Motor Vehicle Crashes and Land Use
Empirical Analysis from Hawaii

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At first glance, the relationship between crashes and land use appears obvious. Various types of land uses tend to generate and attract different types of trips, and trip-making behavior affects the nature and volume of traffic. As the use of land intensifies, it does not seem unreasonable to expect that the potential exposure to crashes would also increase. Yet upon closer inspection, it is evident that crashes are more a function of the characteristics of drivers and travelers than the underlying uses of land. Using comprehensive police crash data linked to a land use database, the relationships between land use and automobile crashes in Hawaii are investigated. Recent developments in geographic information system technology and the availability of spatial databases provide a rich source of information with which to investigate the relationships between crashes and the environments in which they occur. Although the patterns in terms of crashes and the underlying use of land are difficult to describe, the implications of these findings for planners, developers, and those interested in traffic safety are apparent.

While much emphasis has been placed on the influence of human factors, vehicle characteristics, roadway conditions, and other environmental variables, such as weather or time of day, on vehicle crashes, there have been few studies examining the relationship between land use and motor vehicle crashes. At first glance, the relationship between land use and traffic accidents seems obvious, albeit indirectly related. There are certain uses of land that tend to generate activities that help produce or attract travelers. However, it must be noted that people, more specifically those driving and traveling in automobiles, are the ones involved in motor vehicle collisions. Hence it is not surprising to find that human factors typically dominate in terms of theories of accident causation.

The purpose of this study was to examine the relationship between land use and accidents. The analysis has been made possible because of advances in geographic information system (GIS) technologies and the increased availability of spatial databases. By linking police crash data with land use data at the parcel level, the authors were able to investigate not just the human factors associated with motor vehicle crashes, but also the relationships between land use and traffic accidents.

Several basic questions frame this research. First, are there discernible patterns in terms of the general relationship between automobile accidents and land use? Second, do certain types of land uses generate proportionately more crashes? Third, using linked injury outcome data, which types of land uses produce the most injury collisions? Finally, do the associations between land use and accidents vary by type of crash—is there a difference between vehicle-to-vehicle versus pedestrian, bicycle, or motorcycle crashes? The questions arise both out of a general curiosity regarding the relationships between land use and motor vehicle crashes, and an interest in better understanding the connections between urban planning, development, traffic, and accidents.

The research presented in this paper builds on the authors’ earlier efforts related to the modeling of the causes and consequences of motor vehicle crashes (1, 2) and extends the work done on geocoding and spatial analysis of crashes using data from Hawaii. Hawaii provides a most interesting context for the research of traffic accidents. With its geographic isolation and its extreme centralization of government (there are only four units of local government in the entire state, with only four police departments, all using the same crash report form), there are some comparative advantages in terms of comprehensive data collection. Due to the limited land area, combined with recent advances in geospatial data processing, Hawaii has been one of the first states to develop a comprehensive statewide database capturing all motor vehicle collisions (3, 4). For purposes of analysis, in this paper, the focus is only on the largest county, the City and County of Honolulu, in which more than 70% of the population resides. Covering the entire island of Oahu, Honolulu consists of more than 386,164 acres of land. Only about 25% of the land is zoned, under the state land use law for urban uses. Approximately 45% of the land is classified as conservation land. The remainder of Oahu, about 30% of the land area, is classified for agricultural uses. Although the state land use commission is responsible for broadly determining land use in Hawaii, the four counties (Honolulu, Maui, Kauai, and Hawaii) have responsibility for determining the nature and extent of residential, commercial, institutional, and industrial land uses. They achieve this control through zoning, infrastructure development, development plans, and subdivision ordinances.

DATA AND METHODS

The data from this project were derived from the Hawaii CODES (Crash Outcome Data Evaluation System) Project, funded by the U.S. Department of Transportation, NHTSA. This project involved acquiring and linking police crash data, emergency medical services (EMS), and hospital and injury data. The linkage technique described elsewhere (5) enabled the investigation of the relationships between crashes and injuries (6). As part of the effort in Hawaii, a comprehensive GIS database was constructed in which data from various spatial databases, including the U.S. Bureau of Census, U.S. Geological Survey, and the City and County of Honolulu's Land Information System, were integrated. Using Environmental Systems Research Institute's GIS software, Arc/Info and ArcView, a variety of different maps and spatial analyses were produced. In addition to geocoding and mapping the locations of every crash, the GIS technology also aided in the examination of the relationships between land use and traffic accidents.
At one level, the analysis of accidents and land use is simple. Through overlay mapping techniques, one can see the relationships between accidents and the underlying land uses. But in order to analyze these relationships statistically, it was necessary to go further—to assign a land use code to a particular point location. Where possible, an automated procedure was developed to accomplish this task. The rationale is summarized in Figure 1.

