Analyzing the relationships between travel mode indicators and the number of passenger transport fatalities at the city level

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ABSTRACT

Objective: A number of efforts have been conducted on travel behavior and transport fatalities at the neighborhood or street level, and they have identified different factors such as roadway characteristics, personal indicators, and design indicators related to transport safety. However, only a limited number of studies have considered the relationship between travel behavior indicators and the number of transport fatalities at the city level. Therefore, this study explores this relationship and how to fill the mentioned gap in current knowledge.

Method: A generalized linear model (GLM) estimates the relationships between different travel mode indicators (e.g., length of motorway per inhabitant, number of motorcycles per inhabitant, percentage of daily trips on foot and by bicycle, percentage of daily trips by public transport) and the number of passenger transport fatalities. Because this city-level model is developed using data sets from different cities all over the world, the impacts of gross domestic product (GDP) are also included in the model.

Conclusions: Overall, the results imply that the percentage of daily trips by public transport, the percentage of daily trips on foot and by bicycle, and the GDP per inhabitant have negative relationships with the number of passenger transport fatalities, whereas motorway length and the number of motorcycles have positive relationships with the number of passenger transport fatalities.

Introduction

Fatalities from traffic accidents are considered global health and development problems (Ngheim et al. 2013), and the largest single cause of fatalities among people aged 15 to 29 is transport crashes (Eurostat 2014). Road traffic fatalities will become one of the 3 major causes of death in low- and middle-income countries in the near future (Abdul-Manan and Várhegyi 2012; Grimm and Treibich 2010; Sarani et al. 2012; The World Bank 2014; World Health Organization 2009, 2014). In addition, in 2012, approximately 28,000 road fatalities were recorded in European countries (European Commission 2013). Therefore, concerns regarding traffic safety are very serious in developing countries, and they still exist in European countries (Asadi-Shekari, Moeinaddini, and Zaly Shah 2015a, 2015b; Moeinaddini et al. 2014b; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2015).

Although safety is one of the most important factors to consider when investigating mode choice (Can 2013; Deka 2013; Lovegrove et al. 2010; Lovegrove and Sayed 2006a, 2006b, 2007; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2015), in previous efforts, several important macroscopic factors were not considered (De Leur and Sayed 2001). For instance, there is limited research on exploring the impacts of travel mode choice on traffic fatalities in different contexts at a macroscale. In addition, the majority of previous efforts examined the relationship between each travel mode, including walking, cycling, public transport, motorcycles and cars, with traffic fatalities separately and on the microscale. There are limited studies that identify the effects of these travel options on traffic fatalities when considering all of these travel modes in one relationship model (refer to Appendix A, online supplement). Therefore, this research fills this gap by formulating a generalized linear model (GLM) to explain the relationships between travel mode choice indicators and transport fatalities at the macrolevel while controlling gross domestic product (GDP) impacts. The independent variables in this model include GDP per inhabitant, length of motorway per inhabitant, percentage of daily trips on foot and by bicycle, percentage of daily trips by public transport, and number of motorcycles per inhabitant. The dependent variable is the passenger transport fatalities per inhabitant.

Data and methodology

The majority of previous studies focus on microlevel indicators that are related to one of the travel modes (e.g., walking, cycling, public transport, motorcycle, and car), and there are a limited number of studies that try to identify the effects of these travel options on traffic fatalities in one relationship model at the macroscale. In addition, there are a limited number of studies regarding the relationship between travel mode choice indicators and traffic fatalities while controlling the impacts of GDP.
Therefore, this study focuses on GDP and travel mode choice indicators (percentage of daily trips on foot and by bicycle, percentage of daily trips by public transport, number of motorcycles per hundred thousand inhabitants, and length of motorway per hundred thousand inhabitants) as independent variables and traffic fatalities as the dependent variable at the macroscale (city level). The Mobility in Cities Database (International Association of Public Transport 2006) is an urban mobility database that is used for data collection. This database is the most complete urban mobility database at the city level. Although this database has 120 urban mobility indicators from 52 cities in different parts of the world, the lack of travel mode choice data for some cities limited the research data. Table 1 presents these research data.

