The National Center for Intermodal Transportation

Final Report

for

Assessing Economic and Demographic Impacts of Intermodal Transportation Systems

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ABSTRACT

There exists a large literature of transportation impacts on economic and demographic change. Prior studies have focused on single modes of transportation individually rather than integrating these modes. Yet, little work has been undertaken to study the economic and demographic impacts of intermodal transportation systems. This study fills the gap in the literature by examining intermodal passenger transportation on demographic change. Specifically, this research investigates the effects of highways and airports on population change in the minor civil divisions of Wisconsin by adopting an integrated spatial approach. The results show that overall, airport accessibility and highway improvement affect population change, but highway accessibility and airport improvement do not. However, the effects exhibit variation across rural, suburban, and urban areas. Highway improvement acts as an investment input and airport accessibility uses the locational advantage to promote rural population growth. In suburban areas, airport accessibility promotes population growth but highway accessibility acts as a facilitator of out-migration. The effects on urban population change are not statistically significant and are likely constrained to land use policies and regulations. This study have important implications to transportation planning as transportation planning practices are focusing more attention on intermodal transportation systems as a whole rather than any single mode of transportation. Intermodal transportation systems have become increasingly important for transportation performance and efficiency.

1. INTRODUCTION

Transportation impacts on economic and demographic change have been studied in several disciplines including planning, economics, engineering, geography, and sociology, resulting in a complex assortment of theoretical and empirical studies. Yet, little work has been undertaken to study the economic and demographic impacts of intermodal transportation systems. Typically, prior studies have focused on single modes of transportation individually rather than integrating these modes. Intermodal transportation systems have become increasingly important for transportation performance and efficiency. Transportation planning practices are focusing more attention on intermodal transportation systems as a whole rather than any single mode of transportation.

The main objective of this research is to study how intermodal transportation systems affect economic and demographic change. Economic and demographic impacts have many components, including economic outputs, employment change, population change, age-race-gender dynamics, and so on. This research focuses on population change, and examines the effects of intermodal transportation systems on population change with a focus on passengers rather than freight. The impacts of individual modes of transportation have been widely studied, but the effects of intermodal transportation systems as a whole have been neglected in the existing literature. This research focuses on passenger transportation rather than freight transportation, as the former is more relevant to population and employment growth. While intermodal transportation systems are composed of roadways, airways, railways, and waterways, this proposed research focuses only on highways and airways, because they are the two most widely studied modes of transportation and the most important modes of transportation for passengers' regional travels.

Specifically, this research investigates the effects of highways and airports on population change at the minor civil divisions (MCDs) in Wisconsin by adopting an integrated spatial approach. First, the impacts of highway segments expanded from 1970-1990 on population change from 1980-2000 are analyzed. Second, the relationships between highways and airports (measured as accessibility and improvement) and population change are examined. For both of the two research parts, the spatial variations of the impacts are examined across rural, suburban, and urban areas.

This report is organized into six additional sections. The next section reviews literature of highway and airport impacts on population change. The data and analytical approach used in this study are then introduced. The results section reports the findings of highway expansion impacts on population change, highway and airport impacts on population change, and the spatial variations of the impacts across rural, suburban, and urban areas. The summary and discussion section summarizes the findings and suggests future research directions. The last section summarizes the dissemination of the research findings.

2. LITERATURE REVIEW

The literature review section includes three parts: highway impacts on population change, airport impacts on population change, and the impacts of highways and airports as a whole (intermodal transportation) on population change.

2.1 Highway Impacts on Population Change

A vast literature, distributed across several disciplines (e.g., planning, economics, geography, and sociology), has resulted in a multifaceted mixture of theoretical and empirical approaches to describe the effects that highways have on population redistribution. This literature suggests that highway effects on population redistribution vary with different geographical scales and stages of highway construction, and across rural, suburban, and urban areas (Chi et al. 2006).

First, the effects vary at different scales, such as regions (e.g., Morrison and Schwartz 1996), counties (e.g., Lichter and Fuguitt 1980), municipalities (e.g., Humphrey 1980; Humphrey and Sell 1975), and neighborhoods (e.g., Corsi 1974). Studies at each of these scales have produced dissimilar and conflicting findings. For example, at the larger scales highways effects are found to be primary (Dalenberg and Partridge 1997) or secondary to other factors (e.g., Hulten and Schwab 1984). At the smaller scales, the effects are found to be significant (e.g., Smith, Deaton, and Kelch 1978) or insignificant (e.g., Dorf and Emerson 1978).

Second, the effects differ in the three stages of highway construction — pre-construction, construction, and post-construction periods. In the pre-construction period, population growth is a positive causal factor of highway construction (Lichter and Fuguitt 1980; Miller 1979). In the construction period, highway construction may affect population growth either positively or negatively (Chi et al. 2006). On one hand, the inconvenience caused by construction makes people unwilling to move in, and the temporary closure of business affects local economic development. On the other hand, the increased future value attracts people to move in. In the post-construction period, an improved or newly-built highway may not only serve to increase but may also decrease population, depending on the broader and secular trend in overall regional population growth (Voss and Chi 2006).

Third, highway effects on population redistribution vary across rural, suburban, and urban areas. The majority of studies on nonmetropolitan counties discovered that highways have a positive effect on population growth by drawing in migrants and fostering employment growth (e.g., Humphrey and Sell 1975; Lichter and Fuguitt 1980). However, a convenient highway can also attract rural residents to travel to the urban areas for employment prospects and urban amenities — a backwash or negative spillover effect (Boarnet 1998). In suburban areas, enhanced or newly-built highways strengthen the process of suburbanization, and generally have a positive effect on economic growth and development in addition to associated population growth (Moore et al. 1964). Highway effects in urban areas are uncertain because new or improved highways can either assist or thwart the development of urban areas depending on numerous other factors and the net effects of spread and backwash (Boarnet 1998, 1999).

These complex findings lead to different definitions and explanations of the function that highways serve in affecting population redistribution. Regional economic theories are particularly robust at describing the effects of highway construction on economic and population growth. For example, neoclassical growth theory regards highway infrastructure as an input into the production process via production relationships (Boarnet 1997a; Eberts 1990), an enhancer to increase the productivity of other inputs such as labor (Dalenberg and Partridge 1997; Eberts 1994), or a household amenity factor to attract workers (Dalenberg and Partidge 1997; Eberts 1994). Growth pole theory regards highway investments as a catalyst for change – an improved highway is neither necessary nor sufficient to influence population growth in its surrounding areas (Thiel 1962). Location theory regards highway infrastructure as a facilitator for the flow of raw materials, capital, finished goods, consumers, and ideas among central places and their neighborhoods and a barrier of these flows (Thompson and Bawden 1992), as a means of importing inputs into and exporting outputs out of a location (Vickerman 1991), or as necessary but not sufficient means for local economic growth and development (Halstead and Deller 1997).

These differences may be due to the limited examination and understanding of highway effects on economic and population growth. Many existing studies do not sufficiently control for other influential factors of economic and population growth, and do not appropriately take into account the spatial dynamics of highway effects (Voss and Chi 2006). Considering these issues, this study attempts to study the effects of highway expansion on population redistribution by take a relatively integrated spatial approach.

2.2 Airport Impacts on Population Change

There also exists a large literature studying airport impacts on economic growth and development. The conventional wisdom is that airports play an important role in promoting economic growth and development. Most of the literature focuses on economic and employment growth rather than population change. Reviewing the sizable literature provides a preliminary understanding of the impacts on population change, which can assist in designing an effective research procedure for investigating those impacts.

Most of the studies are conducted in metropolitan areas. For example, Irwin and Kasarda (1991) studied the causality between airline network and employment growth in U.S. metropolitan areas. They found that airline network is a cause rather than a consequence of employment growth. Brueckner (2003) found that good airline service, which is measured by passenger enplanements, is an important factor in promoting urban economic growth. However, airline service has effects on promoting service employment growth but not manufacturing employment growth. Green (2007) found that enplanement is a powerful predicator of population and employment growth in metropolitan areas.

