Relationships between urban planning variables and traffic crashes in Damascus

Hashem R. Al-Masaeid and Ghassan Suleiman

Abstract
This study investigated the relationships between city planning and street network variables and traffic accidents at the zone level. Damascus, the capital of Syria, which consists of fourteen urban zones, was selected as a case study. For each zone, cross-sectional data on traffic accidents, vehicle-kilometres of travel (VKT), population, zone area, land-use developments, and street network variables were collected.

Multivariate regression analyses were conducted to develop mathematical relationships that could have practical applications for use by city planners and traffic safety engineers. The results indicated that VKT, population density, percentage of open space, percentage of commercial frontages, distribution of public buildings, street network length, and intersection density were significantly related to the number of accidents in each urban zone. Indicators for estimating urban zone accidents were also derived, to remind city planners and traffic safety engineers of the potential impacts of some planning variables and urban characteristics on traffic safety in urban areas. While the specific results relate to the study city, they at least sound cautions about the need to consider the safety trade-offs implied in some urban form choices.
INTRODUCTION

The last decade has seen a rapid growth in urban areas in both developed and developing countries. The growth in urban size increases the demand for travel and requires an expansion or improvement of the existing transport network. However, several obstacles such as insufficient resources, the prevailing conditions and current urban form may prevent the expansion or improvement of the existing network. For these reasons, substantial increases in the level of travel would significantly contribute to the deterioration of traffic safety and air quality. Under these conditions, manipulating urban form and socio-demographic variables and also the form of the street network may help to minimise the potential for traffic crashes. Put more positively, urban planning may be able to play a role in improved road safety.

Previous studies have acknowledged the role of urban planning in road safety (Bennett and Marland 1978; Brindle 1984; Cameron 1977). Consequently, the term ‘safety-conscious planning’, or planning for safety, has received the attention of researchers. The major principles of safety-conscious planning include minimisation of the need for travel, adoption of speed management and segregation of movements. Accordingly, planning guidelines such as the use of network types with fewer intersections, separation of access from through movements on traffic routes, maximising the percentage of dwelling units on low-connectivity roads and the use of short collector/distributor streets within a development, among others, were suggested to provide a safer environment in Australian states (Brindle 2001).

BACKGROUND

For the purpose of this study, Damascus city, the capital of Syria, was chosen as a case study. The city, which consists of fourteen zones, is administratively considered as the Damascus District. The city contains a large number of historical buildings and trading activity centres and is considered to be the oldest capital in the world.

Damascus city has a population of about 1.6 million, rising perhaps to more than 2 million during the daytime. Furthermore, the city has a total area of 83 square kilometres and a total street length of 1360 km. Thus, the city has an overall population density of 19,320 inhabitants/km² and a street density of 16.4 km/km². Compared with many European cities, these figures are very high. In 1998, for example, Hamburg, Germany, had a population of 1.7 million and the corresponding population and street densities were 2,257 inhabitants/km² and 5.2 km/km², respectively (Schlabbach et al. 1999).

Different arterials straddle Damascus city. The street network structure consists of grid, ‘organic’ (hierarchical), and limited access elements. In 2002, the total number of Syrian vehicles was nearly one million, of which a quarter of a million were registered in Damascus. Although Damascus’ population represents about one-tenth of the Syrian population, more than one-third of traffic accidents occurred in the city (see Table 1). Therefore, Damascus faces a high level of accident risk, both in terms of proportion of population and proportion of registered vehicles.

The main objective of this study was to investigate the influence of city planning variables, such as population level, land-use developments, spatial distribution of public buildings, and street network characteristics, on traffic accidents at the zone level. To accomplish this objective, data on traffic accidents, vehicle-kilometres of travel, population, land-use developments and the street network in Damascus city were collected for two years, 2001 and 2002. Multiple regression analyses were carried out to develop statistical relationships that could have practical implications for city planners and traffic engineers.
Relationships between urban planning variables and traffic crashes in Damascus

Table 1
Traffic accidents in Syria and Damascus, 1998-2002

<table>
<thead>
<tr>
<th>Year</th>
<th>Traffic accidents in Syria</th>
<th>Traffic accidents in Damascus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>14123</td>
<td>5354</td>
</tr>
<tr>
<td>1999</td>
<td>13145</td>
<td>5191</td>
</tr>
<tr>
<td>2000</td>
<td>14261</td>
<td>5882</td>
</tr>
<tr>
<td>2001</td>
<td>14234</td>
<td>5097</td>
</tr>
<tr>
<td>2002</td>
<td>16262</td>
<td>4316</td>
</tr>
<tr>
<td>Total</td>
<td>72025</td>
<td>2584</td>
</tr>
</tbody>
</table>

