) was positive and linear when OECD nations were examined but negative and linear for non-OECD nations. This suggests that analysis of more current, especially health-derived data may be of advantage and that the relationship between economic development and RTC fatality rates may not be as clear as proposed by previous authors.

1.2.4 Factors associated with the variation in international road traffic crash fatality rate

While variation in national RTC fatality rates is usually explained in terms of per capita income, for example Gross National Income (GNI), it is not wealth *per se* which causes road crashes. This raises the question as to what risk factors underlie the observed association with income. This may indicate areas for action for nations wishing to reduce the RTC toll including evidence regarding the efficacy of the WHO Pillars of Action. Moreover, closer examination of the factors associated with economic development may act in opposing directions with respect to RTC fatality for some factors associated with RTC risk increase the risk of RTC as the nation's wealth increases while others are protective. For example, health spend as a percentage of GDP (Anderson et al., 2000) increases with per capita GNI. Theory suggests that this should reduce national RTC fatality rates. However, alcohol consumption (WHO, 2004b), vehicle ownership (Kopits & Cropper, 2005) and road energy use (Wohlgemuth, 1997) also increase with per capita GNI and these may act to increase the national RTC fatality rate.

A number of studies have attempted to understand the reasons for the substantial international variations in fatalities. A number of factors have been cited as influencing temporal or geographical variations in RTC fatality rates within or between nations. These include level of vehicle ownership and use (exposure to the risk of death on the road), socioeconomics (principally age structure and employment levels), condition of the road infrastructure, relative safety of the national fleet in terms of composition and market penetration of safety features, quality of medical care available to road casualties and attitude and behaviour of road users including speeding, adherence to road safety legislation and drink and drug driving (Bester, 2001; Page, 2001; Kopits and Cropper, 2005; Anbarci et al., 2006; Bishai et al., 2006; Paulozzi et al., 2007; Law et al., 2009). While many studies have examined the effect of one or more of these factors at the within-nation level, few have examined variations in fatality rates between nations. Those that have attempted to do so are described below.

Greater exposure to risk by means of increased annual vehicle kilometres travelled is generally taken to be associated with higher RTC fatalities. However, annual vehicle kilometre data is available for a restricted number of nations (Kopits and Cropper, 2005) and other exposure proxies have been examined including transport fuel use (Bishai et al., 2006) and vehicle ownership (Kopits and Cropper, 2005; Law et al., 2011). Results have not always been consistent with the exposure hypothesis. For example Bishai et al. (2006) found that transport fuel use was significantly positively associated with road fatalities in high income but not in lower income nations.

There is evidence that variations in the age of the road user population may be important. In most nations the RTC fatality rate is highest for those aged 15 – 24 years (Kopits and Cropper, 2008), and Page (2001) found that the percentage of the population aged 15 – 24 was significantly positively associated with national RTC fatality rates. Page also found that the percentage of the population who are employed was positively associated with fatality rates, with the hypothesis that employment is associated with increased road use.

The heterogeneity of the vehicle fleet or mode of travel has been found to influence RTC fatality rates. Road deaths are lower when a majority of road users in a country are travelling within the protection of a car (Paulozzi et al., 2007; Law et al., 2009) or by public transport (Page, 2001). The presence of many vulnerable road users, such as pedestrians, cyclists or two- or three-wheeled vehicles, or slow-moving heavy vehicles which induce potentially risky overtaking manoeuvres have also been associated with higher road fatality rates (Navon, 2003), though the associations described have not been consistent across all studies. For example, Kopits and Cropper (2008) found that the proportion of motorised two-wheelers in the national fleet was not significantly associated with RTC fatalities in a sample of high income OECD nations for the period 1970 – 1999.

Several studies have examined the effect of health care on international variations in RTC fatality rates, though all have used proxies rather than direct measures of the quality of care given to road crash casualties. These proxies include health spend as percent GDP (Söderlund and Zwi, 1995), average hospital stay for acute care (Noland, 2003), infant mortality rate (Noland, 2003; Law et al., 2009) and physicians per capita (Noland, 2003; Kopits and Cropper, 2008: Law et al., 2009; Law et al., 2011). Whilst largely supporting the hypothesis that better health care is associated with lower RTC fatality rates, not all studies have found a significant relationship.

Road safety enforcement has not been directly assessed at the international level (Bishai et al., 2006). A number of authors have, however, analysed the effect of a corruption index proxy on national RTC fatality rates. The hypothesis is that in a corrupt society road safety legislation will be poorly adhered to and enforced with a resultant high level of RTC fatality (Anbarci et al., 2006; Law et al., 2009, 2011). Again results have been inconsistent and dependent on the type of road user studied or level of economic development of the nation.

The effect of alcohol consumption on individual road user risk of crash involvement and of death is well known (Zador et al., 2000). As information on alcohol use amongst road users is not available for comparison between countries, a number of proxies have been used, principally mean annual per capita alcohol consumption (Page, 2001: Bishai et al., 2006; Kopits and Cropper, 2008). Nevertheless, a positive relationship between alcohol consumption and national RTC fatality rate has not always been demonstrated. Bishai et al. (2006) found that, while alcohol consumption was significantly positively associated with RTC fatalities in a group of 41 nations, when the group was subdivided on the basis of per capita income the relationship between per capita alcohol consumption and road deaths was negative for lower income nations and positive for the higher income nations.

Chapter 2: The problems in determining international road mortality

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2.1 Introduction

Pillar 1 of the measures proposed to reduce RTC fatalities is improved safety management. As part of this the WHO advocate the setting up and maintenance of an adequate RTC database for each nation. This chapter investigates the available international RTC fatality data sources. A review of available datasets is undertaken. Known deficiencies are identified and discussed. Two procedures to adjust for some of these deficiencies are described and implemented using RTC fatality rate estimates from the World Health Organisation (WHO) and International Road Federation (IRF) for the year 2002. The validity (correspondence to the true national crash mortality rate) of the original and adjusted datasets is examined by comparing them with a set of measures which have been shown to be associated with RTC mortality. We also examine implications of a recently published WHO rates for 2007, which, unlike earlier WHO work, uses mostly police not health service records (WHO, 2009). This raises the question as to which of the two data sources (health or police) is a more reliable measure for international comparisons of RTC mortality. As the recent WHO report does not evaluate this, we do so in this paper. We believe this is the first time such an analysis has been undertaken at the international level. While the Decade for Action for Road Safety continues to advocate use of police-derived RTC data the analyses detailed here suggest that health-derived data may be a better tool for both monitoring national RTC fatality rates over time and for comparing road safety between nations.

2.2 Method

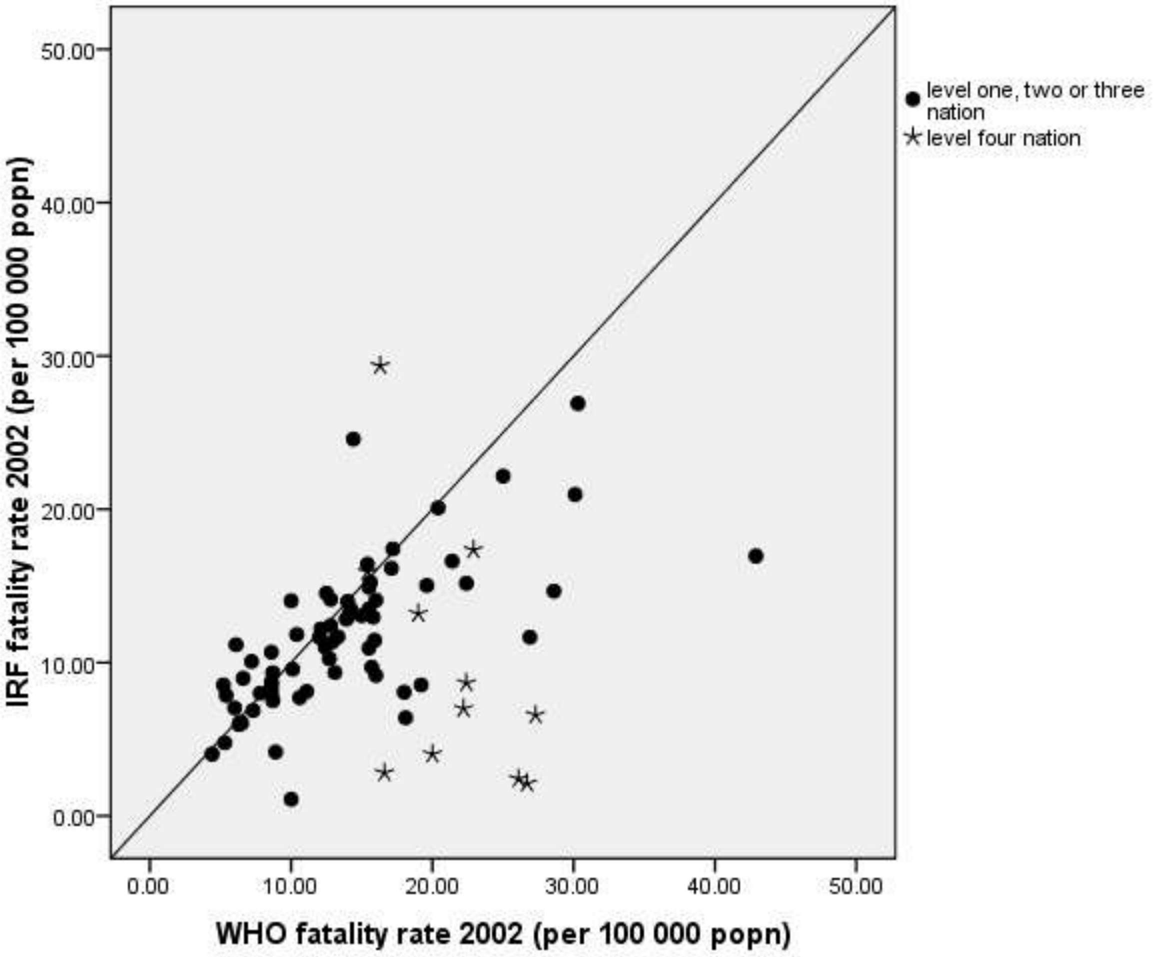
WHO and IRF RTC fatality rates for 2002 were examined. The year 2002 was chosen since this was the most current data presented by the WHO when the work was commenced. RTC fatality rate estimates (deaths per 100,000 population) were obtained from the World Health Organisation Global Burden of Disease project (WHO, 2004a) and World Road Statistics (International Road Federation, 2006). The World Health Organisation Global Status Report on Road Safety (WHO, 2009) was also consulted.