A few studies have been conducted in rural areas. For instance, Rasker et al. (2009) found that access to airport plays a vital role in promoting economic development in high-amenity rural areas. However, Isserman, Feser, and Warren (2009) found that in rural areas, distance to major airports is relatively unimportant, contradicting conventional wisdom.

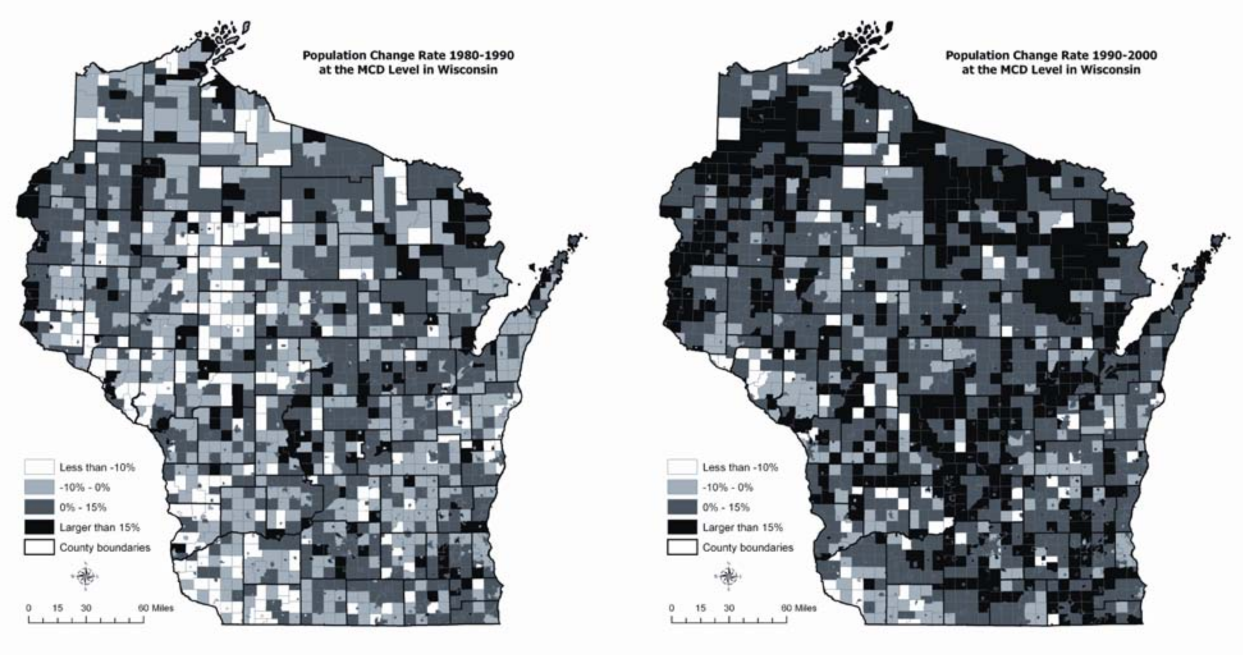
2.3 Intermodal Impacts on Population Change

There exists a small literature examining the impacts of highways and airports as a whole rather than individually on population and employment change. This literature sees highways and airways as passenger intermodal transportation, in which passengers optimize the use the highways and airways to reach their destination. This literature often measures the intermodal impacts by calculating the accessibility that highways and airways can collectively best provide. For example, Paez (2004) examined the relationship between intermodal network accessibility and the spatial distribution of economic activities in East Asian countries. The findings suggest that the impact of intermodal accessibility is negligible when contextual factors are considered. Further, Combes and Linnemer (2000) found that the addition of airports promotes relocation of firms, which in turn leads to population flows.

3. DATA

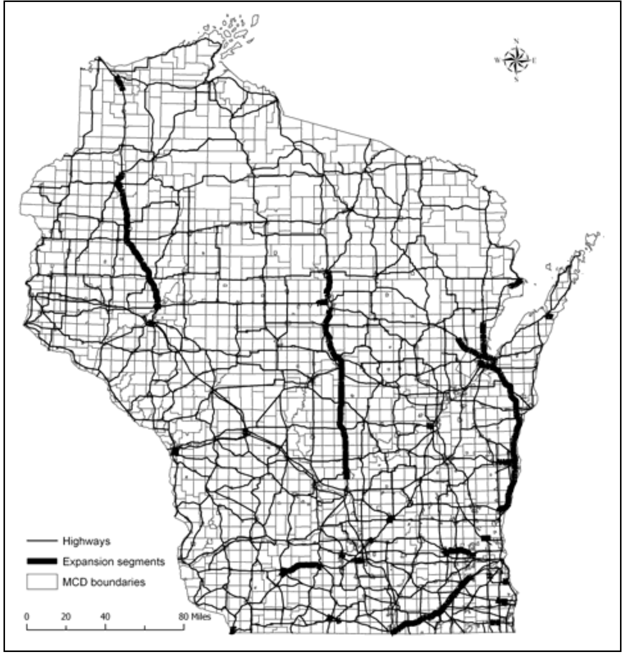
The research case for this study is the state of Wisconsin. This study investigates the effects of highway expansion, highways, and airports on population change at the minor civil division (MCD) level. Population data are from decennial censuses 1970-2000 (Figure 1).

Figure 1. Population Growth from 1980-2000 at the MCD Level in Wisconsin



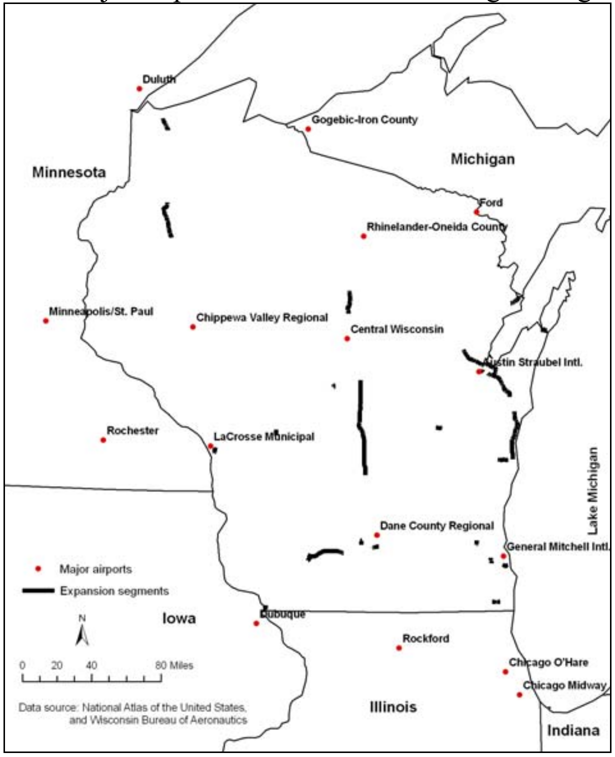
The Wisconsin Department of Transportation (WDOT) provided major highways in Wisconsin (Figure 2). The WDOT also provided the highway expansion data from 1970 to 1990 at five-year intervals, and the data are restricted to highway expansion of two lanes to four or more lanes (Figure 2).

Figure 2. Highways and Expansions from 1970-1990 in Wisconsin



Major airport location and enplanement data (Figure 3) come from the Wisconsin Bureau of Aeronautics of Department of Transportation, the National Atlas of the United Sates, Iowa Office of Aviation of the Department of Transportation, the Michigan Bureau of Aeronautics and Freight Services of the Department of Transportation, the Minnesota Office of Aeronautics of the Department of Transportation, the O'Hare International Airport, and the Duluth International Airport.