Globalization, occupational structure, welfare regimes, social inequalities, and housing systems are the main structural factors for urban socioeconomic segregation (Hamnett 1994; Kemeny 1995; Marciniak et al. 2015; Sassen 1991). Because of data availability, most of the cities in this study are European cities. Because economic restructuring and globalization lead to socio-housing divisions in most European cities, economic restructuring and globalization are the main factors that represent socioeconomic and residential segregation (Arbaci 2007; Jones and Murie 2006; Kleinhans and Van Ham 2013; Van Ham and

| City         | GDP per hundred thousand inhabitants | Length of motorway per hundred thousand inhabitants | Number of motorcycles per hundred thousand inhabitants | Percentage of daily trips on foot and by bicycle | Percentage of daily trips by public transport | Passenger transport fatalities per hundred thousand inhabitants |
|--------------|-------------------------------------|----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------------------|
| Amsterdam    | 0.34                                | 0.17                                               | 0.64                                                | 0.51                                          | 0.15                                          | 330                                                     |
| Athens       | 0.12                                | 0.39                                               | 0.66                                                | 0.34                                          | 0.19                                          | 840                                                     |
| Barcelona    | 0.17                                | 0.9                                                | 0.66                                                | 0.34                                          | 0.19                                          | 840                                                     |
| Berlin       | 0.2                                 | 0.2                                                | 0.24                                                | 0.36                                          | 0.25                                          | 190                                                     |
| Bern         | 0.36                                | 1.57                                               | 0.66                                                | 0.38                                          | 0.21                                          | 350                                                     |
| Bilbao       | 0.21                                | 1.2                                                | 0.19                                                | 0.49                                          | 0.16                                          | 540                                                     |
| Bologna      | 0.31                                | 1.52                                               | 1.02                                                | 0.29                                          | 0.14                                          | 990                                                     |
| Brussels     | 0.24                                | 0.36                                               | 0.18                                                | 0.28                                          | 0.14                                          | 460                                                     |
| Budapest     | 0.1                                 | 0.14                                               | 0.07                                                | 0.23                                          | 0.44                                          | 630                                                     |
| Chicago      | 0.4                                 | 0.95                                               | 0.2                                                 | 0.06                                          | 0.06                                          | 800                                                     |
| Clermont Ferrand | 0.24                        | 0.42                                               | 0.3                                                 | 0.33                                          | 0.06                                          | 1,140                                                   |
| Copenhagen  | 0.34                                | 1.25                                               | 0.19                                                | 0.39                                          | 0.12                                          | 470                                                     |
| Dublin       | 0.22                                | 3.95                                               | 0.04                                                | 0.16                                          | 0.07                                          | 2,030                                                   |
| Ghent        | 0.27                                | 1.46                                               | 0.28                                                | 0.3                                           | 0.05                                          | 400                                                     |
| Glasgow      | 0.21                                | 1.11                                               | 0.05                                                | 0.24                                          | 0.11                                          | 530                                                     |
| Graz         | 0.3                                 | 0.8                                                | 0.49                                                | 0.35                                          | 0.18                                          | 400                                                     |
| Hamburg      | 0.39                                | 0.26                                               | 0.37                                                | 0.16                                          | 0.16                                          | 340                                                     |
| Helsinki     | 0.37                                | 0.91                                               | 0.16                                                | 0.29                                          | 0.27                                          | 210                                                     |
| Hong Kong    | 0.28                                | 0.16                                               | 0.04                                                | 0.38                                          | 0.46                                          | 300                                                     |
| Krakow       | 0.07                                | 0.22                                               | 0.11                                                | 0.33                                          | 0.4                                           | 44                                                     |
| Lille        | 0.22                                | 1.44                                               | 0.24                                                | 0.31                                          | 0.06                                          | 240                                                     |
| Lisbon       | 0.17                                | 0.87                                               | 0.26                                                | 0.24                                          | 0.28                                          | 730                                                     |
| London       | 0.36                                | 0.1                                                | 0.14                                                | 0.31                                          | 0.19                                          | 420                                                     |
| Lyons        | 0.27                                | 0.68                                               | 0.26                                                | 0.33                                          | 0.13                                          | 220                                                     |
| Madrid       | 0.2                                 | 0.98                                               | 0.3                                                 | 0.26                                          | 0.22                                          | 710                                                     |