Information for 177 nations was obtained. The IRF and WHO fatality rates for each nation are available in a supplementary table. For two nations the WHO estimates for 2000 (Albania) and 2001 (Slovakia) were used since the 2002 estimates appeared anomalously low (Albania: WHO RTC fatality rate per 100,000 for 2002 = 2.50, for 2000 = 11.1, mean IRF rate 1999 – 2004 inclusive = 9.09. Slovakia: WHO 2002 RTC rate = 1.10, for 2001 = 12.90, mean IRF rate = 11.77).

IRF RTC fatality estimates were available for 79 (44.6%) of the 177 nations. WHO RTC fatality rates for 2002 were available for all 177 nations. Level four nations constituted 69 of the 177 (39.0%). Eleven of the 69 WHO level four nations also had RTC fatality rate data supplied by the IRF. The lowest IRF fatality rate was 1.08 per 100,000 population (Philippines), the maximum was 29.36 (Botswana) with a median fatality rate of 11.00 per 100,000. The lowest WHO fatality rate was 2.00 per 100,000 population (Jamaica), maximum 64.30 (Sierra Leone) with a median fatality rate of 15.60 per 100,000.

Figure 1 shows the scatterplot of IRF versus WHO 2002 RTC fatality rates for the 79 nations for which both estimates were available. Overall there is a relatively weak correlation between the two datasets (Pearson correlation coefficient, $R = 0.400$, $p < 0.001$). There is a tendency, especially amongst the level four nations (marked by stars in the figure) for the WHO rate to be greater than that published by the IRF. For the 68 level one to three nations the correlation between the two 2002 RTC fatality rates was 0.673, $p < 0.001$.

Figure 1: WHO versus IRF RTC fatality rates by country (2002). All nations.



Due to the fact that data for level four nations are based on modelled estimates and show a poor correspondence with police records, their use in international comparisons is not recommended and hence level four nations were omitted from further analysis.

Of the remaining 68 nations 58 (85.3%) had an IRF RTC fatality rate within ±50% of the WHO fatality rate, and 41 (60.3%) had an IRF RTC fatality rate within ±20% of the WHO rate. 49 of the 68 nations (72.1%) had a WHO RTC fatality rate greater than the IRF rate. The mean difference between the two RTC fatality rates was 8.46%, S.D. 30.53; the median was 7.19%. Percentage differences ranged from −82.95% (Georgia, IRF rate greater than WHO) to 89.20% (Philippines, WHO rate greater than IRF).

2.2.1 Adjustment for fatality definition and under-reporting

Both datasets have different problems that can lead to underreporting, and the IRF dataset suffers from a lack of fatality definition standardisation. There are inherent problems in making any adjustment to the WHO RTC rate as unreported deaths are likely to be unevenly distributed. Consequently WHO RTC fatality rates were not adjusted. It was possible to adjust the IRF RTC fatality rates for both under-reporting and fatality definition and this was done for the 68 level one-three nations which had both WHO and IRF RTC fatality rates.

2.2.1.1. Adjustment of IRF fatality rates

Two previously published techniques were used. The first is fully described in Jacobs et al. (2000) and adjusts for fatality definition issues. The second is described by Koornstra (2007) and adjusts for under-reporting.

2.2.1.1.1 Adjustment method 1: Jacobs et al. (2000)

The adjustment made to the IRF fatality rate was to standardise to the Vienna Convention for definition of an RTC fatality. The European Council of Ministers of Transport (ECMT) has produced a set of correction factors to standardise RTC fatality rates to the “within-30-day” fatality definition. Using these factors, the reported IRF RTC fatality rate for those nations adopting an RTC fatality definition of death at the scene or within one day of the crash is increased by an additional 30% to account for deaths assumed to occur on days 2 – 30 post crash. These ECMT correction factors were also used by the 2009 WHO Global Status Report to adjust nationally reported RTC fatalities, where necessary, to the 30-day standard (WHO, 2009).

Jacobs et al. (2000) used the ECMT correction factors for all Western European nations, USA, Canada, Japan, New Zealand and Australia (categorised as High Motorised Countries, or HMCs). For all other nations Jacobs et al. (2000) assumed that police RTC fatality reports would be completed at the time the crash occurred, irrespective of the stated national time period, and no adjustment would be made for those dying on subsequent days. For these nations Jacobs et al. adopted a correction factor of +15%. The correction factors used are detailed in Table 1.

Table 1: Correction factors for different fatality time period definition (from Jacobs et al. 2000)

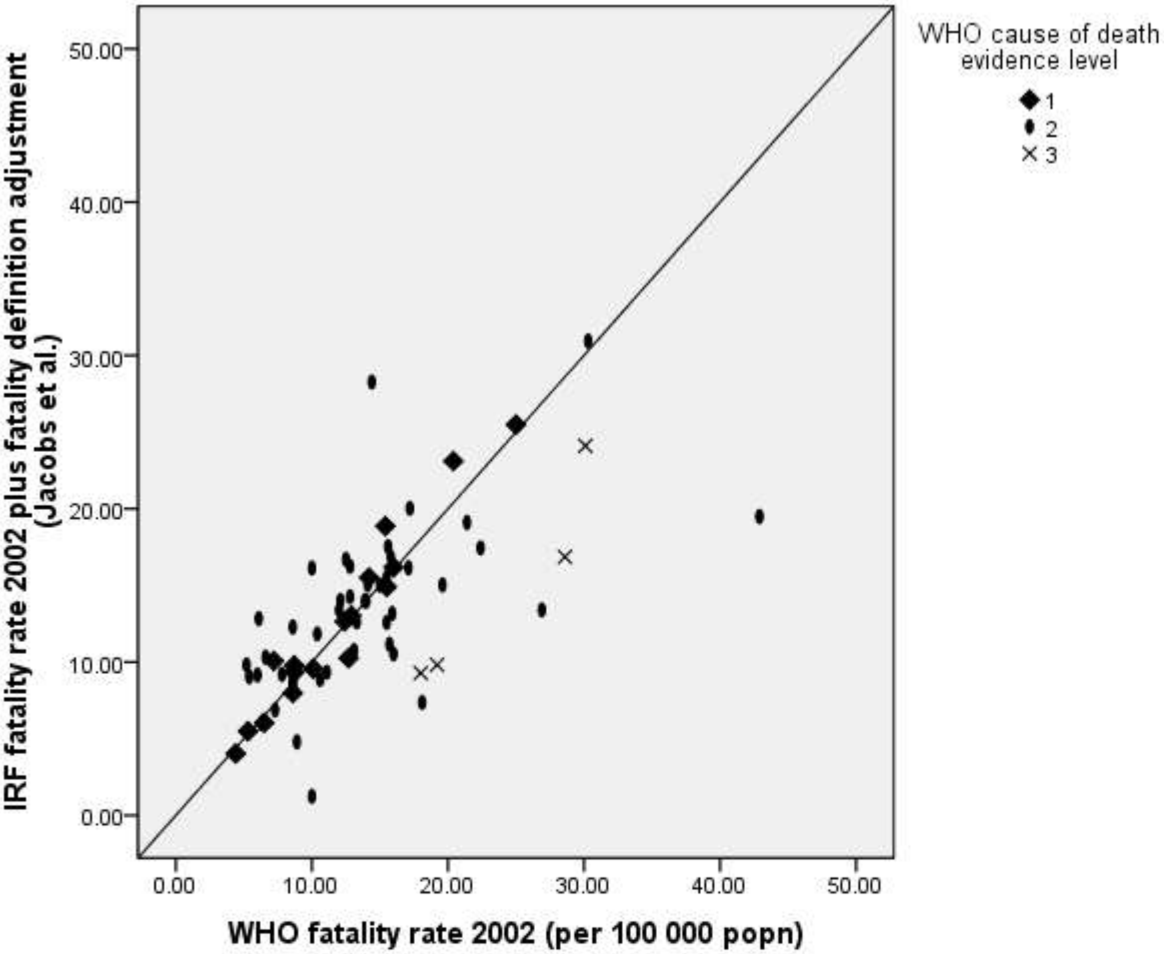
Definition of death	*Country*	*Adjustment factor (additional % added)*
Scene or 1 day	Japan, Spain, Switzerland	30
6 days	France	9
7 days	Italy	8
30 days	Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Greece, Iceland, Ireland, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Sweden, UK, US	0
All other countries		15

The ECMT adjustments do not take account of deaths at 31 or more days following the crash. These would not appear among the road deaths recorded by police in nations adopting the Vienna Convention. However, Broughton (2000) found that less than one percent of casualties died at 31 or more days following the crash in nations such as the UK, Netherlands and Japan. No addition was made to the IRF RTC fatality rates for deaths occurring after 30 days after the crash.

Jacobs et al. (2000) were concerned to estimate the global total of road fatalities from police data and suggested a second adjustment to account for under-reporting. However, the empirical adjustment factors used were determined from nations with both police and health data and were designed to bring the IRF RTC fatality rates into line with WHO RTC fatality rates, with the unstated assumption that the WHO rates might be more accurate. Since we were concerned with determining whether either the IRF or WHO RTC fatality rates were more valid, we did not adjust IRF RTC fatality rates using the Jacobs et al procedure.

Figure 2 shows the scatterplot of IRF RTC fatality rate adjusted for fatality definition versus WHO 2002 RTC fatality rate. Adjusted IRF rates are detailed in the supplementary table. Thirty-six of the 68 nations (52.9%) had an adjusted IRF RTC fatality rate greater than the WHO rate. The mean difference between the WHO and IRF RTC fatality rates was –1.84%, S.D. 35.02, whilst the median was -0.18%. Percentage differences ranged from -110.39 (Georgia, IRF rate greater than WHO) to 87.58 (Philippines, WHO rate greater than IRF). The Pearson correlation coefficient for the two variables was 0.683 ($p<0.001$). Figure 2 illustrates that disparities remain between the WHO and IRF RTC fatality rate estimates for 2002 for most nations, although their magnitude is reduced.

Figure 2: WHO versus IRF adjusted for fatality definition (Jacobs et al. method) RTC fatality rates by country (2002). Level One – Three nations only.