Figure 3. Major airports in Wisconsin and neighboring states



Data source: National Atlas of the United States, and Wisconsin Bureau of Aeronautics

In addition, an extensive review of the pertinent literature results in more than 70 variables that are believed to significantly affect population redistribution theoretically or empirically. Thirty-seven influential variables are selected for this study based on: 1) theoretical or empirical relationships judged to be important to this study, and 2) the availability of data. The variable categories include demographic characteristics, socioeconomic conditions, physical infrastructure, environmental and geophysical factors, cultural resources, and potential legal constraints. See Chi (2009) and Chi (2010) for a review of the variables. The data are quantified by a variety of datasets. Demographic and socioeconomic data are obtained from the U.S. Census Bureau, the Wisconsin Department of Public Instruction, the Federal Bureau of Investigation, and the State of Wisconsin Blue Books. The data of geophysical factors and natural amenity characteristics are provided by the Wisconsin Department of Natural Resources, the U.S. Geological Survey, and the Environmental Remote Sensing Center and the Land Information and Computer Graphics Facility of the University of Wisconsin-Madison.

The unit of analysis is MCD. Wisconsin is a "strong MCD" state and its MCDs are functioning governmental units (with towns, cities, and villages that have elected officials who provide services and raise revenues). The MCD geography is comprised of non-nested, mutually exclusive and extensive political territories. The primary advantage of using MCDs is their relevance to public policy-making and planning[1]. Another advantage in using MCDs as units of analysis is that transportation planners often forecast traffic demands at the level of city, village, and town.

MCD boundaries are not static over time: boundaries change, new MCDs emerge, old MCDs disappear, names change, and status in the geographic hierarchy shifts (e.g., towns become villages and villages become cities). Three rules are applied to modify the data to account for these changes: 1) new MCDs must be merged back into their original MCDs from which they emerge; 2) the difficulty of disappearing MCDs can be resolved by dissolving the original MCDs into their current "home" MCDs; and 3) occasionally, several individual MCDs must be merged into one super-MCD to establish a consistent data set. Following these rules, the final analytical dataset is composed of 1,837 MCDs with an average size of 29.56 square miles.

4. ANALYTICAL APPROACH

This section addresses an integrated spatial approach for examining highway and airport impacts on population change (Chi 2010). This section further details the methods and procedures of examining highway expansion impacts on population change, and comparing the impacts of highways and airports on population change.

4.1 An Integrated Spatial Approach

This research uses an integrated spatial approach (Chi 2010) to examine highway effects on population change. The integrated spatial approach includes three parts: a simultaneous consideration of spatial lag and spatial error dependence, considering spatial variations of the impacts, and a systematic selection of the optimal spatial weights matrix.

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[1] In most parts of the State, census tracts have an average size similar to MCDs and provide an alternative unit of analysis. However, census tracts are geographic units delineated by the Census Bureau only for counting population purposes, and they have no political or social meanings.

A Simultaneous Consideration of Spatial Lag and Spatial Error Dependence

Each set of models are estimated by two OLS regressions, a spatial lag model, a spatial error model, and a SARMA model. The three spatial regression models are to encompass spatial dependence into the model. In spatial econometric terms, spatial lag and spatial error dependence are the two most frequently referred forms of spatial dependence.

However, spatial lag and spatial error dependence are examined separately in numerous studies of highway-population dynamics that account for spatial dependence. For example, Voss and Chi (2006) use a spatial lag model and a spatial error model to study highway effects on population growth. They found that their examination of spatial dependence appears to have little effect on the original OLS coefficient estimates and their significance. In addition, their diagnostics show that both spatial lag and spatial error dependence remain in one or more of the models. Thus, the questions are "Are the models specified appropriately?", or, "Can the models be improved?" Simultaneously considering both spatial lag and spatial error dependence is one potential improvement, which can be achieved in a simple SARMA model combining a first-order spatial lag term with a first-order spatial error term.

Considering Spatial Variations of the Impacts

Besides spatial dependence, spatial heterogeneity is another type of spatial effects. Spatial heterogeneity refers to variations in coefficients or error patterns across geographic areas (LeSage 1999). The effects of highway expansion on population change might exhibit spatial heterogeneity. Prior research suggests that highway effects on population change vary across rural, suburban, and urban areas (for a detailed discussion, see Chi et al. 2006). Most studies on nonmetropolitan counties discovered that highways have a positive effect on population growth by drawing in migrants and fostering employment growth (e.g., Humphrey and Sell 1975; Lichter and Fuguitt 1980). However, a convenient highway can also attract rural residents to travel to the urban areas for employment prospects and urban amenities — a backwash or negative spillover effect (Boarnet 1998). In suburban areas, enhanced or newly-built highways generally have a positive effect on economic and population growth (Moore et al. 1964). Improved highways better facilitate the connection between urban and suburban areas, and strengthen the process of suburbanization. Highway effects in urban areas are more complex because new or improved highways can either assist or thwart the development of urban areas depending on numerous other factors and the net effects of spread and backwash (Boarnet 1998, 1999).

Thus, the spatial variations across rural, suburban, and urban areas should be considered in examining the effects of highway expansion on population change. This study applies a spatial regime model[2] (Anselin 1990; Patton and McErlean 2003) to deal with the spatial heterogeneity issue. Three regimes are assumed to exist – one for the urban areas, one for the suburban areas, and one for the rural areas. The spatial regime model estimates coefficients separately for each regime. The overall structural stability and coefficient stability for each variable are diagnosed by the spatial Chow test. Ideally, we would like an estimation of spatial heterogeneity together with a simultaneous consideration of spatial lag and spatial error dependence. Practically, the spatial regime model can be run within the context of a spatial error model with lag dependence. Coefficients are still estimated separately for each regime. Spatial lag effects are also estimated separately for each regime, and a spatial error effect is estimated for the overall model.

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[2] Alternatively, the spatial heterogeneity issue can be dealt with by using the geographically weighted regression (GWR) method (Fotheringham et al. 2002), or partitioning study area into several regions that exhibit different spatial patterns (e.g., Baller and Richardson 2002). However, the GWR method cannot consider spatial heterogeneity and dependence simultaneously. Partitioning data is a common practice to deal with spatial heterogeneity in sociological studies. However, it imposes practical difficulty in controlling spatial dependence because the partitioned urban and suburban areas are not continuous.

The Optimal Spatial Weight Matrix

To account for spatial dependence in spatial regression models, it is essential to create a neighborhood structure for each location by specifying those locations on a lattice that are considered as its neighbors (Anselin 1988). Specifically, we need to designate a spatial weight matrix corresponding to the neighborhood structure such that the resulting variance-covariance matrix can be expressed as a function of a small number of estimable parameters relative to the sample size (Anselin 2002). However, many studies select a spatial weight matrix without sound justification or evaluating the selected spatial weight matrix to others. While a spatial weight matrix is needed for spatial regression modeling, the selection of neighborhood structure usually receives little theoretical guidance in practice. A spatial weight matrix often is defined exogenously, and comparison of several spatial weight matrices should be done before choosing a justifiable one. For example, we can develop and compare several spatial weight matrices, and choose the one that achieves a high coefficient of spatial autocorrelation in combination with a high level of statistical significance, although currently there is little theoretical support for this method (Chi and Zhu 2008; Voss and Chi 2006).

In this study, the magnitudes and significance of Moran's I for each model are independently examined and tested by using 40 different spatial weight matrices. The optimal weight matrix to select is the one that achieves the highest coefficient of spatial autocorrelation in combination with a high level of statistical significance. The spatial weight matrices include the rook's case and queen's case contiguity weight matrices with order 1 and order 2, the k-nearest neighbor weight matrices with k ranging from 3 to 8 neighbors, and the general distance weight matrices and the inverse-distance weight matrices with power 1 or power 2, from 0 to 100 miles at 10-mile increments based on the distance between the centroids of MCD.