Figure 1 shows a particular location (an intersection) in which there are a number of potential land uses. In one cell, the land use classification is easy to determine because it is all the same, residential. In two of the cells, the majority of land uses are the same, either residential or commercial. In only one of the cells, in which the land uses are evenly divided between residential and commercial uses, is it necessary to interpret the land use, depending on the direction of travel and the vehicle position in the intersection. Since vehicles travel on the right side of the roadway, those traveling east would be assigned commercial land use, while those traveling west would be given a residential land use. Those north of the intersection would be assigned residential, whereas those south of the intersection would be assigned a commercial land use. Using this sort of assignment procedure, the underlying land uses were assigned to each crash in the database.

**FINDINGS**

Figure 2 reveals the location of all vehicle-to-vehicle crashes in the City and County of Honolulu. The map reveals a close association between development and motor vehicle crashes. Most of the crashes are clustered in the built-up areas of the island. They are concentrated in the southeastern region of the island, where most people reside and work. The map reveals a general association between crash locations and land use as there are many more crashes occurring in the urbanized built-up areas than in either the rural or less developed regions of the county. At the same time, there is a need to investigate the relationships between different types of land uses and crash frequencies much more carefully.

Figure 3 illustrates the location of motor vehicle crashes with an overlay map depicting land use. This particular map shows only a portion of the entire island—the area with both the highest density of crashes and the greatest amount of urbanization. The majority of the land is used for residential purposes. While there are other uses such as commercial, institutional, and recreational, land for housing, both single family detached units and multifamily housing (apartments and condominiums), dominates the landscape. It is interesting to note, however, that the highest crash frequencies occur near commercial

![Diagram of land use classification](image)
or business properties, where presumably the traffic levels are the greatest.

This map reveals the difficult nature of trying to understand the relationships between land use and traffic accidents. First, accidents occur on roadways and generally not on the abutting or adjacent properties. Second, the classification of land according to the various uses (residential, visitor lodging, educational, military, public service, manufacturing, commercial, utilities, agricultural, and vacant) are no doubt familiar and useful for appraisal, tax collection, and planning and development purposes, yet these may not necessarily be the best categories for accident analysis. Indeed, while the tax collectors may see a reason to distinguish between general commercial property and commercial property within a tourist district, the distinctions in terms of traffic patterns and accident frequencies may not be all that apparent. Third, it is also evident to one who knows a community that the land use map does not completely portray all uses of land. There may be residential uses occurring within commercial or office districts. Although some land may be zoned for conservation, there could be parks or golf courses or other visitor destinations that generate higher than expected traffic volumes. Commercial activities may also be occurring within industrial districts. While a bargain box outlet might well be classified as a warehouse in an industrial district, it might better be described as a retail or commercial operation.

Figure 3 excludes a great deal of pertinent information. While the roadways are visible as a layer on the map, there is little distinction by roadway class. Other features such as the number of lanes, the speed, the vertical and horizontal alignment, factors that could affect crash probabilities, have also been ignored. Moreover, information related to the vehicle characteristics, as well as vital crash-relevant information on drivers, has also been excluded.

In spite of these limitations, there are, nonetheless, some interesting patterns to note when examining the relationships between crashes and land use: (a) the frequency of crashes by land use category, (b) crashes produced per acre of land, (c) injury crashes produced by acre of land, and (d) crash types by land use.

Crash Frequencies by Land Use

Table 1 shows the frequency of crashes produced by various land uses for the entire island. It shows the number of crashes produced in a 10-year period of time (1986 to 1995) by various land use categories. It reveals, quite clearly, that the largest proportion of vehicle-to-vehicle crashes, more than 33%, occur on residential lands. The second largest category, amounting to almost 30% of all crashes, includes commercial land. Other significant categories include vacant/open land, recreational, and institutional land. These include popular destinations in Hawaii such as beaches, parks, and prominent tourist destinations. The large number of crashes occurring near universities, schools, and other institutions reflect both the intensity of traffic and the composition of drivers. Approximately 3% of crashes occur near on or military land. In Hawaii, the military maintains a significant presence and there are several large
military bases on Oahu. It was surprising to find that visitor lodging land uses accounted for so few crashes. Given the state’s extraordinary dependence on tourism (more than 6 million tourists account for approximately half of the state’s total economy), one might have expected to see more connection between tourism and crashes. At the same time, it should be recognized that the travel of tourists is not restricted to merely visitor districts such as Waikiki. It is clear that some of these categories (visitor and commercial) might be combined and others (residential and commercial) might be further disaggregated.