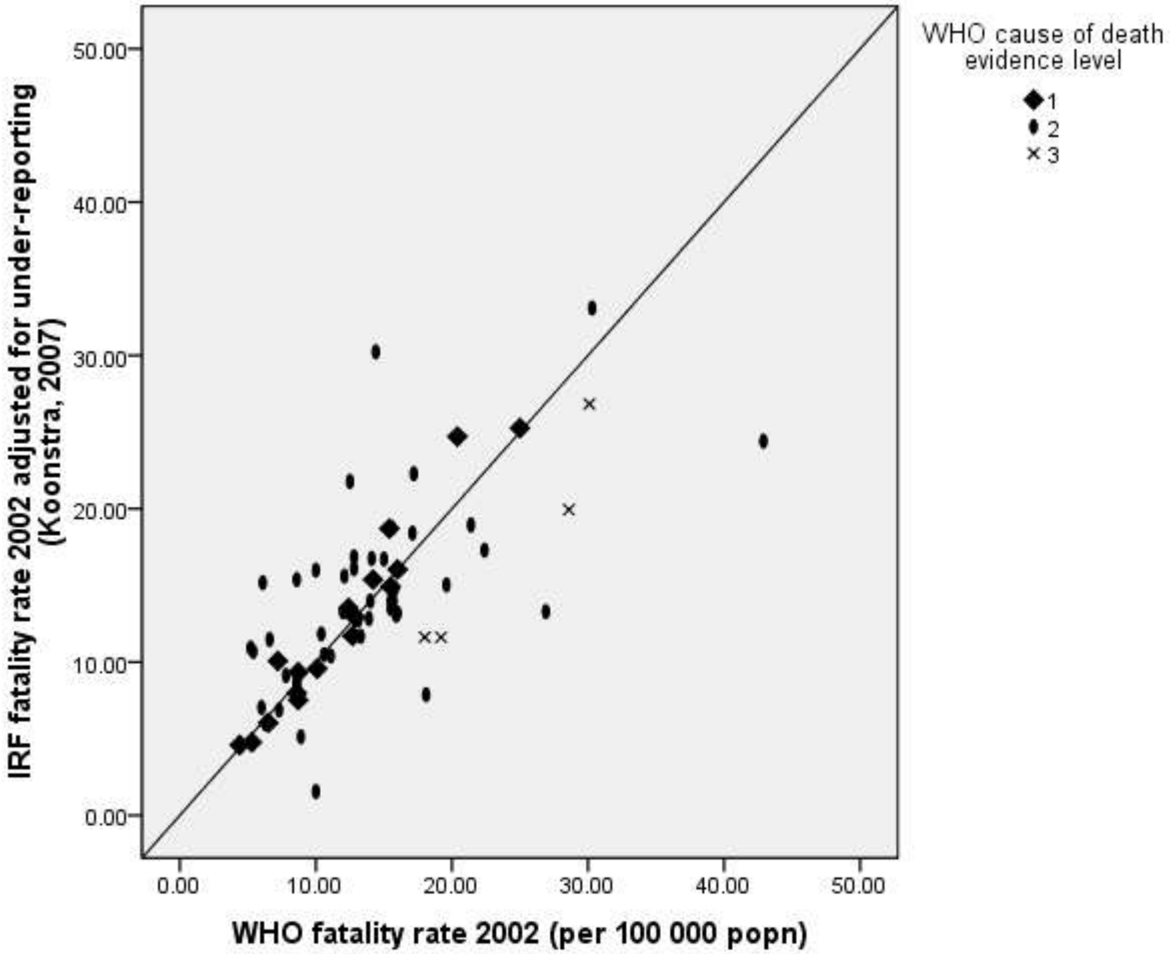
2.2.1.1.2 Adjustment method 2: Under-reporting adjustment based on Gross National Income

Koornstra's (2007) method was used to adjust IRF RTC fatality rates for under-reporting. No adjustment was made for fatality definition. This method is based on the assumption that nations with similar income levels, and therefore levels of motorisation, have similar rates of RTC fatalities. Koornstra's work also acknowledges that the relationship between income and RTC fatality rate might be non linear. Gross National Income (GNI, Atlas Method) per capita data was available for all 68 level one-three nations with IRF and WHO RTC fatality rate data. The Atlas Method converts national income in local currency to an international standard currency, the US dollar (World Bank, 2009). Nations were divided into octiles on the basis of GNI. IRF fatality rate for the lowest income group is adjusted by x 1.57, and the highest income group by x 1. (Adjustment factors in increasing order of GNI were 1.57, 1.50, 1.44, 1.36, 1.28, 1.23, 1.14, 1.00).

Thirty-five of the 68 nations (51.5%) had a WHO RTC fatality rate greater than the GNI adjusted IRF rate. The mean difference between the WHO 2002 and GNI adjusted IRF RTC fatality rates was -7.05%, S.D. 39.56, whilst the median was 0.61%. Percentage differences ranged from -148.81 (Georgia, IRF rate greater than WHO) to 84.45 (Philippines, WHO rate greater than IRF).

Figure 3 shows the scatterplot of IRF RTC fatality rate adjusted using the Koornstra correction factors versus WHO RTC fatality rate. Koornstra's adjustment brought closer agreement with the WHO 2002 RTC fatality rate for the majority of nations. The Pearson correlation coefficient increased to 0.711 (p<0.001). However, some outliers remain.

Figure 3: WHO versus IRF (adjusted for under-reporting using Koonstra's adjustment) RTC fatality rates by country (2002). Level One – Three nations only.



2.2.2 Validation of datasets

To assess which of the RTC fatality rates appears to more accurately reflect the true variations in mortality between nations, correlations between the fatality rates and a set of explanatory variables associated with RTC fatality risk were explored. We assumed that the more accurate measures of RTC fatality rate would have a tendency to be more strongly correlated with the explanatory variables.

A large number of explanatory variables have been assessed previously. These include density of road network (Jacobs and Cutting (1986); Söderlund and Zwi (1995)); number and type of vehicle per kilometre of road (Jacobs and Cutting (1986); Söderlund and Zwi (1995)), number of vehicles per 1,000 population (Page, 2001; Noland, 2003), exposure to risk (kilometres travelled per year (Haight, 1984)), quality of available medical services (Noland, 2003), behavioural factors (seat belt use, speeding and alcohol consumption) and national economic factors including percent population unemployed (Wagenaar, 1984; Gerdtham and Ruhm, 2006), Human Development Index (Bester, 2001) and per capita Gross Domestic Product (GDP) (Söderlund and Zwi, 1995; Kopits and Cropper, 2005; Bishai et al., 2006).

Seven variables were selected here because they were available for a large number of countries, had been used in previous studies and were readily justifiable in terms of RTC fatalities. Table 2 details the variables assessed together with known associations. The Human Development Index (HDI) is a composite measure derived from life expectancy at birth, adult literacy, educational enrolment ratio and per capita GDP, and is taken as a proxy for level of development. The variables are very similar to those used estimate road traffic fatalities by WHO (2009), except that we did not include measures of alcohol consumption and the presence of road safety policies.

Table 2: Explanatory variables found to be associated with RTC fatality rate

Explanatory variable	*Previous studies*	*Location of study*	*Previous findings*
Road density	Bester (2001)	175 nations. 1994-96.	Negative association.
Vehicles per km road	Jacobs and Cutting (1985)	20 developing nations. 1980.	Negative association.
	van Beeck et al. (1991)	Netherlands-regions. 1980-84.	
Vehicles per 1,000 population	Jacobs and Cutting (1985)	20 developing nations. 1980.	Negative association.
	Page (2001)	OECD nations. 1980-94.	Positive association.
	Bester (2001)	159 nations. 1994-96.	Positive association.
	Noland (2003)	22 OECD nations. 1970-96.	Positive association.
	Paulozzi et al. (2007)	44 nations. 1996-2002. One year WHO fatalities,	Relationship varies with road user type. For motor vehicle occupants relationship is an inverted U.
Million vehicle kilometres travelled per annum	Lassarre (2001)	10 EU nations. 1950s-1990s. Time series	Negative exponential. Varies with time-road system becomes safer over time.
	Scuffham (2003)	New Zealand. 1970-94.	Non linear relationship.
Doctors per 1,000 population	Noland (2003)	22 OECD nations. 1970-96.	Negative association.
	Law et al. (2009)	25 nations. 1970-99. Motorcycle fatalities.	Negative association.

Table 2 continued.

Explanatory variable	*Previous studies*	*Location of study*	*Previous findings*
Human Development Index (HDI)	Bester (2001)	165 nations. 1994-96.	Developed nations-negative association. Less developed nations-positive association.
Gross Domestic Product (GDP) per capita	van Beeck et al. (1991)	Netherlands-regions. 1980-84.	Negative association.
	van Beeck et al. (2000)	21 industrialised nations. 1962-90. Time series.	Until 1975 positive relationship, thereafter negative relationship.
	Söderlund and Zwi (1995)	83 countries. 1990.	Inverted U shape relationship.
	Bester (2001)	170 nations. 1994-96.	Inverted U shape relationship.
	Kopits and Cropper (2005)	88 nations. 1963-99.	Inverted U shape relationship.
	Bishai et al. (2006)	41 nations. 1992-96.	Inverted U shape relationship.
	Law et al. (2008)	25 nations. 1970 – 99. Motorcycle fatalities.	Inverted U shape relationship.

Some previous studies have suggested that the relationships between RTC fatality rate and GDP, HDI, vehicles per kilometre of road, vehicles per unit of population or vehicle kilometres travelled per annum are non-linear. At low levels, increase in the explanatory variable is associated with an increase in RTC fatality rate; at higher levels an increase in the explanatory variable is associated with a decrease in RTC fatality rate i.e. the relationship approximates to an inverted U shape. We allowed for the possibility of non linear relationships by modelling all explanatory variables as quadratic terms, but found no quadratic term was statistically significant ($p < 0.05$). The quadratic terms were accordingly dropped. RTC fatality rates were found to be approximately normally distributed and were assessed without transformation.

Correlations between explanatory variables and the four RTC fatality rates are given in Table 3. Of the explanatory variables chosen, only road density was significantly associated with all four RTC fatality rates assessed. As the density of the road network increased the rate of RTC fatality, however measured, decreased.

Consistent negative associations, not always significant, were observed between fatality measures and vehicles per 1,000 population, HDI and GDP per capita. The other associations were generally weaker and less consistent. In all cases, the WHO data produced stronger associations than either the raw IRF figures or after fatality definition adjustment. In some cases, Koornstra's adjustment of the IRF data produced higher correlations, notably with the HDI and GDP. However, both GDP and HDI are positively associated with GNI ($R = 0.759$ for HDI and 0.951 for GDP, $p < 0.001$) and it is important to remember that this is the measure used to adjust the IRF RTC fatality rate for under-reporting.