The optimal weight matrix for running the spatial lag model is chosen by comparing Moran's I of population growth rate. The optimal weight matrix for running the spatial error model is selected on the basis of Moran's I of the OLS residuals. The SARMA needs two spatial weight matrices, one based on Moran's I of population growth which is the spatial lag term, and the other based on the Moran's I of the SEM residuals which is the spatial error term. In addition, a z-score (the test statistic for the significance of the Moran's I statistic) is computed as the ratio of Moran's I and the corresponding standard error. The p-values are calculated using a normal approximation.

For Set 1 models, the 5-nearest neighbor weight matrix, which encompasses the highest spatial autocorrelation of the response variable, is chosen for running the spatial lag model. The 5-nearest neighbor weight matrix, which encompasses the highest spatial autocorrelation of the residuals, is also chosen for running the spatial error model. The SARMA model has both a spatial lag term and a spatial error term. The 5-nearest neighbor weight matrix is chosen to account for the spatial lag term, and the squared inverse distance (distance decay) within 10 miles weight matrix is chosen to control for the spatial error term as this matrix encompasses the maximum spatial autocorrelation of the residuals after fitting a spatial lag model.[3]

For Set 2 models, the 4-nearest neighbor weight matrix is chosen for running the spatial lag model, and the 5-nearest neighbor weight matrix is chosen for the spatial error model. The SARMA model employs the 4-nearest neighbor weight matrix to account for the spatial lag term and the squared inverse distance within 10 miles to encompass the spatial error term.

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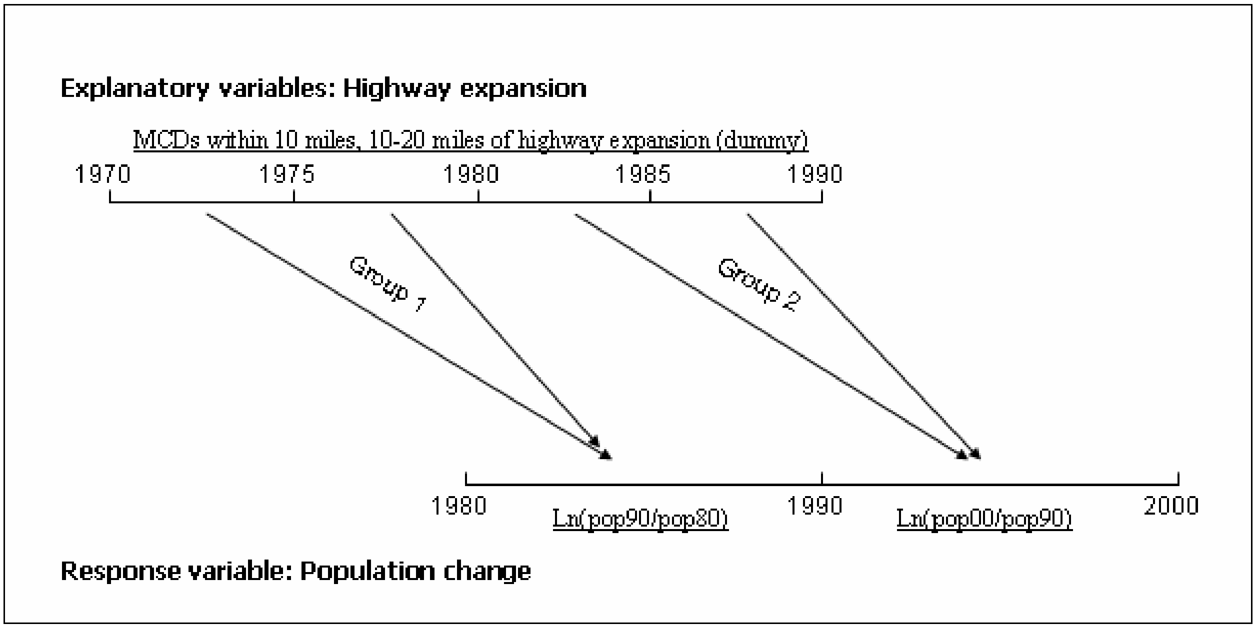
[3] The detailed results are available from the author upon request.

4.2 Examining Highway Expansion Impacts on Population Change

When examining highway impacts only on population change, I focus on expanded highway segments rather than existing highways. Presently most highway and interstate highway systems have been completed. Current highway construction activities primarily focus on expanding or improving existing highways instead of building new highways. According to the executive director of the National Academies' Transportation Research Board, "[m]uch of the existing highway systems, particularly interstates and primary arterial highways, must be reconstructed in the coming years" (Skinner 2002, p. 34). It is essential to know the impacts of highway expansion on population redistribution as well as economic growth and development. In this part of the analysis, highway expansion refers to added travel lanes based on existing highway segments, for example, expanding a highway from 2 lanes to 4 or more lanes.

This analysis investigates the effects of highway expansion on population redistribution from 1980-2000 at the MCD level in Wisconsin. The population redistribution process demonstrated diverse patterns in the two decades — "deconcentration slowdown" in the 1980s and "rural rebound" in the 1990s (Johnson 1999). This research examines the impacts of highway expansion separately in two sets of models — the first set evaluates the effects of highway expansion completed in 1970-75 and 1975-80 on population growth in 1980-90, and the second set evaluates the effects of highway expansion concluded in 1980-85 and 1985-90 on population growth in 1990-2000 (Figure 3; from Chi [2010]). Comparing the two different redistribution processes can provide a more complete understanding of highway expansion's impacts on population redistribution, and indicate the consistency of the effects.

Figure 3. Two Groups of Models



In both model sets, two ordinary least squares (OLS) regression models, one controlling influential factors of population redistribution and the other not, are first fitted to the data to reveal the importance of synthetically considering the influential factors of population redistribution. Model diagnostics are then performed to check the model assumptions. If spatial autocorrelation in the OLS residuals is found (as in this study), three spatial regression models — a spatial lag model (SLM), a spatial error model (SEM), and a spatial error model with lag dependence (SEMLD) model — are employed to re-evaluate the effects of highway expansion on population redistribution. The SEMLD model is further selected to examine highway expansion effects on population change across rural, suburban, and urban areas within a spatial regime context. These different models will finally be assessed and compared using log likelihood, Akaike's Information Criterion (AIC) and Schwartz's Bayesian Information Criterion (BIC).

4.3 Comparing the Impacts of Highways and Airports on Population Change

This subsection compares the impacts of highways and airports on population change. Their impacts are measured on the basis of the accessibility that highways and airports provide. Highway accessibility is measured as the natural log of highway density, i.e., the total lengths of highways in a MCD divided by its geographic area (Eq. 1). The higher the highway density, the higher the accessibility that a MCD has.

$$\text{Highway accessibility} = \ln(\text{Highway density}) \qquad (1)$$

The accessibility to airports is measured as a function of the distance from a MCD to its nearest airport and the enplanement in 1980 (Eq. 2). The farther away from the nearest airport, the lower accessibility to it. The larger the airport in terms of enplanement, the greater the accessibility from the airport to other regions.

$$\text{Airport accessibility} = \ln\left(\frac{1}{d_a^2} \times Enplanement_{1980}\right) \qquad (2)$$

where d_a represents the distance to nearest airport; and

$Enplanement_{1980}$ represents the enplanement in the nearest airport in 1980.

In addition, the accessibility improvement of highways and airports is also measured. The accessibility improvement of highways is measured as the natural log of the inverse distance-squared to nearest highway segment expanded from 1980-1990 (Eq. 3). The closer to a highway expansion segment, the more improved the accessibility.

$$\text{Highway improvement} = \ln\left(\frac{1}{d_h^2}\right) \qquad (3)$$

where d_h represents the distance to nearest highway segment expanded from 1980-1990.

