Spatial and Temporal Patterns of North Carolina Pedestrian and Bicycle Plans

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Context: Pedestrian and bicycle plans support community-level physical activity. In North Carolina, pedestrian/bicycle plans are becoming more prevalent. However, no studies have examined the spatial and temporal diffusion of pedestrian/bicycle plans. **Objectives:** This study assessed (*a*) temporal trends associated with municipal pedestrian/bicycle planning from 1974 to 2011 and (*b*) spatial patterns associated with municipal plans, specifically, whether the publication of a pedestrian/bicycle plan in a given year was associated with the number of neighboring municipalities with plans. **Setting:** North Carolina from 1974 to 2011. **Main Outcome Measures:** The main outcome was date of publication of all North Carolina municipal pedestrian and bicycle plans (1974-2011). We calculated Euclidean distances from each municipality center to all other municipality centers to derive whether municipalities were within 20 and 50 miles of each other. Sociodemographic covariates (eg, education, grant funding status, poverty, urbanicity, racial composition, population size, population growth) were collected from the US Census of Population (1980-2010) and the American Community Survey (2006-2010). Time series models fitted by generalized estimating equations were used to assess relationships between plan presence and the temporal and spatial predictor variables. **Results:** The number of pedestrian and bicycle plans significantly increased over time, especially after 2006 when a state grant funding program was initiated. Unadjusted models indicated that municipalities were significantly more likely to have a pedestrian plan if higher numbers of neighboring municipalities had pedestrian plans. After adjustment for sociodemographic covariates and funding source, this relationship was attenuated but remained statistically significant. For bicycle plans, no significant associations were observed between plan presence and the number of neighboring municipalities with bicycle plans in adjusted models. **Conclusions:** Findings from this study can be used to generate hypotheses to test theories about diffusion of innovation and social contagion processes in pedestrian/bicycle planning.

KEY WORDS: **diffusion, environment, physical activity, planning, policy**

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Pedestrian and bicycle plans support active community environments.[1] Although pedestrian/bicycle plans are becoming increasingly popular in the United States, there is a lack of research examining diffusion of these plans. An examination of the diffusion of pedestrian/bicycle plans could be useful for multidisciplinary professionals interested in supporting

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activity-friendly environments through local planning. This gap is mirrored in the public health literature, in which the dissemination of evidence-based physical activity interventions, especially those targeting planning and policy, is poorly understood.[2]

Diffusion of innovation theory seeks to explain how and why new ideas are adopted.[3] Policy diffusion is "the process by which innovation is communicated through certain channels over time among the members of a social system."[3(p5)] Several policy diffusion models have been developed that describe how localities may communicate with and influence one another.[4] Most diffusion models incorporate at least one of the following characteristics: (*a*) localities learn from each other; (*b*) localities may also compete with each other; and (*c*) localities respond to incentives.[5,6] The regional policy diffusion model[5,7] integrates geography into diffusion of innovation theory by positing that a locality is likely to be influenced by the actions of its neighbors—both proximate neighbors and those within their geographic region. Prior research suggests that there is a greater likelihood that a locality will adopt a policy innovation if a neighboring locality has already adopted it.[6]

The purpose of this exploratory study was to examine temporal and spatial patterns associated with municipal pedestrian/bicycle planning in North Carolina. Our objectives were (*a*) to assess temporal trends associated with pedestrian/bicycle planning from 1974 to 2011 and (*b*) to assess spatial patterns associated with these plans, specifically, whether the presence of a pedestrian/bicycle plan in a municipality in a given year was associated with the number of neighboring municipalities with plans.

We chose North Carolina because of our knowledge of planning in the state, and because of the relatively large number of municipal pedestrian/bicycle plans, due in part to state incentives to create such plans. In 2004, the North Carolina Department of Transportation (DOT) initiated a competitive grant program to encourage the development of local pedestrian/bicycle plans and to stimulate more diversity in planning.[8] This funding program has continued through our study period and funded plans annually since 2004.