METHODOLOGY
As previously mentioned, Damascus city consists of fourteen administrative zones. For each zone, data on traffic accidents, population density, land-use developments, level of travel, road network, intersection density, and the distribution of public buildings were measured through field surveys or obtained from relevant authorities. In this study, a cross-sectional approach was adopted to focus on the differences in safety between urban zones at one point in time. The resultant models are essentially descriptive rather than predictive. While it has acknowledged limitations compared with time series data in terms of identifying causation and ability to reflect detailed differences in characteristics, this approach can suggest the marginal effects of different zone attributes on traffic accidents.

Mathematical modelling was used to develop relationships between zone traffic accidents and the variables mentioned above. In the analysis, a correlation matrix was established to identify variables that had an influence on traffic accidents and to check possible multicollinearity between pairs of independent variables. In the modelling process, the first step was to identify the best transformation for variables that had an impact on traffic accidents. In the second step, multivariate regression analysis was carried out to develop traffic accident predictive models. The developed models can be used in sensitivity analysis of alternative safety measures.

DATA COLLECTION
Traffic data
For each zone, traffic accident data for a period of two years were obtained from Damascus Traffic Department. Traffic accidents included all reported accidents (fatal, injury and property damage), both vehicle and vehicle-pedestrian accidents. Accident data for 2001 and 2002 were used to compute the average number of accidents per year for each zone. To avoid possible effect of external factors, a two-year period was considered to be sufficient for analysis purposes (Pendleton 1992; Shen and Gan 2002).

Safety studies have reported that the number of accidents is proportional to the exposure measure (Miaou 1994). Typical exposure measures may include population, length of street network, number of vehicles, and annual kilometres driven, among others (Ernvall 1997). For each urban zone, the exposure measure may be taken as the sum of products of the average daily traffic volume and the corresponding street length within the zone. Since the average daily traffic volume for each arterial or major collector/distributor street was not available, the peak hour volume on each street segment was considered in computing the exposure measure. The peak hour volume on each street segment was obtained through field study during the summer season.

Urban planning data
For each zone, population, area, and urban development data were obtained from the Damascus Municipality. Types of developments in each zone were also checked through field survey. Residential, industrial (light industrial premises), and open space (gardens and playgrounds) areas in each zone were estimated as a percentage of the total zone area. It was difficult to estimate the percentage of commercial area in each zone. Most commercial and trading activity in Damascus comprises individual stalls alongside the streets rather than commercial centres or malls.
covering large areas of land. For this reason, the percentages of commercial and office developments were estimated as a percentage of the total street frontages in each zone.

Finally, the spatial distribution of public buildings (schools, ministries, embassies, etc.) in Damascus was identified and quantified. The percentage of public buildings in each zone was computed as a percentage of the total number of public buildings in Damascus as a whole. These buildings are considered as major traffic and pedestrian attracting locations.

Road network

Functional, operational, and structural characteristics of the street network have a great impact on traffic safety. The main function of arterial and collector/distributor roads is to enable travel between locations, while the function of local streets is to enable access within a locality. In this study, arterial and collector/distributor roads were considered in computing the exposure measure. The effect of operational characteristics of the street network on traffic safety was investigated at a micro level in previous studies (Al-Masaeid 1997). In fact, the structure of the street network (grid, organic or limited access) may affect traffic safety, accessibility, liveability, and network cost. In this study, the structure of the street network was represented in terms of total length of streets, street density, and intersection density. Street density was computed as the total length of streets (arterial, collector/distributor, and local) divided by the zone area. Intersections were classified into T and cross-intersections. Intersection density was computed as the total number of intersections divided by the zone area. Table 2 presents the statistical characteristics of the data collected.

ANALYSIS AND MODELLING RESULTS

Correlation analysis

Table 3 presents the correlation matrix for the variables included in this study. This table indicates that traffic accidents are strongly and positively correlated with vehicle-kilometres of travel (VKT), population density, number and density of intersections, total street length, percentage of commercial streets, and percentage of public buildings in each zone. The analysis confirmed that traffic accidents are directly related to the amount of travel (see Figure 1). Furthermore, urban zones with high population densities may generate higher levels of traffic and pedestrians; therefore, higher accidents are expected.