The accessibility improvement of airports is measured as a function of both inverse distance-squared to the nearest airport and enplanement growth rate from 1980-1990 (Eq. 4). The greater the enplanement growth rate, the greater the accessibility improvement of airports.

$$\text{Airport improvement} = \ln\left(\frac{1}{d_a^2} \times \frac{Enplanement_{1990}}{Enplanement_{1980}}\right) \qquad (4)$$

The measures of accessibility and accessibility improvement of highways and airports are used for examining highway and airport impacts on population change. The four measures of highway and airport accessibility incorporate spatial effects: they consider the spatial effects from neighboring states (Michigan, Minnesota, Iowa, Illinois, and Indiana). Thus, spatial lag models, spatial error models, and spatial error models with lag dependence as used in the previous section are not used for this part of analysis. Instead, basic OLS models and spatial regime models are used to examine and compare the impacts of highways and airports on population change.

A number of variables are controlled for in examining highway and airport accessibility and improvement on population change. These variables are retained from Section 4.2 in examining highway expansion impacts on population change, and they are: *population density* (persons/kilometers squared), *young* (percent young population [aged 12-18]), *Bachelor's degree* (percent population [age≥25] with bachelor's degree), *female-headed families* (percent female-headed families with children under 18 years old), *unemployment* (unemployment rate), *income* (median household income), *public water* (percent housing units using public water), *seasonal housing* (percent seasonal housing units), *agriculture* (percent workers in agricultural industry), *commute time to work* (percent workers traveling>30 minutes to work), and *land developability* (percent lands available for development).

5. RESULTS

This section reports the findings on 1) the impacts of highway expansions on population change, 2) the spatial variations of highway expansion impacts, 3) the impacts of highways and airports on population change, and 4) the spatial variations of the impacts of highways and airports.

5.1 Highway Expansion Impacts on Population Change

Highway expansion segments completed from 1975-80 have a significant positive impact on population change from 1980-1990 when only population change in the previous decade is controlled (OLS 1; the first panel of Table 1). However, the significant impact disappears after controlling other influential factors of population change in OLS 2 model (the second panel of Table 1), which offers a better model fitting balanced with model parsimony. It suggests that it is essential to control other influential factors in examining the effects of highway expansion on population change. Among the three spatial regression models, the SEMLD model is the most appropriate model to interpret the regression coefficients, judging from the AIC and BIC values. Highway expansion segments completed from 1975-1980 gain slightly statistically significant negative effects on population change for MCDs within 10 miles of the expansion segments (SEMLD; the last panel of Table 1). Voss and Chi (2006) had similar findings and explained that the influence of highway expansion was unable to overcome the low overall population growth in the state. It may also be due to that the 1980-1990 was a period remarked with economic disruptions such as the farm debt crisis, de-industrialization, and urban revival (Johnson 1999). Highway expansion may simply facilitate population outflows. Population growth rate in the previous decade has positive effects on population growth, and one percent growth in the previous decade contributes 0.104 percent growth. MCDs that underwent rapid growth in the 1970s tended to keep growth into the 1980s.

Both spatial lag and spatial error effects explain population change significantly. The spatial lag effects come from the spatially-lagged population change. Each MCD gains 0.711 percent for each percent of weighted population growth in its neighbors. For the 1980-90 models, each MCD is specified to have five neighbor MCDs. If each of the five neighbors has gained 10% population growth, the spatial lag effects contribute 7.11% population growth to the MCD. The 7.11% growth is not from "organic" growth, but rather comes as a "gift" from its neighbors. The spatial lag effects can be understood somewhat as an indirect effect of highway expansion on population growth. Expanded highways provide improved accessibility to connect the MCDs together. Improved transportation infrastructure provides people additional autonomy in choosing their residency MCDs. When population growth in a MCD's neighbors leads to an increase of housing prices, it drives residents of neighbor MCDs and in-migrants to the MCD where housing prices are lower until an equilibrium is reached. In contrast, when population decline in a MCD's neighbors leads to a decrease of housing prices, it drive people out of the MCD to its neighbor MCDs until an equilibrium is reached. Thus, highway expansion is best regarded as a facilitator in strengthening the spatial lag effects of population redistribution. The significant spatial error term reveals spatial dependence in errors, which may be caused by not including important explanatory variables in the model. The inclusion of the spatial error effects assist in controlling those variables.

Table 1. Regressions of Highway Expansion on Population Growth from 1980-1990

	OLS 1	OLS2	SLM	SEM	SEMLD
Explanatory variables					
Within 10 miles of highway expansion, finished 5-9 years before population change period	0.010	0.012	0.009	0.012	0.003
At a range of 10-20 miles from highway expansion, finished 5-9 years before population change period	0.002	0.005	0.004	0.003	0.001
Within 10 miles of highway expansion, finished 0-4 years before population change period	0.024**	-0.009	-0.010	-0.005	-0.014*
At a range of 10-20 miles of highway expansion, finished 0-4 years before population change period	0.033***	0.016	0.011	0.017	0.003
Control variables					
Population growth rate from 1970-1980	0.196***	0.147***	0.129***	0.127***	0.104***
Population density in 1980	/	-2.72e-5	-2.37e-5	-2.24e-5	-1.87e-5
Percent young population (Age 12-18) in 1980	/	-0.819***	-0.814***	-0.855***	-0.660***
Percent population (Age 25+) with Bachelor's degree in 1980	/	0.042	0.024	0.038	0.004
Percent female-headed families with children under 18 years old in 1980	/	-0.003	-0.029	-0.019	-0.072
Unemployment rate in 1980	/	-0.143*	-0.126*	-0.135*	-0.079
Median household income in 1980	/	3.43e-6***	2.89e-6**	3.13e-6**	1.58e-6*
Percent housing units using public water in 1980	/	0.027*	0.033**	0.031**	0.036***
Percent seasonal housing units in 1980	/	0.059*	0.055*	0.073**	0.006
Percent workers in agricultural industry in 1980	/	-0.091***	-0.069**	-0.071**	-0.041
Percent workers traveling 30 minutes and less to work in 1980	/	0.019	0.010	0.011	-0.006
Land developability†	/	0.024	0.025	0.026	0.018
Constant	-0.024***	0.038	0.046	0.046	0.055**
Spatial lag effects	/	/	0.231***	/	0.711***
Spatial error effects	/	/	/	0.213***	-0.494***
Measures of fit					
Log likelihood	1374.99	1453.38	1478.56	1477.72	1603.36
AIC	-2737.98	-2872.76	-2921.13	-2921.43	-3170.72
BIC	-2704.89	-2778.99	-2821.84	-2827.66	-3071.43

Notes: * significant at p≤0.05 for a two-tail test; ** significant at p≤0.01 for a two-tail test; *** significant at p≤0.001 for a two-tail test; standard errors in brackets.

In the 1990-2000 models, highway expansion segments completed from 1985-1990 have a significant positive impact on population change from 1990-2000 no matter if population change's other influential factors are controlled (Table 2). These two explanatory variables remain significant in the spatial lag model and spatial error model, although the regression coefficients and significance are lesser in magnitude. However, none of the four highway expansion variables are significant in the SEMLD model. Similar as in the 1980-90 models, the most appropriate model to interpret the regression coefficients is the SEMLD model.

