A Sketch Planning Methodology for Determining Interventions for Bicycle and Pedestrian Crashes: An Ecological Approach

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Abstract

Bicycle and pedestrian safety planning have recently been gaining increased attention. With this focus, however, comes increased responsibilities for planning agencies and organizations tasked with evaluating and selecting safety interventions, a potentially arduous task given limited staff and resources. This study presents a sketch planning framework based on ecological factors that attempts to provide an efficient and effective method of selecting appropriate intervention measures. A Chicago case study is used to demonstrate how such a method may be applied.

Keywords

Pedestrian, bicycle, safety, sketch planning framework, ecological factors

1. INTRODUCTION

As society moves increasingly towards encouraging “green” modes of transportation, cycling and walking continue to reap much patronage, financial and other support. Persons reporting cycling to work to the US Census Bureau rose from 450,000 in the year 1990 to over 490,000 in the year 2000. Total personal trips doubled in the year 2001 to 38.6 billion from 19.7 billion in the year 1990. The annual spending of federal transportation funds on walking and cycling rose from approximately 6 to 8 million dollars per year in the late 1980s to nearly 340 million dollars in the year 2001. Transportation agencies have increased research, planning studies, and the hiring of staff dedicated to cycling and walking (Clarke, 2003). Simultaneously, pedestrian and cyclist traffic fatalities nationwide have dropped from approximately 7,500 in 1990 to 5,500 in 2000. Thus, the increased patronage in both the modes, cycling and walking, has not so far negatively impacted on their joint safety record.

Still, cycling and walking remain more dangerous than car travel, both on a per-trip and per-mile basis (Pucher, et al., 2003). Beck, Dellinger and Neil (2007) assessed that nationwide fatal injury rates expressed per 100 million person-trips were highest for motorcyclists, pedestrians and bicyclists whereas nonfatal traffic injury rates were highest for motorcyclists and bicyclists. The nonfatal injury rate of walking was tantamount to that of a bus passenger. Not surprisingly, The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) allocated in 2005 increased resources and high recognition to the planning for multimodal safety, as a means to enhance its record. As a result, cycling and walking safety are increasingly of concern to transportation professionals and decision-makers.

New programs, such as Safe Routes to School and the Non-motorized Transportation Pilot Program, and the continuation or expansion of programs, such as bicycle and pedestrian safety grants, indicate a continuing commitment towards increasing bicycle and pedestrian trips, and in enhancing their safety. With any commitment to increased safety planning, also come increased responsibilities on the part of planning agencies and organizations tasked with the evaluation and selection of safety projects. Agencies with limited resources must develop efficient methods for the planning and implementation of effective safety intervention projects.

Planning interventions to address pedestrian and bicycle safety concerns may occur in the form of engineering design and operational programs (facility enhancement, conflict avoidance between non-motorized and motorized modes, traffic calming, etc.), educational and awareness programs (road safety education, training and publicity, etc.), enforcement, emergency medical services and cross-cutting programs targeting, for instance, particular demographic groups (special training, sign and device for the impaired, etc.). However, it is often difficult to determine, at a macro level and without examining detailed site-level and individual factors, the types of interventions that may be useful in particular subareas. The aim of this article is to enable this very determination by planning agencies with limited resources using readily available data and models.

To this end, the article advances a sketch-level analysis to develop a typology of areas based on the extent to which ecological factors explain bicycle and pedestrian crashes. The analysis hinges on the use of (i) readily-available and specially-constructed indicators of neighborhood characteristics or ecological factors, (ii) spatial regressions and finally (iii) model residual analysis. Specifically, the analysis affords an initial determination of the types of bicycle- and pedestrian-specific interventions that may be appropriate for subareas within a metropolitan area to address their safety concerns. The paper demonstrates the use of the analysis for the Chicago metropolitan region.

The sections that follow provide a brief review of prior literature in the area of bicycle and pedestrian safety interventions and safety performance studies within the ecological framework described above. They further describe the sketch planning method and present details of its actual implementation using the Chicago metropolitan area as case study. Finally, a summary of the steps involved in the methodology precedes the conclusions

2. PRIOR LITERATURE

Four streams of literature motivate the present paper. Firstly, we review current safety intervention programs and policies relating to non-motorized transportation safety. Secondly, we review a framework, called the ecological framework, widely used in previous research to derive the proposed sketch planning methodology. This framework rests on the types of data and information programs typically housed in, or easily available to, planning organizations. We briefly review the modeling approaches that may be undertaken to operationalize the methodology and a continually updated data infrastructure that may be built for this purpose and for related community planning activities.

2.1 Bicycle and Pedestrian Safety Interventions: Policy and Planning Practice

Any attempt at efficiently planning bicycle and pedestrian safety interventions necessitates data. While basic information, such as crash numbers and rates at particular intersections or along specific sections of roadway, may be useful for determining individual engineering and design projects, the planning universe of safety interventions for cycling and walking extends beyond such facility/structure-specific projects. The “Four E’s” of transportation safety, including engineering, education, enforcement, and emergency medical services (TRB, 2005), make apparent the need to develop models that extend beyond modal-specific facilities and account for a broad collection of factors relevant to planning both cycling and walking.

