OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

OKLAHOMA'S TRANSPORTATION INFRASTRUCTURE: INVENTORY AND IMPACTS

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16 . ABSTRACT

This project comprehensively analyzed Oklahoma's transportation infrastructure and its impact on the state's economy via network analysis techniques that are widely used in and outside geography. The focus was on the context, connectivity, and condition of the state's transportation system. Geographic Information Systems (GIS) both organized and stored a large transportation infrastructure database and served as an analytical platform. This project assessed comparable data (e.g. road and rail networks, highway and bridge conditions) for Oklahoma and its neighbors to determine the state's comparative transportation advantages and disadvantages, permitting a detailed analysis of the state's regional transportation competitiveness. Deliverables included: (1) a comprehensive transportation inventory for Oklahoma and three of its neighbors, (2) a GIS database with the states' highway and other appropriate networks, linked with socioeconomic and business data to permit further research by other interested parties, (3) a statistical analysis measuring the impacts of transportation in the four states, and (4) a comprehensive report summarizing the data and methods used, the analyzes of the context, connectivity, and condition of the states' transportation networks, and the overall results from the project. Deliverables 1 and 2 are accessible online through a project web page at http://www2.geog.okstate.edu/oklahomatransportationinventory/ while this report comprises deliverables 3 and 4.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

OKLAHOMA'S TRANSPORTATION INFRASTRUCTURE: INVENTORY AND IMPACTS

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EXECUTIVE SUMMARY

Oklahoma's dependence on transportation, its generally lagging economic development with respect to its neighbors and particularly within the United States, and the currently lean national economic situation has every locality battling for every job, factory, and service center it can get. In addition to other inducements such as tax breaks, subsidies, and infrastructure improvements, the ability to efficiently move resources, goods, and people can greatly influence the private sector's location decisions. Thus, it is crucial to understand the role that the transportation network plays and this understanding can only come from a comprehensive analysis of the context, connectivity, and condition of the state's transportation system. The research reported here addresses this need by assembling a comprehensive spatial database of transportation infrastructure, by conducting several comparative analyses using this database, and by providing a platform upon which future research can be based.

The spatial aspect of the study involved the use of numerous network analysis techniques that are widely known and used both in and outside geography. Geographic Information Systems (GIS) was used to both organize and store a large transportation infrastructure database as well as providing analytical capabilities that would be extremely difficult to obtain through non-spatially-oriented software packages or methods. This project accumulated comparable data for Oklahoma and its neighbors to determine the state's comparative advantages and disadvantages with respect to highway transportation. There were three major tasks that together provide a detailed picture of the relationship between the state's transportation infrastructure and its ability to compete with neighboring states.

INTRODUCTION

This project comprehensively analyzes, from a spatial perspective, Oklahoma's transportation infrastructure and its impact on the state's economy. The state's dependence on transportation, its generally lagging economic development with respect to its neighbors, and the currently lean national economic situation has local governments battling for every job, factory, and service center they can get. Thus, it is crucial to understand the role that the transportation network plays in a state. This understanding can only come from a comprehensive analysis of the context, connectivity, and condition of the state's transportation system.

The spatial aspect of the study involves the use of numerous network analysis techniques that are widely known and used both in and outside geography. Geographic Information Systems (GIS) play a role, both as a means of organizing and storing a large transportation infrastructure database as well as providing analytical capabilities. This project accumulates comparable data for Oklahoma and some of its neighbors to determine the state's comparative advantages and disadvantages with respect to transportation. There are several major pieces of this project that together provide a detailed picture of the relationship between the state's transportation infrastructure and its ability to compete with neighboring states.

Transportation infrastructure is a fundamental component of any society's built environment. Particularly in the United States, where transportation connectivity and dependability are high, most aspects of daily life are built around the transportation network. Agricultural producers and manufacturers must get their products to the market or consumers quickly and efficiently, and many industrial location decisions are made in part by the accessibility of various locations to the highway network. Transportation services like trucking companies are particularly invested in central, well-connected locations, either at major interstate interchanges, major rail or port hubs, or airports. Within cities, uncongested highway routes are prized, and beltways continue their encirclement of the nation's metropolitan areas.

While in developing countries infrastructure issues revolve around building, adding to, or connecting infrastructures, in the U.S. a solid, integrated infrastructure is a given. Instead, non-engineering transportation issues focus on improvements in efficiency, in identifying key nodal locations for facility locations, and in ensuring the smooth flow of traffic. Thus, analysis of transportation issues in the U.S. necessarily focuses on the economic and logistical aspects of transportation, not from the viewpoint of how much it costs (though that is a component of state and federal government activity), but on how well the network serves the populace.

A key, and initial, aspect of measuring "service" includes understanding what transportation resources exist in a given place, and how they impact the economy of that place. Since the concept of "service" can be broadly interpreted, this study narrows the definition down to three main components: context, connectivity, and condition. This final project report first reviews pertinent literature about transportation inventories and impacts analyses as well as basic ideas and approaches from transportation geography. Then, the research methods for assessing the three tasks relating to context, connectivity, and condition are defined and described. Last, current findings are presented along with a description of the Internet-based delivery of research products (especially maps and datasets) that were created as part of the final deliverables.

Because this project focused as much on the inventory as on the impacts, research will continue beyond the completion of the project as further explorations of the impacts of transportation investment are conducted using the comprehensive database that was assembled for this project. Though this report provides some analysis, the project served as a stepping-stone to continued investigations as opposed to being a closed-end, self-contained project.

BACKGROUND

Relationship of Research to Past Efforts

This project was conceived in part as an outgrowth of the past work the PI has done for the Oklahoma Department of Transportation (ODOT) and the Oklahoma Transportation Center (OTC), but this project came about due to a general absence of comprehensive work in the area of transportation inventories and analysis. In the process of developing a method and model for studying the economic impacts of highway bypasses in small communities in Oklahoma in 1999-2000, the PI discovered a modest presence of prior work in the literature but little consistency in methods, variables, study area selection, or results. Part of what made engaging in a bypass project in Oklahoma a challenge was finding appropriate data regarding the highway network, obtaining economic variables pertaining to small towns, and determining whether the experiences of small communities in the state were similar or different to those in other states. The most comprehensive body of work on bypass studies that could be found was done in Texas through the Texas Transportation Institute (TTI); the OTC was just getting started and thus a comparable body of literature did not exist for Oklahoma.

Furthermore, it was hard to determine, after reviewing the numerous Texas bypass studies, whether the methods and outcomes would be applicable to Oklahoma. Thus, the need for a comprehensive model and database of the state's highway network would have been helpful. Thus, the natural progression was to move on to a larger scale of analysis, both in terms of studying the state of Oklahoma in comparison to its neighbors as well as documenting and evaluating the broader transportation inventory and its impact on the level of economic activity in the study area. Studying the entire commercial transportation network permits an assessment of its impacts on industry, retail, energy, and transportation sectors, among others.

Literature Review

Transportation infrastructure is a fundamental component of any society's built environment. Particularly in the United States, where transportation connectivity and dependability are high, most aspects of daily life are built around the transportation network. Agricultural producers and manufacturers must get their products to the market or consumers quickly and efficiently, and many industrial location decisions are made in part by the accessibility of various locations to the highway network. Transportation services like trucking companies are particularly invested in central, well-connected locations, either at major interstate interchanges, major rail or port hubs, or airports. Within cities, uncongested highway routes are prized, and beltways continue their encirclement of the nation's metropolitan areas.

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A key, and initial, aspect of measuring "service" includes understanding what transportation resources exist in a given place, and how they impact the economy of that place. The first sub-section below reviews pertinent literature about transportation inventories as well as basic ideas and approaches from transportation geography. Then follows a review of research on the relationship between transportation investment and economic development, the area in which the results of this project are situated.

Transportation Inventory and Transportation Geography

An analysis of a region's transportation inventory of the type proposed here is not evident in the literature. A comprehensive inventory was conducted by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) as part of *A Regional Transportation System Plan for Southeastern Wisconsin: 2035*, which is presently on-going (SEWRPC, 2004). Though exhaustive, this inventory focused on resources from the perspective of regional/urban planning and was geared towards commuter traffic. Three main categories of streets and highways, public transit, and bicycle and pedestrian facilities served as the basis for classification of transportation types, an exhaustive listing of these resources, and reporting of traffic counts and congestion. Though this is the most focused inventory found in the literature, it clearly has a different focus than the current project in that it represents a specific plan for the next few decades in a localized corner of Wisconsin (SEWRPC, 2004).

A few other inventory-type examples exist; they typically appear as part of a regional transportation plan such as is described above, though most are not as thorough as the Wisconsin example. The Central Okanagan region of British Columbia recently published a Transportation and Mobility report as part of their *Regional Growth Strategy Planning for the Future* (Central Okanagan Regional Growth Strategy, 2003), which focused on an analysis of future expansion possibilities for their highways, airport, rail line, roads, and recreational water amenities. Though the inventory is far less comprehensive than the Wisconsin example, the policy recommendations for future expansion may prove more valuable to the proposed research. The Delaware River Joint Toll Bridge Commission (2004) was even more focused because of its charge to provide river crossings over approximately 140 miles in its jurisdiction between New Jersey and Pennsylvania. In this case, the inventory focused solely on bridges and highways.

From the discipline of geography, transportation inventories are generally just part of the preparation for conducting specific transportation analyses. Two leading books in the field of transportation geography (Black, 2003; Taaffe *et al*., 1996), while differing somewhat in their selection of topics, nonetheless present many of the same larger themes: history of transportation (particularly in the U.S.), network and flow analysis, and policy/planning issues. Furthermore, both works are heavily organized around analysis methods, an understandable approach given geography's focus on space, spatial patterns, and movement through space. These works will provide most of the guidance on the methodological approaches to using the inventory data, and the specific methods will be reviewed later in the pertinent sections relating to the tasks.

Beyond simply quantifying the amount of each type of transportation mode (inventory), linking these transportation resources to economic development and growth is the ultimate goal of this research as the results can inform and guide policy and spending decisions. There is a larger body of literature on this topic, of which a modest sampling is provided next.

Infrastructure Investment and Economic Development

The impact of transportation investment on economic development is heavily debated, focusing on whether indirect, long-term benefits exist and whether they can be measured. Black (2001) felt that the belief that development follows investment was a myth, especially in the places like Europe and the U.S. Banister and Berechman (2001) instead argued that economic development results only when three conditions are all present: the availability of funds for projects (investment factors), agglomeration economies such as a skilled labor force (economic externalities), and organizational, legal, and regulatory bodies and policies (political factors). They felt that transportation investment alone was a necessary but not sufficient condition for economic development (p. 212).

In spite of such critique, a huge body of research attempts to quantify the economic impacts of transportation investment and to further demonstrate cause and effect. Most of this research falls into four categories: 1) forecasting the impacts of proposed projects; 2) planning reviews, including environmental impacts, of proposed projects; 3) educating the public about the value of transportation infrastructure; and 4) assessing the impact of projects already completed (Weisbrod, 2000, p. 14). The research presented later in this paper mostly falls in the last category, as our goal is to determine the comparative transportation advantages of each state. A focus on individual projects would be infeasible, and the impacts of individual projects and levels of investment are in any case increasingly difficult to isolate (NCHRP, 1998).

When assessing the economic impacts of infrastructure investment, two complementary approaches are commonly used: benefit-cost analyses (BCA) and economic impact analyses (EIA). BCA studies assess the direct, immediate benefits and costs of transportation spending on users and non-users alike, evaluating such variables as travel time reductions, operating costs, and direct construction costs. In contrast, EIA studies examine how the direct benefits and costs as measured in BCA studies translate into indirect, long-term benefits and costs with respect to land values, tax revenues, and employment changes, among others variables (Weisbrod, 2000). Most of the research presented later in this report is closely aligned with the EIA approach in its attempt to link the long-term consequences of transportation spending to long-term socio-economic patterns in the study area. Another aspect that distinguishes our work is its analysis at the meso (intermediate) scale, examining conditions at the county level primarily, whereas most studies operate at either the national (macro) scale or on specific route projects at the micro scale (NCHRP, 1998). While the spending decisions for highways are generally made at the state or national level, the long-term impacts are spread throughout and include very direct impacts on home and business owners near these routes. Analysis at the county-level, while still relatively aggregate, is nonetheless more fine-grained than is typical of many EIA studies.

Within the area of EIA studies, the link between transportation investment and economic development is often contradictory. Most research finds that there have been overall net positive benefits to transportation investment, but these benefits have declined over time (Madrick, 1996; Nadiri and Mamuneas, 1996) and are harder to isolate or determine cause and effect (NCHRP, 1998). Several factors contribute to this situation. First, the 1950s and 1960s experienced a strong demand for transportation infrastructure when the Interstate Highway System was started. These initial needs were met and further investments resulted in smaller impacts. Second, the benefits of public transportation investment were not industry-specific but were shared across much of the economy. Third, the returns on the investment varied spatially with some studies showing negative economic impacts (Madrick, 1996). Contributing to the diverse results produced by past studies is lack of a clear definition of economic development and many different statistical measures and analytical methods are subsequently used (Weisbrod, 2000).

In summary, there is a great deal of research focusing on analyzing some aspect of the transportation inventory. The more basic tools for analyzing network connectivity, accessibility, and dimension are less contentious but do not address the long term economic impacts of transportation spending. Impacts analysis research, on the other hand, has clearer policy application but far less agreement on how to do it, what the results mean, what the spatial scale of the research should be, and how meaningful spending decisions can be implemented. Given these issues, the research reported here attempts to further advance transportation research by building a comprehensive inventory database and employing some geographically-oriented analysis tools that have been seldom-used to date in the field.

Study Area

This project focused on Oklahoma and three of its neighbors, Arkansas, Kansas, and Texas (Figure 1). These states are the most integrated with Oklahoma and share many locational, geographic, economic, and cultural characteristics. These are the states that Oklahoma has a tendency to compare itself and to compete with for resources. Further, these states are the primary routes out of Oklahoma to other parts of the U.S. and the world, and it makes more sense to evaluate the state's situation relative to these neighbors than to more distant parts of the U.S. that have different subcultures, population densities, topographies, and economies. Choosing these three states and excluding Oklahoma's three other neighbors, Colorado, Missouri, and New Mexico, was partly for practical reasons and partly based on the degree of integration between Oklahoma and its neighbors.

Colorado, Missouri, and New Mexico share only short borders with Oklahoma and their centers of population and commerce are quite removed. Denver clearly dominates Colorado and likewise St. Louis in Missouri, while New Mexico features a central corridor of linked cities that comprises most of its activity. Denver, St. Louis, and central New Mexico are fairly removed from Oklahoma and not common destinations for day trips. However, Wichita and Dallas-Fort Worth are both within three hours of central Oklahoma and Little Rock is only a little further away, and hence these places are stronger regional competitors with Oklahoma City and Tulsa.

The study area map shown in Figure 1 represents a simplified highway network system, removing some nodes that in actuality represent non-aligned segments of the same route and/or overlapping routes (*i.e.*, routes labeled as both Interstate and U.S. Highways). The map is also the result of other simplifications that were made to facilitate the second task of this project, connectivity analysis, which will be described later in this report.

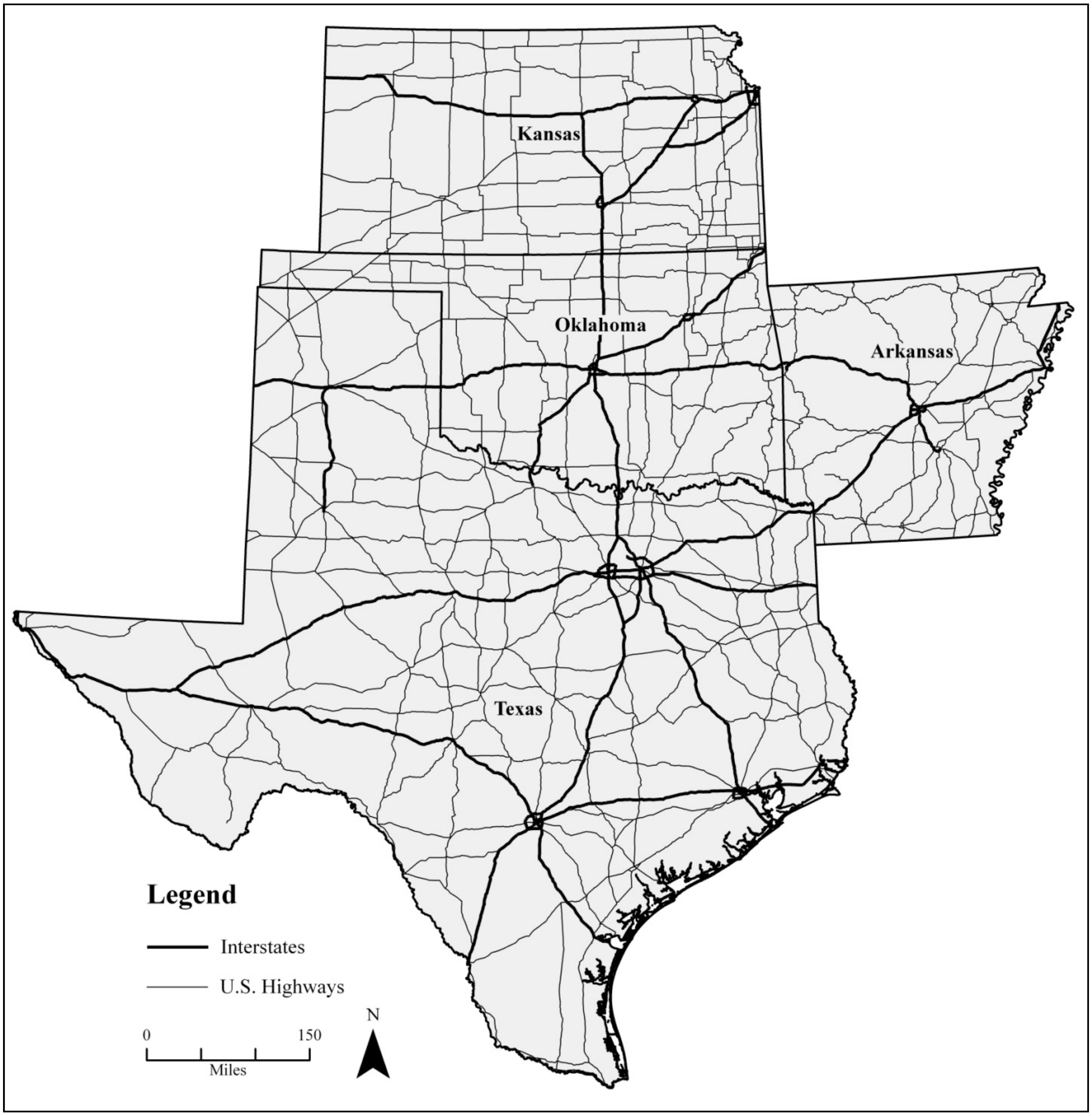


FIGURE 1
U.S. AND INTERSTATE HIGHWAYS IN THE FOUR STATE STUDY AREA

INVENTORY AND IMPACTS

The three sub-sections that follow describe the methods and results of the three main tasks that make up this project, the context, connectivity, and condition of Oklahoma's transportation inventory in comparison to three of its neighbors. Taken together, these three tasks provide a comprehensive view of the state of Oklahoma's transportation context and provide a platform upon which economic analyses can be conducted. Future work by us and hopefully others will extend the impact of this project into the immediate future.

Task 1: Context

Few would argue that Oklahoma's network is sufficient in all ways; finding funds to address deficiencies, however, is a different matter. Thus, the ability and willingness of the state to invest in infrastructure, including roads, are key contextual characteristics that must be assessed to see if bureaucratic roadblocks exist. Many avenues exist for analyzing the context of the transportation system. Comparative analyses of state funds devoted to transportation, of federal funds awarded and expended, and of state budget structures can reveal whether the state's governmental structure helps or hinders the maintenance of a good transportation system. Documenting such characteristics will yield a better understanding of the state's prospects for improving its economy through transportation investments and improvements. This aspect requires extensive research into the neighboring states' funding patterns.