Table 2. Regressions of Highway Expansion on Population Growth from 1990-2000

	OLS 1	OLS2	SLM	SEM	SEMLD
Explanatory variables					
Within 10 miles of highway expansion, finished 5-9 years before population change period	-0.008	0.002	0.003	0.001	0.003
At a range of 10-20 miles from highway expansion, finished 5-9 years before population change period	-0.009	-0.010	-0.010	-0.012	-0.007
Within 10 miles of highway expansion, finished 0-4 years before population change period	0.042***	0.034**	0.026*	0.037**	0.012
At a range of 10-20 miles of highway expansion, finished 0-4 years before population change period	0.041***	0.033***	0.027***	0.037***	0.011
Control variables					
Population growth rate from 1980-1990	0.311***	0.206***	0.176***	0.164***	0.160***
Population density in 1990	/	-7.26e-5***	-6.34e-5***	-6.04e-5**	-6.24e-5***
Percent young population (Age 12-18) in 1990	/	-0.174	-0.153	-0.115	-0.241*
Percent population (Age 25+) with Bachelor's degree in 1990	/	-0.097	-0.087	-0.082	-0.076
Percent female-headed families with children under 18 years old in 1990	/	-0.054	-0.102	-0.095	-0.155
Unemployment rate in 1990	/	-0.169	-0.161	-0.156	-0.159
Median household income in 1990	/	2.90e-6***	2.55e-6***	2.49e-6***	1.99e-6***
Percent housing units using public water in 1990	/	0.071***	0.070***	0.068***	0.062***
Percent seasonal housing units in 1990	/	0.240***	0.221***	0.244***	0.147***
Percent workers in agricultural industry in 1990	/	-0.155***	-0.127***	-0.145***	-0.080*
Percent workers traveling 30 minutes and less to work in 1990	/	0.098***	0.083**	0.089**	0.062**
Land developability	/	0.079***	0.075***	0.081***	0.050**
Constant	0.083***	-0.057	-0.060*	-0.056	-0.037
Spatial lag effects	/	/	0.185***	/	0.551***
Spatial error effects	/	/	/	0.201***	-0.380***
Measures of fit					
Log likelihood	933.48	1046.79	1065.23	1067.57	1099.43
AIC	-1854.96	-2059.58	-2094.47	-2101.15	-2162.86
BIC	-1821.86	-1965.81	-1995.18	-2007.38	-2063.57

Population change in the previous decade has positive effects on population change from 1990-2000, and each percent growth in the previous decade contributes 0.160 percent growth. Both spatial lag and spatial error effects are significant in explaining population change. Each MCD gains 0.551 percent growth for each percent of weighted population growth in its neighbor MCDs. Highway expansion, through its role as a facilitator, influences population redistribution indirectly by strengthening the spatial lag effects. The spatial lag effects are much greater than the temporal effects.

The comparison across the five models in each decade suggests that it is essential to holistically consider population change's influential factors and simultaneously incorporate spatial lag and spatial error dependence. Highway expansion appears to influence population change as a facilitator of population redistribution directly and indirectly. But, is the influence uniform over the whole Wisconsin? Previous studies suggest that highway effects differ across principal cities, suburbs, and rural areas. The effects of highway expansion may follow the similar patterns. Thus, the SEMLD, the best model among the five regression models, is applied in a spatial regime context to re-analyze the impacts across principal cities, suburbs, and rural areas.

5.2 Spatial Variations of Highway Expansion Impacts on Population Change

The results suggest that both direct and indirect effects of highway expansion differ across urban, suburban, and rural areas – no statistically significant effects in urban areas, but direct and indirect effects in suburbs, and indirect effects in rural areas.

First, highway expansion has both direct and indirect effects on population change in suburbs. Highway expansion completed from 1975-1980 had direct effects on population change in the 1980s for suburban MCDs within 10 miles of expansion segments. Suburban population change in the 1990s was also directly affected by two highway expansion variables. However, the effects were negative in the 1980s but positive in the 1990s. This phenomenon can be explained by the "spread" and "backwash" effects of the growth pole theory. The 1980s was the slowest growth period in Wisconsin history and was remarked with economic disruptions such as farm debt crisis, de-industralization, and urban revival (Johnson 1999). The metropolitan areas grew while the nonmetropolitan areas declined – a characteristic of backwash effects. Here highway expansion acts as a facilitator of population flows. The suburbs with highway expansion have lost residents to principal cities. The 1990s has experienced rural rebound and spread effects. Natural amenities attracted retirees into the recreational counties (Johnson 1999). Again, highway expansion acts as a facilitator of population flows. Given the locational advantages to access both job opportunities in urbanized areas and natural amenities in rural areas, the suburban areas benefited from highway expansion.

Highway expansion also has indirect effects on population change in suburbs, and the effects are positive in both decades. As discussed in the previous section, the indirect effects can be understood as population growth gained from neighbors. A suburban MCD will likely gain (or lose) population if its neighbors do. Highway expansion can still be understood as a facilitator of population flows in suburban areas.

Second, highway expansion has indirect but no direct effects on population change in rural areas. The effects are positive in both decades. A rural MCD will likely gain (or lose) population if its neighbors do. Again, highway expansion can still be understood as a facilitator of population flows in rural areas. However, highway expansion has no direct effects in rural areas in any decade. One possible reason is that the direct effects occur at the regional level rather than the MCD level – the scale effect of the modifiable areal unit problem (citation). Growth and development in rural areas more relies on the regional growth and development. This explanation can be implicitly supported by the comparison of indirect effects across rural areas, suburbs, and principal cities. The indirect effects are the strongest in rural areas in both metropolitan growth and rural rebound. Rural MCDs benefit the most from its neighbors' growth. Thus, highway expansion plays a more important role in facilitating population flows in rural areas, and tends to unit rural MCDs into a region.

Table 3. Spatial Regime Spatial Error Model with Lag Dependence by Principal Cities, Suburbs, and Rural Areas

	1980-1990			1990-2000		
	Principal cities	Suburbs	Rural areas	Principal cities	Suburbs	Rural areas
Explanatory variables						
Within 10 miles of highway expansion, finished 5-9 years before population change period	0.034	-0.009	0.005	0.005	0.055**	-0.001
At a range of 10-20 miles from highway expansion, finished 5-9 years before population change period	0.032	2.10e-4	0.004	0.041	-0.005	-0.002
Within 10 miles of highway expansion, finished 0-4 years before population change period	-0.024	-0.030*	-0.013	0.084	0.008	-0.005
At a range of 10-20 miles of highway expansion, finished 0-4 years before population change period	-0.054	0.013	-0.007	0.024	0.036**	0.006
Control variables						
Population change in previous decade	0.304***	0.150***	0.054***	0.446***	0.455***	0.015
Population density	8.27e-6	-4.66e-5	-3.26e-6	-7.46e-5	-6.20e-5	-5.42e-5
Percent young population (Age 12-18)	-1.374*	0.024	-0.721***	0.192	-0.799**	-0.139
Percent population (Age 25+) with Bachelor's degree	-0.225	0.127	-0.024	-0.085	-0.056	-0.020
Percent female-headed families with children under 18 years old	-0.145	-0.145	-0.089	-1.830	0.078	-0.210
Unemployment rate	-0.860	-0.172	-0.092	0.408	-0.033	-0.097
Median household income	5.72e-6	1.27e-6	6.55e-7	5.75e-8	3.08e-6*	2.15e-6**
Percent housing units using public water	0.057	0.096***	0.010	0.062	0.097**	0.045**
Percent seasonal housing units	1.606	0.062	0.011	-5.584	0.105	0.153***
Percent workers in agricultural industry	3.924***	-0.064	-0.064**	4.018	0.036	-0.104**
Percent workers traveling 30 minutes and less to work	0.045	0.025	-0.016	0.694***	0.032	0.054*
Land developability	-0.024	0.027	0.025	-0.081	0.087*	0.056**
Constant	0.075	-0.065	0.093***	-0.013	-0.056	-0.060
Spatial lag effects	0.117	0.579***	0.740***	0.080	0.298***	0.617***
Spatial error effects		-0.501**			-0.379***	
Measures of fit						
Spatial chow test	94.26 with (36, 1837) degrees of freedom ***			123.77 with (36, 1837) degrees of freedom ***		
Log likelihood	1650.80			1188.92		
AIC	-3193.60			-2269.84		
BIC	-2895.74			-1971.98		

Third, highway expansion has neither direct nor indirect effects on population change in principal cities. As discussed in previous studies, highway effects in principal cities are uncertain because new or improved highways can either help or hinder the development of urban areas depending on many other factors as well as the net effects of spread and backwash (Boarnet 1998, 1999). This study suggests two additional possible reasons. One is that the effects of highway expansion in principal cities should be studied at a finer geographic level such as census tracts, block groups, or even blocks. Principal ciies are more densed than suburban and rural areas. Highway expansion may be unpleasant to immediate neighborhoods but may be favorable to neighborhoods a few blocks away. The other is that population growth in principal cities is more vulnerable to land use planning and policy regulations. The divisions of residential, commercial, and other developments companioned with zoning regulations complicate population growth and make highway expansion less important in promoting local growth and development.