In “Pedestrian and Bicycle Data Collection in United States Communities: Quantifying Use, Surveying Users, and Documenting Facility Extent” Schneider, *et al*. (2005) report that while many communities have bicycle and pedestrian data collection plans in place and clearly see a benefit for collecting such data, the following issues may hamper the actual data collection processes:

- The agency has a limited budget and staff resources for collecting data;
- Departments charged with collecting data for the entire agency do not see pedestrians and bicycles as an important part of the transportation mix; and
- Data collection results could show too few pedestrians and bicyclists using facilities to justify spending on them.

The variety of factors that influence the use and safety of bicycle and pedestrian facilities may combine with the impediment to their data collection to cause planners and planning agencies to feel overwhelmed, and may dissuade effective project selection and evaluation processes. For example, Landis, et al. (2001) identified the following factors as influencing the comfort level of pedestrians in the walking environment and thus, the likelihood of pedestrian travel:

- Personal safety (i.e., the threat of crashes),
- Personal security (i.e., the threat of assault),
- Architectural interest,
- Pathway or sidewalk shade,
- Pedestrian-scale lighting and amenities,
- Presence of other pedestrians, and
- Conditions at intersections.

The limitations identified above may render the collection of such low-level data difficult for many agencies tasked with evaluating and selecting project proposals. Additional difficulties, such as the time frame of project selection and the need to compare project proposals, may further impede this effort.

Sketch planning, using ecological factors, constitutes one method that may prove useful for planners of bicycle and pedestrian facilities and their safety programs, as these factors are generally readily available and easy to collect and to incorporate in decision-making processes. Further, such factors are more relevant to a neighborhood or a jurisdictional area that may be impacted by the proposed project. This paper thus utilizes an ecological model of pedestrian and bicycle crashes as part of an overall methodology, described below, to identify areas in need of safety interventions. Contributing factors to these safety concerns are identified, and potential interventions suggested.

2.2 Ecological Safety Literature on Non-Motorized Crashes

The research approach used in this paper stems from an ecological framework. The ecological design is characterized by its consideration of differences between groups rather than individuals (Walter, 1991), where the groups can be defined by place (multiple group design), by time (time trend design), or by a combination of the above. In the pedestrian safety literature, the ecological framework has been utilized to study demographic and environmental correlates of pedestrian injuries including the characteristics of neighborhood-level traffic flow and the built environment such as the presence of pedestrian walkways, multifamily dwellings, and curbside parking (LaScala *et al*., 2000; Roberts *et al*., 1995; Stevenson *et al*., 1995; Agran *et al*., 1996). Other authors have examined the effect of the number of unsupervised children playing or running errands in their immediate neighborhood (Bass, *et al*., 1995) and income at the neighborhood level (Dougherty, *et al*., 1990) on pedestrian crashes.

In the bicycle safety literature, a number of studies have utilized the ecological framework; for example, several authors have examined the effect of wearing bicycle helmets as an intervention in preventing bicycle injuries and fatalities using such an approach (Lee, *et al*., 2000; Floerchinger, *et al*., 2000; Wesson, 2000; Durkin, 1999). Other authors have utilized the framework to examine crash risk to school age bicyclists near schools (Abdel-Aty *et al.*, 2007), in urban neighborhoods (Bagley, 1994).

The benefit of the use of ecological studies lies largely in their low cost, convenience, and the simplicity of analysis and presentation rather than any conceptual advantage (Greenland and Morgenstern, 1989; Stevenson and McClure, 2005). Additional rationale cited for using the study design have been due to the fact that measurement is often easier at the population or group level rather than at the individual level and a wider range of exposures can often be obtained (Morgenstern, 1998). Although they can lend valuable insights about the crash process, there are several limitations to published ecological analyses, including failure to control for confounding factors (Kelsey, *et al.*, 1996) and ecological fallacies (Selvin, 1958). Ecological correlational studies that assess associations at the environmental and neighborhood level have limited ability to determine crash causation – however, pedestrian and bicycle crash data when linked to ecological factors, can yield insights regarding community and neighborhood attributes that, in turn, potentially lend themselves to planning and policy interventions, as long as there is no attempt to draw inferences regarding individual level associations.