Table 3: Correlation between explanatory variable and RTC fatality rate (R values)

Variable	*N countries*	*WHO*	*IRF*	*IRF adjusted for fatality definition (Jacobs et al. 2000)*	*IRF adjusted for under-reporting (Koornstra, 2007)*
Road density	68	-0.356**	-0.288*	-0.278*	-0.335**
Vehicles per km road	54	-0.139	-0.066	-0.077	-0.153
Vehicles per 1,000 population	64	-0.178	0.011	-0.060	-0.211
Million vehicle kilometres travelled per annum	45	0.034	0.028	-0.015	-0.033
Doctors per 1,000 population	54	-0.186	0.103	0.089	0.052
Human Development Index	68	-0.368**	-0.180	-0.240*	-0.399**
GDP per capita	68	-0.295*	-0.138	-0.214	-0.350**

* = $p < 0.05$, ** = $p < 0.01$

2.3 Discussion

We believe that this is the first study to compare RTC fatality rates published by the World Health Organisation and the International Road Federation. This study has shown that, in the case of RTC fatalities, international comparisons are hampered by data quality issues. Some of these issues can be identified and partially resolved, though no methodology examined here was fully successful in this.

Substantial differences between the WHO and IRF RTC fatality rates remain for a number of nations after adjustments have been made. It is not possible to say which of the two databases is more valid for any given nation. However, all the hypothesised explanatory variables were more strongly associated with the WHO figures than with the IRF data or the IRF data adjusted for fatality definition. Coupled with the greater number of nations for which data is available, this suggests that the WHO RTC fatality rate database (level four nations excluded) may be the most suitable for international comparative studies. This conclusion is significant in light of the most recent work by the WHO which makes use of a database which is largely derived from the same sources as that employed by the IRF.

The World Health Organisation provides RTC fatality rate estimates for almost all nations. The IRF database reports data from fewer nations, predominantly the wealthier, more motorised ones. For nearly 60% of nations the WHO RTC fatality rates are derived from the national vital registration systems. These may be less than 100% complete. For 69 level four nations (39% of the sample examined) the WHO derive RTC fatality rates via mathematical modelling. Reference nations used in modelling tend to be more economically developed and more highly motorised than the nations modelled. As a consequence, we suggest that the procedure used over-estimates RTC fatalities, and hence use of WHO data for these 69 nations is inadvisable for international comparison studies.

The 2009 WHO report also found that data from the level four nations was inaccurate and, furthermore, questioned the reliability of vital registration data from some more economically developed level two and three nations. For international comparative studies, the safest strategy is to restrict analysis to the 75 countries identified in WHO (2009). However, our analysis has shown that figures from level two and three countries are not grossly out of line.

The WHO acknowledge that a proportion of deaths in some countries do not enter the national vital registration system. However, the WHO recognises that adjustment of the national RTC fatality rates in such nations in proportion to the number of road deaths reported may be unwise.

IRF data can suffer from fatality definition and under-reporting issues. In some instances the level of under-reporting can be large and, again, predominantly affects less economically developed nations. Two previous studies have attempted to account for these factors. However, while both improve the strength of the association neither brings consensus with the WHO RTC fatality rates.

The method used by Jacobs et al. (2000) to adjust for fatality definition was based on work undertaken in the early 1990s and may not be appropriate for a number of nations today. In particular, the use of the +15% addition to the RTC fatality rate in all Less Motorised Countries may lead to over-estimation in a number of nations. The +15% addition was made since it was considered that in practice the police would only record fatalities occurring at the time of the crash, or shortly after, regardless of the officially stated fatality definition. Major political changes in nations such as those of Central and Eastern Europe may have improved the standard of data available, and the proposed adjustments could lead to over-estimation of RTC fatality rate.

Use of the Koornstra (2007) method for correcting for under-reporting relies on use of GNI and may lead to collinearity and double-counting problems if adjusted RTC fatality rates are used in, for example, regression modelling. This is because many putative explanatory variables are in fact significantly correlated with both GDP and GNI.

Unlike previously published time series analyses, we found no evidence of a non-linear relationship between RTC fatality rate and the three predictor variables in this cross sectional analysis of data for 2002. However, van Beeck et al. (1991) in a regional study of RTC fatality in the Netherlands in 1980-84 also found linear analysis more appropriate.

One of the deficiencies of this study is that it examines data for one year only. This was necessitated by the availability of WHO RTC fatality rate data. We do, however, examine RTC fatality rate data for a larger number of nations than most previous studies. The nations assessed were diverse socioeconomically and geographically.

Our work highlights the difficulties in making international comparisons of RTC mortality. While the most recent 2009 WHO report uses a sophisticated modelling methodology to overcome some of these problems, the estimates produced are predominantly based on records provided by police forces. We have shown that vital registration data derived from health services is more strongly associated with various predictors of RTC fatality. Contrary to the practice recently adopted by the World Health Organisation (WHO, 2009; WHO, 2012), we suggest that vital registration data should be used in preference to police or transport data in international comparative work.

Chapter 3: The relationship between national development and road traffic crash fatalities

3.1 Introduction

Road traffic crashes (RTCs) have been referred to as a disease of affluence, with road use and road deaths increasing with the economic development of a nation (van Beeck et al., 2000). However, there are wide variations in road traffic crash fatality rates, even between nations of approximately similar economic development. For example, 2002 data from WHO showed that deaths per 100,000 population varied from 4.1 (Fiji) to 32.1 (Belize). In the case of Mexico (2008 per capita Gross National Income (GNI) US$9,980) the RTC fatality rate was 12.0 per 100,000 while in the Russian Federation (GNI US$9620) the RTC fatality rate was 30.9 per 100,000 population. Even in apparently similar nations socially and economically there were wide variations in RTC fatality rate reported. For example, Poland (GNI US$11,880) RTC fatality rate was 15.6 per 100,000 while in Latvia (GNI US$11,860) the fatality rate was 25.0 per 100,000 (WHO, 2004a).

While variation in national RTC fatality rates is usually explained in terms of per capita income, for example Gross National Income (GNI), it is not wealth *per se* which causes road crashes. This raises the question as to what risk factors underlie the observed association with income.

We suggest that the previous literature describing international variations in RTC fatalities and the factors associated with that variation (literature review, chapter 1) is limited in three key respects. Firstly, many studies have relied on fatality data that is collected by transport authorities and which suffers from differential underreporting and lack of standardised definitions. Secondly, those studies which have examined international variation have predominantly analysed data from the most economically developed nations only, especially those in the OECD. Thirdly, studies that have described associations with development have generally not attempted to measure and test the effect of national level risk factors that may be underpinning observed associations with indicators such as Gross National Income (GNI), and those that have have produced sometimes conflicting results dependent on the group of nations or road users studied. We therefore suggest it is timely to re-examine previously observed associations between development and road traffic crash fatality rates. The aims of this study are to determine the relationship between economic development and national RTC fatality rates using more reliable health service derived mortality data, and to identify some of the macroscopic socioeconomic, road and vehicle related factors associated with economic development which may be responsible for the variation in national RTC fatality rates seen. In addition, we include novel measures of national road safety legislation enforcement and quality of the road network. This allows some comment to be made regarding the potential efficacy of some of the Five Pillars of Action advocated by the WHO.

3.2 Method

The WHO (2009) Global Status Report on Road Safety identified 73 nations which were considered to provide accurate and timely vital registration data. This data is available for a range of nations, both economically and geographically varied, using health service data collected in 2002 (WHO, 2009). Accuracy was assessed by the WHO from the proportion of deaths ascribed to non-specific diagnoses, while timeliness refers to the currency of the released database. The availability of data concerning presumed risk factors of national RTC fatality rates ranged from 49 to 56 nations. Twenty one countries in the study reported here were classified high income OECD, 8 high income non-OECD, 16 upper middle, 11 lower middle and none low income (World Bank, 2010). Eight were in East Asia and the Pacific, 34 in Europe and Central Asia, 7 in Latin America and the Caribbean, four in the Middle East and North Africa, two in North America and one was in Sub Saharan Africa. No reliable data were available for large sections of Africa, the Middle East and South East Asia. Figure 1 depicts the nations analysed with nations coded according to quartile of national WHO RTC fatality rate per 100,000 population. Fatality rates for the year 2002, the most current complete data available when this work was undertaken, were analysed (WHO, 2004a). Fatality rates are displayed in figure 4 and detailed in table 4 to allow direct comparison between nations.

Figure 4: Road traffic deaths per 100,000 population (quartiles) for 56 nations. Data source: WHO, 2004a

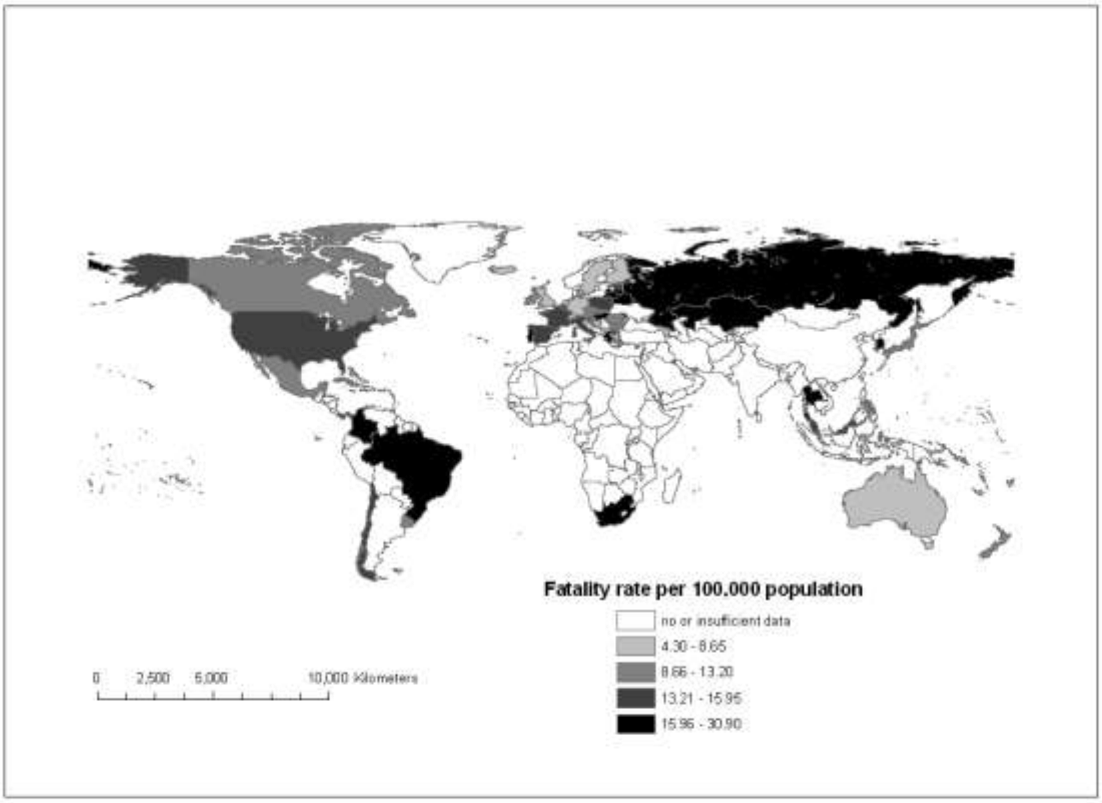


Table 4: Road traffic crash fatality rate per 100,000 population (56 nations used in the study)