Methods

State Department of Transportation (DOT) budget and expenditure data were obtained for each of the four states through National Association of State Budget Officers (NASBO, 2008). Each state's budget can be compared historically back to 1985. However, specific categories such as salaries and construction costs are only available through each state's DOT.

Nonetheless, the NASBO information allows for historical study and general fund analysis. NASBO data are presented in four funds: general, federal, other state funds, and bonds. Since categories vary between states, exhaustive study is necessary to create similar categories for the purposes of comparing relative allocations of state DOT funds to various activities. Ultimately, the budget data for Kansas, Oklahoma, and Texas were relatively comparable, but the categories reported by Arkansas were very different and only a few categories such as salaries and construction costs could be compared to the other three states.

These impediments resulted in the contextual analysis being the least satisfying of the three tasks. The aforementioned difficulties in building a detailed expenditure database limited the analysis possible to a few simple quantitative measures that are reviewed below. Future improvements to this line of inquiry would need to focus heavily on this area in order to obtain better information and stronger results.

Results

A comparison of 2008 state DOT budget data (2006 data were the most recent for Arkansas) reveals several interesting findings that seem to refute the idea that simply spending more money on an issue is always the best course (Table 1). Oklahoma spends the largest percentage of its budget on highway construction and the second highest amount per mile, yet has the roughest pavements as indicated by its International Roughness Index (IRI) average (the IRI will be explained in detail under Task 3 but briefly the IRI is a direct measure of road roughness in which higher values indicate rougher pavement). In contrast, Kansas spends the lowest percentage, the least amount per mile, and yet has the best pavements in the study area. These results imply notable differences in how effectively the states use transportation construction funds as well as highlighting differing allocation priorities within each state DOT.

TABLE 1
COMPARISON OF STATE CONSTRUCTION EXPENSES AND CONDITIONS

State	Percent of budget for construction	Total spent on construction	Construction expenditure per mile	Average IRI for all highways	Percent of bridges not satisfactory
Oklahoma	67.90	$799,659,873	$159,615	108.20	31.47
Arkansas	52.97	$510,821,057	$143,165	97.98	45.51
Kansas	45.50	$666,415,607	$118,400	77.25	30.28
Texas	60.32	$5,343,962,800	$241,985	91.56	23.14

The bridge condition data likewise do not reveal a consistent pattern. Oklahoma spends the highest percentage of its budget on construction while Kansas spends the lowest, yet non-satisfactory bridges comprise about 30 percent of the total in both states. Texas spends the second highest percentage and has the smallest proportion of its bridges rated not satisfactory. However, without any way to separate the construction expenditures between roads and bridges, these are merely rough inferences assuming consistent spending proportions on bridges versus roads across the four states. Nonetheless, these inferences do provide some insight as to how efficiently the four states are spending their highway construction dollars, and Kansas emerges as the best steward of its resources followed by Texas. Oklahoma clearly has the worst roads while nearly half of Arkansas' bridges are not satisfactory.

To even out state-to-state differences, the ratio of miles to bridges is computed, which provides a relative measure of how many more bridges a state has built compared to overall mileage. Table 2 reveals that Texas, though with the largest mileage and bridge totals, has the lowest miles-to-bridge ratio. This ratio could be interpreted as the average number of miles between bridges. Hence, proportionally Texas has had to construct about half as many bridges per mile than the other three states, while Arkansas, having the hilliest terrain, has the most bridges in relative terms. In this light, it may be easier to understand why Texas has such good bridges, though the differences between Oklahoma and Kansas are harder to parse given their near identical totals of both miles and bridges and their roughly similar terrains. Table 2 also gives the average bridge condition (ABC) index, which is essentially the average bridge condition on a scale of 1 (worst) to 10 (best) and which is more fully described under Task 3.

TABLE 2
COMPARISON OF STATE HIGHWAY MILES AND BRIDGES

State	ABC	Miles	Bridges	Miles : Bridges
Oklahoma	7.14	5,010	4,477	1.12
Arkansas	6.73	3,566	3,287	1.09
Kansas	7.15	5,660	4,201	1.35
Texas	6.97	22,084	9,633	2.29

While the average IRI value and percentage of non-satisfactory bridges for each state in Table 1 provide a picture of how the states perform, a more detailed analysis allows a better comparison of the states' performance in constructing and maintaining highways and bridges. To this end, Figure 2 shows the percentage of miles in each state falling into three categories (IRI below 95 is good, IRI between 95 and 170 is fair, and IRI above 170 is poor) while Figure 3 shows the percentage of bridges falling into four groupings of the original ten categories (excellent through good, fair and satisfactory, poor and serious, and critical through failed) which are given later in this report in Table 5. Figures 2 and 3 clearly show differences between states that reinforce the findings given previously but with better detail, especially in terms of Kansas' roads but also of its proportion of "good" bridges (*i.e.*, the excellent through good grouping). Meanwhile, Texas emerges slightly ahead of Arkansas and Oklahoma, two states that look very similar in terms of roads but rather different in terms of bridges.

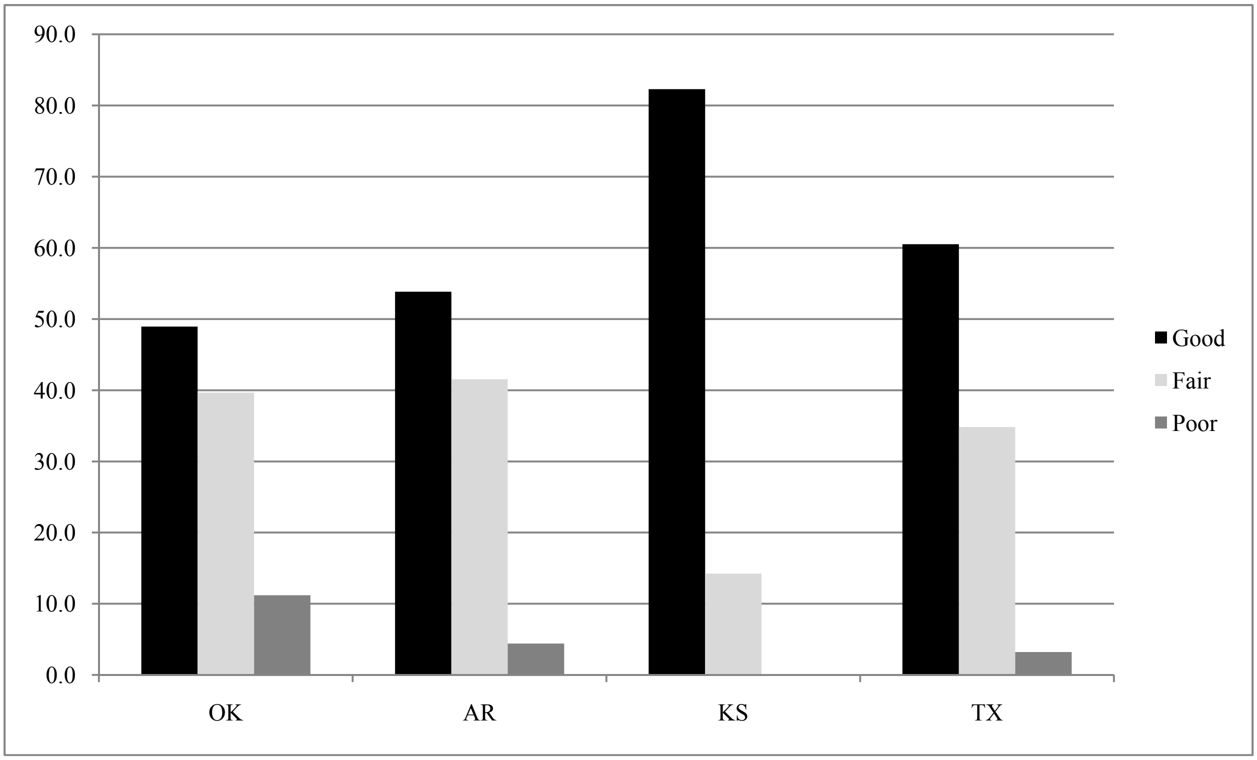


FIGURE 2
PERCENTAGE OF ROAD MILES IN CONDITION RANGES, BY STATE

Kansas' low IRI values are even more apparent in Figure 2, as over 80 percent of its highway miles are rated good and just 0.1 percent rated poor. Arkansas, Oklahoma, and Texas, meanwhile, fairly strongly resemble each other with 49 to 60 percent of highway miles being good, 35 to 40 percent being fair, and 3 to 11 percent being poor. Notably for this paper is the fact that Oklahoma is the only state with less than 50 percent of its roads rated good and over 10 percent rated poor, reinforcing the *a priori* belief that Oklahoma has the worst roads in the four state study area, if not the overall southwest region as a whole. As mentioned earlier, Texas appears to be slightly better off that Oklahoma and Arkansas with a better ratio of good to fair roads and a smaller percentage of poor roads.

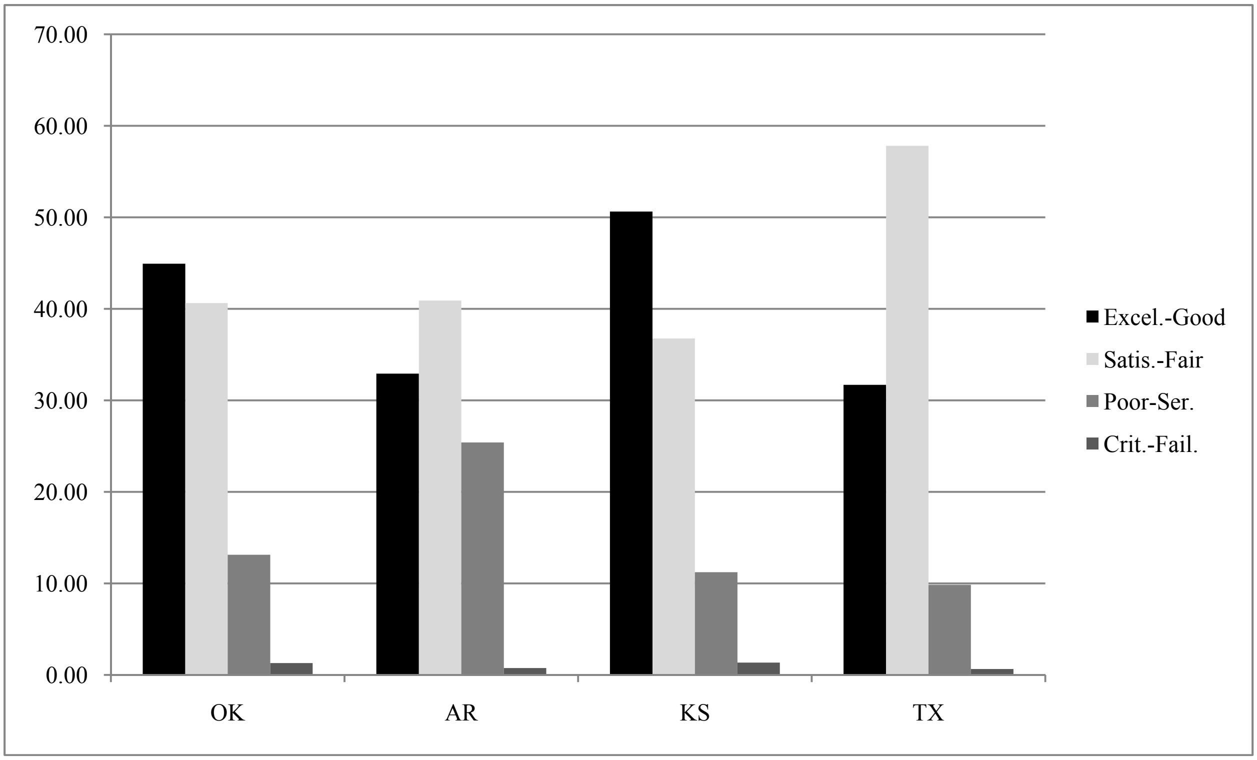


FIGURE 3
PERCENTAGE OF BRIDGES IN CONDITION RANGES, BY STATE

Kansas also shows a very strong result for bridges, with Figure 3 providing stronger evidence based on categorical percentages. Kansas is the only state with more than 50 percent of its bridges rated good or better, although interestingly it also has the highest percentage of critical or failed bridges at 1.36 percent (Oklahoma is second at 1.30 percent). Texas has the best overall satisfactory rating as noted in Table 1, but this is the result of a very high share (58 percent) of bridges in the satisfactory and fair categories even though Texas has the smallest percentage in the top category (just under 32 percent are good or better). It is notable that Oklahoma and Kansas strongly resemble each other in distribution of bridges across the four groupings (as well as the original ten categories), so there is some aspect of highway construction for which Oklahoma greatly lags its neighbors but not in bridge construction.

Task 2: Connectivity

The next task in this project is network connectivity. The connectivity of a transportation system can be assessed in many ways as there is a large body of research and methods for assessing transportation networks. These assessments can come in the form of overall network connectivity, nodal accessibility, road density, or efficiency. A state's network must be evaluated not just in absolute terms, but also with respect to neighboring states to determine how far behind or ahead the state is compared to its regional context. Since states are neither isolated nor insulated from one another, the extent to which connections exist, and their role in bringing in (or letting out) business, is another important facet of this project.

Methods

Developing a network topology, or connectivity structure, is necessary to assess the connectivity of the state's transportation network. A topology is essentially a mathematical representation of a network. This topology can be as simple as a matrix of 1s and 0s where 1s denote direct connections and 0s represent the absence of such a connection. This simple connectivity matrix serves as the theoretical underpinning of many network connectivity measures, including those mentioned above (Taaffe *et al*., 1996). Modifications to this topology can include travel times and distances, route weights (such as for single or multi-lane routes), route capacities, and intervening opportunities and alternate routes.

Implementing this aspect requires many decisions in terms of how to model the various networks and represent them mathematically, so that advanced methods of analyzing the accessibility and connectivity of the network can be employed. This is a computationally heavy component of the project. Add-ons to basic GIS platforms exist to automate this process and to aid in analysis, though simple networks can be analyzed in spreadsheets as well.

The total number of direct and indirect connections for each node (typically a city), total connections for the entire network, the shortest route between nodes (either in distance, time, or links), and the ability to rank nodes are all outputs from this methodology. This section provides the clearest and most direct way to compare Oklahoma to its neighbors, since each state's network can be coded and studied in an identical fashion, and the statistics generated in this section most directly aid in formulating policy and planning recommendations (Black, 2003).

While the connectivity measures described here are very valuable and are heavily used in transportation geography, they do have limitations. They are less useful for assessing air transportation, for example, given that mode's unique lack of need for infrastructure on the routes themselves and instead requiring a huge infrastructure at the nodes (airports). Overall, however, the most important criterion when employing these features is consistency of coding.

In order to establish a road network for Oklahoma, Texas, Kansas, and Arkansas, the functional class system codes were employed (see table below). For the purposes of this study, rural code 1 and urban code 11 were used for the interstate network. Rural codes 2 and 6 and urban codes 12 and 14 were used for the other principal arterial roads (Table 3).

TABLE 3
FUNCTIONAL CLASS SYSTEM CODES

RURAL	**URBAN**
1 – Principal Arterial; Interstate	11 – Principal Arterial; Interstate
2 – Principal Arterial; Other	12 – Principal Arterial; Freeways & Expressways
6 – Minor Arterial	14 – Principal Arterial; Other
7 – Major Collector	16 – Minor Arterial
8 – Minor Collector	17 – Collector
9 – Local Road	19 – Local Road

The connectivity of each state's highway system was determined for the interstates and U.S. Highways only using the method described above. To achieve this, the polylines representing the interstate and U.S. Highways within the GIS highway shapefile for each state were queried out to form a separate shapefile of the network for that state. In order to simplify the connectivity analysis, U.S. Highways that directly paralleled interstate routes were deleted from the network shapefile. Also, within metropolitan areas, the routes were simplified leaving only the major routes through the city.

Using the intersect tool in ArcMap (the GIS package used for this project), a point node was added at the end of each segment of road within the network. Since the polyline for each road contained multiple segments, all of the segments between points where two roads intersected were merged using the merge feature on the editor toolbar, creating one continuous road segment between each intersection. The extra nodes between intersections were then deleted leaving point nodes only at the intersection of the road segments. Each remaining node was given a unique identifying number. In order to complete a connectivity matrix, each road line segment was identified according to the nodes at each end of the segment. A separate Excel spreadsheet was created with all connections for each state's highway network. This allowed for the total network links for each state to be easily calculated. The matrix multiply function (=mmult) was used to determine the diameter of each state's network, which is a measure of the minimum number of links necessary to connect the two most separated nodes.

With each state's network built and diameter determined, it is then possible to accumulate summary statistics and derive network comparison indices. First, the *beta* index (β) is the ratio of links to nodes; higher numbers indicate stronger connectivity. This is one simple, unitless measure that allows comparisons across networks.

L_{max} is computed as 3*(N-2), where N is the number of nodes (cities) in a network. L_{max} indicates the number of links (highway connections) necessary to maximally connect all nodes on a planar network. L_{max} is then used to compute the *gamma* index (γ), which is the actual (total) links divided by the maximum number of links L_{max}. The γ index provides another unitless measure of how well connected is a network, with a value of 1 representing perfect total connectivity and a value of approximately ⅓ representing a minimally connected network in which it is eventually possible to reach all other nodes (Taaffe *et al*., 1996).

Networks with γ values between ⅓ and ½ are referred to as "spinal" networks, those that permit travel between all nodes but which are minimally connected. Values of γ between ½ and ⅔ define "grid" networks that are moderately connected. Finally, γ values between ⅔ and 1 represent the most connected networks; these are designated "delta" networks because of the strong visual appearance of triangles connecting adjacent groups of three nodes.

The completion of this process provides an analysis platform in which future connections between nodes can be evaluated in terms of the overall network efficiency improvement of that proposed route addition. While some comparative analysis is provided below, the primary outcome of this task has been to create and disseminate a database that other researchers can use to evaluate the benefits of a new route in the study area.

Results

Table 4 provides summary statistics for the four states with respect to the information that can be summarized from the connectivity analysis. Each state's number of nodes and links (cities and highways; see Figure 1), the diameter, the number of links to achieve maximal connectivity (L_{max}), the β index, and the γ index are all given.

TABLE 4
HIGHWAY CONNECTIVITY

	Oklahoma	**Arkansas**	**Kansas**	**Texas**
Total nodes	128	122	186	317
Total links	179	168	274	510
Diameter	21	18	18	26
L_{max}	378	360	552	945
β index	1.40	1.38	1.47	1.61
γ index	0.47	0.47	0.50	0.54

The first four rows of Table 4 are scale-dependent, and simply reveal that Texas has by far the largest network. This is obvious given Texas' much greater territory and population. However, it is interesting to note that Texas' diameter is only about 24 percent larger than Oklahoma's despite Texas being nearly four times larger in total area than Oklahoma. This indicates that the Texas network is much better connected than Oklahoma's. Oklahoma and Kansas are very comparable; Oklahoma is about 19 percent larger than Kansas and its diameter is about 17 percent larger. Meanwhile, Oklahoma is nearly twice as large as Arkansas but its diameter is only 17 percent larger, indicating poorer connectivity in Arkansas.

The β index supports these rough assessments of the diameter, showing Arkansas slightly behind Oklahoma, Kansas somewhat ahead, and Texas having by far the best link-to-node ratio of 1.61. Similarly, the γ index rates Oklahoma and Arkansas equally, and at the low end of the spectrum with spinal networks, Kansas right on the boundary between spinal and grid, and Texas leading with a grid network. By all measures, then Texas has the best connected of the four networks, though not by a huge margin, while Arkansas and Oklahoma vie for worst in the study area. These results seem to parallel macro-economic conditions across the four states as well.