The ecological approach utilizes statistical methodology to estimate crashes as a function of covariates relating to the crash circumstances and to the overall neighborhood and community-level factors that previous researchers have found to affect crashes. An instance of non-motorist accident involving a vehicle can be viewed as the outcome of a Bernoulli trial consisting of exposing the non-motorist to the applicable design, environmental, and other conditions. Let p be the probability of such an outcome, and let (1-p) be the probability of no accident occurrence. Then, the number of accident occurrence follows a binomial distribution. Given a large trial set (large bicycle flow through a section) and a low probability of accident (low value of p), this number follows a Poisson-like, or over-dispersed Poisson distribution. A multiplicative function as given in (1) typically describes μ_j, the mean accident number per year and per roadway mile (or mean accident frequency) at census tract j:

$$\mu_j = \Pi_i \alpha_i x_{ij}^{\beta_i} \qquad (1)$$

where β_i represents the percent change in μ_j associated with one percent change in contributing factor x_{ij} or the elasticity of the earlier with respect to the latter and α_i is a coefficient associated with the same factor. Eq. 1 does not differ from a linear regression model given natural logarithmic transformations of the dependent and independent variables.

$$\log \mu_j = \sum_i \log \alpha_i + \beta_i \log x_{ij} \quad (2)$$

It is thus typical to model accident frequencies as a generalized regression model, using the obvious transformations implied by Eq. 3, below, with negative binomial or over-dispersed Poisson noise (Jovanis and Chang, 1986, Shankar et al., 1995, Miaou, 1994).

$$\log \mu_j = \beta_0 + \sum_i \beta_i X_{ij} + \varepsilon_j \qquad (3)$$

The prior model implicitly assumes the independence of the total crash count or frequency of individual census tracts across geographic space. To address the evidence of spatial correlation in crash data spatial models were introduced. These models, often inspired by traditional econometric methods, make the assumption of correlation in either the error terms or in the dependent variables. Models of the first type are entitled spatial autoregressive models. Those of the second type are entitled spatial error models (Anselin, 1988).

The methodology proposed in this paper also depends upon having an adequate data infrastructure to operationalize the ecological framework for the purposes of identifying area-specific planning interventions. Decision makers historically have indicated that inaccessibility of required geographic data and difficulties in synthesizing various recommendations are primary obstacles to spatial problem solving (Ascough, *et al*, 2002). However, the use of GIS among planning organizations has proliferated to a great extent and spatial data infrastructures currently combine data from a wide variety of sources are being coupled together at the same source in an enterprise GIS environment. An approach that takes such spatial data environments one step farther are Spatial Decision Support Systems (SDSS), in which Multi-Criteria Decision Making (MCDM) methods are integrated together with GIS information for informed decision making and participant input in the planning process (Densham, 1991; Crossland, *et al*, 1995). SDSS as a concept has evolved over time and can be defined to be interactive, computer-based systems designed to support a user or group of users in achieving a higher effectiveness of decision-making while solving semistructured spatial decision problems (Malczewski, 1999). Transportation applications with SDSS has been in the area of hazardous materials truck routing (Frank and Thill, 2000), evacuation planning (de Silva and Eglese, 2000), housing relocation with transportation preferences (Sriraj, *et al*., 2007) and evaluating transit availability and employment accessibility (Minocha, *et al*., 2008). The spatial decision support infrastructure in a planning organization is not a static entity; rather, as new problems emerge and as new data sources or computer model outputs become available, such systems could be continually updated over time to reflect changes in a region, thus enabling a current representation of the ecological factors that may be used in the type of planning approach presented in this article.

2. SKETCH PLANNING APPROACH

The purpose of the sketch planning methodology is to provide a way to provide information towards determining the types of safety interventions that may be useful to address bicycle and pedestrian safety concerns in an area. The approach makes use of (i) readily-available and specially-constructed indicators of neighborhood characteristics or Ecological Factors; (ii) spatial regressions; and finally (iii) model residual analysis to develop a typology of areas based on the extent to which ecological factors explain bicycle and pedestrian crashes. Specifically, the methodology allows an initial determination of the types of mode-specific (cycling and walking) interventions that may be appropriate for subareas within a metropolitan area, in order to address bicycle and pedestrian safety. The specific steps undertaken by the sketch planning methodology are the following:

1) *Determine a preliminary set of ecological factors (EF's)* that are applicable to a study area, relevant to non-motorized travel safety based on published literature on spatial models of safety performance, and that are readily available. Ecological factors are both, social/behavioral (for example, **the characteristics** of the surrounding population) and environmental, as they relate to the built environment (for example, population density, the pedestrian and driving environment); as shown below in the Chicago area case study, the EF's were part of a Spatial Decision Support System that integrates spatial data from a number of sources.
2) *Model Spatial Patterns in Bicycle and Pedestrian Crashes:* Model pedestrian and bicycle crash frequencies at the census tract level as a function of the EF's selected in Step 1 using statistical models, from published literature or otherwise simply derived, which fit the data and explain spatial dependencies that may be present;
3) *Classify Residuals:* Assign the residuals generated in Step 2 for each census tract to one of the six cells of Table 1. This sextet classification approach provides a typology of the

universe of census tracts along two dimensions: crash frequency level, from low to high, and crash residual, from low to high positive or high negative as measured in quartiles.