Nation	*ISO-Alpha-3 code[1]*	*Population (millions)*	*RTC fatality rate*	*Nation*	*ISO-Alpha-3 code[1]*	*Population (millions)*	*RTC fatality rate*
Australia	AUS	20.74	8.6	Finland	FIN	5.28	8.6
Austria	AUT	8.36	10.4	France	FRA	61.65	13.9
Bahrain	BHR	0.75	12	Georgia	GEO	4.40	6.1
Belarus	BLR	9.69	17.2	Germany	DEU	82.60	8.6
Belgium	BEL	10.46	13.5	Greece	GRC	11.15	19.6
Bosnia and Herzegovina	BIH	3.93	4.3	Hungary	HUN	10.03	16.0
Brazil	BRA	191.79	19.8	Iceland	ISL	0.30	7.2
Brunei Darussalam	BRN	0.39	15.9	Ireland	IRL	4.30	10.1
Bulgaria	BGR	7.64	12.1	Israel	ISR	6.93	7.8
Canada	CAN	32.88	8.7	Italy	ITA	58.88	13.3
Chile	CHL	16.63	14.8	Japan	JPN	127.97	8.7
Colombia	COL	46.16	18.5	Kazakhstan	KAZ	15.42	16.0
Croatia	HRV	4.56	12.8	Korea, Rep. of	KOR	48.22	22.4
Cuba	CUB	11.27	13.1	Kuwait	KWT	2.85	15.5
Cyprus	CYP	0.85	26.9	Latvia	LVA	2.28	25.0
Czech Republic	CZE	10.19	10.0	Lithuania	LTU	3.39	20.4
Estonia	EST	1.34	15.4	Macedonia, TFYR	MKD	2.04	5.4

Table 4 continued:

Nation	*ISO-Alpha-3 code*[1]	*Population (millions)*	*RTC fatality rate*	*Nation*	*ISO-Alpha-3 code*[1]	*Population (millions)*	*RTC fatality rate*
Malaysia	MYS	26.57	14.4	Singapore	SGP	4.44	5.3
Malta	MLT	0.41	4.4	Slovakia	SVK	5.39	12.9
Mexico	MEX	106.53	12.0	Slovenia	SVN	2.00	14.2
Moldova, Rep. of	MDA	3.79	15.7	South Africa	ZAF	48.58	30.3
Netherlands	NLD	16.42	6.4	Spain	ESP	44.28	15.8
New Zealand	NZL	4.18	12.7	Sweden	SWE	9.12	6.3
Panama	PAN	3.34	14.1	Switzerland	CHE	7.48	6.0
Poland	POL	38.08	15.6	Thailand	THA	63.88	30.1
Portugal	PRT	10.62	17.1	United Kingdom	GBR	60.77	6.5
Romania	ROU	21.44	12.4	United States	USA	305.83	15.5
Russian Federation	RUS	142.50	30.9	Uruguay	URY	3.34	10.5

[1] ISO-Alpha-3 code is a three-letter code for each nation. These have been developed by the International Organisation for Standardisation as part of the ISO 3166 Standard (United Nations Statistics Division, 2010).

Rates depicted in Figure 4 vary from 4.3 (Bosnia/Herzegovina) and 4.4 (Malta) to 30.1 (Thailand), 30.3 (South Africa) and 30.9 (Russian Federation) per 100,000 population. The majority of nations in the lowest quartile of RTC fatality rate are located in Europe while the Russian Federation and many states in South America fall within the highest quartile.

The sources and descriptive statistics for the outcome and predictor variables we examined are detailed in Table 5.

Table 5: Descriptive statistics for dependent and predictor variables

Variable	*Mean*	*Minimum*	*Maximum*	*N nations*	*Source*	*Measure of*
RTC fatality rate per 100,000 (vital registration data)	13.71	4.30	30.90	56	A	Dependent variable
Gross National Income per capita US$	18 845	890	56 800	56	B	
Vehicles per thousand population	477.5	58.4	974.4	56	C	Exposure
Road energy consumption (million tonnes oil equivalent)	19 999	137	492 577	56	D	Exposure
Road quality score	4.44	1.60	6.70	54	E	Road network safety
Percent paved roads	70.28	5.50	100.00	51	F	Road network safety
Percent national fleet which is two- or three-wheeled	9.82	0.90	63.00	56	C	Road user risk
Percent national fleet which is heavy vehicles	17.19	1.87	57.92	53	C	Road user risk
Road safety enforcement and legislation score	5.99	1.50	8.40	49	C	Road user risk
Percent population aged 15 – 24 years	15.11	10.80	20.50	56	G	Road user risk
Percent population 15 years and older who are illiterate	3.41	0.20	17.60	55	H	Road user risk
Alcohol consumption (litres per capita per year)	7.87	0.00	13.70	56	I	Road user risk
Health spend as percent GDP	7.53	2.80	15.40	56	B	Quality of health
Hospital beds per 10,000 people	53.09	10	141	54	C	Quality of health
Doctors per 100,000 people (1999 – 2004)	275.80	37	591	56	C	Quality of health

Source: A WHO, 2004a; B World Bank, 2007; C WHO, 2009; D International Road Federation, 2006; E World Economic Forum Executive Opinion Survey 2008; F CIA, 2009; G US Census Bureau International Database; H United Nations Human Development Report 2007/08; I WHO, Global Information System on Alcohol and Health (GISAH) database (WHO, 2004b)

Per capita Gross National Income (GNI) (World Bank, Atlas Method) was used as a headline proxy for economic development. GNI was analysed in preference to Gross Domestic Product (GDP) since GNI reflects national income including receipts from non-resident assets and businesses. It is the preferred term for analytical purposes used by the World Bank (World Bank, 2011). Per capita GNI varied from US$890 (Republic of Moldova) to US$56 800 (Switzerland). Road traffic energy consumption and levels of vehicle ownership were used as proxies for annual vehicle kilometres travelled. It is acknowledged that employing fuel use as a proxy for vehicle travel will be influenced by a number of factors influencing the overall efficiency of the national vehicle fleet. These include the proportion of newer, fuel efficient vehicles, proportion of diesel engine vehicles, engine size, road conditions, speed limits, environmental temperature (Kwon, 2006). This additional data was not available at the national level and so road traffic energy consumption was analysed without further adjustment.

The percentage of two- and three-wheeled vehicles and heavy vehicles were chosen to examine the effect of fleet composition. Two- or three-wheeled vehicles are known to be a higher risk means of transport than four-wheeled vehicles. Kopits and Cropper (2008) considered that the proportion of two- or three-wheeled vehicles in the national fleet was also indicative of the variance of vehicle speeds on the road network. Slow moving heavy vehicles may induce a larger number of potentially risky over taking manoeuvres, a feature of vehicle flow with greater speed variance. The greater mass of a heavy vehicle presents a greater risk of fatality to occupants of smaller vehicles involved in any collision (Navon, 2003; Elvik et al., 2009). It is acknowledged that percent of the national fleet which are two- or three-wheeled is a poor proxy for overall safety of the national fleet (WHO Pillar 3). However, detailed comparable data regarding for example the age of the fleet or penetration of safety features such as antilock brake systems was not available at the international level.

The road quality score and percentage paved roads were selected to represent relative safety of the national road infrastructure (WHO Pillar 2 actions). The road quality score is data published by the World Economic Forum (WEF) in their 2007 Executive Opinion Survey (WEF, 2008). The WEF asked an average of 90 business leaders in each contributing nation to rate their national road infrastructure on a Likert scale from 1 (underdeveloped) to 7 (extensive and efficient by international standards). The WEF determined an average national score with responses weighted dependent on the relative importance of the respondent’s sector to the overall national economy. The resultant national average score was used in the study presented here.

The enforcement score was a derived variable calculated from data published in the WHO Global Status Report on Road Safety (WHO, 2009) and was taken to be a proxy for WHO Pillar 4 actions (safer road user behaviour). Road user behaviour (speeding, drink-driving, seat belt, child restraint and helmet use) was assumed to be safer in nations with higher levels of safety legislation and enforcement. For each contributing nation, the WHO had asked up to eight national road safety experts to quantify their perception of the level of enforcement of legislation regarding behavioural risk factors for road fatality (speed, drink-driving, use of motorcycle helmets, seat belts and child restraints). Enforcement of each factor was ranked on a scale of 0 (no legislation and enforcement) to 10 (enforcement is highly effective). The experts included representatives of health, transport and police authorities and could also include representatives from non-governmental organisations and academia. The national experts were then asked to determine a consensus national rank for each risk factor. Full details of the methodology undertaken to obtain national ranks is detailed in the WHO Global Status Report on Road Safety (WHO, 2009). The process was specifically designed to produce directly comparable national data, and for the purposes of this study we derived an enforcement score from the average of all ranks given.

Two socioeconomic variables were assessed; the percentage of the population aged 15 -24 years, the highest RTC fatality risk age group, and adult illiteracy, a proxy for level of general education and safety education of road users in particular. Per capita alcohol consumption was analysed since the association between the risk of fatal road injury and alcohol consumption at the individual road-user level is proven. Three medical care proxies (WHO Pillar 5) which may affect crash survival were examined; health spend as a percent of GDP, hospital beds and physicians per capita. Three variables were assessed since there has been no consensus regarding which proxy better expresses the quality of health care available to crash victims.