Task 3: Condition

With networks constructed and connections added, the condition of the transportation system is the final aspect that affects users. Though good transportation systems in the U.S. are generally assumed, there exists the perception that Oklahoma's roads are in poorer condition than neighboring states' roads. The focus of this research is on Oklahoma's highways and bridges and determines their quality with respect to their neighbors. Also, the relationship between road/bridge conditions and economic indicators is also explored.

Methods

Pavement condition data collection and organization

Pavement roughness is determined by the International Roughness Index (IRI), which provides a measure of a vehicle's axle movement along the road. These data are a required part of each state's biennial Highway Pavement Management System report submitted to the Federal Highway Administration. The IRI is obtained by driving a vehicle with special sensors along all road segments within the state to record the axle movement for both wheel paths (Loizos and Plati, 2008). Higher IRI values indicate rougher surfaces, with values below 95 considered good, values between 95 and 170 providing acceptable (fair) ride quality, and values above 170 rated poor (AASHTO, 2009). Although there are other measures of pavement quality and often several are used in conjunction, the IRI value is an international standard that allows consistent analysis across different locations (Loizos and Plati, 2008) and Arkansas uses the IRI exclusively to evaluate roads (Papagiannakis *et al.*, 2009) and so must be used here. Data for the IRI in each state were collected from a representative in each state Department of Transportation. For Arkansas, Oklahoma, and Texas the data consisted of geo-referenced shape files, while the Kansas data came in spreadsheet form and had to be manually geo-coded (see Appendix 1).

Pavement condition analysis

Road conditions were formally analyzed for the Interstate and U.S. Highway systems in each of the four states. In order to do this, these highway types were queried from the GIS database based on their route designations in the attribute table, and placed in separate shapefiles (one for each of the four states) for easier analysis. Within each state, the IRI value is given for segments of various lengths along each route. Therefore, the attribute table for the highways contains the following columns:

- County Code – the FIPS code for each county within the state;
- Functional Code – the functional class code for each highway (see discussion of functional codes and Table 3 above);
- Section Length – the length of the section of road in miles; and
- Roughness – the IRI value for that road segment.

In order to properly analyze the roughness data, it needed to be comparable between states, and between counties. Therefore, the weighted IRI value was calculated for both the Interstates and U.S. Highways in each county throughout the four states. A new column was added to the attribute table in order to calculate the segment length times the IRI value. This was done by right-clicking on the column within the table and selecting "Field Calculator" from the menu. A command was then input that multiplied the two desired columns.

In order to calculate the weighted IRI value for the roads within each county, the summarize tool in ArcMap was used. The overall goal of this particular analysis was to obtain a weighted IRI value for all Interstate segments and for all U.S. Highway segments by county within each state. Therefore, the summarize tool was used on the column representing the FIPS code for each county. Right-clicking on this column heading and selecting “Summarize” from the menu brings up an option box where the section length column and the column representing the weighted IRI value can be chosen to sum by road type. The result of this operation is an output table (in .dbf form) that is opened in Excel. Within this table, the length and weighted IRI value for all Interstates within a county have been summed into one row and these two fields for all U.S. Highways within a county have also been summed into one row. Within this table, a new column was created and the weighted IRI value was divided by the summed length, giving the weighted average IRI value for each road type within each county. All federal highway mileage in each county was thus averaged to produce an IRI value for each county in the study area through which a federal highway passes; 486 of 511 counties in the study area have at least one such route.

Bridge condition data collection and organization

Bridge location and condition data for Oklahoma, Texas, Arkansas, and Kansas were obtained from the United States Department of Transportation’s National Transportation Atlas Database 2008 (NTAD). The dataset were in shapefile format, making them compatible with most GIS software packages.

The file that was used for the bridges was called NBI, for “national bridge inventory”. This database provided information for all fifty states for more than 600,000 bridges on public roads, including Interstates, U.S. Highways, state and county roads, as well as publicly accessible bridges on federal lands. Each state department of transportation collects information on the condition and quality of its bridges, which is then placed in the NBI.

In the NBI, each bridge has been given a numerical value that corresponds to its condition. For mapping purposes, four categories of bridges were created. The top four values

(6, 7, 8, and 9) were combined to form a Good category. The values (4 and 5) were combined to form the Fair category, the values (2 and 3) were combined to form the Critical category, and the values (0 and 1) were combined for the Failure category. The categories were combined for easier map interpretation and to focus on the poorer rankings, which was done because the lower quality bridges that exist in a state are of greater research interest.

TABLE 5
BRIDGE CONDITION CATEGORIES IN THE NBI

BRIDGE CATEGORIES		
Score	Description	Category
N	Not Applicable	--
9	Excellent	Good
8	Very Good	
7	Good	
6	Satisfactory	
5	Good	Fair
4	Poor	
3	Serious	Critical
2	Critical	
1	Imminent Failure	Failure
0	Failed Condition	

Bridge condition analysis

While the IRI is already in ratio form and suitable for statistical analysis, the bridge condition data consist of frequency counts in ordinal categories (excellent through failed, ten categories total) so modification is necessary to conduct ratio tests using bridge quality. This research employs a simple method, computing a weighted average for each county by assigning the ordinal value of 10 to excellent bridges, 9 to very good bridges, and so forth down to an ordinal of 1 for failed bridges. Then, for each county, the number of bridges in each category is multiplied by the appropriate ordinal score, these products are summed, and this sum is divided by the total number of bridges in a county to produce an average bridge condition (ABC) score for that county's bridges. This method assumes that the difference between an excellent and very good bridge (ordinals of 10 and 9, respectively) is the same as the difference between a poor and serious bridge (ordinals of 4 and 3), but this method requires the fewest assumptions and is simply a way to determine the average condition of bridges in each county, rendering a ratio-level statistic for analysis.

Correlation analysis of county-level data

Having established baseline comparisons of the relationship between state transportation spending, pavement conditions, and bridge quality at the state level earlier, the analysis probes deeper into the connection between transportation and the economy by assessing the degree to which road and bridge conditions relate to economic development. It is unlikely, however, that one could posit a strong, direct path of causation between transportation and the economy, as there are many factors that influence the economy besides transportation. Also, the direction of causality is hard to delineate. Does a better economy in a place equate to better roads, or do better roads result in increased economic development? Due to these issues, it is more appropriate to conduct a correlation analysis between the bridge condition data, the IRI pavement measures, and various measurements of economic development. Also, there are no *a priori* expectations of high correlations because of the convoluted relationship between economic development and transportation. However, it does prove interesting to determine just how strongly transportation quality correlates to economic measures, and to compare the four states individually as well as to conduct the analysis across the entire study area.

For economic conditions, four indicators at the county level are employed. Many others could be justified, but in order to attain a reasonable scale of analysis for this research these four indicators are chosen to represent distinct aspects of the economy that could be related to transportation quality. From the population census (U.S. Census Bureau, 2000), per capita income and the percent of population living below poverty level are used. This provides two different dimensions of overall economic quality of life for the citizenry. From the economic census (U.S. Census Bureau, 2002) the annual payroll and number of employees for the retail trade sector (NAICS 44-45) are used to compute average pay per employee. Retail trade is a major component of the economy, especially in rural areas, and a significant consumer of the population's disposable income. Lastly, from County Business Patterns publications, a historical record of the total number of employees in all sectors is used to compute employment change between 1998 and 2006 (U.S. Census Bureau, 2009). This statistic captures economic change that has taken place over nearly a decade and furthermore captures the change in all employment irrespective of sector.

Both the IRI and ABC indices are correlated with these four economic indicators. In each case, the economic data represent the most recent available, which unfortunately spans a period of eight years, from 1998 to 2006 with respect to the employment statistics from the County Business Patterns. Meanwhile, the per capita income figure is reported for 1999 and the retail employment and payroll are for 2002. Given that the economic censuses and the population censuses do not occur simultaneously, there will always be a slight time offset. However, it is unlikely that significant economic changes have taken place over less than a decade in most parts of the study area, and the alternative would be manual adjustments or estimates to force the datasets into better temporal alignment. We prefer to simply make use of the most recent data as published by the Census Bureau and accept the temporal mismatch.

Spatial autocorrelation analysis

This analysis computes a local measure of spatial autocorrelation to determine the degree to which concentrations of like values occur in space that are unlikely to have arisen due to chance. The Getis-Ord G_i* statistic is used here, in which the locations of concentrations of high or low values are evaluated for significance (Fotheringham *et al*., 2000). Using each county's centroid as its representative location, an inverse weighted distance function is used to compare each county's value for IRI, ABC, and the economic indicators against its neighbors. Raw G_i* scores are converted to *z* scores so that pockets of statistically-significant clustering of high-high (hot spots) and low-low (cold spots) values can be mapped and identified. On the maps that follow (Figures 5 and 6), 99 percent significance corresponds to *z* scores larger than 2.58 ($\alpha = 0.01$), 95 percent significance equates to *z* scores bigger than 1.96 ($\alpha = 0.05$), and 90 percent significance indicates *z* scores exceeding 1.65 ($\alpha = 0.10$). We can thus identify areas where both good (or poor) roads and bridges co-locate with good (or poor) economic conditions.

Geographically-weighted regression

The main focus of this analysis will be on developing a local regression model using road (IRI) and bridge (ABC) conditions as predictors of economic development. Unlike ordinary least squares (OLS) regression, geographically weighted regression (GWR) measures the influence of each variable at a point *i*, and weights the influence of the data around *i* according to distance decay. Hence, data points closer to point *i* will have a greater amount of influence than those data further away from *i* (Fotheringham *et al*., 2002). For this project, this technique will show how each variable within a county behaves in relation to the same variable in neighboring counties, but instead of one measure of how road conditions influence economic development across Oklahoma, the GWR model will provide 77 measures, one for each county in the state.

Results

State-to-state comparisons of the IRI and ABC indices were presented earlier in the Context (Task 1) section, but such gross aggregations tell little about spatial variations in road and bridge quality. The results below consist of economic analyses of the relationship between transportation investment, as indicated by ABC and IRI scores, and various economic indicators at the county level.

Correlation analysis

Table 6 summarizes the correlations and p-values (in parentheses) for the analysis conducted across all four states as well as analyses within each state. The number of observations is not equal to the number of counties in each state as some counties do not have a federal highway passing through them: five of Arkansas' 75 counties, three of Kansas' 105 counties, one of Oklahoma's 77 counties, and sixteen of Texas' 254 counties lack such routes. Overall, the four states comprise 511 total counties but with 486 counties having federal highways. Also, the correlation statistics shown in Table 6 are Spearman's rank correlation coefficients (r_s) for ordinal data rather than the standard Pearson's correlation coefficients (r) for ratio data. All six variables failed both the Kolmogorov-Smirnov and Shapiro-Wilk tests of normality at the 0.05 significance level (and all but average pay per retail employee failed at the 0.01 level as well), so Spearman's ordinal correlation coefficient is more appropriate and reliable. For all of the flagged correlations below (** for significance at the 0.01 level and * for 0.05 significance), the magnitudes are relatively similar between the (unreported) Pearson's and Spearman's correlations, and all of the signs are consistent. Larger values of the ABC index are representative of better bridge conditions but lower values of the IRI index are representative of better highway surfaces, and so the signs of the correlations below must be carefully interpreted.

TABLE 6
SPEARMAN'S CORRELATIONS OF CONDITIONS AND ECONOMIC INDICATORS

Scale of analysis	Condition index	Per capita income	Percent of pop. in poverty	Average retail employee pay	Employment change 1996-2008

Overall (n=486)	IRI	-.089* (.049)	.153** (.001)	.017 (.717)	.030 (.506)
	ABC	.019 (.675)	.003 (.943)	.127** (.004)	.178** (.000)
Arkansas (n=70)	IRI	.029 (.814)	-.013 (.916)	.121 (.318)	-.022 (.858)
	ABC	.161 (.168)	-.004 (.982)	.391** (.001)	.031 (.790)
Kansas (n=102)	IRI	-.044 (.662)	-.020 (.841)	-.191 (.055)	-.135 (.176)
	ABC	-.023 (.818)	-.057 (.566)	.083 (.400)	.054 (.583)
Oklahoma (n=76)	IRI	-.077 (.510)	.091 (.433)	.005 (.968)	.007 (.952)
	ABC	-.203 (.076)	.245* (.032)	-.079 (.496)	-.020 (.864)
Texas (n=238)	IRI	.104 (.110)	-.117 (.073)	.044 (.504)	.045 (.490)
	ABC	-.002 (.981)	.077 (.224)	.199** (.002)	.302** (.000)

** Correlation is significant at the 0.01 level (2-tailed).
*   Correlation is significant at the 0.05 level (2-tailed).

As expected, there are no overwhelmingly strong correlations between the IRI and ABC indices and the economic indicators chosen, given the many factors that influence the economy, but some significant and interesting correlations do appear and differences across the states also emerge. Notably, each one of the four economic indicators is significant in the overall (four state) analysis, per capita income and poverty rates with IRI (roads) and retail employee pay and total employment change with ABC (bridges). However, these correlations are all below 0.200 in real terms and the significance levels are mostly attributable to the sample size of nearly 500. Of greater interest is that the IRI index is not significant for any of the state-level analyses, only for the overall analysis, while the ABC index features at least one significant correlation for each state but Kansas.

Arkansas reveals the strongest correlation in absolute terms, between average retail employee pay and bridge conditions (ABC) with a correlation of nearly 0.400. This implies a moderately strong, positive relationship in the expected direction. On the other hand Kansas, the state with the best combined road and bridge conditions, has very weak correlations and only road conditions (IRI) and retail employee pay approach significance, with the hoped-for negative relationship (better roads correlate with higher retail pay). Oklahoma has one significant correlation, for bridge conditions and poverty, but with a positive sign it is in the contrary direction (better bridges correlate with higher poverty), while Texas has two very significant correlations for bridges, with retail employee pay and employment growth, both in the expected direction (better bridges correlate with better pay and more job growth). Texas' significance levels are aided by a sample size two to three times larger than the other states, thereby making weaker correlations look more significant, though the correlation of bridge conditions and job growth exceeds 0.300 and is the second-highest correlation (in absolute terms) found.

The analysis reported above is a useful first step in evaluating the potential relationship present between the socioeconomic variables and condition indicators, but the fact that the observations (counties) are spatial units almost certainly means there are spillovers that classical, non-spatial statistics fail to capture. In essence, the assumption of the independence of observations is likely invalid. *Spatial autocorrelation analysis* measures the extent to which this lack of independence affects the results, and many techniques exist for measuring, as well as removing or incorporating, local spillover effects. These techniques are employed next.

Spatial autocorrelation analysis

The results presented in this section have been published in the *Papers of the Applied Geography Conference* (Comer *et al.*, 2009) in an expanded but substantially identical form. An abridged version is given here.

Figure 4 depicts the hot/cold spot maps for the highway pavement (IRI) and bridge (ABC) condition data. In order to facilitate easier interpretation of these maps, white shading always represents good conditions and black indicates bad conditions, regardless of the sign of the *z* score for a given variable. This convention is also used for the economic indicators later.

Before evaluating the economic indicators, a comparison of highway and bridge quality clusters reveals some interesting patterns. There are no large areas that experience both good or bad highways and bridges simultaneously, but there are several pockets of good highways but bad bridges, or vice versa. The western edge of Kansas has a cluster of very good IRI values (as well as three counties with no federal highways), but three southern counties with good highways also form the northern edge of a cluster of counties with bad bridge in southwestern Kansas. North Central Arkansas has a similar pattern. Overall, a very noticeable corridor of bad highways covers most of eastern Oklahoma and extends well into Texas, while southeastern Arkansas features a minor cluster of bad highways. Besides the two clusters of bad bridges noted before, a third cluster exists in western Texas along the New Mexico border. The two maps in Figure 4 imply that no locations in the study area have been completely neglected with respect to transportation investment and maintenance, but the maps do imply that states may be making a trade-off between highway and bridge maintenance in many locations depending on whether the highways or bridges are in the worst shape. However, these are simply conjectures based on the aggregate results of examining the clustering of good and bad bridges and roads.

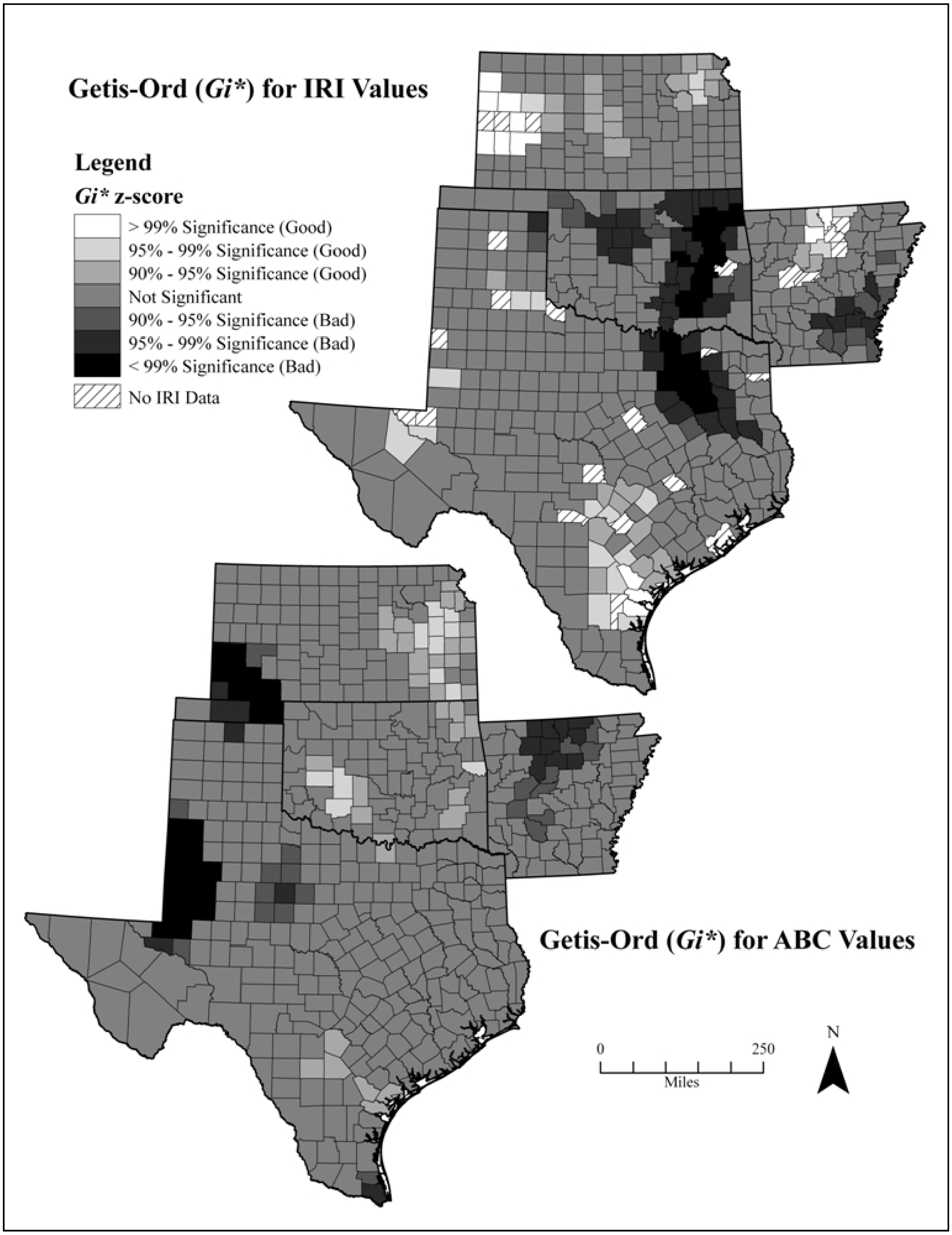


FIGURE 4
SPATIAL CLUSTERS OF HIGH AND LOW PAVEMENT AND BRIDGE QUALITY

The primary question of this section is to what extent clusters of good highway and bridge conditions correlate with indicators of economic development or growth. Funding decisions on highway and bridge maintenance and construction are a mixture of federal and state funding decisions over long time frames, so rather than conducting either BCA or EIA studies of individual projects or time periods, we look at the present (circa 2008) situation with respect to highway and bridge quality as a proxy for the overall level of transportation investment in building and maintaining highways and bridges. Likewise, the economic indicators, though collected for specific dates or intervals, are a snapshot of present conditions that are the result of decades (or more) of socioeconomic processes operating in the region. Hence, a comparison of strong and weak pockets of economic development and of highway and bridge conditions can provide a long term view of whether transportation investment and economic development spatially correlate, even if cause and effect is circular or there are other, underlying influences.