| Manchester   | 0.22                                | 0.71                                               | 0.1                                                 | 0.23                                          | 0.09                                          | 420                                                     |
| Marseilles   | 0.23                                | 0.41                                               | 0.19                                                | 0.34                                          | 0.11                                          | 620                                                     |
| Melbourne    | 0.23                                | 0.2                                                | 0.18                                                | 0.06                                          | 0.06                                          | 770                                                     |
| Milan        | 0.3                                 | 0.5                                                |                                                      |                                               |                                               |                                                         |
| Moscow       | 0.06                                | 0.11                                               | 0.04                                                | 0.24                                          | 0.49                                          | 470                                                     |
| Munich       | 0.46                                | 0.48                                               | 0.42                                                | 0.38                                          | 0.22                                          | 220                                                     |
| Nantes       | 0.25                                | 1.23                                               | 0.29                                                | 0.23                                          | 0.13                                          | 650                                                     |
| Newcastle    | 0.18                                | 1.29                                               | 0.09                                                | 0.27                                          | 0.16                                          | 230                                                     |
| Oslo         | 0.43                                | 1.7                                                | 0.41                                                | 0.26                                          | 0.15                                          | 390                                                     |
| Paris        | 0.37                                | 0.7                                                | 0.39                                                | 0.36                                          | 0.18                                          | 660                                                     |
| Prague       | 0.15                                | 0.64                                               | 0.45                                                | 0.21                                          | 0.43                                          | 590                                                     |
| Rome         | 0.27                                | 1.11                                               | 0.81                                                | 0.24                                          | 0.2                                           | 1,080                                                   |
| Rotterdam    | 0.28                                | 0.18                                               | 0.42                                                | 0.1                                           | 340                                           |                                                         |
| Sao Paulo    | 0.06                                | 0.2                                                | 0.22                                                | 0.37                                          | 0.29                                          | 1,090                                                   |
| Seville      | 0.11                                | 1.16                                               | 0.35                                                | 0.42                                          | 0.1                                           | 1,030                                                   |
| Singapore    | 0.29                                | 0.45                                               | 0.4                                                 | 0.14                                          | 0.41                                          | 580                                                     |
| Stockholm    | 0.33                                | 2.69                                               | 0.13                                                | 0.31                                          | 0.22                                          | 360                                                     |
| Stuttgart    | 0.32                                | 0.49                                               | 0.44                                                | 0.3                                           | 0.11                                          | 570                                                     |
| Tallinn      | 0.07                                | 0.25                                               | 0.03                                                |                                               |                                               |                                                         |
| Tunis        | 0.02                                | 0.21                                               |                                                      |                                               |                                               |                                                         |
| Turin        | 0.27                                | 1.72                                               | 0.52                                                | 0.25                                          | 0.21                                          | 980                                                     |
| Valencia     | 0.14                                | 0.29                                               | 0.42                                                | 0.46                                          | 0.12                                          | 340                                                     |
| Vienna       | 0.34                                | 0.26                                               | 0.42                                                | 0.3                                           | 0.34                                          | 260                                                     |
| Warsaw       | 0.13                                | 0.45                                               | 0.19                                                | 0.2                                           | 0.52                                          |                                                         |
| Zurich       | 0.42                                | 1.09                                               | 0.58                                                | 0.3                                           | 0.23                                          | 450                                                     |
Manley 2009; Van Kempen and Murie 2009). Therefore, economic globalization indicators such as GDP can provide an overview of the main trends in globalization and socioeconomic segregation for the majority of the cities that are selected in this study.

When the sample size is not large, the maximum likelihood estimates may be biased. This bias is usually ignored (e.g., Moeinaddini et al. 2014b; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2015) because it is negligible compared to the standard errors (Cordio and McCullagh 1991). In addition, the risk function called Akaike’s information criterion (AIC) occasionally has a nonnegligible bias when the sample size is not large (Akaike 1973). The bias may lead to more parameters for the selected model among the candidate models as the best model based on AIC (Shibata 1980). There are various studies regarding bias-corrected AIC for a small sample size in various models (e.g., Davies et al. 2006; Hurvich and Tsai 1989; Kamo et al. 2013; Sugiura 1978; Wong and Li 1998; Yanagihara et al. 2003). The finite sample corrected AIC (AICc) that is proposed by Hurvich and Tsai (1989) is used in this study to avoid biased AIC.