The variables listed in Table 5 were available for between 49 and 56 of the initial 73 nations studied. Preliminary tests established that the road quality score, the percentage of paved roads, the percent of the national fleet that is heavy vehicles, road safety enforcement and legislation score, percent adult population who are illiterate, hospital beds per 10,000 people and doctors per 100,000 people were not significant predictors of the RTC fatality rate when other variables on the list were included in the model. Subsequent analysis was therefore restricted to the variables measured in 56 nations for which full significant explanatory data was available.

The first part of the statistical analysis was to examine the relationship between per capita Gross National Income and the health service derived national RTC fatality rate. The association between fatality rate and GNI was determined using linear regression. Both linear and quadratic relationships were explored. This was done for the 73 nations considered by the WHO to supply accurate and timely vital registration data and then for the 56 nations for which we had full explanatory data.

Further statistical analyses were restricted to the 56 nations for which there was full explanatory data and investigated the relationships between national RTC fatality rates and potential predictors, one at a time and then together. All associations between pairs of potential predictors were assessed to check for collinearity. Then bivariate analyses were undertaken to identify the association of each potential predictor with log fatality rate before adjusting for the effects of other variables. The linear and the quadratic form of each predictor variable was assessed. This was because the relationship between economic development and national RTC fatality rate has been demonstrated to be non-linear in nature (Kopits and Cropper, 2005).

Finally, all predictors, in both linear and quadratic forms, were inserted in a multiple variable model predicting the health service derived national RTC fatality rate. Non-significant variables were removed in a backward stepwise manner with the least statistically significant variable being removed until $p<0.05$ for all remaining variables. Predictor variables remaining in the final model were assessed for collinearity again. Unstandardised residuals from the final regression model predicting the log transformed national RTC fatality rate were then plotted against log per capita GNI.

3.3 Results

Figure 5 shows the scatterplot of the natural log transformed national RTC fatality rate (WHO, health data) versus natural log transformed per capita Gross National Income (GNI) for all 73 nations considered by the WHO to provide accurate and timely vital registration data. The 56 nations with adequate data on potential explanatory variables, and subsequently studied in the regression analysis presented here, are identified. Log transformed variables are displayed because some of the nations exhibited very high levels of either road fatalities or of GNI. Figure 5 shows that there is considerable variation in national RTC fatality rate for any given level of per capita GNI, and that highest fatality rates are generally seen in middle income nations. The graph does not show any clear linear or quadratic relationship between log transformed GNI and log transformed RTC fatality rates.

Figure 5: Natural log national RTC fatality rate per 100,000 (2002) versus natural log per capita GNI (2005). Health data. 56 nations with adequate predictor variable data are marked with asterisks

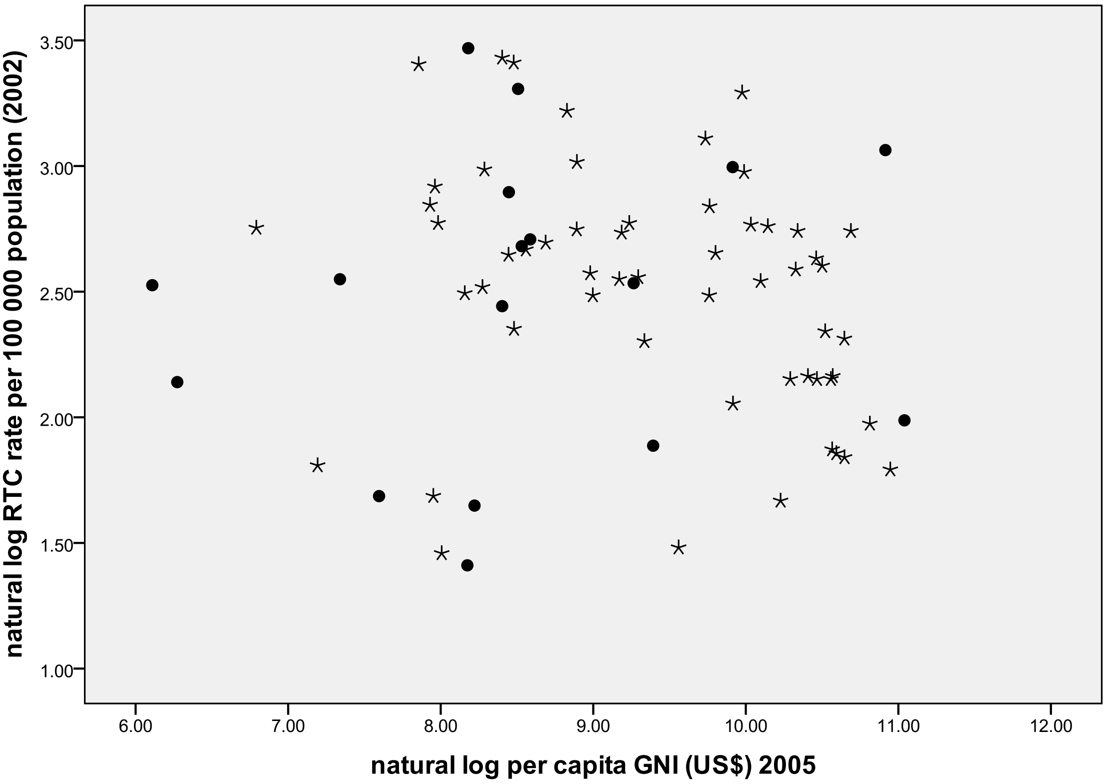


Table 6 shows the results of regression analysis using the natural logarithm of GNI to predict the natural logarithm of national RTC fatality rates. Results are shown for all 73 nations and for the group of 56 studied further.

Table 6: Regression analysis of the natural log of per capita GNI as a predictor of the natural log of WHO national RTC fatality rates per 100,000 population (2002)

Fatality rate data source and number of nations examined	*Standardised beta values*		*Adjusted R^2*
	linear	*quadratic*	
World Health Organisation 73 nations assessed by WHO to supply accurate and timely vital registration data	-0.129		0.003
	-3.401*	-3.541*	0.062
World Health Organisation 56 nations assessed by WHO to supply accurate and timely vital registration data and with full explanatory variable data	-0.287*		0.065
	5.452*	-5.747*	0.153

* $p < 0.05$

Table 6 shows the results of regression analysis using the natural logarithm of GNI to predict the natural logarithm of national RTC fatality rates. Results are shown for all 73 nations and for the group of 56 studied further. For the 73 nations there was a significant quadratic relationship confirming the inverted U-shaped association reported in analyses of transport data. However, the association was weak and accounted for only 6% of the variation in national RTC fatality rates seen. For the 56 nations studied further, there was a significant association between income and national RTC fatality rate when either the linear or quadratic terms were analysed. Again, the associations were weak and natural logarithm of per capita income only explained around 7% (linear) or 15% (quadratic) of the variation in natural logarithm of national RTC fatality rate seen. The turning point at which income was associated with a decline in national RTC fatality rate for these 56 nations was around US$4 100 (2005 values).

Table 7 shows the bivariate associations between the natural log WHO RTC fatality rate and each of the potential predictors, unadjusted for the effects of other variables. Standardised beta values for both the linear and quadratic relationships are shown.

Table 7: Unadjusted relationship between the predictors (linear and quadratic) and natural log of the WHO national RTC fatality rate per 100,000 population (2002)

Variable	*Standardised beta values*	
	Linear	*Quadratic*
Vehicles per million population	-0.140	
	1.013	-1.186*
Natural log road energy use (million tonnes oil equivalent)	0.166	
	1.095	-0.936
Road quality score	-0.088	
	0.837	-0.938
Percent paved roads	-0.069	
	-0.193	0.126
Natural log percent national fleet which is two- or three-wheeled	0.180	
	0.003	0.187
Natural log percent national fleet which is heavy vehicles	0.115	
	0.751	-0.646
Road safety enforcement and legislation score	-0.147	
	0.625	-0.784
Percent population aged 15 – 24 years	0.459**	
	0.477	-0.018

Table 7 continued:

Variable	*Standardised beta values*	
	Linear	*Quadratic*
Adult illiteracy rate (%)	0.155	
	-0.145	0.317
Alcohol consumption (litres per capita per year)	0.070	
	0.106	-0.038
Health spend as percent GDP	-0.270*	
	-0.651	0.394
Hospital beds per 10,000 people	0.006	
	-0.250	0.267
Doctors per 100,000 people (1999 – 2004)	-0.101	
	-1.234*	1.171*

*p < 0.05, ** p < 0.01

In table 7 only four of the presumed predictors showed statistically significant associations. The proportion of the population aged 15–24 years was positively linearly associated with the natural log of national RTC fatality rates. Nations with a higher percentage of individuals in the 15–24 year age group are predicted to have higher RTC fatality rates, whilst nations with a greater health spend as a percent of GDP are predicted to have lower rates. The relationship between physicians and RTC fatality rate was quadratic. Initially, a larger number of physicians are predicted to be associated with lower national RTC fatality rates. However, at higher levels of medical staffing national RTC fatality rate was predicted to increase. The association with vehicle ownership was only statistically significant for the squared term in the quadratic analysis.

There were no strong associations between the potential predictors. No two predictors had an R square value greater than 0.39. In particular the three health proxies were not strongly correlated; the highest R square was 0.20 between doctors per capita and hospital beds per capita.