**TABLE 1 Crash Frequencies by Land Use**

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>34475</td>
<td>0.3002</td>
</tr>
<tr>
<td>Visitor Lodging or Other</td>
<td>1222</td>
<td>0.0117</td>
</tr>
<tr>
<td>Education, Religious, &amp; Social Institutions</td>
<td>7159</td>
<td>0.0686</td>
</tr>
<tr>
<td>Recreational and Cultural Activities</td>
<td>7718</td>
<td>0.0739</td>
</tr>
<tr>
<td>Military</td>
<td>3214</td>
<td>0.0303</td>
</tr>
<tr>
<td>Public Services</td>
<td>1283</td>
<td>0.0123</td>
</tr>
<tr>
<td>Manufacturing &amp; Industrial</td>
<td>1747</td>
<td>0.0167</td>
</tr>
<tr>
<td>Commercial &amp; Services</td>
<td>30464</td>
<td>0.2918</td>
</tr>
<tr>
<td>Utilities and Communication</td>
<td>1755</td>
<td>0.0168</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2296</td>
<td>0.0220</td>
</tr>
<tr>
<td>Vacant/Open Land</td>
<td>13069</td>
<td>0.1252</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>104402</strong></td>
<td><strong>1.0000</strong></td>
</tr>
</tbody>
</table>

**Crashes per Acre of Land**

Table 2 shows the frequency of crashes over the 10-year period (1986 to 1995) divided by the area for each of the particular land uses. This provides a way to compare the various land use categories in terms of the number of crashes that are "produced" by each acre of land in a specific land use category per decade. There are two different justifications for doing this. First, it provides a way of standardizing the crashes occurring on or adjacent to land used for a specific purpose so that they might be compared. Second, it reveals the potential effects of changing land use from one category to another, from agricultural or vacant land to perhaps a more intensive use of land such as urban or commercial uses. Obviously, if one would want to estimate the crashes produced per acre annually, one could merely divide the values by 10, since this comprises 10 years’ worth of crash data.

Table 2 shows that, per acre, commercial and visitor lodging land uses produce the highest number of crashes. Although overall there are approximately 0.31 crashes produced per acre of land, the number of crashes produced per acre of commercial land is 6.6 crashes and 5.15 for visitor lodging land uses. Put another way, per acre commercial property produces more than 21 (6.6/0.31) times more crashes than the number of crashes produced overall per acre of land. Commercial land produces more than 6 times the number of crashes produced per acre of residential land (1.23 crashes per acre).

It is interesting to note, moreover, that the number of crashes pro-
duced per acre of commercial land is similar to the number of crashes produced per acre of visitor lodging land. It is also interesting that manufacturing and industrial land uses also produce a high number of crashes per acre (3.57), whereas public services (primarily government offices) produce a similar level of crashes per acre (2.9) to institutional land uses (2.8). Military, agricultural, and vacant lands all produce small numbers of crashes per acre, in part because of the vast land areas in these classifications.

In comparing Table 1, which shows the relative frequencies by land use, to Table 2, which shows the frequencies controlled by land area for each of the categories, some very interesting differences emerge. Although Table 1 reveals quite clearly that residential and commercial uses dominate in terms of the absolute frequency of where crashes occur, Table 2 shows that visitor lodging and commercial properties on a per acre basis produce the highest number of vehicle crashes. Although 12% of all vehicle-to-vehicle crashes occur in the vicinity of vacant or open land, because of the immense size of these lands (approximately 206,000 acres), the number of crashes per acre drops precipitously. The relative figures in Table 2 reveal that although residential land uses exceed the overall crash production on a per acre basis, the number is still far below the level of crashes produced by commercially intensive land uses.

Injury Crashes per Acre of Land

Table 3 goes one step further. Using linked injury outcome data for 1 year in the series, one can examine which types of land use produce the greatest number of injury crashes. Other research has examined more closely the nature of crashes and injury outcomes. In this table, the crashes are restricted to only those for which an injury requiring an EMS transport was required. A total of 1,827 EMS transports were linked to police crash records. In terms of frequency, the highest land use categories were residential (663 transports), commercial (374), vacant land (302), recreational (137), institutional (105), military (88), and agricultural (77). The remaining land use categories generated relatively few EMS transports for motor vehicle collisions.

On a per acre basis, commercial and visitor lodging land uses produce the highest frequency of injury crashes (0.081) and (0.084), respectively. This is almost four times greater than the number of injury crashes produced on an annual basis for residential land uses (0.025) and double the number produced on a per acre basis by manufacturing land uses (0.04).