The first spatial correspondence that emerges from a comparison of Figures 4 and 5 is that of southeastern Oklahoma and also southeastern Arkansas, two areas of lower incomes, higher poverty rates, and poor highway quality. Southeastern Oklahoma contains the most rugged terrain in the state, and has long been a poorly-connected area of the state. In addition to fewer high speed routes, though, the IRI map also shows that pavement quality has been neglected in this area. The persistent poverty of this area has been widely attributed to lower education rates and higher rates of female heads of households (Graham, 2009). Eastern Arkansas' economic woes have long been traced to low education rates as well as large concentrations of minority groups (Duval-Diop, 2006). Again, though cause and effect are hard to assign or disentangle, the co-location of these conditions indicates an area in which the state may need to focus if regional inequity is a condition that warrants remediation.

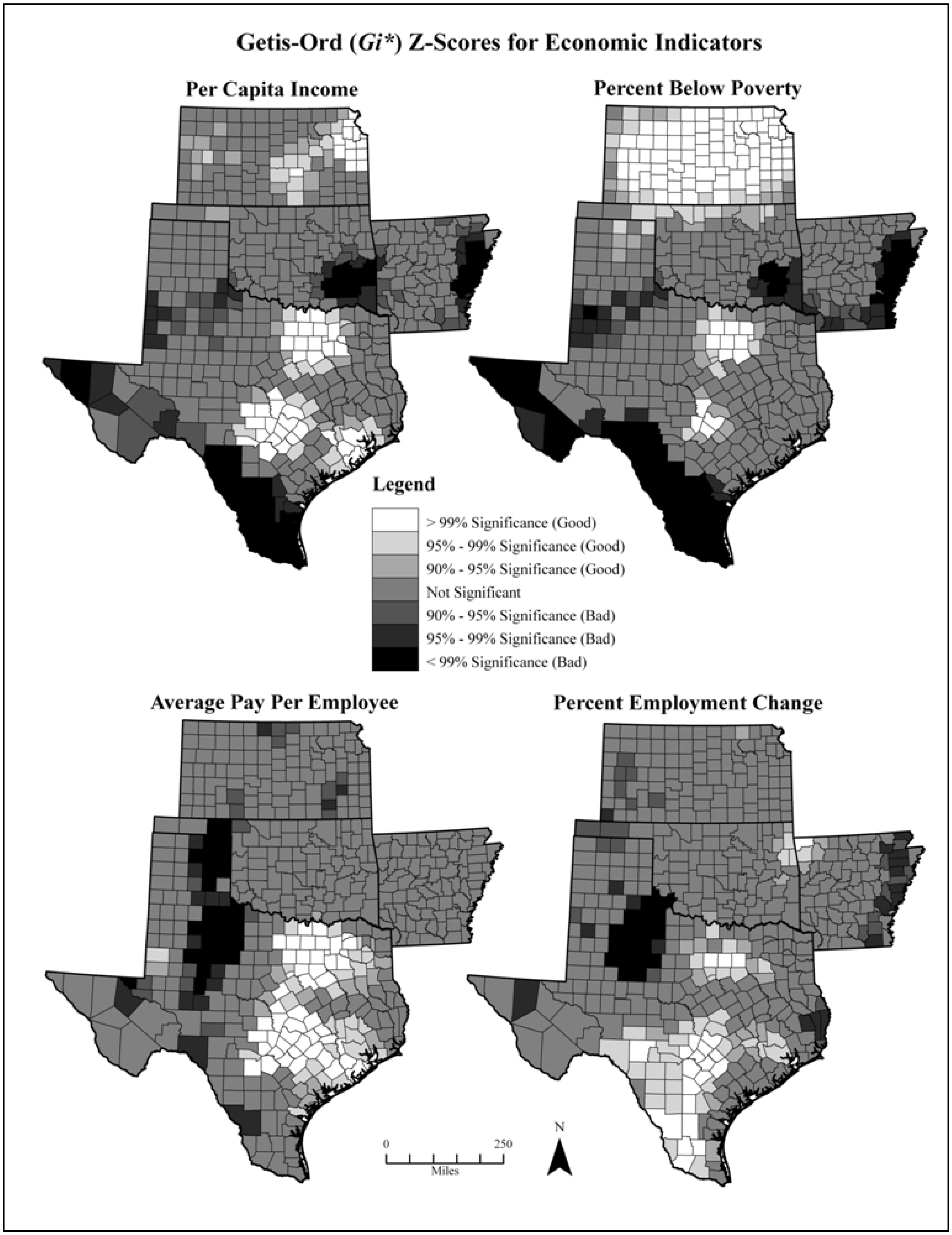


FIGURE 5
SPATIAL CLUSTERS OF ECONOMIC INDICATORS

Another spatial pattern that is evident is that Kansas' high ranking in the Condition section (Task 1) is reinforced here. Kansas has the aforementioned pocket of good IRI values along its border with Colorado as well as a secondary hot spot around Kansas City and has significantly better bridges in the east as compared to the west. Economically, Kansas has no notable clusters of poverty, job loss (or gain), and only moderately significant pockets of lower retail salaries offset by hot spots of higher per capita incomes around Kansas City and Wichita. Kansas' relatively good economic and transportation situation is the bright spot in the study area.

Finally, the borderlands of Texas demonstrate a different outcome, with poor economic development measured by both the poverty percentage as well as per capita incomes. In terms of transportation quality, however, this corridor is very unremarkable, with no counties exhibiting significantly good or bad highways and with just a small cluster of bad bridges near Brownsville in far southeastern Texas. Social and demographic considerations, especially immigration, likely outweigh the impact of transportation on the economy in this area.

Overall, however, the evidence is mixed as there is not a clear-cut spatial association between good highways and bridges and the economic indicators throughout large portions of the study area. The comments of Banister and Berechman (2001) regarding the need for both economic externalities and political factors to work in tandem with investment resources, and of Black (2001) in refuting the myth of economic development following (or even co-locating with) transportation investment, both merit consideration, at least in this study area. There is a complex interplay of factors that have confounded the study of the economic impacts of transportation at various spatial and temporal scales. These findings reinforce the conclusions emerging from various disciplines, approaches, scales, and governments that the benefits and costs of transportation investment are extremely hard to measure, isolate, and attribute.

Geographically weighted regression

The final analysis technique reported here is that of a spatial regression technique known as Geographically Weighted Regression (GWR), the result of work by Fotheringham *et al*. (2002) to account for the likelihood that geographic regression problems violate the assumptions of standard statistics, primarily the assumptions of independent observations and of homoscedasticity. Although assigning cause and effect is challenging in EIA studies of transportation impacts, the GWR technique provides a valuable approach to further quantifying the relationships hinted at in the correlation analysis and spatial autocorrelation analysis sections above. Also, given the temporal and meso-scale analysis approach used in this study, it is far more logical to attribute economic patterns and changes to the quality of the transportation network than the reverse.

Unlike past research assigning transportation investment as the independent variable in econometric analyses, we employ indicators of highway and bridge quality as the independent variables in the regression analysis. We do this both because of the difficulty in acquiring comparable, detailed data across the four states as well as our desire to pursue research avenues that are not apparent in the literature. Despite our different approach, the overall results of the analysis parallel findings by other researchers, with weak correlations between economic indicators and transportation variables. However, there are notably divergent results between variables, and between the four states individually and the overall four-state study area, so a brief review of this preliminary research is provided next. A fuller treatment of these results is currently in progress and a draft manuscript will be completed by the end of October, 2009 for presentation at the North American Meetings of the Regional Science Association International (RSAI) and ultimately for submission to a peer-reviewed geography journal.

Table 7 summarizes the results of the geographically weighted regression analysis for the twenty models that were developed. Models were run for five different territories, one for the aggregate four-state study area and as well as for each of the four states individually. For each of these five territories, four specific models were run, each using one of the four socioeconomic indicators described earlier as the dependent variable: per capita income (PCI), percent living in poverty (POV), retail sector payroll per employee (PAY), and overall employment change 1998-2006 (EMPL). Each model used both the ABC and IRI as independent variables, and for each model both a global R^2 value from standard regression analysis is given as well as the GWR R^2 value. Often, but not always, GWR provides a stronger result by having incorporated the spatial heterogeneity of the relationship between the independent and dependent variables. However, the results below consistently reveal that performing a simple, non-spatial regression analysis results in R^2 values close to zero for all four dependent variables in all five study territories, whereas geographic R^2 values are often much higher and reveal more information.

In reviewing the four models for the four-state study area, far and away the best relationship is between road/bridge quality and poverty (POV), with 60 percent of the variation in county-level poverty explainable by road and bridge conditions. The other three socioeconomic indicators demonstrate modest predictive abilities of 30 percent (PCI), 22 percent (PAY), and 18 percent (EMPL). Note the negative values of R^2 in many instances, a result that would seem impossible since R^2 is theoretically bound by zero and one. This occurs because the R^2 values reported below are *adjusted* R^2 values, which deflate the raw R^2 value somewhat by accounting for both sample size and the number of variables. Since there are only three total variables in each model and two independent variables, very small raw values of R^2 close to zero can translate into negative, though still close to zero, values of adjusted R^2.

TABLE 7
GLOBAL AND LOCAL (GWR) REGRESSION RESULTS

	Model	Global R2	GWR R2
4 STATE AREA	PCI	-0.002	0.301
	POV	0.000	0.601
	PAY	0.007	0.217
	EMPL	0.014	0.184
ARKANSAS ONLY	PCI	-0.013	0.429
	POV	-0.031	0.592
	PAY	0.096	0.117
	EMPL	-0.020	0.291
KANSAS ONLY	PCI	-0.028	0.271
	POV	-0.025	-0.022
	PAY	-0.027	-0.0003
	EMPL	-0.014	0.034
OKLAHOMA ONLY	PCI	-0.016	0.292
	POV	0.013	0.404
	PAY	-0.037	-0.020
	EMPL	-0.005	0.049
TEXAS ONLY	PCI	-0.004	0.312
	POV	-0.011	0.582
	PAY	0.008	0.231
	EMPL	0.025	0.219

No individual state results match the aggregate study area high of 60 percent explanation of poverty, though a few come close. Notably, for all states except Kansas, the predictability of poverty is also highest, a result similar to the aggregate study area result. For Arkansas the explanation of poverty is nearly 60 percent, for Texas it is 58 percent, and for Oklahoma it is 40 percent. In Kansas, meanwhile, the explanatory power of ABC and IRI are so low that the adjusted R^2 value is negative, an outcome that occurs only three times in the GWR analysis.

In each state except Kansas, where it is the sole significant result, per capita income (PCI) results in the second-highest geographic R^2 value, ranging from 43 percent in Arkansas to around 30 percent for the other three states. The best showing for employment change (EMPL) occurred in Arkansas at 29 percent, while the highest geographic R^2 value for retail payroll per employee (PAY) is in Texas at 23 percent. In aggregate, the payroll variable is the hardest to predict from road and bridge conditions, finishing as the worst-predicted dependent variable in Arkansas, Kansas, and Oklahoma and next-worse in Texas, while as noted earlier poverty (POV) produces the highest geographic R^2 value in all states except Kansas. Geographically, Arkansas and Texas seem to have stronger relationships between the independent variables and the four dependent variables, with R^2 values ranging between 59 and 12 percent in Arkansas and between 58 and 22 percent in Texas. Overall, there are clearer connections between road and bridge conditions and socioeconomic indicators in those two states as compared to Kansas and Oklahoma; Oklahoma's best-modeled dependent variable is poverty (40 percent) but both payroll and employment change are near zero, while Kansas' best model is for per capita income (27 percent) while the other three dependent variables' R^2 values are essentially zero.

In addition to these statistical results, the other valuable aspect of GWR is that it provides parameter (coefficient) estimates and R^2 values for each spatial unit in the study area. Hence, one can view how the strength of the relationship between independent and dependent variables varies across space both in terms of predictive ability (R^2) as well as the translation of unit changes in the independent variables into changes in the dependent variable (slope coefficients). The maps that follow show these results across the aggregate study area; maps for the models computed within each state are given in Appendix 2 at the end of this document. Each figure shows the local R^2 value, the slope coefficient for IRI, and the slope coefficient for ABC.

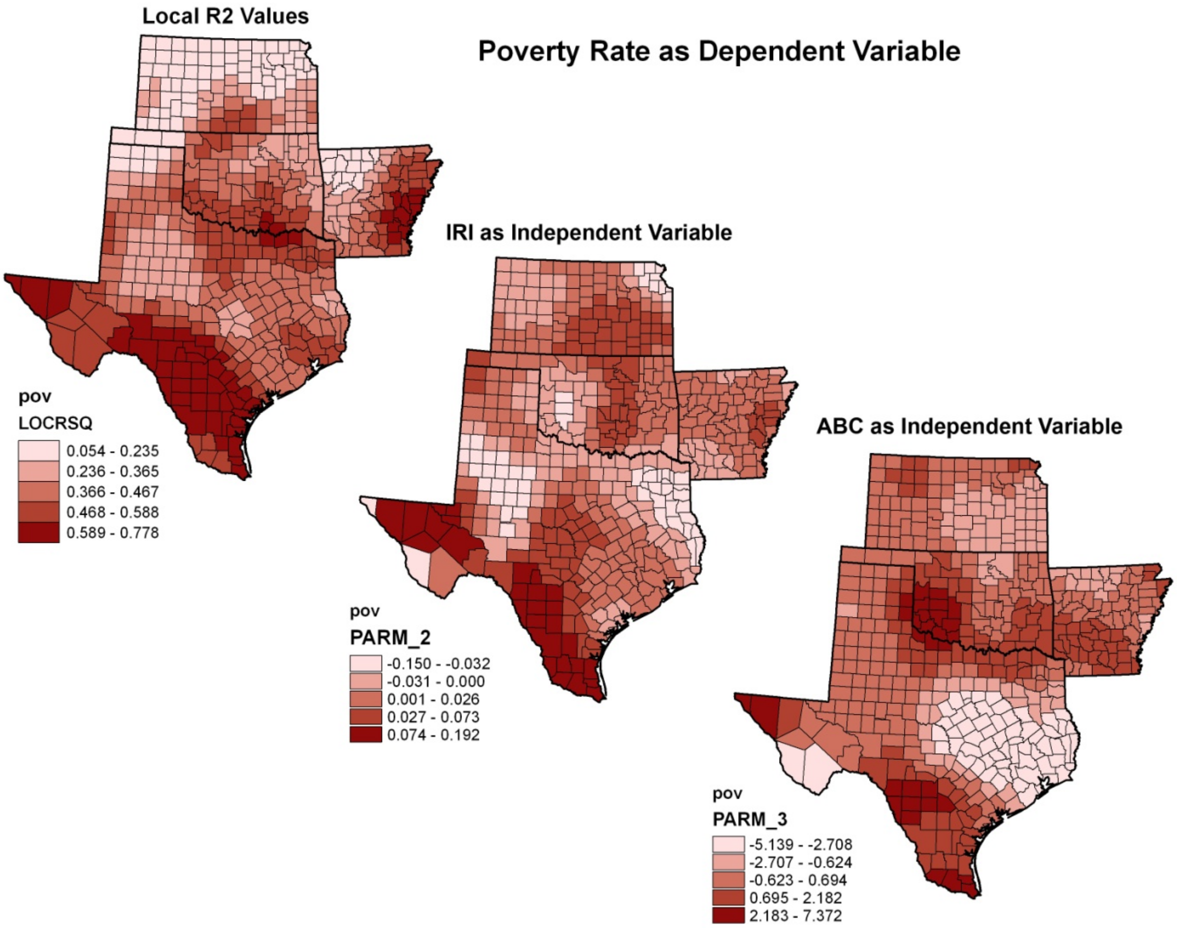


FIGURE 6
GWR RESULTS FOR POVERTY, AGGREGATE STUDY AREA

Model results for the percentage of the population living in poverty, the variable with the strongest aggregate local R^2 values, are shown in Figure 6 above. Some of the areas of the strongest relationship between road/bridge quality and poverty are evident in the Rio Grande Valley, the Mississippi Delta regions of Arkansas, and the Red River border region between Oklahoma and Texas. The other two maps reveal interesting and dissimilar patterns of the slope coefficients for the IRI and ABC indicators, providing evidence of the differential impacts of road and bridge conditions in predicting poverty across the study area.

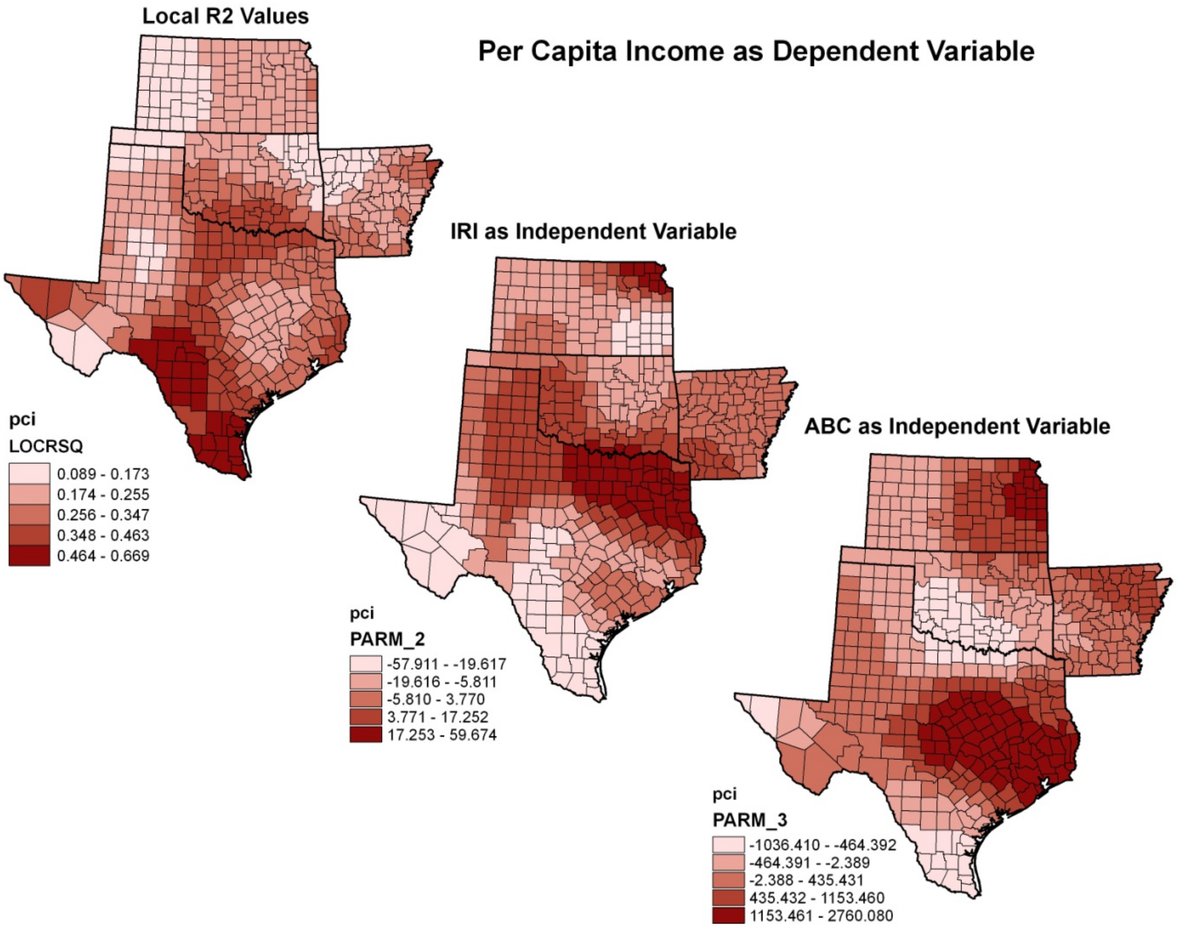


FIGURE 7
GWR RESULTS FOR PER CAPITA INCOME, AGGREGATE STUDY AREA

Model results for per capita income, generally the second-best modeled dependent variable, are shown above in Figure 7. The Rio Grande and Red River Valleys again appear as locations where there is a stronger connection between road/bridge quality and this economic indicator, though overall R^2 values are a bit lower than for poverty. Recalling that in Kansas per capita income was the sole dependent variable for which a modest local R^2 value was obtained (27 percent), it is interesting to note the much smaller amount of variation in local R^2 values across that state when compared to the other three states.

