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긴급재난 대피시간에 대한 도시확산 현상의 효과에 관한 연구: 미국 텍사스 해변 지역사례 연구

Evaluating the Effects of Sprawl on Evacuation Time: An Exploratory Analysis from Texas Coastal Counties

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Abstract

The objective of this research was to test a hypothesis that sprawl increases congestion, and so the estimated evacuation time become longer. For this, sprawl was thought to be poor accessibility so that vehicle miles of travel become longer. This research shows that the daily vehicle miles per lane mile that are thought to be an accessibility index had a strong and statistically significant relationship to the estimated evacuation time, while urban population density has no statistically significant relationship to the evacuation time. The result of this research recommends that we should consider sustainable land use patterns that decrease traffic demand by providing good accessibility.

Key Words: Sprawl, Evacuation Time Estimates, Accessibility, Urban Population Density, Sustainable Land Use

요　지

본 연구의 목적은 무분별한 도시개발의 확산현상과 자연 재난 시 차량의 대피시간과의 관계를 살펴보고 그 연관성을 설명하는 것이다. 자연재난 학자들이 주장한 도시확산으로 인한 긴급대피시간의 지연에 대해 본 논문은 검증을 실시하였다. 본 논문에서 도시확산 측정의 두 가지 상반되는 개념들을 이용하여 무변별한 도시확산이 긴급대피 시간과 어떤 관계를 갖는지 알아보았다. 연구의 대상지역으로는 허리케인으로 인하여 거의 매년 긴급대피를 경험하고 있는 미국 텍사스 해안지역을 사례지역으로 삼았다. 또한 두 가지 다른 도시확산 지수들 (도시인구밀도와 접근성)과 긴급대피시간(ETSs)과의 부분 상관관계분석을 시도하였다. 결론은 다음과 같다. 도시 인구 밀도를 이용한 개념보다 접근성 개념을 통한 도시확산 측정이 통계적으로 더욱 유의미하다는 것이다. 구체적으로 일일 교통량을 이용한 접근성의 지수가 긴급대피시간과 강력한 관계를 가진다는 점이다. 이는 무분별한 도시확산으로 인한 교통시간의 지체가 재난 시 사람들의 대피에 악영향을 미친다는 것을 보여준다. 이러한 결론은 접근성을 높이기 위한 지속 가능한 토지이용 패턴이 긴급대피시간에도 좋은 영향을 미친다는 것을 의미한다.

핵심용어: 도시확산, 긴급대피시간, 접근성, 도시인구밀도, 지속가능한 토지이용

1. Introduction

Sprawl has been an important issue for modern urban planners or urban policy makers as a fundamental cause of urban problems such as the loss of community sense, the deprivation of the environment, the loss of open space, and government financial crisis (Ewing 1994; Ewing 1997; and Burchell et al. 1998; Sole 2005). Characterized by low urban population density or poor accessibility, recently, the sprawling development pattern has been thought by hazard scholars to encourage the exposure of people and property to significant risks from natural hazards and, in particular, to necessitate longer evacuation time (Beatley and Manning, 1997; Godschalk et al., 1999). Although sprawl could be an important factor in estimating evacuation time, little empirical evidence exists to support this notion. This study seeks to fill this void by exploring how sprawl development patterns relate to evacuation time in emergency situations.

This research explains two alternatives to the relationship between sprawl and evacuation time: if the poor accessibility has a positive relationship to the estimated evacuation time or if urban population density has a relationship to the evacuation time. Other than the responsive alternatives such as road construction or effective traffic management plans,

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this research argues that the long-term preventive policies, such as sustainable urban development patterns that decrease vehicle demand and increase road capacity, can have a significant impact on how we reduce the evacuation time. The sustainable urban development patterns mean the land use patterns for preventing urban sprawl (Crawford 2005; Rodrigue 2007). The effects of sustainable urban development include job and housing balance, air pollution reduction, and good accessibility (World Bank, 2005). The examples of this policy for sustainable urban development are growth management and smart growth. Growth management and smart growth policies to prevent urban sprawl may contribute not only to the planning and transportation fields but also to the emergency management fields. This research is motivated by a desire to test whether the sustainable urban form is justified for reducing the evacuation time.