TABLE 1 Review of Crash Bins

		Crash Frequency (L and H on the basis of above and below median crash frequencies)	
		LOW	**HIGH**
Residuals (L – within 25% and 75% quartiles; H-Positive – above 75% quartile; L-Positive – Below 25% quartile)	**LOW**	(A) **Class**: Low Risk and High Ecological Correlate Tracts **Planning Intervention**: Lowest priority – do nothing	(B) **Class**: High Risk and Ecological Correlate Tracts **Planning intervention**: High priority – Address EF concerns
	HIGH-Positive	© **Class**: Low Risk and Ecologically Underpredicted Tracts *(EF's under-predict low crash frequencies)* **Planning intervention**: Low priority but look into site-level and individual characteristics	(D) **Class**: High Risk and Ecologically Underpredicted Tracts *(EF's under-predict high crash frequencies)* **Planning intervention**: High priority – look into details of site-level and individual characteristics
	HIGH-Negative	(E) **Class**: Low Risk and Ecologically Overpredicted Tracts *(EF's over-predict low crash frequencies)* **Planning intervention**: Low priority but look into EF concerns	(F) **Class**: High Risk and Ecologically Overpredicted Tracts *(EF's over-predict high crash frequencies)* **Planning intervention**: High-Priority – Address EF concerns

- *Bin A*: For these tracts, there are a low number of crashes and the model residuals are fairly low. Such a finding indicates that the tract characteristics do not indicate a high likelihood of crashes now or potential for crashes in the future. Such a tract is of the lowest priority and planning intervention measures should generally be limited to existing practices, though if conditions change (such as a roadway or school project) the tract should be reevaluated.
- *Bin B*: For these tracts, there are a high number of crashes and the model residuals are low. In such a tract, the accuracy with which high crash levels are predicted based on the EF's indicate that planning interventions of a fairly broad nature would be most

appropriate. Because crashes are not necessarily linked to specific intersections or sections of roadway, it is possible that education or enforcement interventions would be most useful in lowering the crash rate.

- *Bin C*: In these tracts, the crash rate is low, but the ecological model underpredicts the actual rate. In such a situation, it is likely that the few crashes that occur are due to site-level characteristics (such as limited site distances or other engineering factors) and interventions should be evaluated based on the specific site factors. Such a situation is not necessarily high priority, but the severity of those injuries that occur should be evaluated.
- *Bin D*: In these tracts, the crash rate is high, and the ecological model underpredicts the actual rate. In such a situation, it is also likely that the crashes that occur are due to site-level characteristics. For this bin, crashes should be mapped individually to determine if there are specific intersections or locations where planning interventions are needed.
- *Bin E*: In these tracts, the crash rate is low, but the ecological model overpredicts the number of crashes. In this case, current planning interventions are of low priority, but the tracts should be monitored to ensure that the low rate holds.
- *Bin F*: In these tracts, both the crash rate and the predicted number of crashes are high, indicating that the area is of high priority. In such a case, planning interventions should follow the ecological factors modeled, as outlined in the table below.

Table 2 indicates various ways for the EFs to inform planning interventions within a census tract, depending on the bin in which its model residual falls given its observed crash frequency. Using the categories of Education, Engineering, Enforcement and Encouragement, Table 2 outlines the ecological factors identified as contributing to increased bicycle and pedestrian crash incidences, along with some recommended interventions.

TABLE 2 Ecological Factors and Potential Interventions

Factor of Interest	Factor Description	Intervention Categories			
		Education	Engineering	Enforcement	Encouragement
WLKTOWRK	Percentage of tract population that walks to work		Accessible pedestrian and cycle signals; well maintained bicycle lanes; adequate sidewalks		Parking cash-out programs
RANKTOTAL and PEF	RANKTOTAL is a composite variable created to reflect relative cyclist and pedestrian risk based on the interaction of population, income, number of households, amount of commercial and residential land uses as a percentage of the census tract, weighted trip origins and destinations, and environmental factors; PEF is the Pedestrian Environment Factor.		Provision of pedestrian and cyclist refuges; Institution of reverse-angle parking		
PERTC05POP	Number of crimes per person in the Census tract in 2005.	Neighborhood watch programs		Enhanced law enforcement presence at areas of high pedestrian or cyclist activity	
TTLSCHOOLS and PERCHILDRE	Total number of schools in the census tract and percentage of persons in the tract 16 years of age or less	Safe Routes to School programs; billboards and signage alerting drivers; Safe walking and cycling guides distributed to students and parents	Provision of adquate roadway markings and crossing signage		Provision of bicycle helmets to students participating in SRTS programs
TAI	Transit Availability Index: average of Transit frequency, hours of service, and coverage	Transit driver education and signage	Provision of fencing and barriers along at-grade rail alignments; well-marked pedestrian and cyclist pathways at areas of potential conflict (such as bus pull-outs)		Provision of bike racks or bicycle accommodation on transit vehicles
PER_COMM	Percentage of tract used for commercial purposes		Provision of well-placed bicycle parking; provision of adquate crossing time for pedestrians; limitation of right turn on red		
PERNOCAR	Percentage of tract population without a vehicle available	Mobility training for cyclists and pedestrians	Roadway narrowing; Roadway lighting improvements		Shared bike programs; Assistance with purchasing cycles and helmets
PERLOWENGL	Percentage of the population with low or no English speaking ability	Safe walking and cycling brochures and signage in a variety of languages			

While this is not an exhaustive list, it does identify some of the potential interventions that would be most appropriate given the ecological factors identified in the models presented above.