Methods

We collected all municipal pedestrian, bicycle, and combined pedestrian/bicycle plans in North Carolina through 2011.[9] For the purposes of this article, we subsequently refer to pedestrian/combined plans as "pedestrian plans" and bicycle /combined plans as "bicycle plans." To identify plans, we conducted Web searches, accessed the North Carolina DOT Division of Bicycle and Pedestrian Transportation plan library, and called jurisdictions when necessary for follow-up. Additional plans were identified through a listserv of North Carolina planners and from a survey of municipalities.[10]

Definition of "neighbor"

Using Esri ArcGIS version 10 (Redlands, CA), the geometric center of each municipality was identified using the feature to point tool, using a 2010 US Census Bureau[11] shapefile of 552 municipalities in North Carolina. The Euclidean distance from each municipality centroid to all other municipality centroids was calculated using the point distance tool.

We defined "neighbors" in 2 ways: (*a*) a municipality within 20 miles (Euclidean distance) of another municipality and (*b*) a municipality within 50 miles (Euclidean distance) of another municipality. For each municipality, we then created 4 variables representing (*a*) the number of neighbors within 20 miles that had a pedestrian plan, (*b*) the number of neighbors within 50 miles that had a pedestrian plan, (*c*) the number of neighbors within 20 miles that had a bicycle plan, and (*d*) the number of neighbors within 50 miles that had a bicycle plan.

The distances of 20 and 50 miles were chosen on the basis of our geographic knowledge of the state and to approximate empirical cutpoints. For example, the average distance from one municipality to another in North Carolina was 97 miles, 20 miles was below the fifth percentile in terms of spatial proximity, and 50 miles was below the 25th percentile of spatial proximity.

Temporal variables

The first bicycle plan in North Carolina was published in 1974, and the first pedestrian plan was published in 1994. Thus, our analysis period covered 1974-2011. Three types of time variables were examined: (*a*) a continuous variable representing "year" to assess the linear trend in plan publication; (*b*) a binary variable representing whether the plan was published on or after 2006, because 2004 was the first year that municipalities could apply for North Carolina DOT pedestrian/bicycle planning grants, and most took 2 years to develop a plan; and (*c*) 2 indicator variables, representing the time periods 1996-2004 and 2005-2011, with 1974-1995 as the referent. Because the temporal trend in plan publication was nonlinear, we used the binary variable in the adjusted models, which produced more stable parameter estimates.

Municipal sociodemographics

For each municipality, data were collected using the decennial US Census (1980-2010)[11] and the American Community Survey (2006-2010) estimates.[12] The following variables were considered as covariates, based on previous research,[10,13] and for each variable listed, "population" refers to the municipality; variables were coded as continuous unless otherwise indicated: population, urban area indicator (binary, population size ≥50 000) [14]; population growth index, 2000-2010 (coded on a scale of 0 [rapid population decline] to 4 [fast growth] on the basis of prior research)[1,15]; percentage of the population in poverty (binary, high poverty defined as >18%)[16]; percentage of the population that graduated high school (binary; high education defined as greater than North Carolina median); percentage of the population that identifies as white; percentage of the population that identifies as Hispanic; median population age; and North Carolina DOT grant funding status (coded as: no funding; plan funded by North Carolina DOT Bicycle/Pedestrian Planning Grant Award; 2 = plan funded by North Carolina DOT Small Community Planning Award).[8]

The Census variables were modeled as time-varying covariates (1974-2011).[17] Because we did not have reliable Census data from 1970 for most socioeconomic variables, the 1980 estimates were used. For each year between decennial census years, values were interpolated on the basis of a linear trend.

Statistical analysis

The data were manipulated by creating a row for each municipality in a given year. Each of the 552 municipalities contributed 1 observation per year from 1974 to 2011, generating a final data set of 20 978 municipality-year observations.

Time series models fitted by generalized estimating equations[17,18] were used to assess relationships between the dichotomous outcome (eg, whether a municipality had a plan in a given year) and the temporal and spatial predictor variables. The models used a logit link function and accounted for serial clustering by municipality.[19] Separate models were conducted for (*a*) pedestrian plans and (*b*) bicycle plans (Supplemental Digital Content Tables 2 and 3 available at: http://links.lww.com/JPHMP/A21). Models excluding combined plans were also explored; this did not meaningfully affect the parameter estimates (not shown).