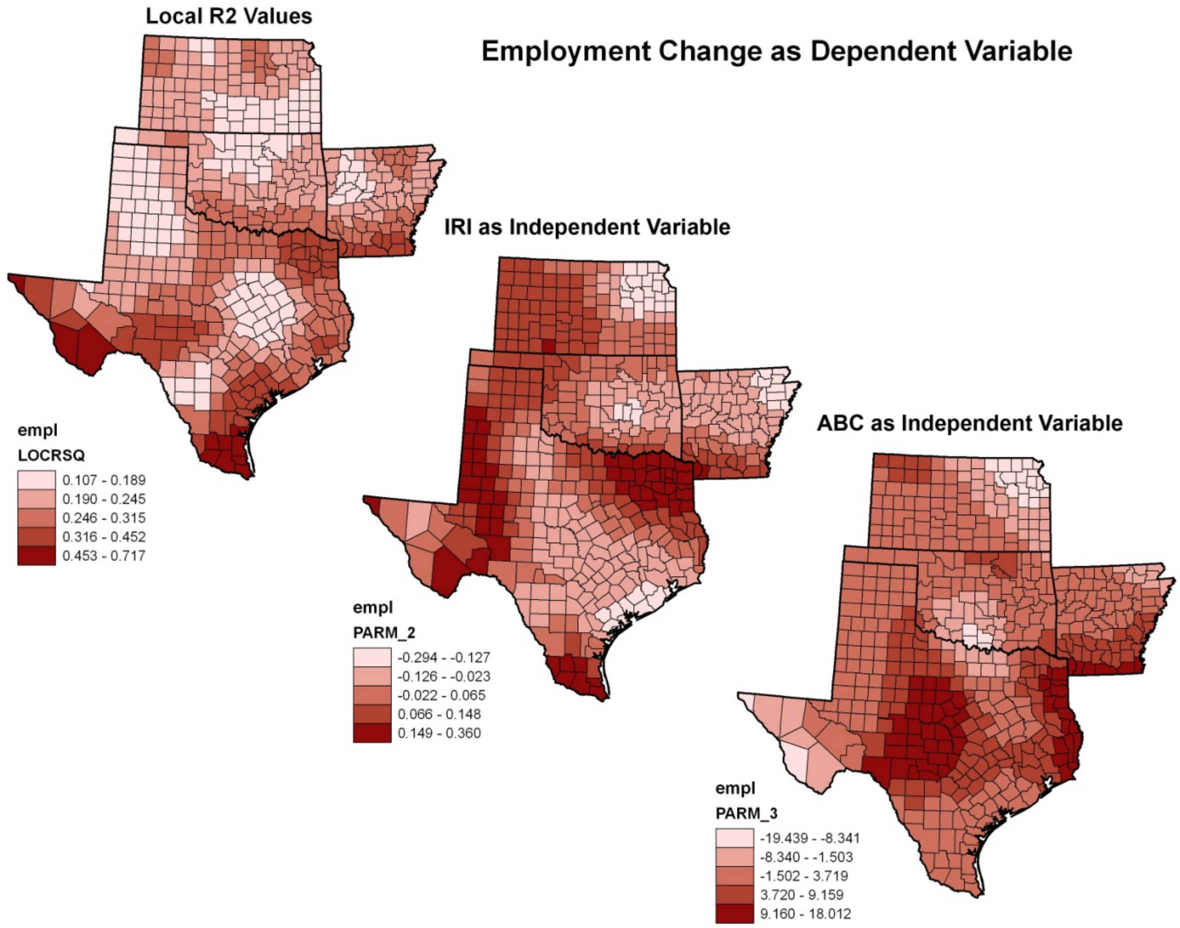


FIGURE 8
GWR RESULTS FOR EMPLOYMENT CHANGE, AGGREGATE STUDY AREA

Model results for employment change across all sectors of the economy, the third-best modeled dependent variable in three of the four states individually, are shown above in Figure 8. Roughly speaking, areas of higher employment levels overall (the more urban parts of the study area) demonstrate lower local R^2 values: the I-35 corridor through Texas, north-central Oklahoma, the Lubbock-Amarillo corridor in the Texas Panhandle, and northwest Arkansas. However, this relationship is not universally true, as the Kansas City region and the I-70 corridor across Kansas do not follow this pattern.

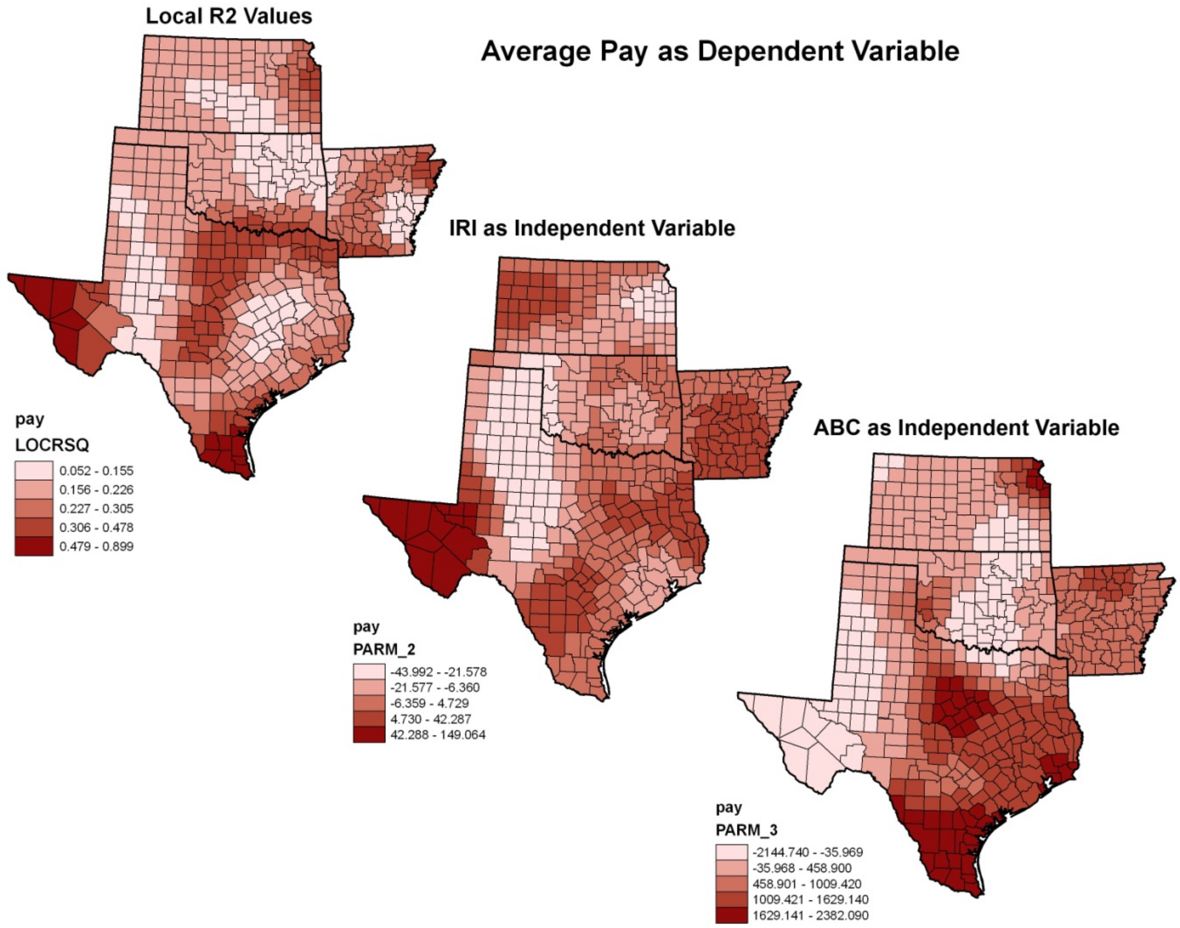


FIGURE 9
GWR RESULTS FOR RETAIL PAY PER EMPLOYEE, AGGREGATE STUDY AREA

The worst-modeled dependent variable, retail sector payroll per employee, is shown above in Figure 9. The maps above reveal smaller overall local R^2 values and correspondingly smaller slope coefficient values for IRI and ABC. Though this variable produced the third-highest local R^2 value for the aggregate study area, it had the lowest R^2 values in Arkansas, Kansas, and Oklahoma, while only barely ranking third in Texas. Though improved transportation routes may lead to better business conditions vis-à-vis more traffic, there are doubtless other influences that confound this result. State-level maps are shown in Appendix 2.

PUBLIC REPORTING DELIVERABLES

Conference Presentations

Through November 2009, three presentations at conferences were given reporting various aspects of this project. These are listed below:

- Annual Meeting, Southwestern Division, Association of American Geographers (SWAAG), North Little Rock, AR, October 29, 2009. Poster title: Oklahoma's Transportation Infrastructure: Inventory and Impact via the Internet.
- 32nd Annual Meeting, Applied Geography Conferences, Baton Rouge, LA, October 30, 2009. Paper title: An Assessment of Road and Bridge Conditions.
- 56th Annual North American Meetings, Regional Science Association International (RSAI), San Francisco, CA, November 19-21. Paper title: The Relationship Between Transportation Quality and Regional Growth: Evidence from the South-Central U.S.

Additional presentations are planned in the future as research continues making use of the database developed in this project.

Manuscript Publications and Submissions

Through November 2009, two manuscripts were written reporting various aspects of this project and related to the two papers given at the above conferences:

- Comer, J.C., Graham, A.K., and S.R. Brown. 2009. An Assessment of Road and Bridge Conditions in Four States. *Papers of the Applied Geography Conferences* **32**: 47-56.
- Comer, J.C., Graham, A.K., and S.R. Brown. 2009. The Relationship between Transportation Quality and Regional Growth: Evidence from the South-Central U.S. Manuscript prepared for RSAI conference, intend to submit to *Economic Geography*.

Project Web Page and GeoPDFs

All of the data and research produced for this project are available on the World Wide Web at http://www2.geog.okstate.edu/oklahomatransportationinventory/. In addition to providing the base connectivity data sets (Excel), a wide array of maps is presented so residents and researchers can review the transportation inventory and condition in their localities.

A new program that works within Adobe Acrobat called GeoPDF, which is available from TerraGo Technologies (http://www.terragotech.com/index.php), works much like on-line mapping software (i.e. Google Earth) but in Adobe's widely-used Portable Document Format (PDF). The use of GeoPDFs provides a platform in which users can turn layers off and on in a static PDF document rather than using GIS software such as ArcGIS or ArcMap, which requires much more labor, special software, and considerable computing power. Despite being a static PDF in the sense that it is not linked to an active database, this software allows the user to zoom in or out and interact with the maps.

Because of the focus of this study on Oklahoma, each county in Oklahoma has its own map of both bridge and road condition data in the GeoPDF format. Thus, county-level maps in Oklahoma are available on the website for county residents, planners, engineers, and others to analyze the conditions of the roads and bridges in their county of interest in Oklahoma. State-level maps for Arkansas, Kansas, and Texas are also available. As noted above, each county in Oklahoma has two GeoPDFs – one map focusing on road conditions in the county and displaying only the locations of bridges (no bridge conditions), the second map focusing on bridge conditions and simply displaying the highway routes for reference (no road conditions). Figure 10 below shows a bridge condition map for Adair County in Oklahoma in which all layers present in the database are currently visible.

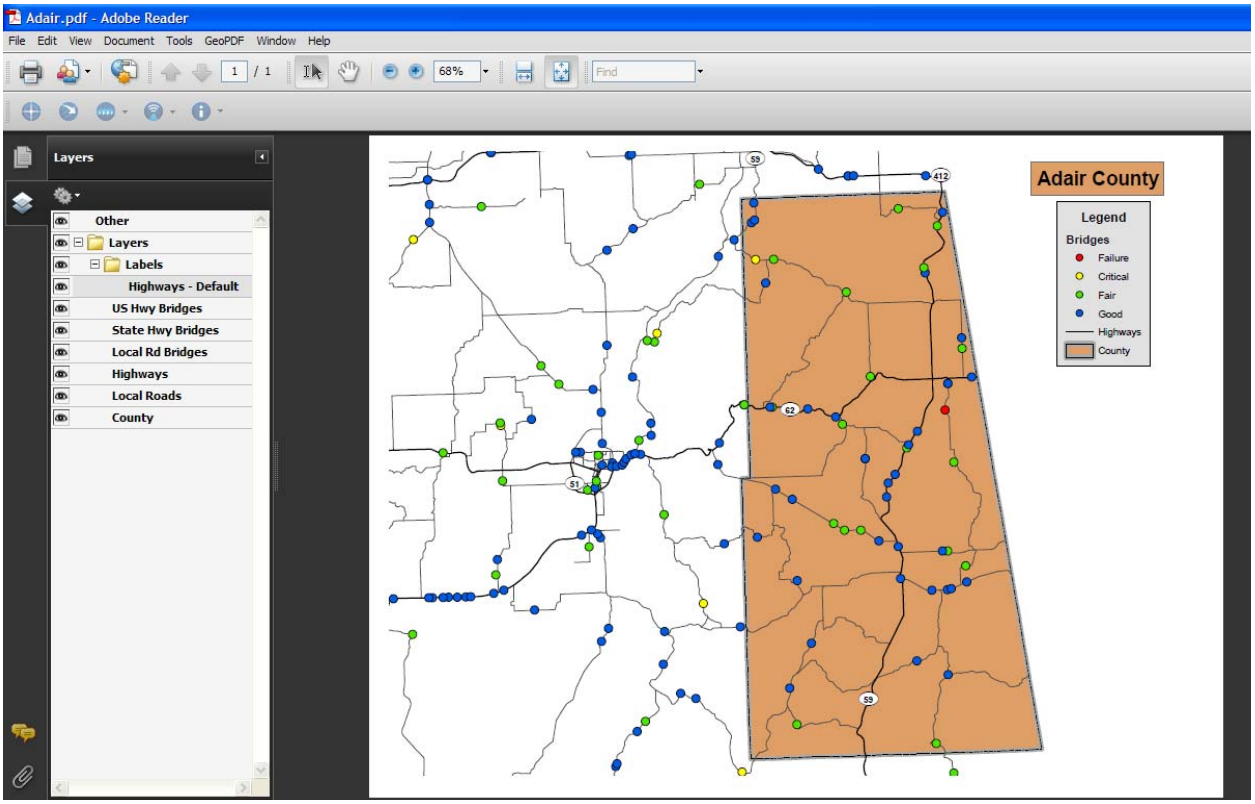


FIGURE 10
GeoPDF OF ADAIR COUNTY –BRIDGES ON ALL ROUTES

As demonstrated in Table 5 earlier, the original ten bridge classification categories are collapsed into four aggregations: Good (shaded blue), Fair (green), Critical (yellow), and Failed (red). Adair County is highlighted and bridge conditions, as well as major highway routes, are visible in the county and some of its surrounding area.

Turning on and off various layers in a GeoPDF is done by opening the Layers tab. The user first selects View, then Navigation Panels, and then Layers. Next to the layer name on the left-hand side are images of an "eye" indicating the layer is visible. When the eye is clicked, the eye disappears as well as that layer on the map. In Figure 11 below, the layers "State Hwy Bridges" and "Local Rd Bridges" have been made invisible.

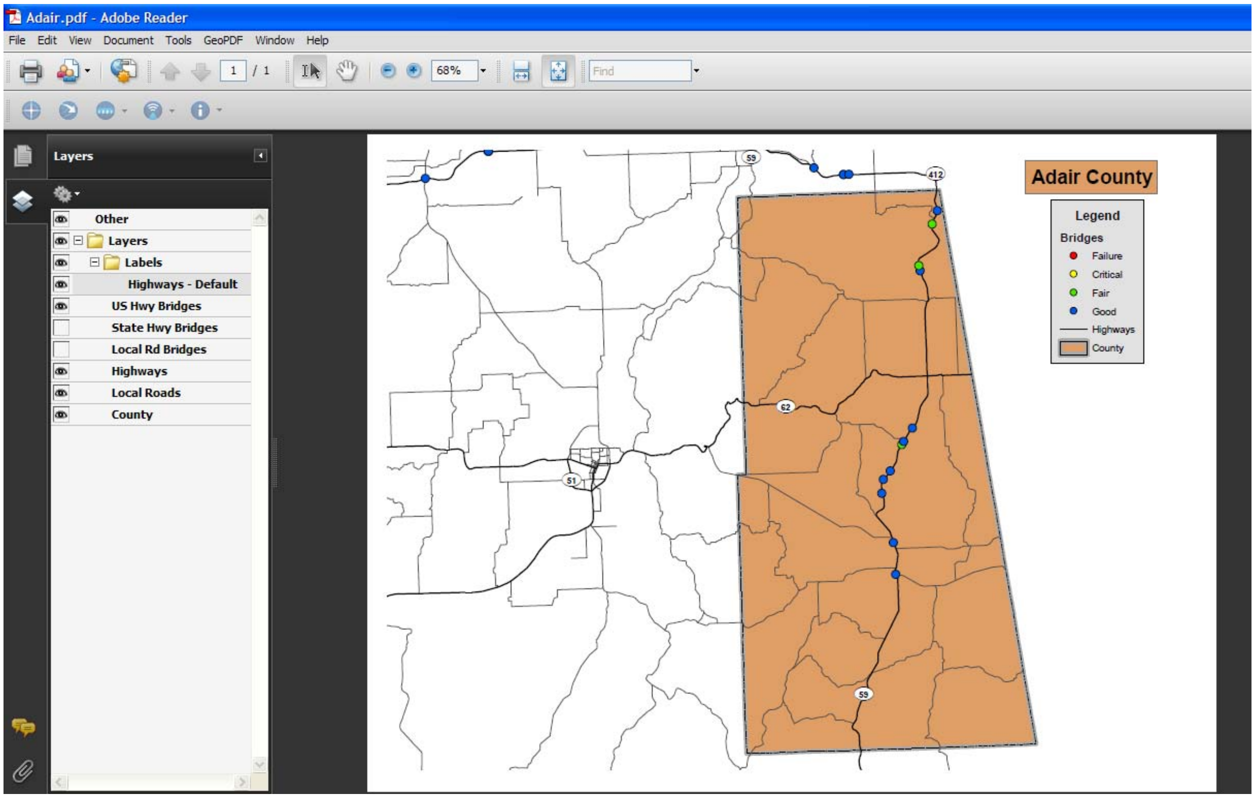


FIGURE 11
GeoPDF OF ADAIR COUNTY – BRIDGE CONDITIONS ON U.S. HIGHWAYS ONLY

The GeoPDF map of road conditions functions in a similar manner, with the roads categorized by functional class (see Table 3 earlier) and IRI value, with bridges visible (if desired) but not classified by condition. GeoPDF allows users to separate roads by Interstate, U.S. Highways, state highways, and local roads. For mapping purposes, IRI values have been classified and shaded as: 1-60 = Very Good (blue), 61-120 = Good (green), 121-170 = Fair (yellow), 171-220 = Poor (orange) and 221-999 = Very Poor (red). The same type of information is displayed as before. All bridges can be left visible or hidden, and different road types can be selected for presentation. Figure 12 below provides an example of a road map with all layers visible and then Figure 13 shows only the U.S. Highway conditions in Adair County.