4) Determine type of safety intervention that may be needed for an area, based on the classification system:

4. CASE STUDY – THE CHICAGO METROPOLITAN AREA

This section illustrates the application of the sketch planning methodology advanced to the six-county Northeastern Illinois region, including Cook, Kane, DuPage, Will, Lake, and McHenry counties. The study makes use of the Bicycle and pedestrian crash frequencies and ecological factors at the census tract level to stratify the tracts by the degree of appropriateness to different planning intervention types. The following data sources were used for this purpose:

1. Illinois Department of Transportation (IDOT) Crash Files for 2005: The Illinois Department of Transportation (IDOT) maintains an accident database of vehicle incidents as well as pedestrian and bicyclists. This database consists of detailed accounts of the accident occurrences within the state and affords in-depth accident analyses using three varied crash files: general crash file, crash person file and crash vehicle file. The crash person file consists of variables such as gender, age, injury severity, driver's action and driver vision. The crash file includes variables that delineate general accident information such as accident date, roadway incident environment, as well as weather and road surface. The vehicle file describes the vehicle involved including vehicle type, vehicle use and vehicle maneuver prior to the crash

2. A Spatial Decision Support System with a mix of Ecological Factors: The Chicago area Spatial Decision Support System (SDSS) consists in a Multi-Criteria Decision Making (MCDM) environment with small-area spatial data integrated in support of transportation decisions linked to factors within the broader community context including housing, community development, economic development and physical planning. Using a variety of data sources, including the 2000 decennial Census and factors developed by the Chicago Metropolitan Agency for Planning (CMAP – the Chicago area MPO), along with transportation modeling outputs, the SDSS contains a set of indicators related to traffic and transportation, accessibility measures, regional employment opportunities, forecast and existing employment estimates, affordable housing, school quality, crime, health, land-use and the built environment. The factors within the SDSS used in this study included both physical environment factors (such as the Pedestrian Environment Factor (PEF), vehicular traffic flow, quality and complexity of the walking environment, a Transit Availability Index (TAI), population density, and the extent of crime) and behavioral factors (such as percent of population with little or no English-speaking ability, an indicator of unfamiliarity with the environment, percent of school-going children and percent of households with no vehicle available). Together, these factors provide robust measures of spatial-level characteristics that may be considered when planning for bicycle and pedestrian safety interventions.

Crash data for the year 2005 was analyzed. During that year, there were a total of 4991 crashes involving pedestrians with motor vehicles and 2547 crashes involving bicycles with motor vehicles. It is important to note that although the total number of pedestrian-vehicle crashes equaled 4991, there were 5367 individuals injured in those crashes. A total of 2574 individuals were injured in the 2547 bicycle crashes on record.

A preliminary examination of bicycle and pedestrian crash maps in the region (given in Figure 1) indicated the potential presence of spatial dependencies, but of a different nature for the two modes. Pedestrian crashes tended to be clustered within the central part of the area whereas bicycle crashes, also present at high frequencies in the central area, were also likely to occur in outlying areas. In particular, spatial kernel density maps developed using point data on bicycle and pedestrian crash locations indicated the presence of many localized clusters in bicycle crashes, outside the central (core) area in the Chicago metropolitan area. The global Moran's *I* for bicycle crashes was estimated to be 0.2105 and that for pedestrian crashes to 0.4018, both larger than the expected value of $I=-[1/(N-1)]$. The result indicates that while crash frequencies for a mode in a census tract is similar to that of the same mode in nearby census tracts, pedestrian crashes exhibit such a pattern more strongly than bicycle crashes.

The first step was to determine the variables that may be used to develop an ecological model of pedestrian and bicycle crashes. As described above, we have used a variety of social/behavioral and environmental factors (the EF's) that quantify such characteristics at the level of census tracts. Developing such a database is likely to be a continuous process that will serve a variety of planning purposes and may also be used for safety analysis towards the goal of determining planning interventions. The SDSS data was helpful for the current application because a number of factors that have been related to non-motorized crashes in the literature were readily available from it.

