Travel Behaviour and Society 1 (2014) 15–21

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

The influence of rainfall on road accidents in urban areas: A weather radar approach

David Jaroszweski *, Tom McNamara

School of Civil Engineering, University of Birmingham, Birmingham, UK

A R T I C L E   I N F O

Article history:
Available online 7 November 2013

A B S T R A C T

This paper presents a novel and rigorous approach to the analysis of the impact of rainfall on road traffic accidents in urban areas. It is argued that previous approaches to rainfall quantification for accident analysis, primarily using a representative surface meteorological station to represent an urban area, may not give an accurate record of the conditions across the city in question. Using an innovative city-wide weather radar approach to rainfall quantification and matched-pairs analysis, road accidents in the UK cities of Manchester and Greater London are examined over a 3-year baseline period (2008–2011). A comparative study is made over the same period used a traditional station-based approach. The resulting relative accident rates demonstrate divergence between the two cities and the two approaches. Although the stricter criteria for a rain event under the weather radar approach gives an increased RAR in Manchester, the RAR observed under these conditions decreases in Greater London. Reasons for the variation in RAR are explored and include traffic volume and speed, other coincident weather conditions and driver behaviour, in accordance with Elvik's (2006) laws of accident causation. It is argued that the approach described in this study offers significant improvements to the analysis of current weather-related accidents by giving a more representative measure of rainfall in urban areas.

Introduction

Rainfall is consistently cited as the weather type responsible for the greatest number of weather-related accidents (Edwards 1999; Qiu and Nixon 2008). Rain causes accidents through a combination of several physical effects that degrade the driving environment, including a loss of friction between the tyre and road and impaired visibility through rain on the windshield and spray from other vehicles. It is this combination of negative factors (Fridstrom et al., 1995) and the resulting strain on cognitive capacity (Elvik 2006) that leads to increased accident rates.

Previous studies investigating the influence of rainfall on road accidents have concentrated on cities and urban areas (e.g. Andrey et al. 2003; Hambly et al. 2013). This focus is justifiable due to the relative and increasing importance of cities as the world becomes increasingly urbanised. Over 50% of the world's population now live in urban areas, a figure which has been projected to rise to 67% worldwide by 2050 and 86% in more developed regions (United Nations, 2012). As a result there has been a growing research agenda around studies on urban areas across the sciences, including a particular focus on cities by the climate change impact community (e.g. Hall et al. 2010).

Although improved vehicle design and driver training have led to reductions in weather-related accident rates across the developed world in recent decades (Qiu and Nixon 2008; Andrey 2010), the growing urbanisation and projected increase in extreme weather events (in particular rainfall: IPCC, 2007) makes an effective approach for rain-related accident analysis essential. However, as will become clear there are currently several key weaknesses in the way that current city-based accident analysis is carried out. The following section reviews the current literature on the effect of rainfall on road accidents.

Rainfall and road accidents in cities

The effect of rainfall is usually expressed through relative accidents rates (RARs), the ratio of accidents recorded during a precipitation event to those during normal conditions. The matched pairs approach is commonly employed to determine RARs, and works on the basis that within a given area, the accidents observed (usually through police reports) during a period experiencing rain can be compared with a corresponding dry period. This is usually achieved by comparing a period exactly a week preceding or following the event, with the assumption being that other factors such as volume of traffic, driver demographic and light conditions will be broadly similar. Table 1 displays the relative accident rates obtained from several city-based studies, in these cases varying between 1.2 and 2.0.

* Corresponding author. School of Civil Engineering, the University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK.
E-mail address: d.j.jaroszweski@bham.ac.uk (D. Jaroszweski).

2214-367X/$ - see front matter
http://dx.doi.org/10.1016/j.tbs.2013.10.005

Table 1
Relative accident rates from previous studies.

Study	Location	Period	Relative accident rate
Smith (1982)	Glasgow, Scotland	1978–1979	1.2–1.3
Andrey and Olley (1990)	Edmonton, Cananda	1983	1.3–1.9
Andrey and Yagar (1993)	Alberta, Canada	1979–1983	1.7
Changnon (1996)	Chicago, USA	1977–1979	2.0 (30% more accidents in densely populated areas)
Andrey et al. (2003)	Various mid-sized Canadian cities	1995–1998	1.75
Keay and Simmonds (2006)	Greater Melbourne, Australia	1987–2002	1.61–1.67
Hambly et al. (2013)	Greater Vancouver, Canada	2003–2007	1.13–1.55

The variation in RAR in previous studies is partly attributable to the particularities of the cities or regions in question and the historical period of the study. Broadly speaking, more recent studies show lower RARs due to aforementioned safety and driver training improvements (Andrey 2010). Differences between locations are attributed to factors such as road design, lighting, speed limits, driver training and frequency of exposure to rainfall (Fridstrom et al., 1995; Elvik 2006). It has also been shown that greater rainfall intensities lead to higher RARs and injury rates (e.g. Hambly et al. 2013). However, there are several longstanding methodological difficulties that call into question the validity of RARs obtained in urban areas and make direct comparison between studies extremely difficult.