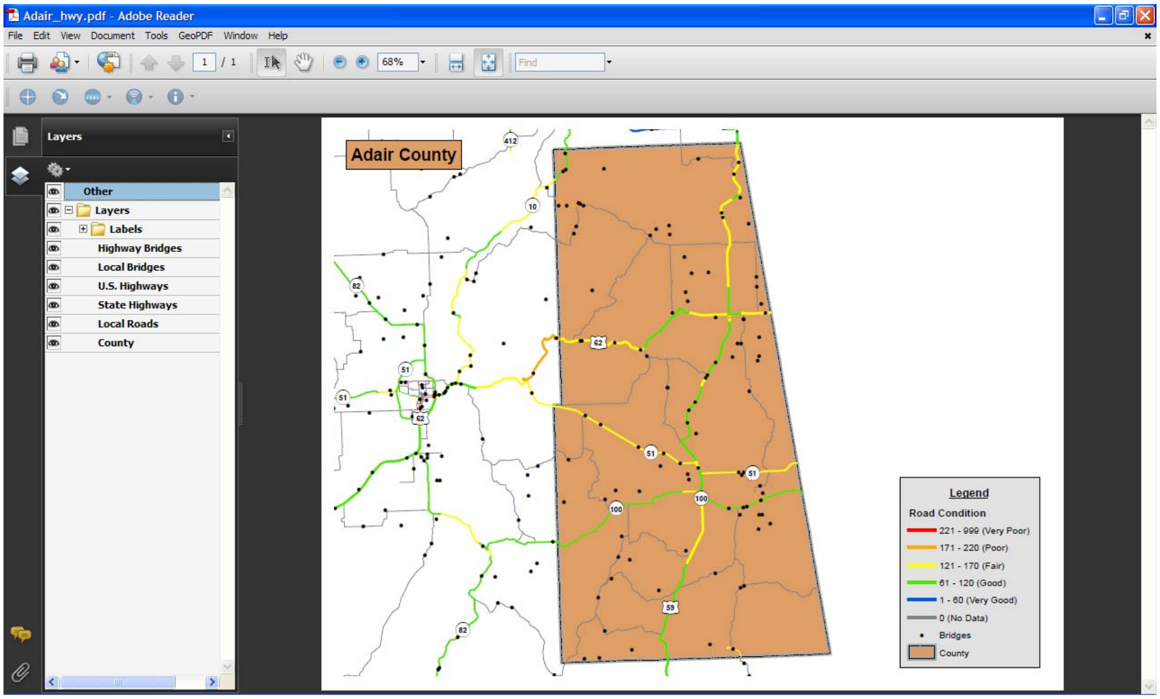


FIGURE 12
GeoPDF OF ADAIR COUNTY – CONDITIONS OF ALL ROADS

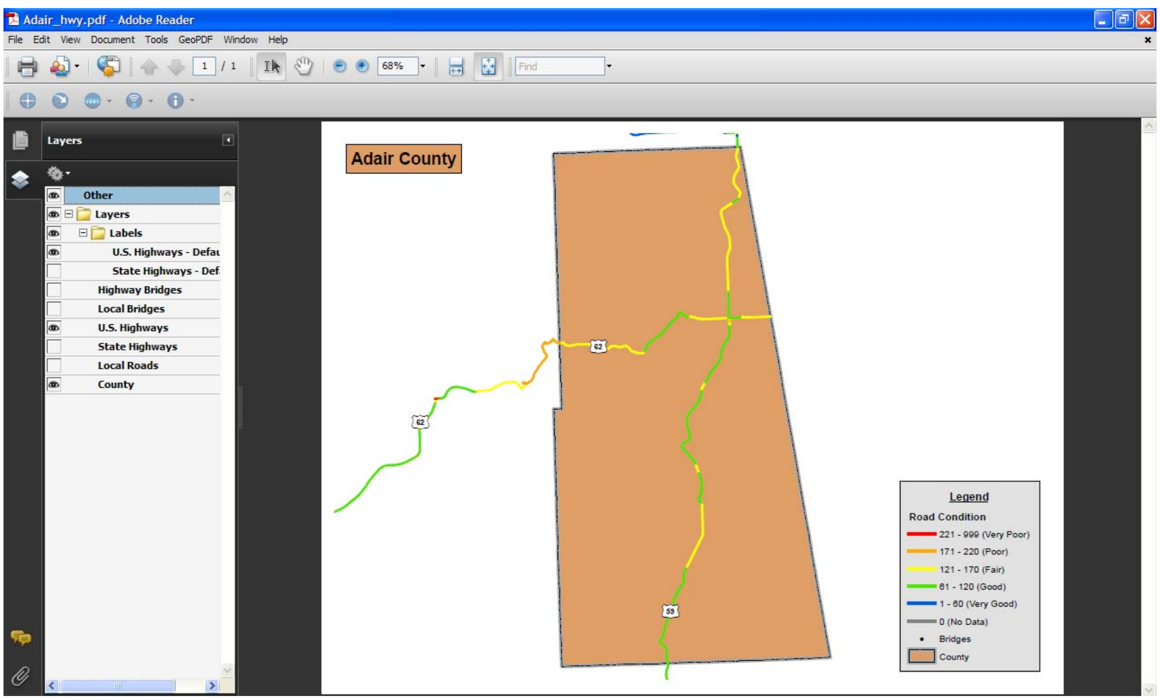


FIGURE 13
GeoPDF OF ADAIR COUNTY – CONDITIONS OF U.S. HIGHWAYS ONLY

Airports, water transportation ports, and railroads are also part of the database inventory, are shown on state-levels, and those layers can be turned on or off at will. Additionally, all maps contain basic geographic identifiers such as county and state outlines.

The reason GeoPDFs were used is that they take up virtually no space. Compared to using a Geographical Information System, GeoPDF compression rates are very impressive and compact. In addition, it is easy for various entities to share these maps. If the maps were being served via an Internet-based GIS-type platform, we would have to send out multiple files in order to reproduce the map, whereas with the PDF it is just one file with all the information in a familiar environment. These maps also can be sent electronically without being caught in a firewall. The ability to create and distribute all the maps with all of the data, in a comfortable electronic environment for others to view and interact with the maps, are desirable traits and possible in GeoPDFs.

CONCLUSION

Overall, several aspects of this project have highlighted the decaying infrastructure of Oklahoma's transportation inventory as well as confirming widely-held beliefs that the state lags its neighbors. Furthermore, the daunting task of trying to assign cause and effect to transportation investment and economic development remains a work in progress; we have conducted analysis at a scale (county-level, but across a relatively large area) that has not been seen in the literature and found that the mixed results in micro- and macro-level studies also emerge at the meso-level of analysis as well. Although policy makers and elected officials want and need to demonstrate good fiscal stewardship of public monies, it may never be the case that definitive economic impacts can be isolated with respect to transportation investment. However, continued study of this problem and phenomenon will hopefully improve our ability to report to the public the value of investing in transportation.

It is anticipated that the outcome of this project will have clear policy implications for the state, both at the governmental level as well as the bureaucratic levels of the Department of Transportation and the state finance office. The completion of a comprehensive inventory and analysis of the state's transportation network, and indirectly its entire transportation infrastructure, can provide useful base data, statistical results, and recommendations that could help the state stretch scarce social capital for the maximum benefit of all citizens. Transportation changes inevitably have winners and losers. The winners tend to be both local and non-local. Local winners include individuals who may sell land to the state for a fair price, businesses that will benefit from improved or increased traffic, and local governments that obtain higher tax revenues from expanded business activities and growing populations. Non-local winners include those who wish to move more quickly through an intermediate location, who work construction jobs while highway improvements are underway, and who might be attracted to an area (both personally and professionally) because of its transportation system. Losers tend to be local; those who must give up land they had no intention of selling, and business owners in locations that do not directly benefit from route changes or improvements (such as a bypass leaving downtown merchants with less traffic). These types of tensions between winners and losers are inevitable, but they also reveal the huge impact of transportation on modern American society. Independent and non-commercially-motivated analysis such as the research being proposed here provides an opportunity to put objective data in the hands of decision makers so that transportation decisions can be made on a pragmatic rather than a partisan basis.

Beyond the general results described above, the specific deliverables promised in the proposal for this project included:

1. a comprehensive transportation inventory for Oklahoma and three of its neighbors;
2. a GIS database with the states' highway and other appropriate networks, linked with socioeconomic and business data to permit further research by other interested parties;
3. statistical analysis measuring the impacts of transportation in the four states; and
4. a comprehensive report that reviews and describes the data and methods used, that analyzes of the context, connectivity, and condition of the states' transportation networks and that summarizes the results and provides recommendations.

Items 1 and 2 are available through the Internet, both via a viewing option (GeoPDFs) as well as well as being partially downloadable. At the outset, a clear delivery mechanism for these items was not firm, but the discovery of GeoPDFs was a huge boon for both the researchers and we hope for the general public. Item 3 is provided in this report, in the manuscripts published or currently in preparation, and in future research. This report comprises Item 4.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). 2009. *Rough roads ahead, fix them now or pay for it later*. Washington, DC: AASHTO.

Banister, D., and Y. Berechman. 2001. Transport investment and the promotion of economic growth. *Journal of Transport Geography* 9(3): 209-218.

Black, W.R. 2001. An unpopular essay on transportation. *Journal of Transport Geography* 9(1): 1-11.

———. 2003. *Transportation: A Geographical Analysis*. New York: Guilford Press.

Bureau of Transportation Statistics (BTS). 2007 (September). *Highway bridges in the United States – an overview*. Washington, DC: U.S. Department of Transportation.

Central Okanagan Regional Growth Strategy. 2003. Transportation and Mobility Options for the Central Okanagan (Discussion Paper). February 2003.

Comer, J.C., A.K. Graham, and S.R. Brown. 2009. An assessment of road and bridge conditions in four states. *Papers of the Applied Geography Conferences* 32: 47-56.

Delaware River Joint Toll Bridge Commission. 2004. Northerly Crossings Corridor Congestion Mitigation Study, Final Technical Memorandum #2. October 11, 2004.

Duval-Diop, D. 2006. *Rediscovering the Delta: A reassessment of the linkages between poverty, economic growth, and public policy using geographically weighted regression analysis* (Unpublished doctoral dissertation). Louisiana State University: Baton Rouge.

Fotheringham, A.S., C. Brunsdon, and M. Charlton. 2000. *Quantitative geography: Perspectives on spatial data analysis*. Thousand Oaks, CA: Sage.

———. 2002. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*. Hoboken, NJ: John Wiley & Sons Inc.

Graham, A.K. 2009. *Measuring the spatial dimensions of poverty in Oklahoma* (Unpublished master's thesis). Oklahoma State University, Stillwater.

Loizos, A., and C. Plati. 2008. An alternative approach to pavement roughness evaluation. *International Journal of Pavement Engineering* 9(1): 69-78.

Madrick, J. 1996. *Economic returns from transportation investment.* Lansdowne, VA: Eno Transportation Foundation, Inc.

Nadiri M.I., and T.P. Mamuneas. 1996. *Contribution of highway capital to industry and national productivity growth*. Report prepared for Federal Highway Administration. http://www.fhwa.dot.gov/reports/growth.pdf. Last accessed 20 July 2009.

National Association of State Budget Officers. 2008. *State expenditure reports*. http://www.nasbo.org/publicationsReport.php. Last accessed 20 May 2009.

National Cooperative Highway Research Program (NCHRP). 1998. *Research on the relationship between economic development and transportation investment.* NCHRP Report 418. Washington, DC: National Academy Press.

Papagiannakis, A., N. Gharaibeh, J. Weissmann, and A. Wimsatt. 2009. *Pavement score synthesis*. College Station, TX: Texas Transportation Institute.

Southeastern Wisconsin Regional Planning Commission (SEWRPC). 2004. Regional Transportation System for Southeastern Wisconsin: 2035. Planning Report No. 49, December 2004.

Taaffe, E.J., H.L. Gauthier, and M.E. O'Kelly. 1996. Geography of Transportation (2e.). Upper Saddle River, NJ: Prentice Hall.

U.S. Census Bureau. 2000. *Census 2000*. http://factfinder.census.gov/servlet/DTGeoSearch ByListServlet?ds_name=DEC_2000_SF3_U&_lang=en&_ts=261396609093. Last accessed 24 May 2009.

U.S. Census Bureau. 2002. *Economic census*. http://factfinder.census.gov/servlet/IBQTable? _bm=y&-geo_id=D&-ds_name=EC0200A1&-_lang=en. Last accessed 22 May 2009.

U.S. Census Bureau. 2009. *County business patterns*. http://www.census.gov/econ/cbp/ index.html. Last accessed 22 May 2009.

U.S. Department of Transportation and the Research and Innovative Technology Administration's Bureau of Transportation Statistics (RITA/BTS). 2008. *National transportation atlas databases*. http://www.bts.gov/publications/national_ transportation_atlas_database/2008/. Last accessed 19 May 2009.

Weisbrod, G. 2000. *Procedures for assessing economic development impacts from transportation investments.* National Cooperative Highway Research Program, Synthesis of Highway Practice. Boston: Economic Development Research Group.

APPENDIX 1

Condition data for all roads in Oklahoma, Texas, and Arkansas consisted of mapped data with attribute tables containing the International Roughness Index (IRI) data collected by each state. These files were combined into one GIS in order to analyze and represent them together. The condition data received from the Kansas Department of Transportation consisted solely of an Excel spreadsheet with the following columns:

- LRS_KEY – a location identifier; 3 digits representing the county, 6 digits representing the route, route suffix (i.e. B for Business), a unique ID, an S for State highways or a T for Turnpike, and a suffix which is 0 for everything here meaning that no planned future roads are included.
- MPBEG – the beginning of the segment within the county
- MPEND – the ending of the segment within the county
- ID – the Pavement Management System unique identifier for the segment. It is made up of many of the same things as the LRS_Key (first 3 = county; next digit 1=I, 2=U, 3=K; next 3 are route numbers; next 1 is code for business (note that 9 here is turnpike); next two are integer portion of the beginning milepost; next two are integer portion of ending milepost; last digit is lane (0 undivided, 1=WB, 2=NB, 3=EB, 4=SB)
- IRIR is the 2008 International Roughness Index value in inches per mile calculated for the right wheelpath on that segment
- IRIL is the 2008 International Roughness Index value in inches per mile calculated for the left wheelpath on that segment
- MIRI is the mean IRI for both wheelpaths
- IRIDATE is the date the profile data was collected that was used to calculate the IRI.

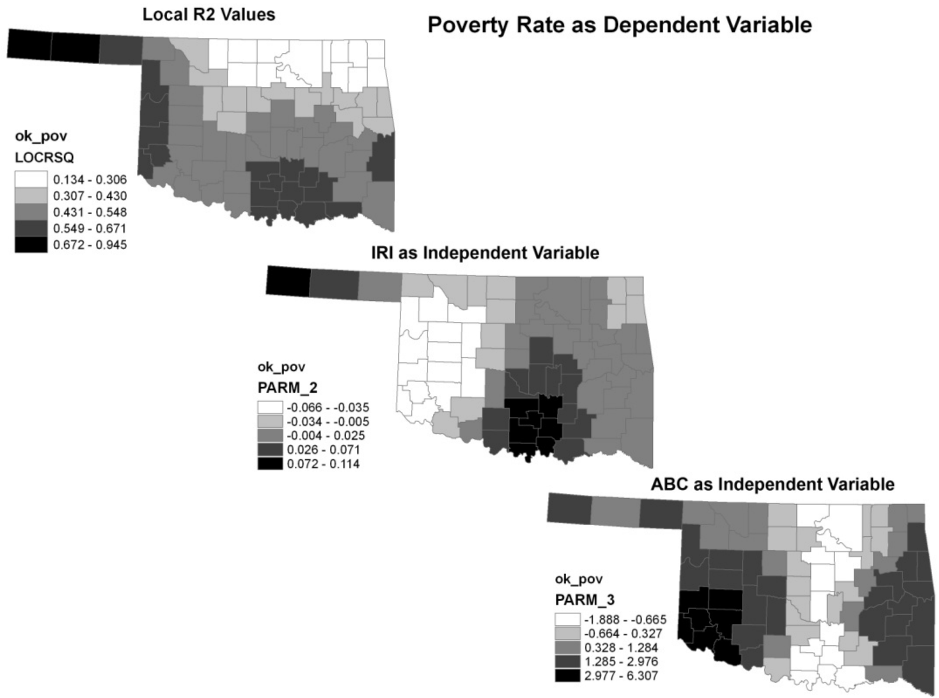
However, these data were not consistent with the highway segment data available from the National Transportation Atlas Database (NTAD) for the state of Kansas. The spreadsheet containing the IRI data from KDOT showed an IRI value for approximately every mile of the road network in Kansas. The shapefile for the Kansas highways available through the NTAD consisted of road segments of varying lengths.

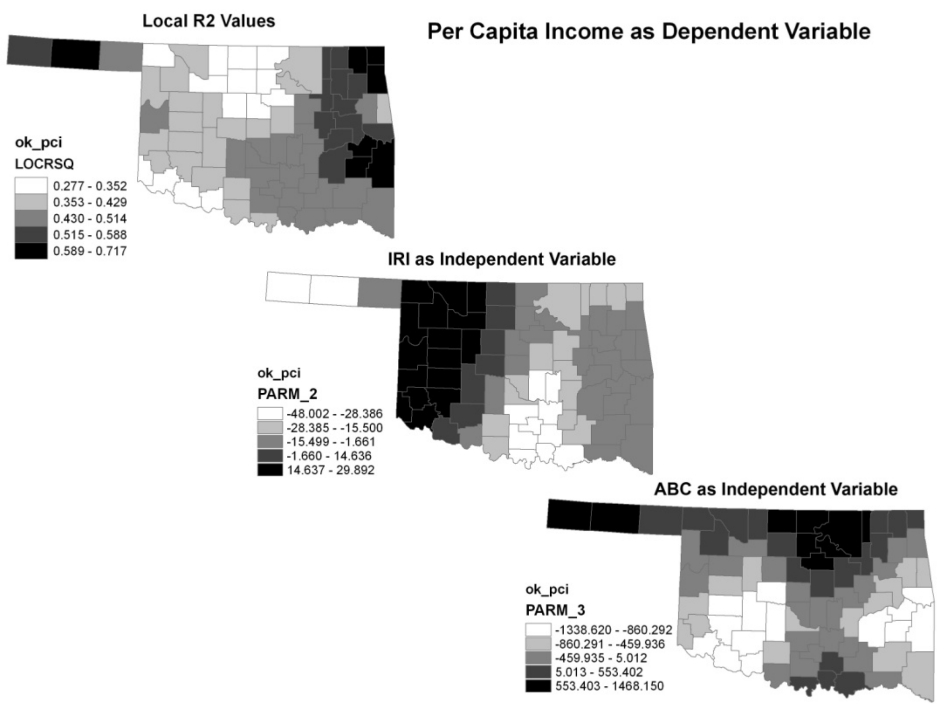
In order to join the roughness data with the highway segment data so that the roughness data could be displayed in a GIS, a common field was created within both the Excel spreadsheet as well as the attribute table for the highway shapefile. Both files contained beginning and ending mileage points for each highway segment. The mileage points were matched as closely as possibly between the two tables and an average IRI value was then obtained from the KDOT spreadsheet and inserted into the shapefile attribute table. Some road segments did not have IRI information associated with them; these segments were given a value of zero in the IRI field. The shapefile attribute table was then rejoined with the highway shapefile and added to the GIS containing data from Oklahoma, Arkansas, and Texas.