5.3 Impacts of Highways and Airports on Population Change

The impacts of highways and airports on population change are compared in three OLS regression models (Table 4). Model 1 compares the impacts of highway accessibility and improvement in highway accessibility on population change from 1980-1990. The improvement in highway accessibility has significant impacts on population change, but highway accessibility does not. Highway improvement from 1970-1980 is associated with population growth from 1980-1990. Model 2 compares the impacts of airport accessibility and improvement in airport accessibility on population change. Airport accessibility has significant impacts on population change, but improvement in airport accessibility does not. Airport accessibility is associated with population growth from 1980-1990. Model 3 compares the impacts of both highway and airport accessibility and improvement in accessibility. Only airport accessibility plays a significant role in promoting population growth.

Overall, airport accessibility has the strongest impact on population growth from 1980-1990. Highway improvement plays a significant role on promoting population growth, only when airport accessibility is not considered. Highway accessibility and airport improvement have no impacts on population growth from 1980-1990. However, as found in highway expansion impacts on population change, the impacts of highways and airports on population change may differ across rural, suburban, and urban areas, which are reported in the next subsection.

Table 4. Ordinary Least Squares (OLS) regressions

	Model 1	Model 2	Model 3
Highway accessibility	0.009	/	0.005
Highway improvement	0.003*	/	0.002
Airport accessibility	/	0.018***	0.017***
Airport improvement	/	-0.004	-0.004
Population density	-5.45E-5**	-7.07E-5***	-7.54E-5***
Young	-0.881***	-0.860***	-0.860***
Bachelor's degree	0.035	0.077	0.077
Female-headed families	-0.028	-0.028	-0.037
Unemployment	-0.148*	-0.091	-0.087
Income	3.46E-6***	3.27E-7	1.32E-7
Public water	0.028*	0.028*	0.029*
Seasonal housing	0.103***	0.108***	0.109***
Agriculture	-0.161***	-0.126***	-0.124***
Commute time to work	0.034	-0.004	-0.000
Land developability	0.040*	0.038*	0.037*
Constant	0.081**	-0.002	0.010
Measures of fit			
Adjusted R^2	0.1357	0.1631	0.1638
Log likelihood	1405.21	1434.81	1436.52
AIC	-2782.42	-2841.61	-2841.05
BIC	-2705.20	-2764.39	-2752.79

Note: Robust standard errors are in parentheses.
$*p \leq .05$; $**p \leq .01$; $***p \leq .001$
AIC = Akaike's Information Criterion. BIC = Schwartz's Bayesian Information Criterion.

5.4 Impacts of Highways and Airports on Population Change across Rural, Suburban, and Urban Areas

Table 5 shows the descriptive statistics of highway and airport accessibilities across rural, suburban, and urban areas. Each of the four measures increases from rural to suburban to urban areas. It is not just that highway and airport accessibilities are higher in urban areas than those in rural areas, but also that the improvement in highway and airport accessibilities are higher in urban areas than those in rural areas.

The impacts of highways and airports on population change are examined across rural, suburban, and urban areas (Table 6). The results suggest that 1) both highway improvement and airport accessibility have positive effects on promoting population growth in rural areas; 2) highway accessibility has negative but airport accessibility has positive effects on promoting population growth in suburban areas; and 3) highways and airports have no effects on population change in urban areas.

Table 5. Descriptive statistics of highway and airport measures

	All	Rural	Suburban	Urban
Highway accessibility	0.822	0.753	0.874	1.644
	(0.527)	(0.475)	(0.468)	(0.786)
Highway improvement	-5.781	-6.088	-5.281	-3.443
	(1.931)	(1.732)	(1.975)	(2.482)
Airport accessibility	5.043	4.426	6.330	8.378
	(1.866)	(1.451)	(1.666)	(1.807)
Airport improvement	-6.665	-7.002	-5.998	-4.671
	(1.148)	(0.841)	(1.205)	(1.511)

Note: Each cell contains a mean followed by a standard error in parentheses.

In rural areas, both highway improvement and airport accessibility are associated with population growth from 1980-1990. Highway improvement acts as an investment to promote rural population growth. The neoclassical growth theory considers highway improvement as an input into the production process via a production function. Many recent literature (e.g., Boarnet 1997; Eberts 1990) uses the production function to examine the linkage between public capital and economic productivity. As the level of highway investment increases, outputs also increase. Airport accessibility is associated with population growth in rural areas: the rural areas that are closer to airports have locational advantages to access airports, and are often argued to be preferred residential areas in the residential preference literature (e.g., Fuguitt and Brown 1990; Fuguitt and Zuiches 1975).

In suburban areas, highway accessibility is negatively but airport accessibility is positively associated with population growth. Wisconsin has experienced the slowest growth in history from 1980-1990. It seems that highways act as a facilitator of out-migration. Location theory see highways as a facilitator for the flows of raw materials, capital, finished goods, consumers, and ideas among central places and their neighborhoods, and a limitation on these flows (Thompson and Bawden 1992). Highways are further argued as a facilitator of population flows (Chi 2010): highways can not only be associated with population growth, but also with population decline. Highways itself does not promote or hinder population change, but only promote population flows.

Airport accessibility is positively associated with suburban population growth. Suburban areas have locational advantages to access both urban amenities and rural amenities, and also have relatively lower housing prices than urban areas. Thus, suburban areas that are closer to airports are more attractive.

In urban areas, none of the four accessibility measures are associated with population change from 1970-1980 due to four possible reasons. First, highway and airport impacts on population change in urban areas are complex— highways and airports can either help or hinder the development of urban areas depending upon many other factors as well as the net effects of spread and backwash. Second, the findings may be limited due to the scale effect—highways are seen as a noise and pollution producer for immediate neighborhoods, but are seen to provide accessibility to neighborhoods just a few blocks away; airport impacts may be larger geographically. Third, population change in urban areas is mot volatile to land use planning and regulations. Fourth, the impacts may be at the later stage of the cycle in which highways and airports do not produce substantial impacts comparing to other factors (Thompson and Bawden 1992).

Table 6. Spatial regime regressions by rural, suburban, and urban areas

	Model 1				Model 2				Model 3			
	R	S	U	Instab	R	S	U	Instab	R	S	U	Instab
Highway accessibility	0.011	-0.020	0.018	*	/	/	/		0.010	-0.025*	0.021	*
Highway improvement	0.004*	-0.004	0.008		/	/	/		0.004*	-0.006	0.011	**
Airport accessibility	/	/	/		0.014***	0.017**	-0.022		0.014***	0.018***	-0.042	*
Airport improvement	/	/	/		-0.007	0.002	0.024		-0.007	0.004	0.038	*
Population density	-5.36E-5	-3.06E-5	-5.55E-5		-4.38E-5	-2.17E-5	-4.14E-5		-5.75E-5	-2.72E-5	-2.01E-5	
Young	-0.970***	-0.361	-1.819**		-0.916***	-0.509	-1.804**		-0.914***	-0.507	-1.972**	
Bachelor’s degree	0.051	0.148	-0.123		0.081	0.145	-0.244		0.075	0.140	-0.336	
Female-headed families	-0.041	-0.113	-0.329		-0.034	-0.132	-0.273		-0.047	-0.123	-0.356	
Unemployment	-0.102	-0.421*	0.041		-0.071	-0.213	-0.922		-0.072	-0.258	-0.907	
Income	1.37E-6	4.71E-6*	9.41E-7		-5.65E-7	2.12E-6	1.30E-6		-1.08E-6	2.35E-6	4.17E-6	
Public water	-0.005	0.104***	0.147*	***	-0.007	0.098***	0.132*	**	-0.004	0.093**	0.134*	**
Seasonal housing	0.092***	0.159*	1.407		0.096***	0.174*	0.749		0.096***	0.190*	0.923	
Agriculture	-0.158***	-0.160*	4.703*		-0.133***	-0.079	5.240*	*	-0.133***	-0.105	4.682*	
Commute time to work	-0.018	0.134**	0.133	**	-0.040	0.111*	0.248	**	-0.036	0.095*	0.394	**
Land developability	0.045*	0.040	0.168		0.047*	0.041	0.179		0.040*	0.046	0.208*	
Population density	0.131***	-0.056	0.131		0.018	-0.099	0.469		0.049	-0.098	0.640*	*
Measures of fit												
Adjusted R^2	0.1723				0.1875				0.1942			
Log likelihood	1459.16				1476.21				1486.89			
AIC	-2834.33				-2868.41				-2877.78			
BIC	-2602.66				-2636.75				-2613.02			