2. Literature Review

2.1 Background

Urbanik said, “The accident at the Three Mile Island nuclear power plant provided a major impetus for developing systematic procedures to assess the length of time required to evacuate a threatened population” (Urbanik, 2000, p.165). Dividing the total evacuating vehicles by the vehicle per hour capacity can get the estimated evacuation time. Prior evacuation time research has explored questions regarding many factors that would affect the evacuation time in an aspect of the effectiveness of the current traffic road situation. As shown in the time formula, many researchers have focused on demand of vehicles and capacity of road (Urbanik, 1978, 2005; Southworth & Chin, 1987; Sinuany &Stern, 1993; Cova & Church, 1997) and argued that population growth and car ownership can be important factors that affect the estimated evacuation time. Also, routing, intersection capacity, human behavior, and the traffic road situation have been considered important research issues (Southworth & Chin, 1987; Sinuany &Stern, 1993; Cova & Church, 1997; Faramand, 1997). So, as a policy implication, Urbanik (2000) proposes the development of effective traffic management plans.

As a result, while more road construction and effective traffic management according to population growth have been recommended as alternatives for reducing the evacuation time, little empirical research has considered the difference in urban development patterns as an important factor affecting the evacuation time. But recently Godschalk et al. (1999) argued that in South Florida, “Massive development, much of it in the form of urban sprawl, had taken place in an atmosphere of relatively low public awareness of the hurricane hazard. Sprawling development patterns make it vulnerable in many ways. Increased population and development necessitate longer evacuation time”(Godschalk et al., 1999, p. 108). In addition, Beatley and Manning (1997) say that natural disasters dramatically illustrate the ways in which contemporary land use and development patterns are not sustainable in the long run. They then argue, “Community land use patterns are not sustainable if they allow or encourage the exposure of people and property to significant risks from natural hazards, and if alternative settlement patterns are available that would avoid such exposure” (Beatley and Manning, 1997, p. 9).

2.2 Evacuation Time Estimates (ETEs)

The current evacuation time formula was made by a model of the demand / capacity relationship (Urbanik, 1978; Urbanik, 2000; Hurricane Contingency Planning, 1999). The vehicular demand for evacuation during a hurricane can be estimated in a three-step process. First, it is necessary to know how many people reside in the area. Second, an estimate of how many vehicles and what types of vehicles will be used in the evacuation is needed. Third, it is necessary to estimate the percentage of the residents that will leave. So, in the estimate of demand, we need following data: first, estimated population using U.S. census data; second, current per capita vehicle rate for the study area (the per capita rate is simply the total number of registered autos and pick-ups owned as personal vehicles divided by the total population for the same area); third, the maximum number of vehicles to be evacuated by multiplying the population by the per capita rate. In prior research, the population and per capita vehicle rate have been considered as important factors that can affect the evacuation time estimate in demand relationships.

Capacity is “the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or roadway during a given time period under prevailing roadway, traffic, and ambient conditions” (Urbanik, 1978, p.7). According to Urbanik’s (1978) research, the formula is as follows:

Capacity = (Ideal Capacity) × (Roadway factors) ×
(Traffic Factors) × (Ambient Factors)

As factors affecting capacity, there are roadway factors, traffic factors, and ambient factors (Urbanik, 1978). First, restrictive physical features in a roadway that reduce the capacity and level of service generally are called “roadway factors” and include lane width, lateral clearance obstacles, grades, shoulders, auxiliary lanes, and surface conditions. Second, capacity and level of service on two geometrically similar highways may be different due to the composition and behavior of the traffic stream. Factors that take these considerations into account are called “traffic factors” and include trucks, buses, and traffic interruptions in particular. Finally, there are ambient conditions, as previously stated, generally ignored in traffic capacity due to their infrequent occurrence. The ambient factors concern weather such as rain, wind, and tide.