After extensive experimentations (based on measures such as the R^2 and the Root Mean Square Error), we used a subset of these EF's to estimate Ordinary Least Squares (OLS) models of bicycle and pedestrian crashes. The selection was based on a combination of the published literature on ecological studies, what was available, local knowledge and statistical measures of fit. The purpose of the models was not predictive, but rather diagnostic, ie, to inform next steps. We have not presented the OLS results here, but the residuals from OLS model for bicycle and for pedestrian crashes were plotted on maps and also summarized by means of several tests of statistical dependence. The maps of the OLS residuals indicated the presence of residual clusters in both bicycle and pedestrian crashes; spatial dependencies are not addressed by the EF's and that structure should be explicitly considered in modeling. This was confirmed by the test statistics, which also informed the type of model structure that may be used for the purpose. The free software, GeoDa, was used for this purpose. The Moran's *I* was highly significant for the bicycle crash OLS residuals while that of the pedestrian crash residuals was of a smaller magnitude, indicating that the EF's explains spatial variations better in the case of pedestrian crashes, whereas peculiarities of site-level factors and individual factors may be more important for bicycle crashes.

Since the empirical example of Chicago is being presented here for the purpose of illustrating the sketch planning method only, we will restrict attention to the remainder of the example to the case of pedestrian crashes. The top part shows the overall fit of the model, which is poor, based on the R^2 and the Root Mean Square Error. On the basis of robust Lagrange Multiplier tests for error and lag, we fitted a spatial lag model of the form: $y = \rho Wy + X\beta + \varepsilon$ where $\varepsilon \sim IIN(0, \sigma^2)$, where y_i denotes pedestrian crash frequency in the i^{th} tract, ρ is a spatial coefficient, *Wy* is a vector of spatially lagged dependent variables, *X* is an an *N X K* matrix of observations and β is the associated regression coefficient of the EF's.

The spatial lag term is estimated to be positive and highly significant. The general model fit improved in comparison to the OLS model, as indicated in higher values of R^2 (of 0.36) and log likelihood (-4663) and a smaller value of the *RMSE* (2.9 compared to 3.6 in the OLS model).

The residuals of this model are classified according to the scheme presented earlier. Based on this binning process, we have the map as shown in Figure 1, for the downtown CBD area, where pedestrian crashes are the highest.