APPENDIX 2

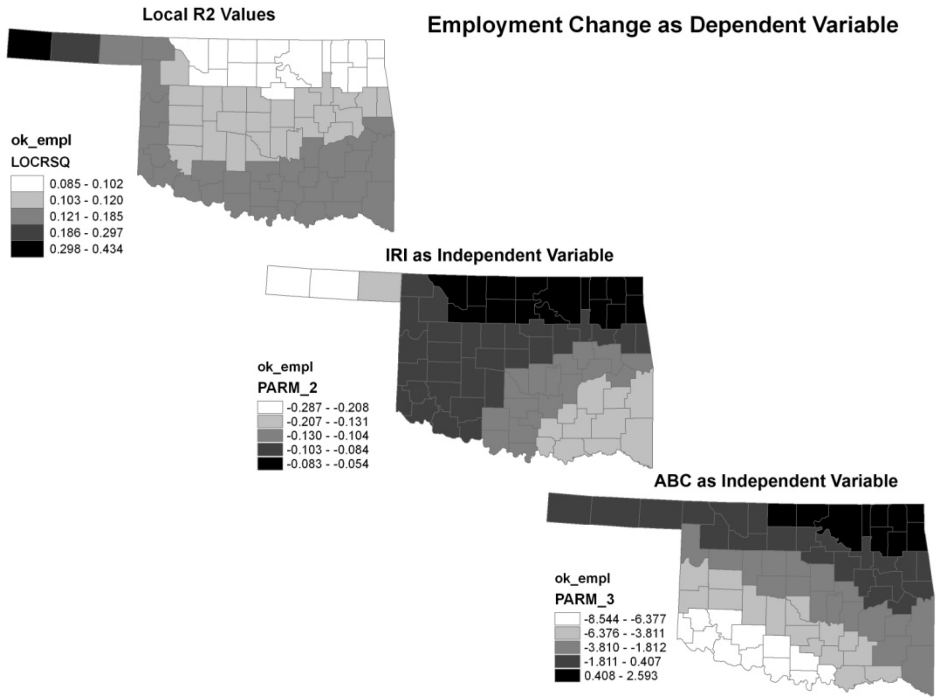
The following pages provide the state-level maps for the GWR analysis explaining variations in four socioeconomic indicators as modeled by both road (IRI) and bridge (ABC) quality indicators. Each figure shows the local R^2 values, IRI slope coefficients, and ABC slope coefficients, mapped for all counties in the state. The overall model R^2 values were given in Table 7 in the body of this report.

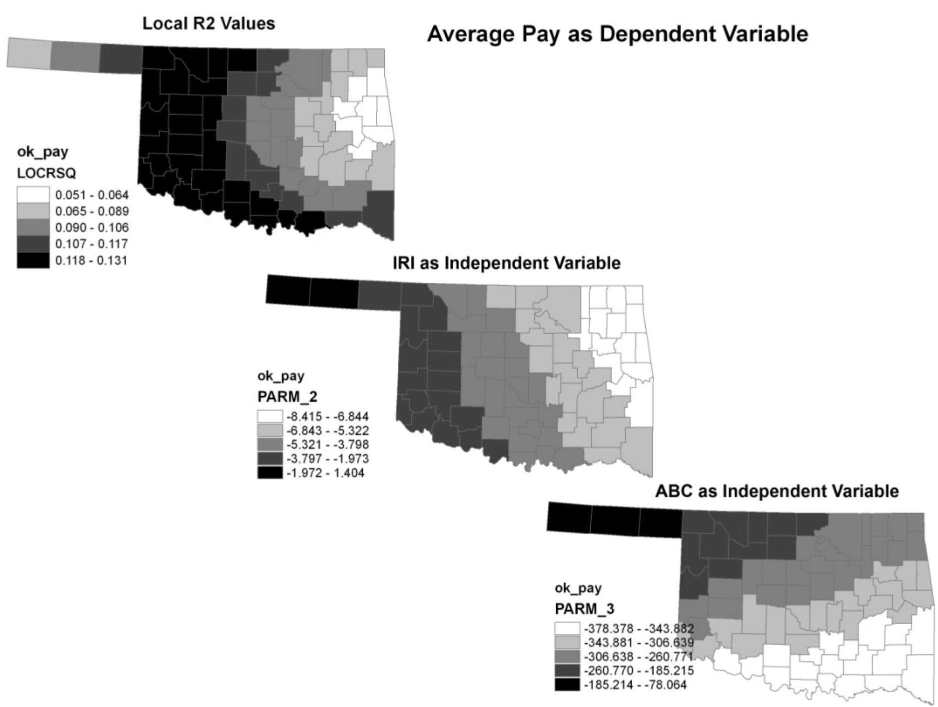
Oklahoma


Local R2 Values
Poverty Rate as Dependent Variable
ok_pov
LOCRSQ
0.134 - 0.306
0.307 - 0.430
0.431 - 0.548
0.549 - 0.671
0.672 - 0.945
IRI as Independent Variable
ok_pov
PARM_2
-0.066 - -0.035
-0.034 - -0.005
-0.004 - 0.025
0.026 - 0.071
0.072 - 0.114
ABC as Independent Variable
ok_pov
PARM_3
-1.888 - -0.665
-0.664 - 0.327
0.328 - 1.284
1.285 - 2.976
2.977 - 6.307

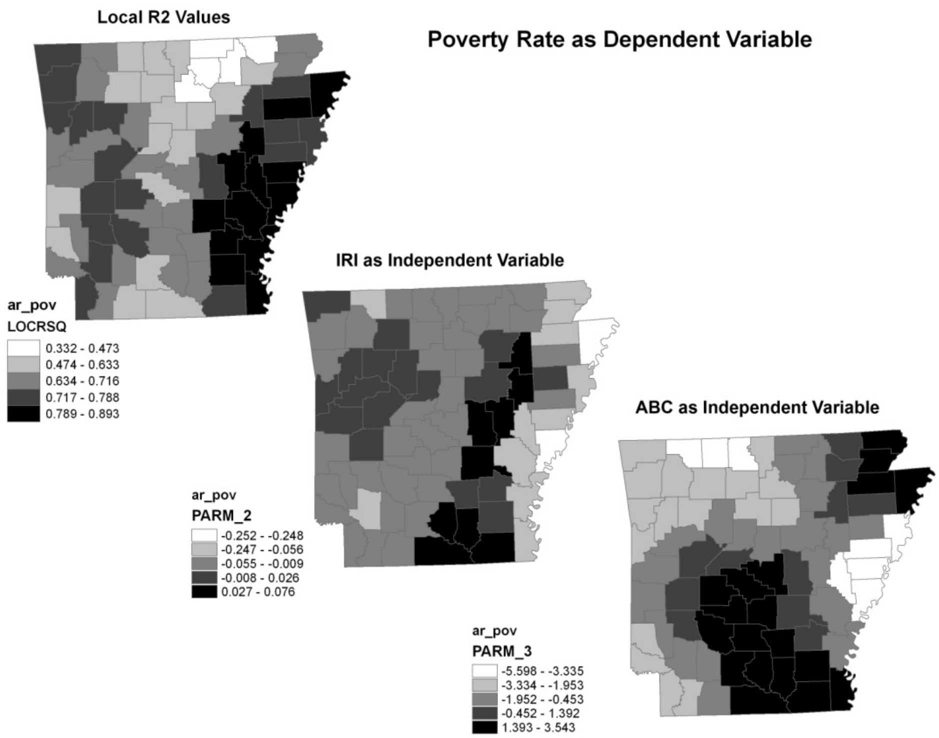

Local R2 Values
Per Capita Income as Dependent Variable
ok_pci
LOCRSQ
0.277 - 0.352
0.353 - 0.429
0.430 - 0.514
0.515 - 0.588
0.589 - 0.717
IRI as Independent Variable
ok_pci
PARM_2
-48.002 - -28.386
-28.385 - -15.500
-15.499 - -1.661
-1.660 - 14.636
14.637 - 29.892
ABC as Independent Variable
ok_pci
PARM_3
-1338.620 - -860.292
-860.291 - -459.936
-459.935 - 5.012
5.013 - 553.402
553.403 - 1468.150

Oklahoma

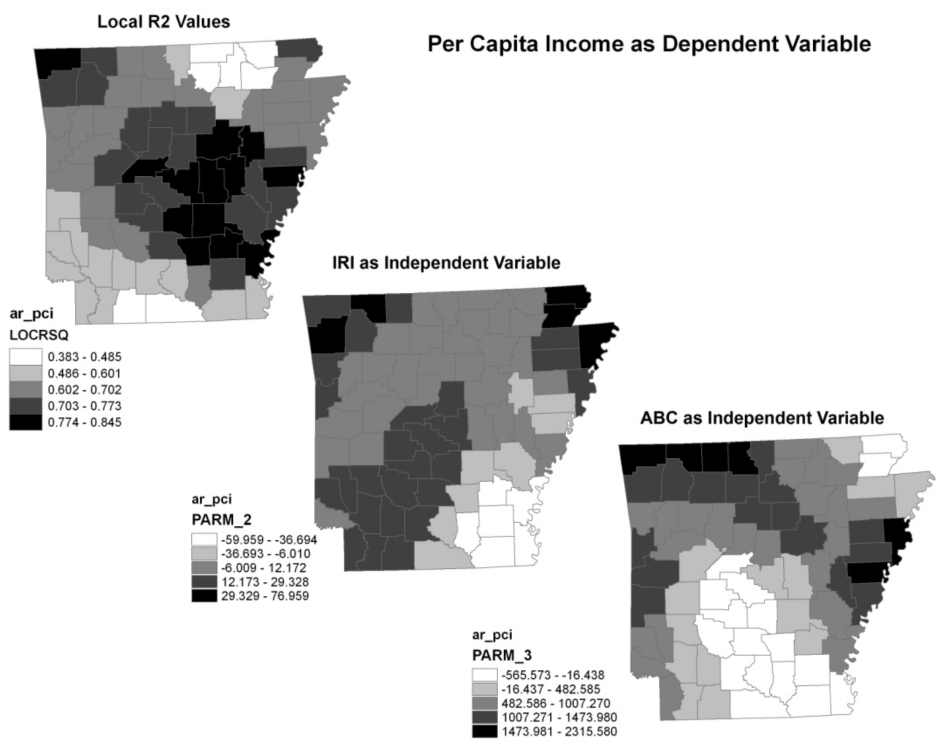

Employment Change as Dependent Variable
Local R2 Values
ok_empl
LOCRSQ
0.085 - 0.102
0.103 - 0.120
0.121 - 0.185
0.186 - 0.297
0.298 - 0.434
IRI as Independent Variable
ok_empl
PARM_2
-0.287 - -0.208
-0.207 - -0.131
-0.130 - -0.104
-0.103 - -0.084
-0.083 - -0.054
ABC as Independent Variable
ok_empl
PARM_3
-8.544 - -6.377
-6.376 - -3.811
-3.810 - -1.812
-1.811 - 0.407
0.408 - 2.593


Average Pay as Dependent Variable
Local R2 Values
ok_pay
LOCRSQ
0.051 - 0.064
0.065 - 0.089
0.090 - 0.106
0.107 - 0.117
0.118 - 0.131
IRI as Independent Variable
ok_pay
PARM_2
-8.415 - -6.844
-6.843 - -5.322
-5.321 - -3.798
-3.797 - -1.973
-1.972 - 1.404
ABC as Independent Variable
ok_pay
PARM_3
-378.378 - -343.882
-343.881 - -306.639
-306.638 - -260.771
-260.770 - -185.215
-185.214 - -78.064

Arkansas

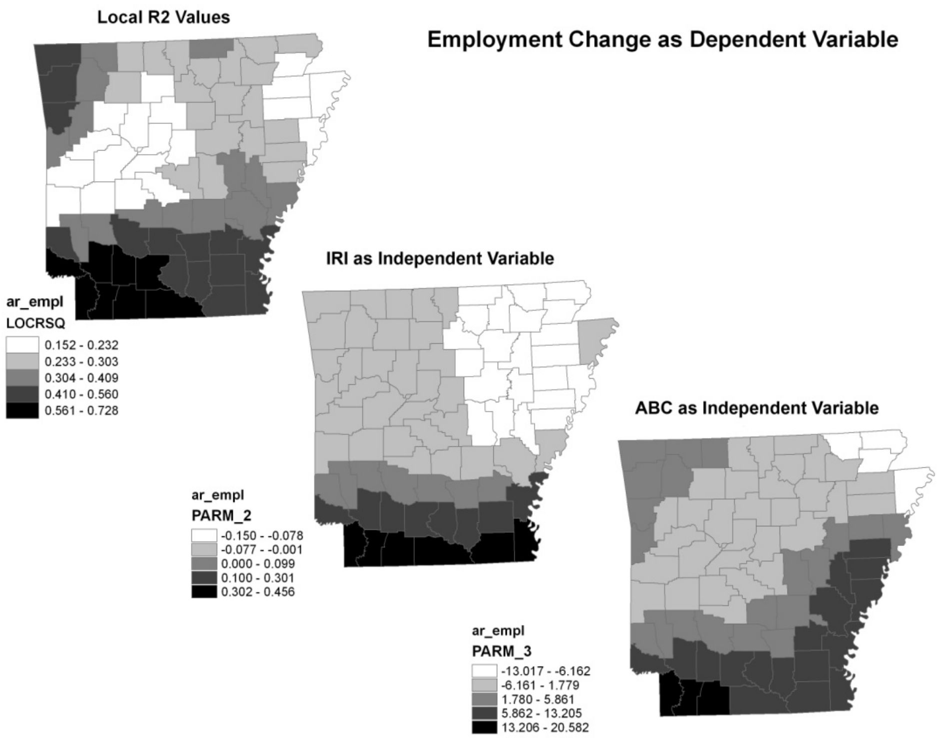


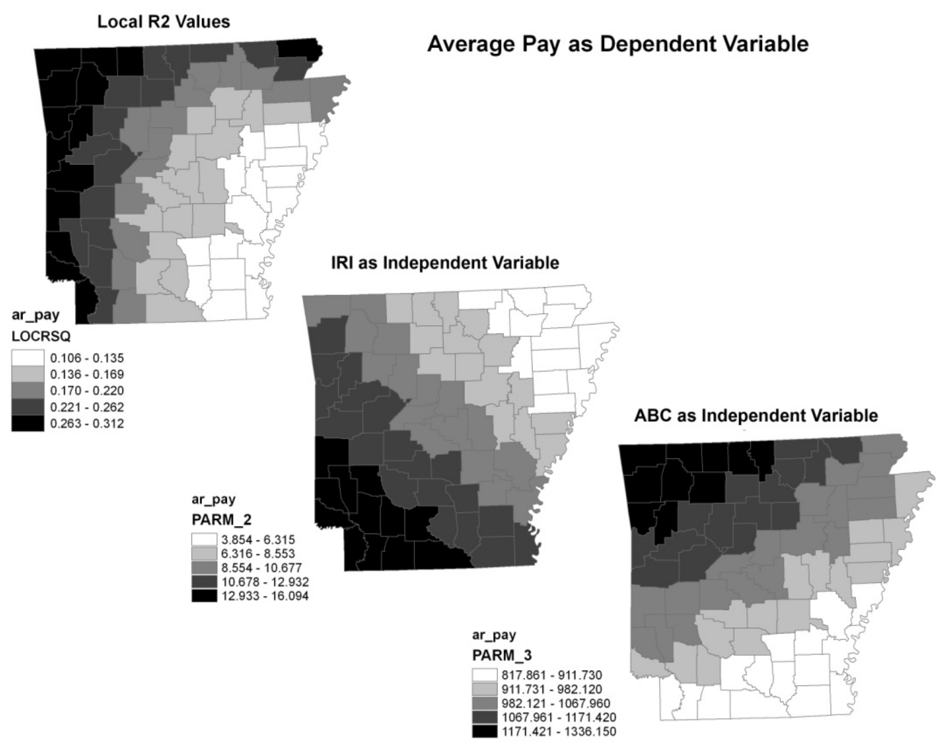
Local R2 Values
Poverty Rate as Dependent Variable
ar_pov
LOCRSQ
0.332 - 0.473
0.474 - 0.633
0.634 - 0.716
0.717 - 0.788
0.789 - 0.893
IRI as Independent Variable
ar_pov
PARM_2
-0.252 - -0.248
-0.247 - -0.056
-0.055 - -0.009
-0.008 - 0.026
0.027 - 0.076
ABC as Independent Variable
ar_pov
PARM_3
-5.598 - -3.335
-3.334 - -1.953
-1.952 - -0.453
-0.452 - 1.392
1.393 - 3.543



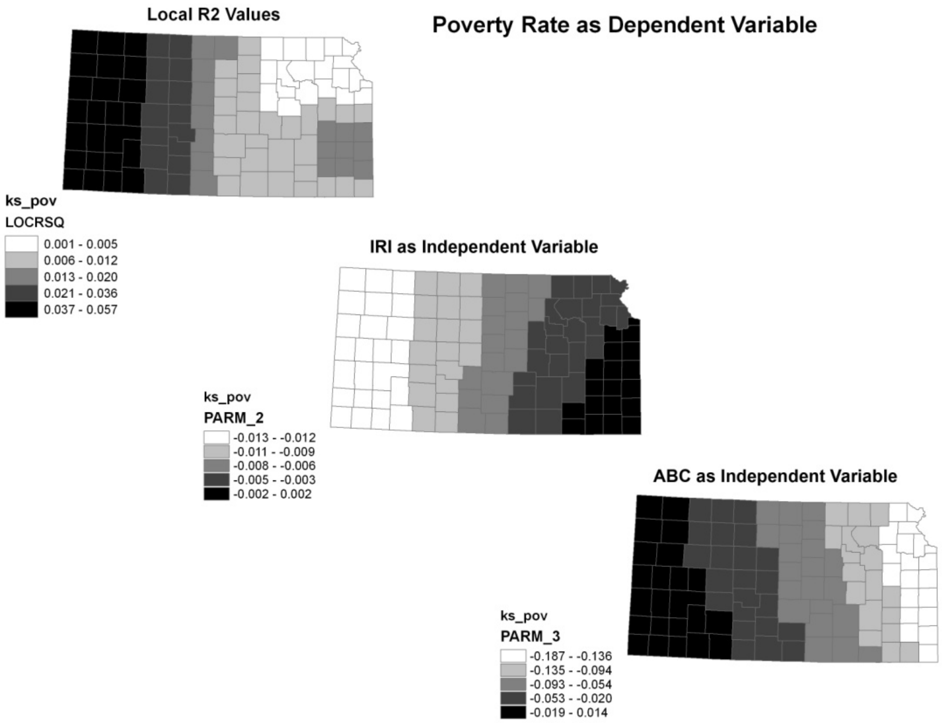
Local R2 Values
Per Capita Income as Dependent Variable
ar_pci
LOCRSQ
0.383 - 0.485
0.486 - 0.601
0.602 - 0.702
0.703 - 0.773
0.774 - 0.845
IRI as Independent Variable
ar_pci
PARM_2
-59.959 - -36.694
-36.693 - -6.010
-6.009 - 12.172
12.173 - 29.328
29.329 - 76.959
ABC as Independent Variable
ar_pci
PARM_3
-565.573 - -16.438
-16.437 - 482.585
482.586 - 1007.270
1007.271 - 1473.980
1473.981 - 2315.580