In comparing Tables 2 and 3, some basic similarities arise. Generally speaking, those land uses that produce the highest number of vehicle crashes also produce the highest number of crashes in which an injury has occurred. On a per acre basis, the immense dimensions of vacant, agricultural, and military land serve to reduce the values of crashes per acre.

Other Findings Related to Land Use and Crashes

Using a method similar to that in Table 2, Table 4 was produced. Table 4 shows the number of pedestrian, bicycle, and motorcycle-moped/scooter crashes produced over the 10-year period per acre by land use category. The results in this study, with respect to bicycle and moped collisions, are consistent with the earlier research (7, 8). The overall number of crashes produced per acre of land for these crash types is much lower than for the vehicle-to-vehicle crashes contained...
in Table 2. Pedestrian crashes, bicycle crashes, and motorcycle-moped-scooter collisions are more rare in comparison with vehicle-to-vehicle collisions. It is interesting to note that on a per acre basis, visitor lodging and commercial land uses still dominate for even these crash types. There are 0.43 pedestrian crashes per acre of visitor lodging land use and 0.3 pedestrian crashes per acre of commercial land use. When controlling for acreage, institutional (0.153), public service (0.197), and manufacturing (0.1407) have similar levels of pedestrian crashes. The number of pedestrian crashes produced per acre of residential land use (0.0618) is much lower than for these land use categories. When it comes to bicycle crashes, on a per acre basis, visitor lodging land uses stand out as producing the greatest number of crashes per acre (0.215), followed by commercial land uses (0.1329). Institutional (0.0673), public service (0.0725), and manufacturing (0.063) land uses have similar levels of bicycle crashes. As Table 4 indicates, there are some general similarities with motorcycle crashes; visitor lodging (0.3752) and commercial (0.2499) land uses produce the highest number of crashes, followed by educational (0.1161) and public service (0.0952) on a per acre basis. In terms of relative overall rankings, pedestrian and motorcycle have similar levels of crashes per acre (0.0138 and 0.0112, respectively), while bicycle crashes are lower in number (0.0077).

One might have expected a higher frequency of pedestrian crashes on a per acre basis in certain neighborhoods or communities, but it does not show up in terms of residential land use. It was also surprising to find that a greater number of bicycle crashes were produced on a per acre basis in areas with visitor lodging and commercial land uses instead of residential areas. As with the other tables, the large amount of vacant, military, and agricultural land served to bring down the per acre estimates of these different crash types.

**DISCUSSION OF RESULTS**

At one level, given the amount of effort it requires to collect and assemble the various databases, to manage and analyze the different spatial databases (alongside the usual problems associated with crash databases), one might have been somewhat disappointed in the findings. In viewing the overall results, there are no major surprises, no startling new discoveries. The findings appear reasonable, given knowledge of the physical environment, the geography of Honolulu, and past work done on traffic safety.

Since most trips are home-based, one might have expected to see more crashes occurring within residential areas. However, densities are much lower and development tends to be more dispersed, at least in comparison to other urbanized areas. Although one might have expected to see more pedestrian or perhaps more bicycle crashes in these areas, the sheer dominance of the automobile as the preferred travel mode is also reinforced by the results. There are simply far more vehicle-to-vehicle crashes than either pedestrian or bicycle crashes.

It is interesting, however, to note that the extent to which commercial land uses (and the variations of it—visitor lodging, manufacturing, retail, office space, etc.) appear to produce both a high frequency of crashes overall as well as on a per acre basis. Given the spatial concentration and intensification of development in key locations within the urbanized areas of the county, it is apparent that there are areas within Honolulu where efforts at crash reduction should be targeted.

The findings raise a number of different methodological considerations. First, an obvious concern, common to other geospatial analyses involving the study of human behavior, is the so-called "ecological fallacy" (9). Put simply, land uses do not have accidents; people, or more precisely, drivers do. This potential problem arises whenever individual behavior is aggregated into a zone or spatial unit and is often found in travel demand studies or other zonal-based analyses. Although at one point during this research, the authors considered building an individual level driver model, that temptation was resisted for several reasons. The average driver is not likely to process information about the surrounding land use in the same way in which this approach has been organized. The driver is more likely to be cognizant of other factors, such as speed, traffic volume, and roadway characteristics, and not likely to notice or care about the underlying land uses. The authors' previous research has illustrated that other factors (driver age, gender, etc.) are more likely to influence behavior rather than whether or not the land use is commercial or industrial in character.