When we quantify the function (Urbanik, 1978, p. 29), the relationship becomes:

$$C = 2000vph/lane \times N \times W \times T \times A \quad (1)$$

Where:

2000vph(vehicles per hour) = If vehicles have complete freedom to pass(opposing volume approaches 0) the capacity in one direction approaches 2000vph.

N = Number of lanes in one direction.

W = A fractional multiplier to account for the reduction effects of lane width and lateral clearance of obstructions.

T = A fractional multiplier to account for the effects of the number of trucks and the type of terrain.

A = A fractional multiplier to account for ambient conditions.

3. Theory: sprawl, congestion and evacuation time estimates

The estimated evacuation time formula may be more related to congestion than just to population growth and car ownership in demand and lane width, truck number, and weather in capacity. Urbanik (2000) says, "The basic methodology for analyzing Evacuation Time Estimates(ETEs) is to determine whether the time- and space-dependent evacuation demand rate exceeds the available road capacity"(Urbanik, 2000, p.167). In this point, the relationship between demand and capacity refers to traffic congestion. Traffic congestion results when traffic demand approaches or exceeds the available capacity of the road system. So, traffic congestion may be the most important factor in estimating evacuation time if we control other important factors such as car ownership, response rate, and other road conditions.

Each year, the Texas Transportation Institute publishes a report on congestion in America. In 1999, the anti-auto Surface Transportation Policy Project followed the Texas congestion report with a report of its own claiming that sprawl causes congestion. "As sprawl grows outward, jobs, housing, and services grow farther apart," says the report. Such sprawl is "a primary cause of congestion" (Texas Congestion Report, 1999, p. 5). The report claims to be based on a "rigorous analysis" of Texas Transportation Institute data. The report's logic goes like this: the amount of driving in cities is growing faster than the population growth. Therefore, most of the difference between the growth in driving and the growth in population must be due to sprawl.

Using Florida County's sprawl data, Ewing (1997) argues that sprawl makes accessibility worse and, thus, vehicle hours of travel (VHT) increase. The data show that "average commute times worsened during the 1980s in 35 of the 39 metropolitan areas with more than one million populations. By the end of the decade, average commute times were significantly greater in the suburbs than in central cities" (Ewing, 1997, p.110). He also points out that sprawl makes vehicle miles of travel (VMT) longer. He says that as densities rise, trips get shorter, transit and walk mode shares increase, and vehicle trip rates drop. By various estimates, doubling urban densities results in a 25~30 percent reduction in VMT or a slightly smaller reduction when the effects of other variances are controlled (Ewing, 1997).

Currently, the planning paradigm is to encourage sustainable urban forms, preventing sprawling development patterns (Beatley and Manning, 1997; Ewing, 1997). The urban policies for sustainable urban forms include smart growth, central cities redevelopment, and growth management policy. However, Gordon and Richardson (1997) criticize the planning view about sprawl. They are economists as well as planning professors at the University of Southern California. Their article challenged current planning thought: sprawl increases congestion because it forces people to drive more. Gordon and Richardson (1997) argued that this view is wrong from a free market economist view. They agree with sprawl and disagree with the planners' efforts to prevent sprawl. They criticize compact cities or central cities redevelopment. In their research, they argue differently to the planners' on sprawl. These different opinions are about open space and agricultural land, energy supply, congestion, and public financing balance (Gordon and Richardson, 1997). They think that sprawl is the process of suburbanization. They reject that sprawl makes congestion worse. They argue that the traffic consequences of suburbanization are benign, and suburbanization has been the dominant and successful mechanism for reducing congestion. According to their argument, suburbanization has shifted road and highway demand to less congested routes and away from core areas (Gordon and Richardson, 1997, p. 98). Their logic is that although average commuting distance increases, this becomes offset by faster travel speeds.