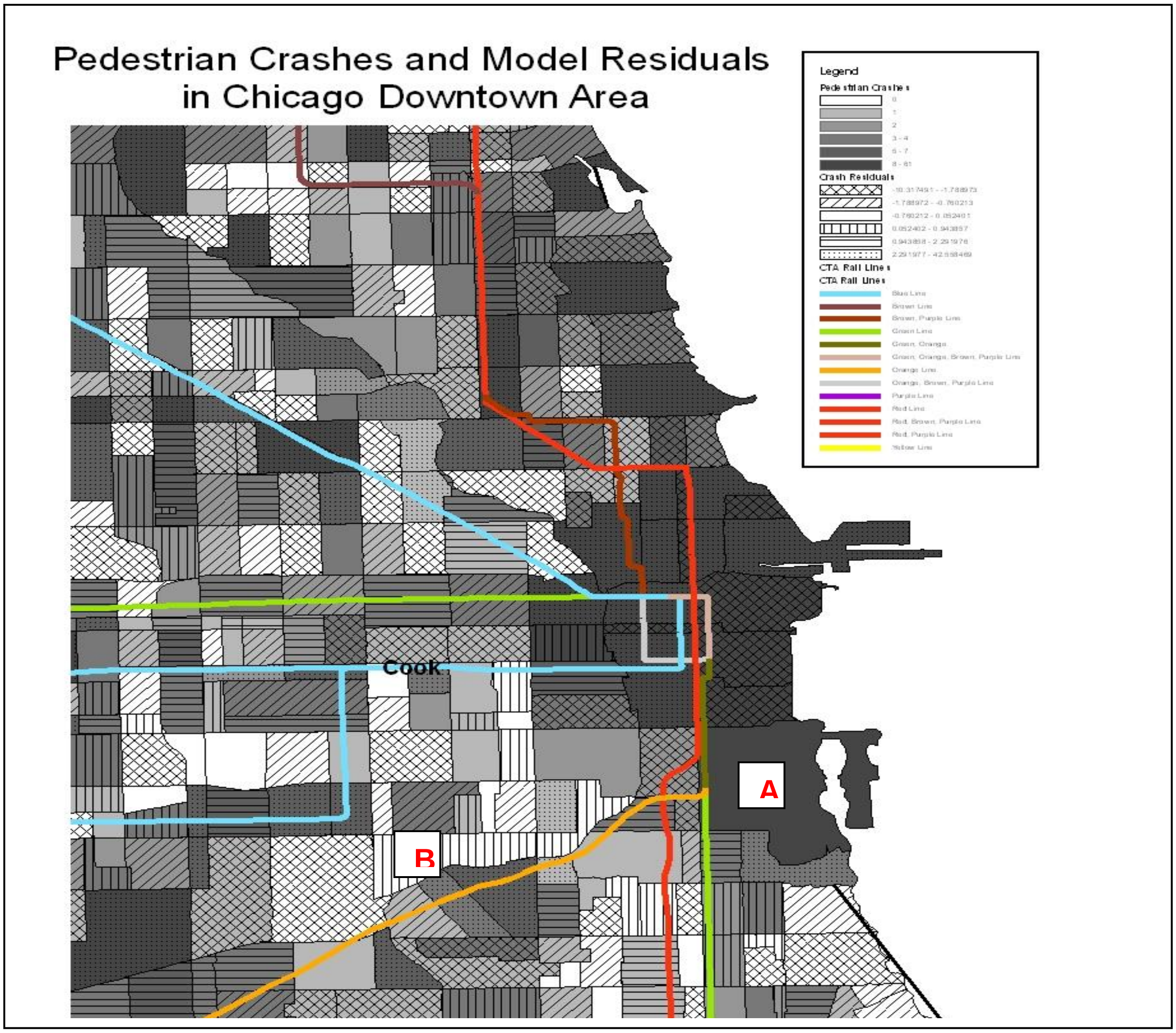

FIGURE 1 Pedestrian Crashes and Residuals

In Figure 1, those tracts that have no color or are light gray with no patterning represent the tracts in Bin A, as both crashes and residuals are low. Darker tracts with no patterning represent tracts in Bin B, as crashes are greater but the EF's predict these crashes accurately. Lighter tracts with cross-hatch or diagonal patterning have slightly more crashes and slightly underpredicted residuals, indicating that they fall into Bin C. Darker tracts with the same patterning fall into Bin D. Light tracts with horizontal, vertical, or stippled patterning fall into Bin E, while darker tracts with this patterning are in Bin F.

For the tract marked "A" above, for example, crash frequencies are relatively high, but there is no patterning present, indicating that the model described here fits well (Bin B). In such a tract, interventions that address ecological factors such as signage or education methods, would likely have a beneficial impact on crash numbers. In the crash marked "B", on the other hand, there is a low number of crashes, but the model overpredicts the number (Bin E), indicating that there is a potential for higher risk dependent upon ecological factors. Such a tract currently needs few interventions, but should be monitored in case events change.

A

5. SUMMARY AND CONCLUSIONS

Planning interventions to address pedestrian and bicycle safety concerns may occur in the form of engineering design and operational programs. The paper proposed a sketch-level planning methodology to develop a typology of areas based on the extent to which ecological factors (relating to social or behavioral and environmental or built-environment-related characteristics) explain bicycle and pedestrian crashes. The methodology uses (i) readily-available and specially-constructed indicators of neighborhood characteristics or ecological factors, (ii) spatial regressions and finally (iii) model residual analysis. The purpose of the methodology is to enable planners to make an initial determination of the types of bicycle- and pedestrian-specific interventions that may be appropriate for subareas within a metropolitan area to address their safety concerns. The paper then demonstrates the use of the analysis for the Chicago metropolitan region.

Decision makers historically have indicated that inaccessibility of required geographic data and difficulties in synthesizing various recommendations are primary obstacles to spatial problem solving (Ascough, *et al*, 2002). Investments in data infrastructure should be continual and methodologies are needed to develop the types of raw and composite indices discussed here. Once in an integrated platform with other planning and governmental information, hazards posed to non-motorized transportation users can be integrated with a wide variety of other sectors beyond transportation agencies, such as public health, school districts and so on.

References

Abdel-Aty, M., S. S. Chundi and C. Lee (2007). Geo-spatial and log-linear analysis of pedestrian and bicyclist crashes involving school-aged children. In Journal of Safety Research, Vol. 38, pp. 571-579.

Agran, P.F., D.G. Winn and C. L. Anderson (1996). Pediatric injuries in Hispanic children and non-Hispanic White children in Southern California. In Archives of Pediatrics & Adolescent Medicine, Vol. 150, pp. 400–406.

Bagley, C. (1994). The Urban Environment and Child Pedestrian and Bicycle Injuries: Interaction of Ecological and Personality Characteristics. In Journal of Community and Applied Social Psychology, Vol. 2, No. 4, pp. 281-289.

Bass, D., R. Albertyn and J. Melis (1995). Child pedestrian injuries in the Cape metropolitan area—final results of a hospital-based study. In Journal of South African Medicine, Vol. 85, No. 2, pp. 96–99.

Beck, L. F., A. M. Dellinger and M.E. O’Neil, American Journal of Epidemiology, Motor Vehicle Crash Injury Rates by Mode of Travel, United States: Using Exposure-Based Methods to Quantify Differences, pp 1-7, April 2007.

Clarke, A. “Green Modes and US Transport Policy: TEA-21” in Sustainable Transport: Planning for Walking and Cycling in Urban Environments. Rodney Tolley, ed. Woodhead Publishing, 2003.

de Silva, F. N. and R. W. Eglese (2000). Integrating simulation modeling and GIS: spatial decision support systems for evaluation planning. In Journal of Operational Research Society, Vol. 51, No. 4, Progress in Simulation Research (Apr., 2000), pp. 423-430

Densham, P.J. (1991). Spatial Decision Support Systems. In: Maguire, D.J., M.F. Goodchild, and D.W. Rhind, eds. Geographical Information Systems: Principles and Applications, vol.1, London: Langman, 403-412.