In conducting this research, the authors were aware that factors such as traffic volume may play a greater role in crash rates and overall crash numbers than land use. Again, in Table 1, it is interesting to note that a greater number of crashes occur in residential neighborhoods, as opposed to higher traffic volume locations, such as commercial neighborhoods. Residential neighborhoods tend to only have high traffic volumes during peak travel times, whereas commercial neighborhoods may experience high volumes throughout the day. Further research must be conducted on time-of-day effects with crashes and land use and the role of traffic volume in these crashes.

Second, another issue involves the question of scale. The analysis was restricted to one county, albeit the most populated one in the state. Even so, the data processing involved hundreds of thousands of parcels, some as small a few thousand square feet, with others con-
sisting of hundreds of acres. For an islandwide analysis, looking at aggregate data, this scale may be appropriate. However, an examination of pedestrian accidents or perhaps bicycle crashes might be better served with a smaller area. Clearly, vehicle-to-vehicle crashes can be analyzed in terms of a much larger territory, but for some types of problem identification and safety program design, it might be more appropriate to operationalize the data at the neighborhood scale.

Third, data quality is always a concern when working with administrative databases (10). There is no doubt that questions regarding the quality of the data used in this analysis are abundant. However, by restricting the analysis to familiar areas (rather than doing a statewide study), and by using linked police and injury outcome data, the quality of the data is better than other places. A combination of automated and manual geocoding and linking procedures were used to ensure that both the location of the crashes and the assignment of land use categories were as accurate as possible.

In this analysis, 10 years of crash data were linked to 1 year of land use information. The crash data are several years older than the land use information. Although the authors would have liked to have matched the land use information to the same years for the crash data, this was not possible because earlier data were not available in an automated, accessible format. Moreover, land use changes quite slowly. Particularly during the decade of the 1990s, when the Hawaiian economy experienced an economic recession, there were very few large-scale projects constructed. It would have been desirable to have had baseline land use data to track changes over time and then correlate the changes from one category to another as a variable explaining traffic collisions over time. It is hoped that in the future this type of time series analysis will be conducted.

These are matters that require additional discussion. As mentioned previously, given the advances in spatial databases, GIS analysis methods, and the limitations of assigning classifications of land use to crashes, further research is necessary to improve the assignment of land use to crashes. What may be needed is a roadway-based land use classification scheme. Developing a scheme that will provide a better assignment of land use to intersection-based crashes will require further experimentation and analysis. Based on Hawaii's experience, another refinement that may be beneficial to those involved in the traffic safety arena will be to develop a set of GIS land use queries that could be utilized as an indicator of potential crash risk. This study has shown, for example, that bicycle and pedestrian crashes have a higher rate in visitor lodging and commercial neighborhoods. Traffic safety administrators who do not have the means to conduct both statistical and spatial analyses may want to use this information as a way to identify where problems may occur and to design more effective safety programs.

Improvements in technology (computer processing, probabilistic data linkage, and geocoding) have enhanced capabilities in terms of conducting this analysis. The availability of other administrative and planning databases, such as travel demand data, aerial photographs, and satellite imagery, can also be used to enhance data quality and better understand the relationship between land use and traffic accidents.

CONCLUSIONS

This paper offers, potentially, three different kinds of contributions. First, for the transportation researcher, it provides a preliminary framework and analysis for the integration of several different administrative databases: police crash reports, EMS run reports, and land use information. Although there are difficulties and complica-

tions arising out of the use of these different databases, the power of linking these different sources of information is obvious. Detailed information on land use is typically not included on police crash reports. Crash reports linked to EMS run reports provide a more definitive indicator of injury severity, because the crash was serious enough to result in calling an ambulance and transporting a victim.

The method and some of the empirical findings provide a start, though not necessarily a definitive estimate of the accidents and injuries produced by various classes or categories of land use. This is important information to land use planners, developers, politicians, general public, and others concerned about the costs and benefits of new growth. It is also useful to those interested in the public costs associated with motor vehicle crashes (police and EMS response, medical treatment, and other costs). The method and the findings may be useful to those attempting to recover costs of development or perhaps to those involved in debates over zoning changes or new development proposals.

Finally, traffic safety program managers, the findings suggest that in addition to targeting specific population groups at risk or identifying "hot spots" or locations for engineering or enforcement actions, it might also make sense to develop programs directed toward specific land uses, such as commercial, retail, and institutional property owners.

Clearly, more research is needed in terms of more sophisticated models for capturing the interactions between land use, human activity, traffic, and collisions. Also there is need to integrate other geospatial databases and administrative files (e.g., zoning, building permit data, aerial photographs, satellite imagery) both to validate existing spatial files and to understand the relationships between land use and traffic accidents.

REFERENCES