Table 8: Multiple regression analysis predicting natural log of WHO national RTC fatality rates per 100,000 population (2002)

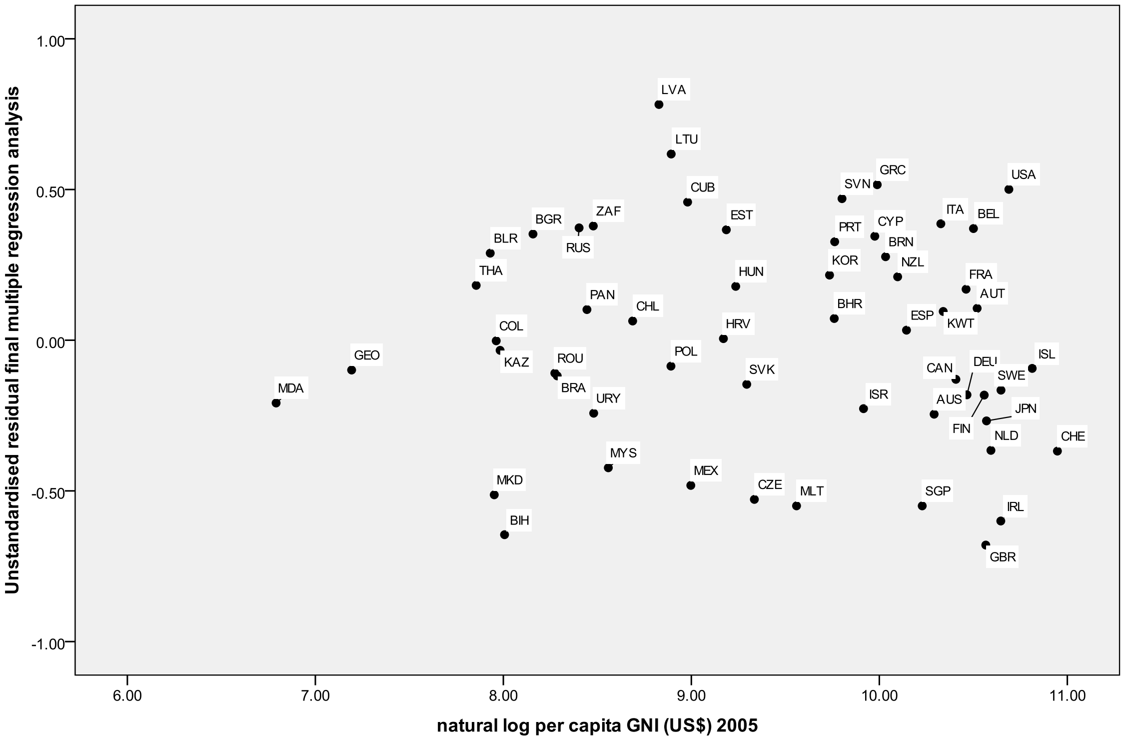
	Unstandardized slope coefficient	*SE*	*Standardized slope coefficient*	*p*
Constant	0.043	0.553		0.938
Natural log road energy use (million tonnes oil equivalent)	0.071	0.031	0.268	0.026
Natural log percent national fleet which is two- or three-wheeled	0.238	0.117	0.223	0.047
Percent population aged 15 – 24 years	0.114	0.025	0.581	<0.001
Health spend as percent GDP	-0.062	0.028	-0.296	0.032
Alcohol consumption (litres per capita per year)	0.056	0.017	0.408	0.002

Adjusted $R^2 = 0.405$

Table 8 shows the results of the final multiple regression model. Both linear and quadratic terms were analysed, although only linear terms remained significant in the final model. In the model, the natural logarithm of road energy use, the natural logarithm of the proportion of road vehicles which are two- or three-wheeled, the proportion of the population aged 15 – 24 years and the average per capita annual alcohol consumption were all positively associated with the natural log national RTC fatality rate. Health spend was negatively associated with the natural log national RTC fatality rate. Controlling for these factors we found no significant effect for road quality, percent paved roads, percent national fleet which are heavy vehicles, enforcement of road safety legislation, percent population who are illiterate and per capita hospital beds and physicians. However, the multiple regression model only explained around 41% of the variation of national RTC fatality rates seen. Only two of the five predictors that were statistically significant in the final multiple regression model had been significant in single variable regression analysis. There was no evidence of collinearity between variables in this model; no R square value between predictors exceeded 0.25, all associations were in the direction expected and none changed direction from that seen in univariate analyses.

Figure 6 plots the unstandardised residuals from the final multiple regression model against natural log per capita GNI. Examination of the residuals offers no suggestions as to potential predictors of national RTC fatality rate which have been omitted from our model. Nations as diverse as the US (ISO alpha 3 code USA), Greece (GRC), Lithuania (LTU) and Latvia (LVA) had residuals greater than +0.5 while the UK (GBR), Bosnia/Herzegovina (BIH), Ireland (IRL), Singapore (SGP), Malta (MLT), the Czech Republic (CZE) and TFYR of Macedonia (MKD) had residuals greater than -0.5. There was no significant correlation between natural log GNI and the unstandardised residuals (linear R = -0.051, p = 0.708; quadratic R = -0.065, p = 0.633).

Figure 6: Unstandardised residuals from final regression model to predict natural log WHO 2002 RTC fatality rate per 100,000 population. 56 nations. Nations identified by ISO-Alpha-3 codes (UN Statistics, 2010)



3.4 Discussion

Using reliable health service derived fatality data we have demonstrated that the association between national road fatality rates and economic development is weak and complex. The presumed drivers of RTC fatality rates may act in opposing directions as a nation develops economically. More economically developed nations usually are heavily reliant on motorised transport and residents will have a greater exposure to risk of road crashes. However, road journeys will be more likely to be undertaken in the relative safety of cars and buses rather than on foot or on two-wheeled vehicles and the lower proportion of more vulnerable road users (pedestrians, cyclists and motorcyclists) should act to reduce the national road fatality rate. More economically developed nations usually have a lower proportion of young people, the age group most at risk from road crashes, but may have a greater proportion of the population in employment which may be associated with a greater level of road use. More economically developed nations would also be expected to have more advanced medical care available for crash victims so that fewer die from their injuries. While per capita alcohol consumption may increase as the population becomes wealthier there are also cultural drivers, unconnected to economic development, which significantly affect consumption.

Our analysis somewhat confirms the curvilinear relationship between GNI (economic development) and national RTC fatality rates. However, the inverted U-shaped relationship is less strong when health rather than transport RTC fatality data is examined. The point of inflection at which economic development appears to become protective for RTC fatalities was lower than that found by Kopits and Cropper (2005) using transport data (period of study 1963 – 1999, inflection point US$ 8 600) but was in line with the findings of Paulozzi et al. (2007) (inflection point US$ 2 200 for WHO fatality data for 1996 – 2003).

It is noteworthy that, in multiple regression, the direction of association of the significant predictors of the national RTC fatality rates was in the expected direction for all variables. These findings support those of Bishai et al. (2006) with respect to road energy use, Page (2001) and Law et al. (2011) for the percentage population aged 15 – 24 years, and Page (2001), Bishai et al. (2006), Law et al. (2011) with respect to average annual alcohol consumption and Söderlund and Zwi (1995), for health spend as a percentage of GDP. Unlike Kopits and Cropper (2008), we found that the percent vehicle fleet which are two- or three-wheeled was significantly associated with national RTC fatality rate. In the multiple regression reported here this variable was a major contributor to the variation in national RTC fatality rates. The nations studied in this analysis included some in which two- and three-wheeled motor vehicles are common modes of transport. The proportion of two- or three-wheeled vehicles in the nations studied here included Brazil 22%, Columbia 39%, Cuba 33%, Malaysia 47%, Mauritius 43% and Thailand 63%. Such vehicles typically represent only around 4% of the national vehicle fleet in OECD nations, those examined by Kopits and Cropper (2008).

In terms of the WHO Pillars of Action, we found no evidence that a safer road network (Pillar 2) or safer road user behaviour through enforcement of road safety legislation (Pillar 4) were significantly associated with the international variation in RTC fatality rates. Better post crash casualty care (Pillar 5) was significantly and negatively associated with the international variation in RTC fatality rates. We found some evidence to support Pillar 3 (safer vehicles) in that the percent of the national fleet which were 2- or 3-wheeled, and whose occupants are vulnerable in the event of a crash, was positively associated with international variation in RTC fatality rates. While we did not find that a higher quality road network was associated with a lower RTC fatality rate, it is possible that the road network proxy analysed did not adequately express the safety of the national road network. It was assumed that higher quality roads engendered a safer driving environment. However, higher quality roads may also allow faster vehicle speeds which may lead to an increase in both the risk of RTC and the severity of injury in the event of a crash. Higher quality roads (for example, with fewer tight bends) may also allow more manoeuvres which allow road users to come into conflict (for example, overtaking). One area for further research is defining just what constitutes a safe road network and how that may be quantified. It should also be remembered that the road network is unlikely to be of uniform quality (or safety) at the national level; the network within and around urban centres is likely to have a greater investment.

Our study has a number of limitations. The RTC fatality data analysed, while the best available, is not complete and may not be a true record of all road deaths in the nation. Paulozzi et al. (2007) adjusted WHO data from 10 of 44 nations to account for incompleteness of national vital registration data, for example due to limited geographical coverage. Ten of the 56 nations studied here had reported completeness of vital registrations less than 100%, with completeness as low as 75% reported in Georgia (Mathers et al., 2005). However, making a mathematical adjustment based on assessed completeness assumes that fatality rates in the areas not covered by the vital registration system are similar to those reported for the rest of the nation. In the case of RTCs this may not be correct; areas contributing to vital registration returns may be more likely to be urban and may have higher or lower RTC fatality rates than less motorised, rural locations.

Road quality was the subjective opinion of a number of business leaders in each nation. While a higher quality network may be designed and maintained with concern to the prevention of crashes, it may also engender higher speed travel and allow more potentially risky behaviour such as overtaking manoeuvres and exceeding the speed limit (Noland, 2003). As a first approximation the risk of RTC increases with the speed of the vehicles involved and the risk of fatality in the event of RTC increases exponentially with vehicle speed (Aarts and van Schagen, 2006)). This brings into question exactly what constitutes a safe road network and how may this be quantified at the national level. It is probable that the safety of the road network varies at the sub-national level which further complicates international comparative work.

Though the legislation and enforcement data for this analysis was obtained from the most current WHO international compilation (WHO, 2009) this data may be criticised since it was, at best, the subjective opinion of up to eight national road safety experts. Analysis of directly comparable international data may be problematic since in a number of nations road safety legislation and enforcement is undertaken at a sub-national level (for example, at State level in the US). Moreover, enforcement activity may vary over time in one specific location (WHO, 2009).

While per capita health spend was found to be protective for RTC fatality rate this measure is acknowledged to be a crude measure of the quality and availability of post-crash health care. It is possible that overall national health expenditure may not reflect the expenditure for or quality of RTC casualty care. As with road quality and safety enforcement, the availability of such a service may vary geographically within a nation and would be expected to be better in urban areas (WHO, 2009).

While the nations we studied represented a more diverse group than previously examined, Asian and especially African nations were under-represented. Whilst our use of per capital fatality rates allows direct comparison with other causes of death in each nation, for example death rates from heart disease, measuring exposure to risk as a rate per million vehicle or passenger kilometres travelled per annum may be more appropriate. However, such exposure data is only obtainable for a restricted number of nations (Page, 2001); estimates of annual vehicle kilometres travelled were available for only 35 of the 56 nations we studied (IRF, 2006).