Durkin, M. S., D. Laraque, I. Lubman and B. Barlow. (1999). Epidemiology and prevention of traffic injuries to urban children and adolescents. In Pediatrics, Vol. 103. No. 6.

Floerchinger, F. G., M. Machala, K. Goodale and S. Gerberding (2000). Evaluation of a pilot program in rural schools to increase bicycle and motor vehicle safety. In Journal of Community Health, Vol. 25, No. 2, pp. 113-124.

Frank, W. C., J-C. Thill and R. Bhatta (2000). Spatial decision support system for hazardous material truck routing. In Transportation Research Part C: Emerging Technologies Volume 8, Issues 1-6, February-December 2000, Pages 337-359

Greenland, S. and H. Morgenstern (1989) Ecological bias, confounding and effect modification. In International Journal of Epidemiology, Vol. 18, pp. 269–74.

James C. Ascough II a, Harriet D. Rector b, Dana L. Hoag c, Gregory S. McMaster a, Bruce C.

Kelsey, J. L., A. S. Whittemore, A. S. Evans and W. D. Thompson (1996). Methods in Observational Epidemiology. Oxford University Press. Second Edition.

Landis, B.W., V.R. Vattikuti, R.M. Ottenberg, D.S. McLeod, and M. Guttenplan. "Modeling the Roadside Walking Environment: A Pedestrian Level of Service." TRB Paper No. 01-0511. 2001.

LaScala, E.A., D. Gerber, P. J. Gruenewald (2000). Demographic and environmental correlates of pedestrian injury collisions: a spatial analysis. In Accident Analysis and Prevention, Vo. 32, pp. 651–658.

Lee, A.J., N. P. Mann, P. Takriti (2000). A hospital led promotion campaign aimed to increase bicycle helmet wearing among children aged 11-15 living in West Berkshire 1992-1998. In Injury Prevention, Vol. 6, pp. 151-153.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. New York: John Wiley and Sons

Minosha, I., P.S. Sriraj, P. Metaxatos, and P. Thakuriah (2008). An Analysis of Transit Quality of Service and Employment Accessibility for the Greater Chicagoland Region. In Transportation Research Record, Vol. 2042, pp. 20-29.

Morgenstern H. (1998). Ecological studies. In: Rothman K, Greenland S, eds. Modern epidemiology. Philadelphia, PA: Lippincott-Raven, pp. 462–480.

Pucher, J., Dijkstra, L., 2003. Promoting Safe Walking and Cycling to Improve Public Health: Lessons from The Netherlands and Germany. American Journal of Public Health, Vol 93, No. 9, pp. 1509-1516.

Roberts, I., R. Norton, R. Jackson, R. Dunn and I. Hassal (1995). Effect of environmental factors on risk of injury of child pedestrians by motor vehicles: a case control study. In British Medical Journal, Vol. 310, pp. 91–94.

Schneider, R., R. Patton, J. Toole and C. Raborn. "Pedestrian and Bicycle Data Collection in United States Communities: Quantifying Use, Surveying Users, and Documenting Facility Extent." Sponsored by FHWA. January 2005.

Selvin, H. C. (1958). Durkheim's Suicide and problems of empirical research. In American Journal of Sociology, Vol. 63, pp. 607-619.

Sriraj, P.S., M. Minor, and P. Thakuriah (2006). Spatial Decision Support System for Low-Income Families: A Relocation Tool for the Chicagoland Region. In Transportation Research Record 1956, pp 119-126.

Stevenson, M. and R.McClure (2005). Use of ecological study designs for injury prevention. In Injury Prevention, Vol. 11, pp. 2-4.

Stevenson, M.R., K. D. Jamrozik and J. Spittle (1995). A case-control study of traffic risk factors and child pedestrian injury. In International Journal Epidemiology, Vol. 24, pp. 957–964.

TRB Subcommittee on Safety Workforce Development. "Core Competencies for Highway Safety." June 14, 2005. Available at: http://www.trb.org/safety/CoreCompetencies.pdf.

Vandenberg a, Marvin J. Shaffer a, Mark A. Weltz a, and Lajpat R. Ahjua (2002). Multicriteria Spatial Decision Support Systems: Overview, Applications, and Future Research Directions. In 2002 Proceedings of International Environmental Modelling & Software Society.

Walter S. D. (1991). The ecologic method in the study of environmental health. Overview of the method. In Environmental Health Perspectives. Vol. 94, pp. 61–65.

Wesson, D., L. Spence, X. Hu and P. Parkin (2000). Trends in bicycling-related head injuries in children after implementation of a community-based bike helmet campaign. In Journal of Pediatric Surgeries, Vol. 35, No. 5, pp. 688-689.