Reid Ewing (1997) attacks Gordon and Richardson's arguments about sprawl from the planners' point of view. He asks, "Is Los Angeles-Style Sprawl Desirable?" (Ewing, 1997, p. 107) He points out the differences in the concept of sprawl between himself and Gordon and Richardson. While Gordon and Richardson consider multicenteral cities as sprawl development, Ewing argues that this polycentered pattern is a compact pattern, not sprawl. He suggests that a conceptual difference exists between them. In the concept of sprawl, Ewing concludes, "sprawl is not suburbanization generally, but rather forms of suburban development that lack accessibility and open space"(Ewing, 1997, p. 108).

The essence of his argument is that the most important sprawl indicator is poor accessibility. The empirical data shows that from an analysis of household travel patterns in a Florida county's sprawl data, "households living in the most accessible locations spend about 40 minutes less per day traveling by vehicle than do households living in the least accessible locations" (Ewing, 1997, p.110).

Also, while Gordon and Richardson (1997) have argued that decentralization of firms and households raises average travel speeds enough to compensate for longer trips, recent evidence suggests an opposite result. Average commute times worsened during the 1980s in 35 of the 39 metropolitan areas with more than one million populations (Rossetti and Eversole 1993, table 4-13). Ewing argues, "By the end of the decade, average commute times were significantly greater in the suburbs than in central cities" (Ewing, 1997, p.111). Despite the two opposite views in accepting sprawl, there is a common conclusion. An agreement is that sprawl makes accessibility worse and vehicle miles of travel longer. That is, sprawl makes for longer trips. Although Gordon and Richardson argue that "that increase was offset by faster travel speeds," they acknowledge "some increase in average commuting distances" (Gordon and Richardson, 1997, p.99). Although there can be many points of view, the essence of this dispute is about congestion. While sprawl-lovers such as Gordon and Richardson (2000) think that sprawl in the form of low-density suburbs is a major solution to, not a cause of, congestion, most planners think that sprawl increases congestion because it forces people to drive more.

4. Research Method

4.1 Hypothesis

The above discussion illustrates a clearly different theoretical link between sprawl and evacuation time estimates. While Gordon and Richardson (1997) view that sprawl, characterized by low urban population density, decreases the congestion and then the estimated evacuation time becomes shorter because vehicle hours of travel (VHT) are faster, planners argue that sprawl, characterized by poor accessibility or longer vehicle miles of travel (VMT), increases the congestion, and then the estimated evacuation time is longer because the congestion makes vehicle demand greater and road capacity worse. In this research, the main hypotheses are that, following the planners' view, sprawl, characterized by longer vehicle miles of travel (VMT), makes the estimated evacuation time longer and, attacking the view of Gordon and Richardson, low urban population density has no impact on evacuation time.

4.2. Area and Data

The research areas are Texas coastal counties that have been the main study areas of hurricane research. Particularly, the area from southern Houston to Galveston County is well known for accelerating sprawl development (METRO, 2001). Because these areas are also vulnerable to the hurricane hazard each year, the estimated evacuation time has been made by the state hazard agency. Among 22 counties in Texas, Kennedy and Newton are excluded because they don't have urbanized areas.

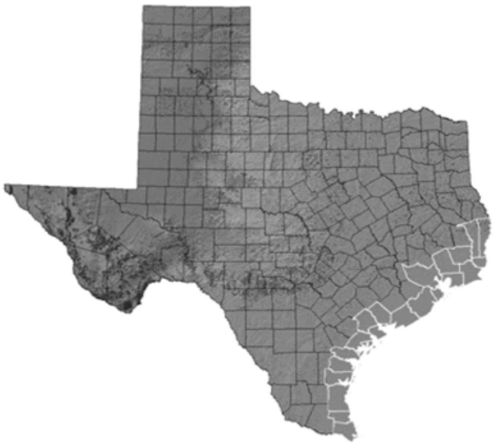

Fig 1. Texas Coastal Areas (county)

This research included a total of 20 counties from Texas. Data for this study were drawn from District and County Statistics, the Census of Agriculture, the Census of Population and Housing, Finances of County Governments, and the Hurricane Contingency Planning Guide. To get the estimated evacuation data of Texas coastal counties, this research used the Hurricane Contingency Planning Guide made by the Hazard Reduction Recovery Center at Texas A&M University.