The correlation analysis also indicated that zones with higher density of intersections tend to have higher accident levels (see Figure 2). This result is logical, since intersections would generate conflicts among traffic streams. Although the number of intersections is correlated with the total street length (see Table 3), the organic and limited access street networks have lower intersection density than the grid structures; that is, for the same access and circulation function, grid networks contain more intersections and have higher accident rates, other things being equal. Thus, grid local networks are likely to be less favourable in terms of road safety. This

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Symbol</th>
<th>Min.</th>
<th>Mean</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of accidents</td>
<td>acc/zone</td>
<td>NA</td>
<td>63</td>
<td>336.21</td>
<td>536</td>
</tr>
<tr>
<td>Amount of travel</td>
<td>1000 veh-km.</td>
<td>TL</td>
<td>6.23</td>
<td>15.90</td>
<td>25.88</td>
</tr>
<tr>
<td>Population density</td>
<td>persons/1000 m²</td>
<td>PD</td>
<td>5.07</td>
<td>21.29</td>
<td>60.52</td>
</tr>
<tr>
<td>Number of intersections</td>
<td>number</td>
<td>NI</td>
<td>33.00</td>
<td>285.43</td>
<td>645.00</td>
</tr>
<tr>
<td>Total street length</td>
<td>km</td>
<td>SL</td>
<td>29.46</td>
<td>97.15</td>
<td>177.86</td>
</tr>
<tr>
<td>Percentage commercial</td>
<td>percent</td>
<td>PC</td>
<td>2.52</td>
<td>7.50</td>
<td>16.42</td>
</tr>
<tr>
<td>Percentage green area</td>
<td>percent</td>
<td>PG</td>
<td>0.14</td>
<td>5.98</td>
<td>44.32</td>
</tr>
<tr>
<td>Percentage industrial</td>
<td>percent</td>
<td>PI</td>
<td>0.00</td>
<td>0.98</td>
<td>5.44</td>
</tr>
<tr>
<td>Percentage public buildings</td>
<td>percent</td>
<td>PPE</td>
<td>0.79</td>
<td>7.14</td>
<td>14.72</td>
</tr>
<tr>
<td>Street density</td>
<td>km/km²</td>
<td>SD</td>
<td>9.09</td>
<td>19.0</td>
<td>28.87</td>
</tr>
<tr>
<td>Intersection density</td>
<td>intersections/km²</td>
<td>ID</td>
<td>13.47</td>
<td>55.93</td>
<td>109.47</td>
</tr>
</tbody>
</table>
Table 3
Correlation matrix of the variables

<table>
<thead>
<tr>
<th></th>
<th>NA</th>
<th>TL</th>
<th>PD</th>
<th>NI</th>
<th>SL</th>
<th>PC</th>
<th>PG</th>
<th>PI</th>
<th>ID</th>
<th>PPB</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL</td>
<td>0.73*</td>
<td>1.00</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD</td>
<td>0.71*</td>
<td>0.46</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>NI</td>
<td>0.87*</td>
<td>0.62*</td>
<td>0.80*</td>
<td>1.00</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>0.78*</td>
<td>0.64*</td>
<td>0.27</td>
<td>0.72*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>0.73*</td>
<td>0.57*</td>
<td>0.72*</td>
<td>0.80*</td>
<td>0.44</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG</td>
<td>-0.52*</td>
<td>-0.17</td>
<td>-0.24</td>
<td>-0.37</td>
<td>-0.59*</td>
<td>-0.01</td>
<td>1.00</td>
<td></td>
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</tr>
<tr>
<td>PI</td>
<td>-0.16</td>
<td>-0.11</td>
<td>-0.34</td>
<td>-0.22</td>
<td>0.22</td>
<td>-0.27</td>
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<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ID</td>
<td>0.70*</td>
<td>0.36</td>
<td>0.88*</td>
<td>0.72*</td>
<td>0.19</td>
<td>0.79*</td>
<td>-0.09</td>
<td>-0.42</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPB</td>
<td>0.78*</td>
<td>0.68*</td>
<td>0.61*</td>
<td>0.64*</td>
<td>0.61*</td>
<td>-0.24</td>
<td>-0.27</td>
<td>0.59*</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.31</td>
<td>0.19</td>
<td>0.42</td>
<td>0.14</td>
<td>0.18</td>
<td>0.49</td>
<td>0.29</td>
<td>-0.19</td>
<td>0.70*</td>
<td>0.19</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*Significant at 95% confidence level

Figure 1
Relationship between traffic accidents and travel level
result is compatible with the findings of previous studies, which indicated that grid and connective networks had worse safety records compared with modern layouts relying on many low-connectivity streets (Bennett and Marland 1978). It is notable that the street density had no effect on traffic accidents. The indications are that traffic volume and vehicle-kilometres of travel are more important factors than street density.