We first estimated unadjusted models and then adjusted models for sociodemographic and North Carolina DOT funding covariates. Sociodemographic covariates that contributed significantly to the model ($P < .05$) or were considered substantively important were retained in the adjusted models.

Results

Temporal trends

Overall, 81 pedestrian plans and 41 bicycle plans were created between 1974 and 2011 The presence of plans increased over time, especially after 2006 (Supplemental Digital Content Figure 1 available at: http://links.lww.com/JPHMP/A20).

Spatial patterns/neighbors

For municipalities with pedestrian plans, the median number of neighbors within 20 miles with pedestrian plans was 1 (range, 0-6); the median number of neighbors within 50 miles with pedestrian plans was 6.5 (range, 1-19). For municipalities without pedestrian plans, the median number of neighbors within 20 miles with plans was 0 (range, 0-7); the median number of neighbors within 50 miles with plans was 0 (range, 0-20).

For municipalities with bicycle plans, the median number of neighbors within 20 miles with bicycle plans was 0 (range, 0-2); the median number of neighbors within 50 miles with plans was 4 (range, 0-10). For municipalities without bicycle plans, the median number of neighbors within 20 miles with plans was 0 (range, 0-4); the median number of neighbors within 50 miles with plans was 1 (range, 0-10). Characteristics of municipalities are shown in Table 1.

Model results

In unadjusted models, municipalities were significantly more likely to have a pedestrian plan if higher numbers of neighboring municipalities had pedestrian plans (Supplemental Digital Content Table 2 available at: http://links.lww.com/JPHMP/A21). In models adjusted for covariates (urbanicity, population growth, education, poverty, time period, and funding status), this relationship was attenuated but remained statistically significant. The magnitude of the odds ratio for the 20-mile neighbor definition was higher than that for the 50-mile neighbor definition (odds ratio, 1.29 vs 1.15, respectively). The strongest independent predictors of having a pedestrian plan were having grant funding to create the plan, time period (≥2006), urban area, and higher education.

For bicycle plans, no significant associations were observed between municipal bike plan presence and the number of neighboring municipalities with bicycle plans in adjusted models (Supplemental Digital

TABLE 1 ● Characteristics of North Carolina Municipalities With Pedestrian and Bicycle Plans[a]

Variable	All Municipalities (n = 552)	Pedestrian Plans (n = 81)	Bicycle Plans (n = 41)
Population size, mean (range)	9656 (25-73, 1424)	15 803 (37-22, 8330)	45 224 (60-73, 1424)
Education (% high school graduates), mean (SD)	81 (10)	81 (9)	87 (7)
North Carolina DOT Grant Funded Plans[b]	18%	90%	68%
Household income, median	$37 059	$37 262	$41 971
Population Growth Index,[c] mean (SD)	2. 2 (1.4)	2.5 (1.2)	2.8 (1.2)
Population age, mean (SD)	41 (7)	39 (5)	37 (6)
Percent white population, mean (SD)	69 (23)	71 (18)	62 (18)

Abbreviation: DOT, Department of Transportation.
[a]Data pertains to North Carolina municipalities in 2011. Unless otherwise specified, data was derived from the US Census of Population.
[b]Coded as: 0 = no funding; 1 = Plan funded by North Carolina DOT Bicycle and Pedestrian Planning Grant Award; 2 = Plan funded by North Carolina DOT Small Community Planning Award (highest quintile of per capita funding).
[c]Growth indicator variable defined as: 0 = fast population decline (−100% to −5.01%), 1 = slow decline to stagnant (−5% to 0), 2 = slow growth (0.1% to 15%), 3 = moderate growth (15.1% to 30%), 4 = fast growth (30.1% to 414%).

Content Table 3 available at: http://links.lww.com/JPHMP/A21). However, significant relationships were observed between presence of municipal bicycle plans and sociodemographic factors. Higher education and urbanicity were the strongest independent predictors of the presence of bicycle plans. Funding status, time period (≥2006), higher percentage nonwhite population, younger median population age, and higher poverty were also positively associated with bicycle plan presence.