4.3 Dependent Variable: evacuation time

The estimated evacuation time is not intended to be precise minute and second estimates, but rather estimates to the nearest hour. Dividing the total evacuating vehicles by the vehicle per hour capacity produces the evacuation time estimates (Hurricane Contingency Planning Guide, 1999). Using the Hurricane Contingency Planning Guide (1999), the calculation of evacuation time was made by the following assumptions: first, the response factors in vehicular demand formula are same in all the Texas coastal counties; second, in the formula of capacity, the other fractional multipliers such as W, T, and A are constant enough in the Texas coastal areas to investigate the impact of sprawl. Although these multipliers can be important (Urbanik, 2000), this research focuses on ideal capacity. In this formula for estimating evacuation time, 2000vph is the ideal capacity that has no congestion (Urbanik, 1978, pp.29-30). But it doesn't reflect the real world well. The ideal capacity part may be related to the congestion that sprawl may cause.

4.4 Independent Variables: sprawl index

While prior sprawl research shows many sprawl indicators such as farmland decrease, fiscal capacity of local government, or connectivity index (Burchell et al. 1998; Ewing, 1994; Batty & Sun, 1999; Oregon's Dept. of Land Conservation and Development, 1992), this research focuses on the theoretical arguments by Ewing (1997) and Gordon and Richardson (1997). Among the defining characteristics of sprawl, the ones most likely to affect the estimated evacuation are: "poor accessibility" (Ewing, 1997) and "low relative density" (Gordon and Richardson, 1997).

Urban population density is used for sprawl as the most frequent indicator (Oregon's Department of Land Conservation and Development, 1992). Dividing the urban population in each county by the urbanized area in the county produces urban population density. From 1969 to 1989, the population of the United States increased by 22.5 percent, and the number of miles driven by that population ("vehicles miles of travel" or "VMT") increased by 98.4 percent. In the 1980s in Oregon, the number of vehicle miles traveled increased eight times faster than the population (Oregon's Department of Land Conservation and Development, 1992). Daily vehicle mile per lane mile is considered an indicator that is related to accessibility: the longer the daily vehicle mile, the poorer the accessibility.

4.5 Statistical Controls

To limit the likelihood of drawing spurious conclusions, the analysis also included some other factors that might be related to the estimated evacuation time. The formula of the estimated evacuation time and prior evacuation research suggest that some factors affect the time: the population, vehicles per person, and number of lanes.

To capture the sprawl effects on the estimated evacuation time, the above factors affecting the estimated evacuation time were included as control variables. Table 1 shows the means and standard deviations of the dependent, independent and control variables.

5. Analysis and Results

A partial correlation model was estimated to assess the relationship between daily vehicle miles per lane miles and urban population density on the estimated evacuation time, while controlling for the factors affecting the formula of the estimated evacuation time. In the analysis, to know the impact the control factors, and zero-order correlations analysis also were included. Through this method, we compare two cases: one is the case that we control the factors affecting the formula; the other is the case that we don't.

Results illustrate the relationships between the estimated evacuation time and other variables: daily vehicle miles per lane mile, urban population density, number of lanes, vehicles per person, and county population. The boldface cells indicate variables that are statistically significant at the .05 level of significance.

Table 2 shows that daily vehicle mile per lane mile, number of lane, and county population have a strong and statistically significant relationship to the estimated evacuation time. Particularly, daily vehicle miles per lane mile and number of lanes have a very high relationship to the estimated evacuation time.