In addition, the analysis illustrated that urban zones with high percentages of commercial streets and public buildings are associated with higher accident risk. Empirical observations revealed that these locations attract considerable traffic and pedestrians; consequently, more accidents would be anticipated. Table 3 also shows that the percentage of open space area is negatively correlated with the traffic accidents. This result is compatible with the results of previous safety studies (Al-Masaeid 1997). The existence of open space in an urban zone can be expected to reduce friction between pedestrians and vehicles, reducing the number of conflicts. The table also suggests that the percentage of industrial area had no impact on traffic accidents but, in view of the small percentages of light industrial areas in each zone, no definite conclusion can be drawn about this. More investigations are needed to explore this issue.

Finally, multicollinearity was found between some urban planning and street network variables (see Table 3). Although multicollinearity does not affect the usefulness of the fitted model for making inferences about mean responses or making predictions (Neter et al. 1985), some variables in this study were dropped in the modelling process in order to lessen the effect of multicollinearity.
Urban zone accident models

Regression analyses were carried out to develop models that are capable of explaining the number of traffic accidents at zone level. Four groups of models were developed. The first group was developed to estimate the number of accidents, \( NA \), as a function of exposure indicators. The models obtained were:

\[
\begin{align*}
NA & = 138.38 \times \exp(0.05 TL) \\
NA & = 5.092 \times PD^{0.694}
\end{align*}
\]

where:
\( NA \) = average number of accidents per zone per annum (2001-2)  
\( TL \) = amount of travel during peak period, in thousand vehicle-kilometres  
\( PD \) = population density (persons/1000 m\(^2\)).

Models (1) and (2) and their parameters were found to be significant at the 95% confidence level. The vehicle-kilometres of travel explained about 32% (\( R^2 = 0.317 \)) of traffic accident variations. Population density explained greater variations in traffic accidents (64%, \( R^2 = 0.64 \)).

The second group of models was developed to estimate the number of accidents in each zone as a function of street network structure indicators. Based on the analyses, the following models were obtained:

\[
\begin{align*}
NA & = 175.91 \times \exp(0.0096 ID) \\
NA & = 70.67 \times \exp(0.008 ID + 0.011 SL)
\end{align*}
\]

where:
\( ID \) = intersection density (intersections/km\(^2\))  
\( SL \) = total street length (km).

The intersection density explained about 37 per cent (\( R^2 = 0.368 \)) of accident variations. Greater improvement in explanatory power was obtained by introducing the total street length variable (Equation 4). The use of intersection density and total street length as independent variables explained 80 per cent of accident variations. Equations 3 and 4 and their parameters were significant at the 95 per cent confidence level.

The third group of models was developed using land-use development indicators. The developed models were:

\[
\begin{align*}
NA & = 370.93 \times \exp(0.034 PG) \\
NA & = 234.16 \times \exp(-0.034 PG + 0.0611 PC) \\
NA & = 200.74 \times \exp(-0.030 PG + 0.0352 PC + 0.0454 PPB)
\end{align*}
\]

where PG, PC, and PPB represent percentage of open space, percentage of commercial streets, and percentage of public buildings, respectively. All previous models and their parameters were found to be significant at the 95% confidence level. In Equation 5, the percentage of open space explained 54% of accident frequency variations. In addition to the percentage of open space, the introduction of percentage of commercial streets improves the model’s explanatory ability to 83% (Equation 6). Equation 7 includes all land-use variables, and together they explained about 91% (\( R^2 = 0.91 \)) of accident variations.

The final group includes only one model. The general model was developed using step-wise multiple regression analysis. The following general regression model was obtained:

\[
NA = 223.631 TL^{3.371} \times \exp(0.007 ID - 0.031 PG)
\]

The model and all parameters were significant at the 95% confidence level. Furthermore, the model explained about 91 per cent of accident variations (\( N = 14, R^2 = 0.91, F = 32.32, p = 0.0001 \)). The normal probability plot of residuals against their expected values when the distribution is normal suggested that the error distribution was almost normal. In addition, no outliers were detected. Despite the fact that the sample size is relatively small (14 urban zones), the analysis of residuals indicated that the regression model is appropriate for accident data.

Finally, a literature survey revealed that various forms of regression models have been used to describe the relationship between traffic accidents and explanatory variables. For example, the linear model (Benekohal and Hashmi 1992), multiplicative model (Al-Masaeid et al. 1994; Zeeger et al. 1987), Poisson model (Al-Masaeid 1997; Joshua and Garber 1990), and negative binomial model (Al-Masaeid et al. 1997; Bowman and Vecellio 1995) have been used in modelling traffic accidents. In this study, however, multiplicative models were found to be the best for explaining variations in traffic accidents at zone level.
PRACTICAL APPLICATION

This study suggests some important implications for improved urban traffic safety, especially under Syrian conditions but possibly elsewhere as well. The mathematical models developed in this study would help city planners, municipal planning boards and traffic engineers to identify planning and management measures and policies for reducing traffic accidents in urban zones.