The number of passenger transport fatalities per hundred thousand inhabitants is a dependent variable in this study, and it is similar to count data (the number of fatalities only takes nonnegative and discrete values). On the other hand, this variable is divided by inhabitants. This division converts this variable to a scaled factor. In addition, the data set does not include a large number of zeros. Therefore, lognormal and gamma with log link models that are contributed to scale data in the GLM framework can be utilized for this variable. Because lognormal is not in the exponential family (e.g., Poisson, gamma, binomial, inverse, negative binomial, etc.) and GLMs with a gamma distribution performed slightly better than the log-transformed model, gamma with the log link model is selected to test the proposed relationships in this study.

### Results

The results of the GLM analysis that tested the relationships between travel mode indicators and transport fatalities while controlling GDP impacts are discussed in this section. Descriptive statistics for the variables included in the model (78.8%) are presented in Table 2. Table 3 presents the correlation matrix. A strong correlation does not exist between the independent variables (see Table 3). The parameter estimates and the significance of the parameters (5% level) are shown in Table 4. The model goodness of fit is represented by the omnibus test (the likelihood ratio chi-square test statistics, $P \approx .0001$), the scaled deviance (SD), and Pearson’s chi-square statistic (Table 5). The final model can be defined as $PF = \exp(7.450 - 2.915G + 0.185L - 0.673M - 1.786FB - 1.269PT)$, where $PF$ is the passenger transport fatalities per hundred thousand inhabitants, $G$ is the GDP per hundred thousand inhabitants, $L$ is the length of the motorway per hundred thousand inhabitants, $M$ is the number of motorcycles per hundred thousand inhabitants, $FB$ is the percentage of daily trips on foot and by bicycle, and $PT$ is the percentage of daily trips by public transport.

The results show that passenger transport fatalities are significantly affected by GDP and travel mode indicators. Among these indicators, the GDP per hundred thousand inhabitants has the highest negative parameter, so a higher GDP has greater impacts on passenger transport fatality reduction in this model compared to other effective factors. The percentage of daily trips on foot and by bicycle and the percentage of daily trips by public transport that have negative relationships with passenger transport fatalities are the second and third effective factors in this model. More walking, more cycling, and a higher rate of public transport usage are associated with fewer fatalities. The fifth effective indicator with a positive relationship is the number

| Model | Collinearity Statistics |
|-------|-------------------------|
|       | Tolerance | VIF  |
| 1     | GDP per hundred thousand inhabitants | 0.853 | 1.172 |
|       | Length of motorway per hundred thousand inhabitants | 0.783 | 1.276 |
|       | Number of motorcycles per hundred thousand inhabitants | 0.916 | 1.092 |
|       | Percentage of daily trips on foot and by bicycle | 0.925 | 1.082 |
|       | Percentage of daily trips by public transport | 0.765 | 1.307 |

Table 2. Continuous variable information.

| Dependent variable | Minimum | Maximum | Mean | SD  |
|--------------------|---------|---------|------|-----|
| Passenger transport fatalities per hundred thousand inhabitants | 41 | 190.00 | 2,030.00 | 593.9024 |

Dependent variable: Passenger transport fatalities per hundred thousand inhabitants.

Table 3. Correlation matrix.

| Model | Collinearity Statistics |
|-------|-------------------------|
|       | Tolerance | VIF  |
| 1     | GDP per hundred thousand inhabitants | 0.853 | 1.172 |
|       | Length of motorway per hundred thousand inhabitants | 0.783 | 1.276 |
|       | Number of motorcycles per hundred thousand inhabitants | 0.916 | 1.092 |
|       | Percentage of daily trips on foot and by bicycle | 0.925 | 1.082 |
|       | Percentage of daily trips by public transport | 0.765 | 1.307 |

`aDependent variable: Passenger transport fatalities per hundred thousand inhabitants.`
of motorcycles per hundred thousand inhabitants, and the last positive effective indicator is the length of the motorway per hundred thousand inhabitants. Thus, more motorways and motorcycles are associated with more transport fatalities in this model.