Note: Robust standard errors are in parentheses.
$*p \leq .05$; $**p \leq .01$; $***p \leq .001$
AIC = Akaike’s Information Criterion. BIC = Schwartz’s Bayesian Information Criterion.

6. SUMMARY AND DISCUSSION

6.1 Summary

There exists a large literature of transportation impacts on economic and demographic change. Prior studies have focused on single modes of transportation individually rather than integrating these modes. Yet, little work has been undertaken to study the economic and demographic impacts of intermodal transportation systems. This study fills the gap in the literature by examining intermodal passenger transportation on demographic change. Specifically, this research investigates the effects of highways, highway expansions, and airports on population change in the minor civil divisions of Wisconsin by adopting an integrated spatial approach. The findings suggest that the impacts of highway expansion on population change differ across rural, suburban, and urban areas: there are only indirect effects in rural areas, both direct and indirect effects in suburban areas, and no statistically significant effects in urban areas. Overall, highway expansion serves as a facilitator of population change within the framework of growth pole theory and location theory. Furthermore, the results show that airport accessibility and highway improvement affect population change, but highway accessibility and airport improvement do not. However, the effects exhibit variation across rural, suburban, and urban areas. Highway improvement acts as an investment input and airport accessibility uses the locational advantage to promote rural population growth. In suburban areas, airport accessibility promotes population growth but highway accessibility acts as a facilitator of out-migration. The effects on urban population change are not statistically significant and are likely constrained to land use policies and regulations. This study have important implications to transportation planning as transportation planning practices are focusing more attention on intermodal transportation systems as a whole rather than any single mode of transportation. Intermodal transportation systems have become increasingly important for transportation performance and efficiency.

6.2 Future Research

Future Research 1: Modeling Population and Employment Change Simultaneously

Future research could model population and employment growth simultaneously in a spatial structural equation context. Empirical studies on regional development often stress the interdependency between household residential choices and firm location decisions, especially in the literature identifying causality between population and employment change (Henry, Barkley, and Bao 1997). Many studies of regional studies treat population and employment change to be endogenous (e.g., Boarnet 1994a, 1994b).

However, these studies have not incorporated spatial effects into their models. Oud and Folmer (2008) developed a spatial structural equation model, which not only models population and employment change simultaneously, but also considers spatial dependence. This model could be used for studying highway and airport impacts on population and employment change.

Future Research 2: Adding Public Transportation System in Metropolitan Areas

This study is conducted in Wisconsin, which is conventionally considered as a rural state. Future research could examine the intermodal passenger transportation in metropolitan areas. In metropolitan areas, passengers can not only access highways and airways, but also have easy accessibility to public transportation. The addition of public transportation could generate more useful and interesting information to transportation planner.

Future Research 3: Measuring the Accessibility of Intermodal Transportation System

Some studies examine transportation effects on population and employment growth through accessibility (e.g., Paez [2004]). However, most studies assess the accessibility of single modes of transportation. Considering the importance of intermodal transportation systems in facilitating passenger travel, evacuation, and disaster relief delivery, it is essential to create an accessibility measure of intermodal transportation systems in which passengers optimize the choice of transportation modes.

There are three types of accessibility measures—cumulative opportunities measures, utility-based measures, and gravity-based or economic opportunities measures (Handy and Niemeier 1997). The gravity-based measure is preferred because it allows flows between counties while accounting for economic opportunities in destination counties. The general formula for estimating accessibility is

$$A_i = \sum_j \frac{W_j^{\beta}}{C_{ij}^{\alpha}}$$

where A_i is the measure of accessibility in county i, j is the potential destination county, W_j represents the economic opportunities in county j and is represented by population size in this study, C_{ij} is the cost of commuting between county i and county j, and α and β are parameters for commuting costs and economic opportunities, respectively.

The cost via highways is measured as

$$C_{ij}^{h} = \sum_j l_{ij}u \; + VT_i \cdot t_{ij}$$

where l_{ij} is the total highway length from county i to county j, u is the unitary transport cost, VT_i is the value of time for residents of county i, and t_{ij} is the total highway travel time from county i to county j.

The cost via airways is measured as

$$C_{ij}^{a} = C_{ij} + VT_i \cdot t_{ij} + l_{ia}u$$

where C_{ij} is the total airfare between county i and county j and l_{ia} is the length from county i to its nearest airport.

The cost via the intermodal transportation system is the smaller of highway cost and airway cost:

$$C_{ij}^{i} = \min\left(C_{ij}^{h}, C_{ij}^{a}\right)$$

Table 7. Accessibility Effects on Population and Employment Growth

	Model 1	Model 2	Model 3
Highway accessibility	X	—	—
Airport accessibility	—	X	—
Intermodal accessibility	—	—	X
Control variables	X	X	X

Once the accessibility of highways, airways, and intermodal transportation systems are estimated, their effects on population and employment growth (in the periods of 1970–1980, 1980–1990, 1990–2000, and 1970–2000) can then be compared (three models for each year or time period; see Table 7). To my best knowledge, this will be the first attempt to create an intermodal accessibility of passenger travels at the county level and to apply it to study population and employment growth.

7. PROJECT DISSEMINATION

This project has not yet received any award, matching fund, or additional fund. The findings of this research has been disseminated in several forms, including one peer-reviewed journal article (already published), one manuscript under review for potential publication, one invited presentation, and one conference presentation. In addition, another manuscript is under development for submission to a journal. This allows for dissemination to both academic researchers and transportation planners.

Referred journal articles/manuscripts

Chi, Guangqing. 2010. "The Impacts of Highway Expansion on Population Change: An Integrated Spatial Approach." *Rural Sociology* 75(1): 58-89.

Chi, Guangqing. "Land Developability: Developing an Index of Land Use and Development for Population Research." *Journal of Maps*. Under review.

Chi, Guangqing. "Comparing the Impacts of Highways and Airports on Population Change." *Rural Sociology.* Under development.

Invited and conference presentations

Chi, Guangqing. 2009. "The Impacts of Highway Expansion on Population Change: An Integrated Spatial Approach." Presented at the 56th North American Meeting of the Regional Science Association International, November 18–21, 2009, San Francisco, CA.

Chi, Guangqing. 2009. "The Impacts of Highway Expansion on Population Change: A Spatial Demographic View." Invited presentation at the Transportation Working Group and National Center for Intermodal Transportation Seminar Series, November 6, 2009, sponsored by the College of Engineering, Mississippi State University, MS.

1. Would you consider your project to be basic research, advanced research, or applied research?	**Basic research**
2. Number of transportation research reports/papers published	**1**
3. Number of transportation research papers presented at academic/professional meetings	**2**
4. Number of students participating in transportation research projects	**1 graduate student**
5. Number of transportation seminars, symposia, distance learning classes, etc. conducted for transportation professionals	**0**
6. Number of transportation professionals participating in those events	**0**

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