Table 3 shows controlling variables affecting the estimated

Table 1 Means and Standard Deviations of Variables Used in Analysis

Variable	Mean	Standard Dev	Cases
Dependent variable			
Evacuation time (hr)	13.6000	10.5651	20
Independent variables			
Density (residents per urban sq. km)	2.4102	1.0779	20
Daily vehicle miles per lane mile	2,781	2163. 1977	20
Control variables			
Number of lane	2.5133	.4257	20
Vehicles per person	.9665	.1694	20
County population	260,710	717,567	20

Table2. Zero-order correlation coefficient without controlling variables

Zero Order Partials								
	V1	V2	V3	V4	V6	V7	V8	Evacuation Time(V5)
Evacuation Time (V5)	.7004 (18) P = .001	.4944 (18) P = .027	−.3187 (16) P = .197	.0760 (18) P = .750	.7507 (18) P = .000	−.2424 (18) p = .303	.4503 (18) p = .046	1.0000 (0) p = .

(Coefficient / (D.F.) / 2-tailed Significance)

Table 3. Partial correlation coefficients

Controlling for.. V6, V7, V8.					
	V1	V2	V3	V4	EVACUATION TIME(V5)
EVACUATION TIME (V5)	.7450 (15) P = .001	.3072 (15) P = .230	.3758 (13) P = .167	−.3628 (15) P = .152	1.0000 (0) P= .

(Coefficient / (D.F.) / 2-tailed Significance) evacuation time. The factors relating to the sprawl were analyzed by partial correlation. The daily vehicle miles and urban population density are factors related to the sprawl. The result shows that the variable of daily vehicle miles per lane mile has a statistically significant relationship with the evacuation time at the .05 level. No term measuring urban population density suggests a substantial relationship between density and the evacuation time estimates. Through controlling variables, the correlation coefficient of daily vehicle miles per lane mile to the estimated evacuation time is increased from .7004 to .7450.

6. Implication and Discussion

The objective of this research was to test a hypothesis that sprawl increases congestion, and so the estimated evacuation time become longer. For this, sprawl was thought to be poor accessibility so that vehicle miles of travel become longer. The problem was whether this sprawl is related to congestion. That is, can the longer travel miles explain congestion?

Economists and planners provided two alternatives about the question. Planners thought that sprawl makes congestion worse, and economists such as Gordon and Richardson thought differently. With these opposing views, I applied these concepts to the study of the estimated evacuation time. Currently, the evacuation time has been estimated by some factors such as population, vehicles per capita, road capacity, and other multipliers. Theoretically, researchers assumed that the ideal capacity is 2000 vehicles per hour. In reality, road capacity has been estimated by sampling the work of transportation agencies. I thought that this capacity was related to congestion and the sprawl affecting congestion had a more important influence on the estimated evacuation time than other factors. While there is little research on whether the sprawl is a more important factor than other multipliers such as roadway factors and ambient factors in estimating evacuation time, in this research I found a positive relationship between sprawl and the estimated evacuation time.

These findings about the positive relationship can an important policy implication to disaster policy and urban planning. At first, in disaster policy, emergency managers have to check transportation congestion areas for emergency period and, when in emergency, must guide evacuee to less congestion roads. In urban planning field, the relation between congestion and evacuation time gives another rationale for planning intervention for sustainable urban development.

In conclusion, this research shows that the daily vehicle miles per lane mile that are thought to be an accessibility index had a strong and statistically significant relationship to the estimated evacuation time, while urban population density has no statistically significant relationship to the evacuation time. The result of this research implies that in order to reduce the evacuation time, we should consider sustainable land use patterns that decrease traffic demand by providing good accessibility. Those patterns will contribute to preventing sprawl, to reducing congestion, and eventually to decreasing evacuation time.

The limitation of this study is that the evacuation time used here is a theoretical time estimate by formula. So, for the future study, the relationship study among real congestion time, accessibility index(urban form) and real evacuation time should be performed.

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