Overall, fewer motorcycles, shorter motorways per inhabitant, a higher GDP per inhabitant, a higher percentage of daily trips on foot and by bicycle, and a higher percentage of daily trips by public transport are effective indicators that are associated with fewer transport fatalities. This suggests that macroscale urban planning that reduces the number of motorcycles and motorway density and increases alternative travel modes (walking, cycling, and public transport) could contribute to fewer transport fatalities across different cities while GDP tends to increase.

**Discussion**

GDP and urban travel mode indicators as independent variables and passenger transport fatalities as the dependent variable are analyzed in this research using GLM analysis at the macroscale. From this study, it can be concluded that the length of the motorway per hundred thousand inhabitants, the percentage of daily trips on foot and by bicycle, the percentage of daily trips by public transport that are urban travel mode indicators, and the GDP per hundred thousand inhabitants are associated with passenger transport fatalities.

The model shows that a higher GDP per inhabitant is correlated with fewer passenger transport fatalities. The results of previous studies show that though increasing GDP leads to an increase in fatalities in the first stages of economic development, the relationship between GDP and transport fatalities will change when economic development reaches a certain level (e.g., Elvik 2010; Kopits and Cropper 2005; Law et al. 2011). The majority of the cities in the proposed model have reached a certain level of economic development, so GDP has a negative relationship with transport fatalities, and this negative relationship is greater than other effective factors in this model. In addition, considering GDP in the proposed model can indicate the impacts of socioeconomic factors (context effects) at the macrolevel on the relationship between travel mode indicators and transport fatalities.

The model also shows that more alternative travel modes (walking, cycling, and public transport) are correlated with fewer passenger transport fatalities. More walking and cycling can be the result of more facilities and connected routes that are used for nonmotorized modes (Asadi-Shekari, Moeinaddini, and Zaly Shah 2013a, 2013b; Asadi-Shekari et al. 2014). These facilities and connected routes are effective in allowing fewer conflicts and transport fatalities (Asadi-Shekari, Moeinaddini, Sultan, et al. 2015; Asadi-Shekari, Moeinaddini, and Zaly Shah 2015a, 2015b). In addition, more transit trips mean fewer private motorized trips and fewer conflicts (Ibrahim Sheikh et al. 2006; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2014a, 2015; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2015). The model also indicates that a longer motorway and more motorcycles per inhabitant are correlated with more passenger transport fatalities. More motorways mean more private motorized vehicle users because motorways belong to motorized vehicles with high speed, and this high speed increases the accident risk (Asadi-Shekari et al. 2013a, 2013b; Atubi 2012; Moeinaddini, Asadi-Shekari, Sultan, and Zaly Shah 2015; Moeinaddini, Asadi-Shekari, and Zaly Shah 2014a, 2014b, 2015). Motorcycle safety can decrease easily in different traffic and weather conditions.
This study evaluates the relationship between urban travel mode indicators and passenger transport fatalities in different cities within various contexts at the city level while controlling GDP impacts. Therefore, the results of this study can be used to explain the impacts of urban travel mode choice on transport fatalities regardless of context effects. In addition, this study also attempts to use a socioeconomic context–related factor (GDP) and urban travel mode indicators at the city level (instead of the neighbourhood level) that have not been sufficiently investigated in previous efforts. These types of relationships can be used in fatality reduction strategies at the city level and to propose better planning decisions for new and existing cities.

This research is limited to the available data in the UITP database in selected cities. Additional studies can improve the proposed model by adding more cities and urban structure indicators. The same method can be used in additional studies to identify more effective factors for sustainable travel patterns regardless of context effects at the city level. In addition, because urban structure indicators change rapidly, these indicators can be updated in regularly future studies to evaluate the changes in the relationship between urban structure indicators (e.g., urban travel mode indicators) and transport fatalities at the macrolevel.

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