The developed Equations 1 through 8 show the impact of different traffic, city planning and street network variables on the expected number of accidents. For example, Equation 2 indicates that the expected number of accidents would be reduced through limiting the population density. This policy conclusion may be unique to Damascus, where the population density in some zones exceeds 60,000 inhabitants/km² (see Table 2).

Also, Equation 7 can be used to explore the effect of planning developments on the expected number of accidents. Using Equation 7, Figure 3 was drawn to show the influence of different commercial development and public building intensities on traffic accidents (PG = 6%). Clearly, the expected number of accidents would be reduced substantially as the percentages of commercial frontage or adjacent public buildings was reduced. Furthermore, Equation 8 can be used to investigate the impact of vehicle-kilometres of travel, intersection density and percentage of open space on the expected number of accidents. Figure 4, which was drawn using Equation 8, indicates that the expected number of accidents would be reduced as the vehicle-kilometres of travel and intersection density reduced. In practice, this can be attained by locating major streets to the edges of an urban zone. The use of organic and limited access street structure may help in reducing intersection density.

FURTHER COMMENTS

The descriptive models developed in this study demonstrate the potential influence of urban zone and street network planning variables on traffic accidents, and suggest some guidelines for safety-conscious planning at least in urban environments similar to that in Damascus. Minimisation of traffic crashes suggests that commercial developments should be distributed across all urban zones and,
instead of permitting such premises to extend alongside major streets, the models imply that commercial centres or malls should be encouraged to locate away from major streets and be accessible through access streets. Similarly, public buildings and other vital facilities such as open spaces and playgrounds, which are pedestrian-attracting locations, should be provided in each urban zone. These planning measures may reduce the need for travel and the interaction between vehicles and pedestrians and ultimately would reduce the probability of accident occurrences. Furthermore, while it was not included in the variables that were analysed, it is important to emphasise the use of public transit as another measure to reduce traffic levels on urban streets.

The models also suggest that a safer urban environment can be attained through controlling Damascus' high population density. This policy can be achieved by reducing the amount of apartment or multistorey developments. Large and densely populated urban areas are characterised by high vehicle-kilometres of travels and poor safety records. Also, this study suggests that the length of street network and intersection density have a close relationship with the level of traffic accidents. Organic street structures have relatively shorter street length and lower intersection density compared with grid and limited access street networks. Existing grid structures may be converted to reduce the intersection density.

It is clear that some of these findings are contrary to some elements of current western planning fashion, e.g. a preference for local grid networks with high street lengths and intersection densities; linear commercial development; and the assumption that higher densities are implicitly good. This suggests that careful consideration should be given to the safety trade-offs when applying contemporary planning ideas in a given urban context.

**CONCLUSIONS**

Based on the results of this study, and keeping in mind the limitations of this sort of analysis, the following points were concluded from the Damascus data. They might have wider application.
Relationships between urban planning variables and traffic crashes in Damascus

1. Levels of travel and population density have a strong influence on urban accidents. Reduction of the need for travel and locating major streets on the edge of an urban zone as well as limiting population density could enhance traffic safety.

2. Traffic accidents in an urban zone are exponentially proportional to intersection density and total street length. In street network planning, the reduction of both intersection density and total street length could provide safer networks.

3. Commercial frontages and the location of public buildings have adversely influenced urban accidents. In the Damascus context, the use of commercial centres and malls rather than individual shops and stalls alongside major streets may reduce traffic and pedestrian friction and ultimately could reduce traffic accidents.

4. The existence of open space in an urban zone could help in reducing the risk of traffic accidents.

5. All the models have a multiplicative form. They successfully explain the variations in accident frequencies at urban zone level.

6. Potential conflicts with some aspects of current planning ideas, specifically questions about the advisability of higher densities and highly-interconnected road systems, are indicated and suggest that care should be taken about the safety consequences of these concepts in specific places.

7. Noting the essentially descriptive nature of this sort of analysis, this work could usefully be replicated elsewhere to see if similar findings are obtained. More confidence about the levels of causation might then emerge.

REFERENCES


BENNERT, G.T. and MARLAND, J. (1978). Road accidents in traditionally designed residential estates, TRRL Supplementary Report 394, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.


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