There were other possible road fatality risk factors which were not examined in this study. These include vehicle speed, fleet safety features, fleet crashworthiness, land use adjacent to the roadway, design and maintenance of the road network, the use of traffic control devices including speed regulation of heavy vehicles, mandatory vehicle inspection, public information and education and the effect of road and fuel pricing. These measures are not available for international comparison studies and hence could not be considered. Their effects may account for some of the unexplained variation in national RTC fatality rates.

We note that our model only explained 41% of the variation in national RTC fatality rates seen. Examination of the residual plot (Figure 3) offers no indication as to what factors are contributing to the unexplained variation. The reasons why national fatality rates are higher than predicted in nations such as Latvia and Lithuania and lower than predicted in nations such as the Czech Republic and Ireland are not known. Further work might investigate factors which we have not been able to model.

Chapter 4: Conclusions

4.1 Summary of main findings

- Data quality issues make the international comparison of RTC fatality data problematic.
- At the national level, road fatality data collated by the World Health Organisation (WHO), and derived from national health service vital registration data, may be a more reliable reflection of the true number of road deaths than the data collated by the International Road Federation from police crash reports. This does not, however, hold for nations for which the WHO estimate deaths-by-cause by mathematical modelling. Modelling tends to overestimate the number of RTC deaths, possibly because baseline data from more highly motorised nations in used.
- For the purposes of the Decade of Action, WHO data may be more appropriate for monitoring purposes since this is available for a larger number of nations than IRF data and it is already collated by the WHO. However, the WHO literature advocates continued us of IRF data.
- Analysing WHO national fatality data for the year 2002, there is little evidence that national economic development in terms of per capita Gross National Income (GNI) is associated with national road traffic crash (RTC) fatality rates. We found that the relationship between per capita GNI and RTC fatality rate was weak and complex. This brings into question some predictions of the total number of road deaths in the future for some are based on the premise that economic development is initially associated with an increase in fatality rate until at higher levels of wealth RTC fatality rates begin to decrease.
- Disaggregating the risk factors for RTC associated with GNI shows that national RTC fatality rates can be predicted by road energy use (with vehicle kilometres travelled per unit time assumed to be a proxy for exposure to risk of crash), the percentage of the national fleet which are two- or three-wheeled vehicles (whose drivers/riders are vulnerable in the event of a crash), per capita alcohol consumption and the percentage of the population aged 15 – 24 years (the group most at risk from RTC). National health spend was found to be protective for RTC deaths.

The period 2011 – 2020 has been declared the Decade of Action for Road Safety (WHO, 2011). To that end the WHO have proposed that nations adopt five pillars of activity in national road safety work. Pillar 1 promotes better road safety management; pillar 2 promotes safer roads and transport systems; pillar 3 promotes safer vehicles; pillar 4 encourages safer road user behaviour including enacting and enforcing road safety legislation and pillar 5 advocates better post-crash care for casualties.

Pillar 1 includes the requirement for member nations to monitor and record road fatalities within the nation. The latest WHO guidance advocates use of police-derived crash records (WHO, 2012). However, we have shown that for many nations analysis of WHO vital registration returns may provide more accurate and internationally comparable data upon which to assess the effect of road safety measures including those implemented as part of the Decade of Action.

In this study, at the national level and controlling for exposure to risk of RTC, quality of healthcare was protective for national RTC fatality rates, supporting the World Health Organisation pillar 5 (better post-crash response) for road safety improvement (WHO, 2011). In contrast, no evidence was found to support the efficacy of pillar 4 in that road safety legislation and enforcement was not found to be significantly associated with national RTC fatality rates. Similarly, no evidence was found that road design (pillar 2, proxied by quality of the road network) was significantly associated with the variation in national RTC fatality rates. Lack of directly comparable international data precluded analysis of the effect of vehicle design and crashworthiness (pillar 3).

In the multiple regression model described in this thesis three factors were found to be significantly associated with the variation in national RTC fatality rate that may be context specific. Percent of the national fleet that were two- or three-wheeled, percent of the population aged 15 – 24 years and per capita average annual alcohol consumption were all risk factors for national RTC fatality rate. These may be influenced by cultural factors operating at the national level and may not be amenable to modification.

4.2 Strengths and limitations of this study

This thesis has examined data which is considered to be of good quality and which is designed by the WHO to be directly comparable between nations. Data from a large number of nations was analysed and these were more economically and geographically diverse than the commonly used datasets which rely predominantly on information from Organisation for Economic Cooperation and Development nations.

We have proposed that RTC data obtained from national health services and maintained by the World Health Organisation may be more reliable than that obtained from police reports and reported by the International Road Federation. However, the WHO recognise that health data from some nations may have deficiencies; records from some nations may not be current; they may have an unacceptable proportion of deaths attributed to non-specific causes; in the least economically developed nations numbers of deaths by cause are estimates and the methodology adopted to produce these estimates has been criticised (Cooper et al., 1998). For these reasons the international analyses detailed in this thesis did not include data for nations in Sub Saharan Africa and for few in South East Asia.

As with many comparative studies the collection and analysis of objective, directly comparable national data would be the obvious extension to the work already completed. In particular the road quality, road safety enforcement and post-crash health care measures analysed in this thesis (chapter 3) may not be adequate proxies as discussed in the conclusion to chapter 3.

It is acknowledged that accurate vehicle kilometres travelled per unit time data was unavailable for study in chapter 3. This has proven a problem in several earlier studies (for example, Quddus, 2008). Neither were pedestrian movement or mass transport passenger kilometre data available. In economically developed nations the technology already exists which monitors and records the movements of vehicles. At present this Global Positioning System (GPS)-based data is used to monitor commercial fleet movements and to offer a degree of vehicle security. Once these systems penetrate the national car fleet further, and if the resultant data is made available for study, then analysis could include more detailed consideration of exposure (vehicle and passenger kilometres travelled) and also of the relative risk per kilometre of travel for the different classes of road experienced.

In this thesis multiple regression analysis was the tool used. However, the statistical analysis of road safety is not without problem and a number of techniques have been advocated by other authors (Lord and Mannering, 2010). There may be a number of alternative proxies for any predictor (for example, unemployment rate, employment rate, retail index, leading index and volume of new car sales have all been taken to indicate the level of economic activity in an area) and a number of statistical models may be used all making different assumptions about the relationship between variables (Tay, 2003). Tay (2003, pg 2) states that "It is important to note that the true effects of most road safety countermeasures are unknown and may never be known, and that definitive evaluation does not exist". Tay goes on to suggest that the best approach is to undertake several analyses, each with different assumptions and methodology, to gain a broad view of the overall effect of the particular safety measure.

Road traffic fatality date is count data and Poisson or negative binomial regression may be the analyses of choice for such data. However, negative binomial regression may be affected by missing data, outliers and collinearity between variables (Karlaftis and Golias, 2002).

4.3 Areas for further research

Road traffic crashes are random events and are brought about by the complex interaction of many factors operating at a number of spatial scales (Miaou and Lum, 1993). While over 75% of crashes are at least in part caused by human error (Stanton and Salmon, 2009), the road, vehicles, vehicle speeds, degree of road congestion, weather, light conditions and many other factors can all play a part (Miaou and Lum, 1993). The aim is to understand the factors which interact and contribute to the risk of crash and injury and, through that understanding, develop measures which will reduce the likelihood of crash and reduce the numbers killed or injured on the road (Lord and Mannering, 2010).

The multiple regression model described in chapter 3 explained only 41% of the variation in the national RTC fatality rates seen. Some of the unexplained variation may be due to, for example, vehicle crashworthiness (pillar 3) for which adequate international data is unavailable. It is to be hoped that the World Health Organisation will attempt to obtain accurate RTC data from all contributing nations during the period 2011 – 2020 (The Decade for Action for Road Safety). More accurate data from a large number of economically disparate nations should help to further elucidate risk factors for RTC fatality. Indeed the WHO asks that member nations keep accurate road safety data as part of the Pillar 1 actions.

Statistical analyses aim to establish the relationship between the variation in crash or casualty numbers seen at some area-level of aggregation with factors assumed to contribute to the risk of crash or injury (Quddus, 2008). Disaggregation of data by injury severity (fatal, serious, slight), by crash type (single- or multiple-vehicle) or by road-user type (for example, motorised vehicle, vulnerable-pedestrian, cyclist or two-wheeled motor vehicle) may also be used to determine if different causal factors act for different injury or crash types and thereby produce further evidence for the causal mechanisms in road traffic crash (Aguero-Valverde and Jovanis, 2006).

While this thesis examined factors assumed to operate at the national level it is acknowledged that road user behaviour is influenced by factors operating at a number of spatial scales with the national-level being the most coarse resolution. This work may be furthered by analysis at the sub national-level. In particular, there are two levels of influence on road user behaviour suggested by Bronfenbrenner's social ecology model (Bronfenbrenner, 1977) that have not been examined in this thesis. Why individuals believe as they do and act as they do with respect to road use and road safety was not examined. Bronfenbrenner considered that individuals were influenced by their peer group, family and the immediate social, community environment and this effect was also not examined. Individual road user beliefs, attitudes and actions have been the subject of numerous studies in the fields of sociology and psychology. However, few have examined cross-cultural differences. Lund and Rundmo (2009, pg 547) stated that "It is reasonable to assume that attitude towards and risk perception of traffic differs in different cultures". While such effects may operate at the national level, there is evidence that cultural drivers may operate at sub-national levels. Factor et al. (2008) in an analysis of 20% of the Israeli population found that the risk of involvement in fatal or serious RTC for Israelis of the Jewish faith was 60% that for those who followed the Druze or Moslem religions. Thus analysis at the national level may not be the most appropriate for the identification of some of the factors associated with RTC fatality.

If some of the causal factors associated with RTC fatality risk operate at the sub-national level and some may be context-specific and driven by cultural influences then that may question the efficacy of the WHO Pillars of Action where a globalisation of road safety mediation schemes proven effective in one or more locations is proposed.

If the proposed WHO Pillars of Action are unlikely to bring about a stabilisation or reduction in global RTC fatalities then further work may be aimed at identifying factors which may be effective at the national level. In particular we could not analyse the effect of road safety education, for example driver training and testing schemes. If over 75% of RTCs have human error as a contributory factor (Stanton and Salmon, 2009) does driver training reduce this and lead to a lower RTC fatality rate? Should this be proven to be the case then the globalisation of a standard driver training regime may be advocated.

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