Discussion

In this study, we examined the diffusion of pedestrian/bicycle planning in North Carolina. Significant spatial and temporal trends were observed, supporting diffusion of innovation theory. First, pedestrian/bicycle plan presence appears to follow the expected logistic diffusion curve[20] (Supplemental Digital Content Figure 1 available at: http://links.lww.com/JPHMP/A20). Second, municipal pedestrian plan presence in North Carolina was associated with having neighbors with plans, as well as with sociodemograpics. This aligns both geographic and socidemographic conceptualizations of social contagion and homophily.[21,22] For example, homophily, described by Rogers[23(p18)] as "the degree to which pairs of individuals who interact are similar in certain attributes, such as beliefs, education, and social status," is likely to help explain the adoption of innovative policies. Similarities between units are thought to accentuate communication and knowledge exchange.[24]

Third, our results are compatible with diffusion theory in terms of why innovation occurs.[25] Three types of factors have been shown to influence successful diffusion: (*a*) qualities of the innovation; (*b*) characteristics of individuals/groups who may influence adoption (eg, policy entrepreneurs,[26] opinion leaders,[27] advocacy coalitions,[28] and communities of practice[29]); and (*c*) contextual factors, such as communication, incentives, and leadership.[29] For example, the North Carolina DOT grant program provided a strong financial incentive for pedestrian/bicycle planning. The grant program also enabled municipalities to hire consultants to assist with plan development. Following the initiation of the grant program, the Healthy Environments Collaborative and the Research Triangle Environmental Health Collaborative[30] were established in 2008 to provide a forum for dialogue and partnerships around environmental health and public policy. Together, these factors likely facilitated communication and sharing of ideas.

Several qualities of the innovation may affect its adoption: complexity, cost, risk, relative advantage (eg, economic advantage, social prestige), compatibility with adopters' values, and flexibility.[3] The differences we observed with respect to predictors of pedestrian versus bicycle planning align with these factors. Compared with pedestrian planning, bicycle planning may be more complex, requiring greater infrastructure investments, coordination with land use planning, and more nuanced behavioral adaptations for both bicyclists and motorists. Sociodemographic and contextual factors (eg, education, racial composition, and urbanicity) were more strongly associated with presence of bicycle plans than with pedestrian plans.

The planning literature also provides important insights about the contextual factors that motivate the adoption of plans at the municipal level. Steele and Luloff[13] explored the relationship between the timing of land use tool adoptions in Pennsylvania from 1975 to 1992. They found that affluence was a significant predictor of the adoption of land use tools. In contrast, we found that municipalities with higher poverty levels and more racial diversity were more likely to develop pedestrian/bicycle plans. This suggests that a more complex socioeconomic dynamic may be emerging for different types of plans, which should be explored in future research.

Limitations

Several limitations warrant mention. First, although we tried to ensure completeness in our collection of plans, it is possible that some plans were missed. Second, we relied exclusively on Euclidean distances to define neighbors. Distance may be serving as a proxy for degree of social interaction. Future research may use other models, such as social network analysis[21] or agent-based models,[31] to examine the mechanisms through which the spread of these planning innovations is occurring.[19] Third, some 2010-2011 municipalities (<3%) did not exist in 1974; these observations were assessed using missing values and interpolation that did not substantially affect the model results. Fourth, we did not have complete time-varying information for all sociodemographic variables and relied on interpolated values for certain years; confidence intervals for some covariates are imprecise. However, wide confidence intervals have been observed by other researchers in social networks.[21] Fifth, different time lags of adoption were not modeled, and unmeasured covariates may affect the results. Sixth, we did not measure plan implementation. Finally, our results may not be generalizable to other states.

Conclusions

We observed patterns suggestive of diffusion of innovation and social contagion processes in pedestrian/bicycle planning in North Carolina. Municipalities that share similar geographic/sociodemographic characteristics were more likely to have plans. In addition, North Carolina DOT grant funding provided an incentive for planning. Findings can be used to generate hypotheses to test diffusion theories using other types of models and to qualitatively assess factors motivating pedestrian/bicycle planning.

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