One of the biggest problems in urban studies is the lack of representative meteorological station observations at suitable spatial and temporal resolutions. Urban areas have distinct microclimatic features attributable to their material and topographical properties as well as associated human activities such as transport and industry. This is most well known through the 'urban heat island' effect where urban areas have higher temperatures than surrounding non-urbanised areas (Oke, 1973). However, urban activity also leads to local effects on precipitation such as rainfall suppression. Aerosols in urban areas which have hygroscopic properties allow water in the atmosphere to be carried in a greater number of smaller droplets which do not precipitate out of the atmosphere (Rosenfeld 2000). Although the growing importance of instrumentation of urban areas has been noted (Oke 2006), efforts to implement urban networks have had mixed success (Muller et al., 2013a).

The relative absence of stations, largely attributable to the failure of such sites to meet the World Meteorological Organisation's guidelines on meteorological instruments and methods (WMO, 2008; Muller et al., 2013b), makes obtaining valid RARs difficult. Airports often provide the closest observations, but as Andrey et al. (2003) notes these can be as far as 35 km away from the city in question. Even where a city-centre station is available such as the one used by Keay and Symonds (2006) in Melbourne, the lack of coverage from a comprehensive city-wide network means the representativeness of the rainfall situation at any given time is questionable. The station in question is used to represent an area of almost 9000 km^2, within which large differences in rainfall timing and amount will be expected. It is clear that a more representative measure of rainfall would be beneficial for the formation of realistic RARs.

A further methodological issue is that RARs have consistently been shown to be highly sensitive to the temporal unit of study (Qiu and Nixon 2008). For example, although Smith (1982) found accident rates increased by 20–30% on days where rain is observed, it is conceded that this was likely to underestimate the precipitation impact, given that the days categorised as 'rainy' will contain periods of dry weather. In contrast, Andrey and Yagar (1993) used a variety of smaller temporal units and hourly rainfall data to capture more accurately the duration of rain events. Although the temporal distribution of precipitation within these periods is likely to vary, it is still clearly a far more accurate method than using daily data which include large variations in both rain and traffic volumes. However, the authors of this study concede that varying the temporal unit of analysis may allow any short-term behavioural change due to exposure to an extended rain event to influence the results.

These behavioural problems associated with the temporal unit of analysis are highlighted by Eisenberg (2004) who investigated the mixed effects of precipitation on traffic crashes in the USA. Monthly and daily units were used, with rainfall being evaluated by total precipitation. A negative and statistically significant relationship between monthly precipitation and monthly fatal crashes is reported, yet the opposite was found when a daily temporal unit analysis was employed. When investigated in further detail it was found that the increase in accident rate for a given rain day was three times greater if 20 days had passed since the last recorded precipitation compared with those events which experienced rain in the previous 2 days. This relates to a study by of Changnon (1996) in Chicago, who found that rain days during dry months produced more accidents and injuries than during normal or wet months.

These findings clearly indicate that short-term behavioural change is taking place, as described by Elvik's 'laws of accident causation' (2006). Increased exposure to hazardous conditions allows drivers more opportunities to learn to cope in these conditions, hence increasing personal and group resilience. It must also be noted that physical conditions are also altered by the frequency of rainfall with long dry spells leading to polished and oily road surfaces that become hazardous when wet. These behavioural and physical observations are also important in the context of climate change, as any change in the frequency of rain events will alter drivers' abilities to cope in these conditions (in both the short and long-term) and affect the physical driving conditions. Hence, it is important to remember that any obtained RAR will be influenced by the temporal unit of study and the particular patterns of rainfall exposure associated with a given city.

Overview of approach

This study attempts to address the two main methodological issues highlighted in the literature review; the spatial and temporal representativeness of meteorological data in city-based accident analysis. Matched pairs analysis is performed on two large UK cities UK Meteorological (Met) Office NIMROD weather radar images directly over the urban areas to give a more representative measure of rainfall than station-based approaches. These high spatial (5 km) and temporal resolution images (1 h) have previously been used to study the effect of rain of road traffic speeds (Hooper et al. 2012). Although this study considers UK cities, discussion is made on how the approach and methods can be applied to any urban area with available weather radar data, with suggestions on how other unconventional data could be used in areas without radar coverage.

Locations and data

Accident data

STATS19 accident data (DfT 2011) were obtained for the three year period of 2008–2011, a time period comparable to other stud-