Arkansas

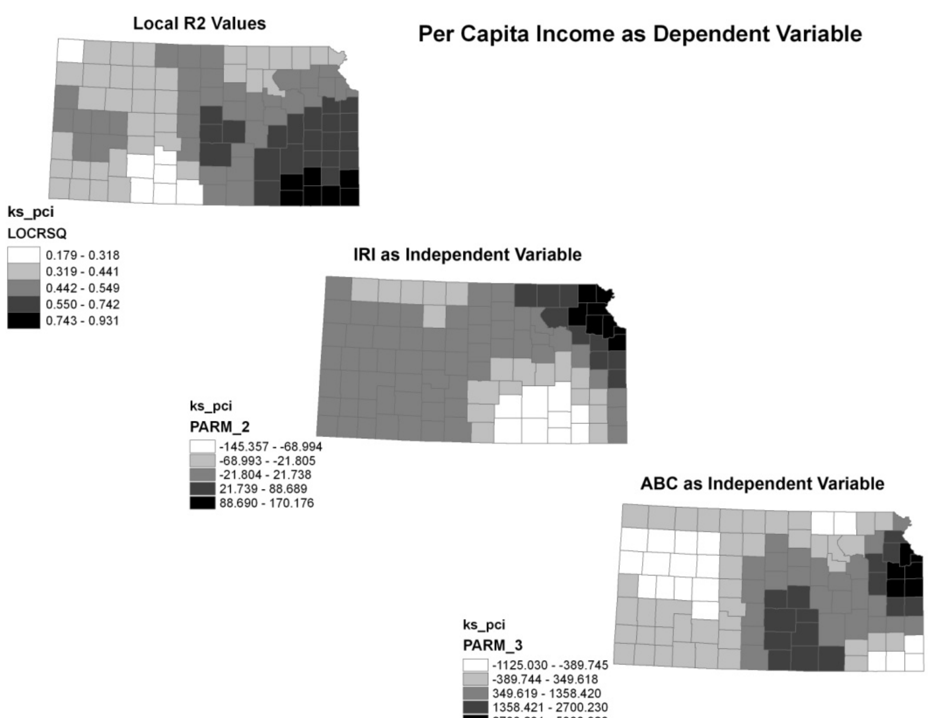

Local R2 Values
Employment Change as Dependent Variable
ar_empl
LOCRSQ
0.152 - 0.232
0.233 - 0.303
0.304 - 0.409
0.410 - 0.560
0.561 - 0.728
IRI as Independent Variable
ar_empl
PARM_2
-0.150 - -0.078
-0.077 - -0.001
0.000 - 0.099
0.100 - 0.301
0.302 - 0.456
ABC as Independent Variable
ar_empl
PARM_3
-13.017 - -6.162
-6.161 - 1.779
1.780 - 5.861
5.862 - 13.205
13.206 - 20.582


Local R2 Values
Average Pay as Dependent Variable
ar_pay
LOCRSQ
0.106 - 0.135
0.136 - 0.169
0.170 - 0.220
0.221 - 0.262
0.263 - 0.312
IRI as Independent Variable
ar_pay
PARM_2
3.854 - 6.315
6.316 - 8.553
8.554 - 10.677
10.678 - 12.932
12.933 - 16.094
ABC as Independent Variable
ar_pay
PARM_3
817.861 - 911.730
911.731 - 982.120
982.121 - 1067.960
1067.961 - 1171.420
1171.421 - 1336.150

Kansas

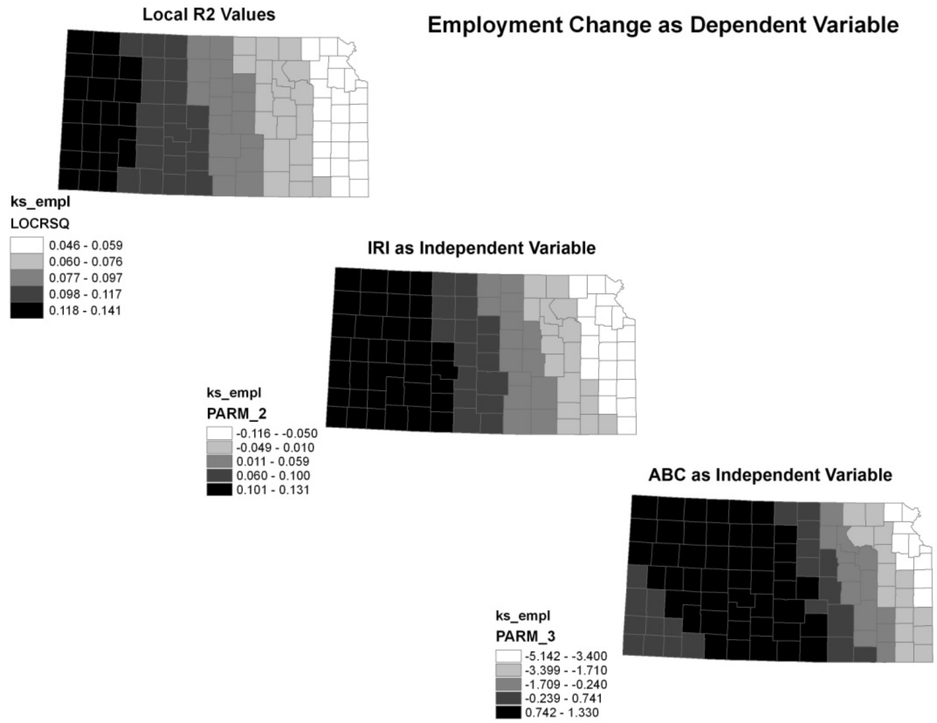


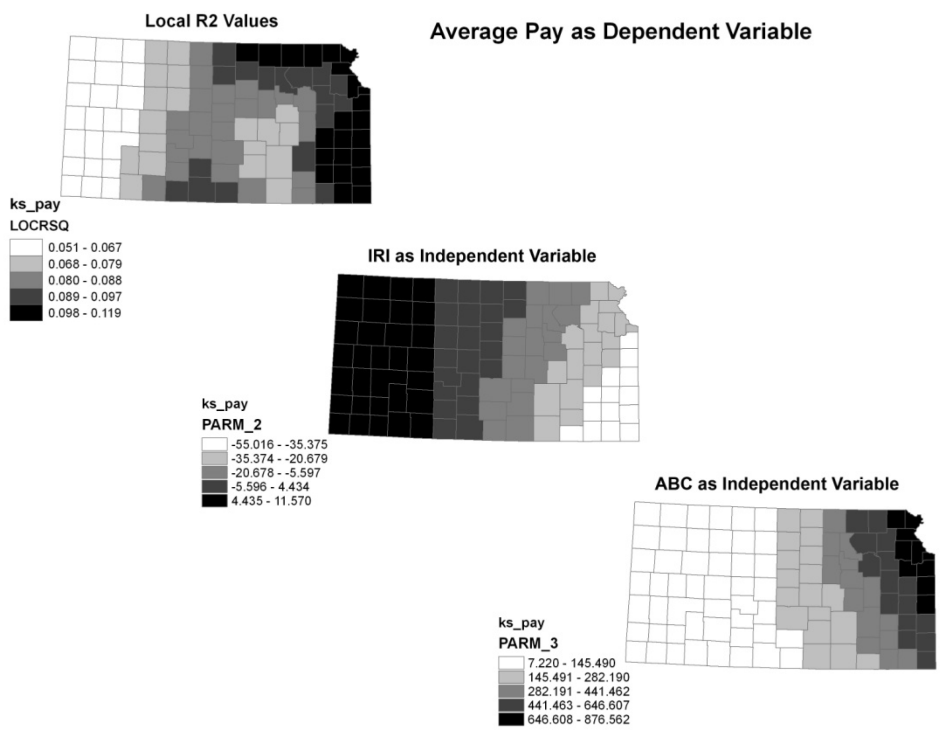
Local R2 Values
Poverty Rate as Dependent Variable
ks_pov
LOCRSQ
0.001 - 0.005
0.006 - 0.012
0.013 - 0.020
0.021 - 0.036
0.037 - 0.057
IRI as Independent Variable
ks_pov
PARM_2
-0.013 - -0.012
-0.011 - -0.009
-0.008 - -0.006
-0.005 - -0.003
-0.002 - 0.002
ABC as Independent Variable
ks_pov
PARM_3
-0.187 - -0.136
-0.135 - -0.094
-0.093 - -0.054
-0.053 - -0.020
-0.019 - 0.014



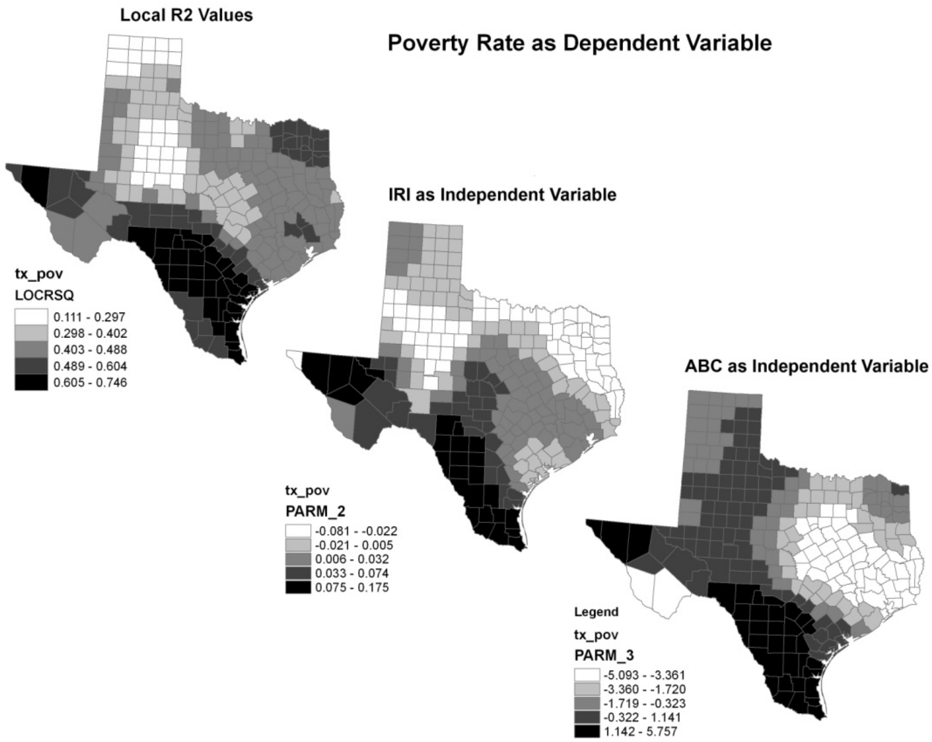
Local R2 Values
Per Capita Income as Dependent Variable
ks_pci
LOCRSQ
0.179 - 0.318
0.319 - 0.441
0.442 - 0.549
0.550 - 0.742
0.743 - 0.931
IRI as Independent Variable
ks_pci
PARM_2
-145.357 - -68.994
-68.993 - -21.805
-21.804 - 21.738
21.739 - 88.689
88.690 - 170.176
ABC as Independent Variable
ks_pci
PARM_3
-1125.030 - -389.745
-389.744 - 349.618
349.619 - 1358.420
1358.421 - 2700.230
2700.231 - 5000.920

Kansas

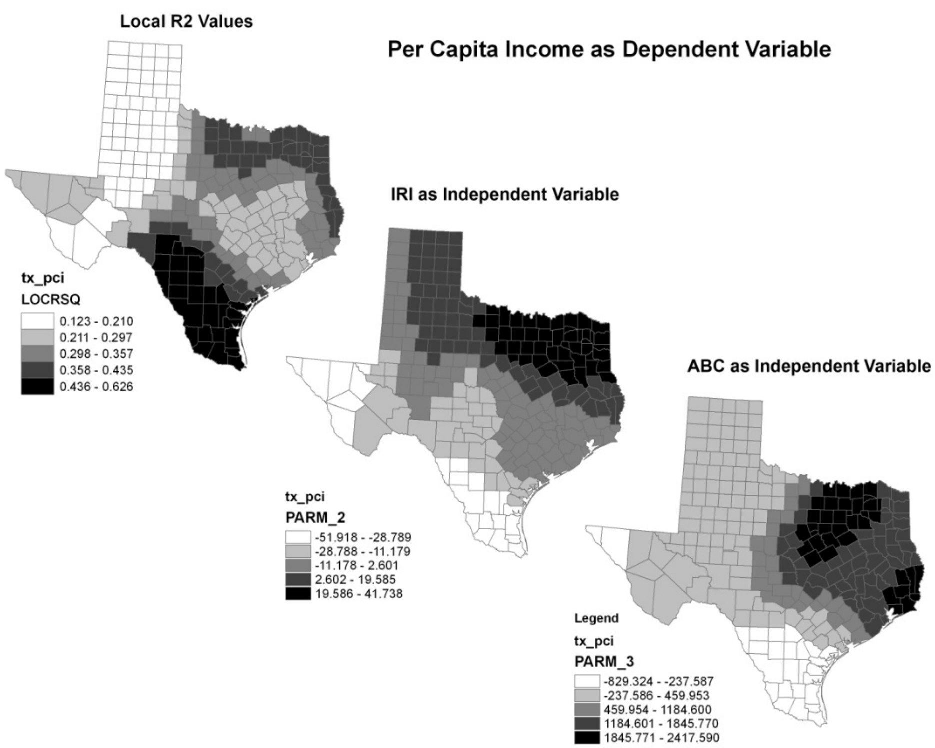

Local R2 Values
Employment Change as Dependent Variable
ks_empl
LOCRSQ
0.046 - 0.059
0.060 - 0.076
0.077 - 0.097
0.098 - 0.117
0.118 - 0.141
IRI as Independent Variable
ks_empl
PARM_2
-0.116 - -0.050
-0.049 - 0.010
0.011 - 0.059
0.060 - 0.100
0.101 - 0.131
ABC as Independent Variable
ks_empl
PARM_3
-5.142 - -3.400
-3.399 - -1.710
-1.709 - -0.240
-0.239 - 0.741
0.742 - 1.330


Local R2 Values
Average Pay as Dependent Variable
ks_pay
LOCRSQ
0.051 - 0.067
0.068 - 0.079
0.080 - 0.088
0.089 - 0.097
0.098 - 0.119
IRI as Independent Variable
ks_pay
PARM_2
-55.016 - -35.375
-35.374 - -20.679
-20.678 - -5.597
-5.596 - 4.434
4.435 - 11.570
ABC as Independent Variable
ks_pay
PARM_3
7.220 - 145.490
145.491 - 282.190
282.191 - 441.462
441.463 - 646.607
646.608 - 876.562

Texas

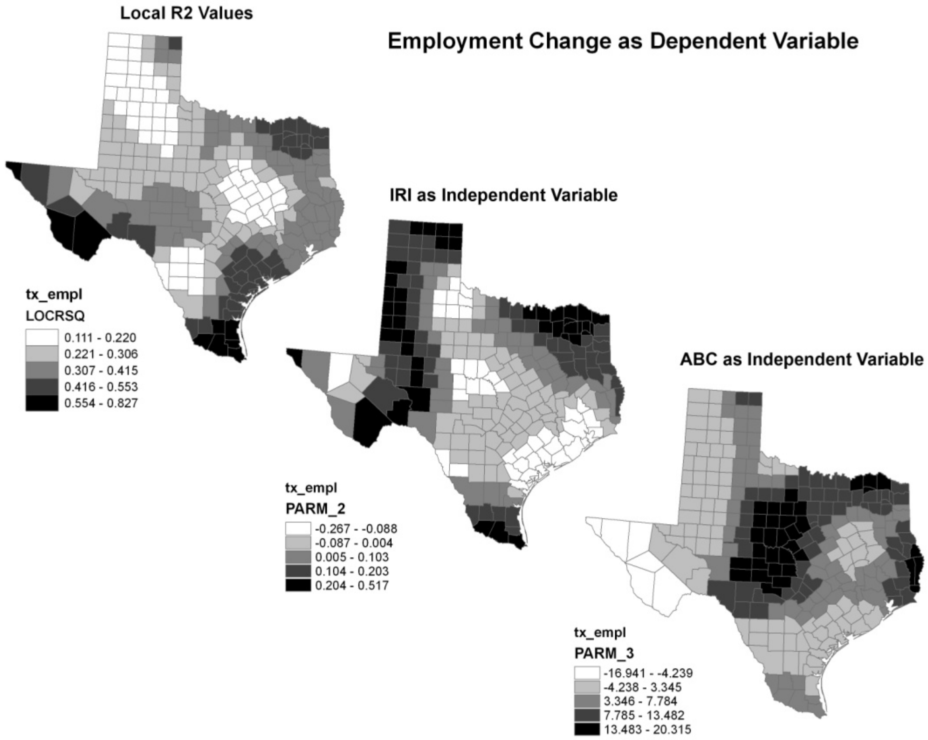


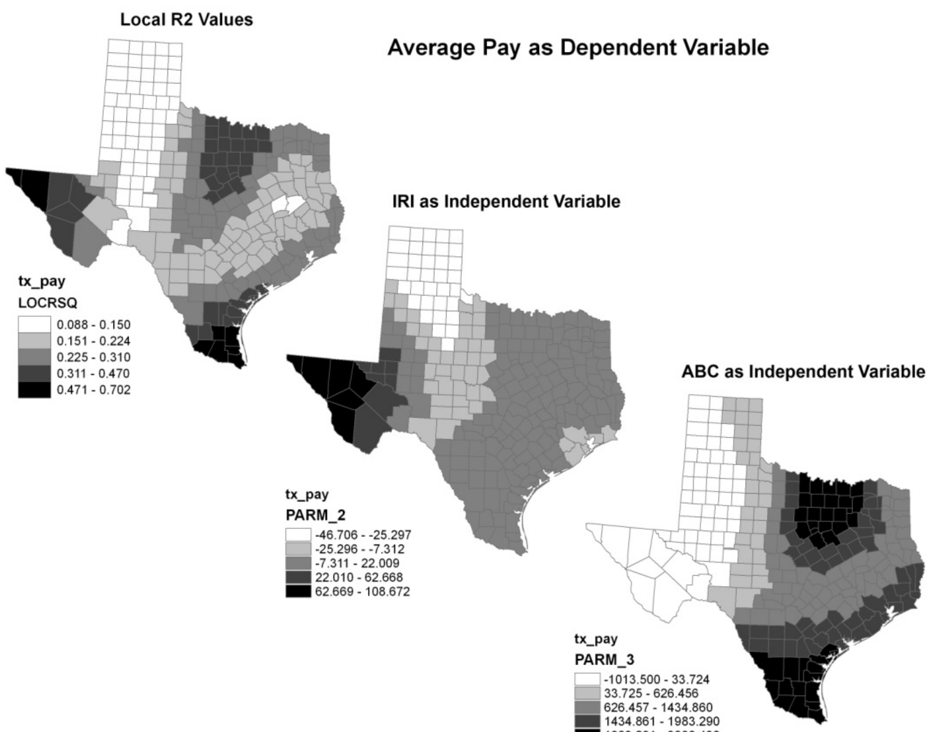
Local R2 Values
Poverty Rate as Dependent Variable
tx_pov
LOCRSQ
0.111 - 0.297
0.298 - 0.402
0.403 - 0.488
0.489 - 0.604
0.605 - 0.746
IRI as Independent Variable
tx_pov
PARM_2
-0.081 - -0.022
-0.021 - 0.005
0.006 - 0.032
0.033 - 0.074
0.075 - 0.175
ABC as Independent Variable
Legend
tx_pov
PARM_3
-5.093 - -3.361
-3.360 - -1.720
-1.719 - -0.323
-0.322 - 1.141
1.142 - 5.757



Local R2 Values
Per Capita Income as Dependent Variable
tx_pci
LOCRSQ
0.123 - 0.210
0.211 - 0.297
0.298 - 0.357
0.358 - 0.435
0.436 - 0.626
IRI as Independent Variable
tx_pci
PARM_2
-51.918 - -28.789
-28.788 - -11.179
-11.178 - 2.601
2.602 - 19.585
19.586 - 41.738
ABC as Independent Variable
Legend
tx_pci
PARM_3
-829.324 - -237.587
-237.586 - 459.953
459.954 - 1184.600
1184.601 - 1845.770
1845.771 - 2417.590

Texas


Local R2 Values
Employment Change as Dependent Variable
tx_empl
LOCRSQ
0.111 - 0.220
0.221 - 0.306
0.307 - 0.415
0.416 - 0.553
0.554 - 0.827
IRI as Independent Variable
tx_empl
PARM_2
-0.267 - -0.088
-0.087 - 0.004
0.005 - 0.103
0.104 - 0.203
0.204 - 0.517
ABC as Independent Variable
tx_empl
PARM_3
-16.941 - -4.239
-4.238 - 3.345
3.346 - 7.784
7.785 - 13.482
13.483 - 20.315


Local R2 Values
Average Pay as Dependent Variable
tx_pay
LOCRSQ
0.088 - 0.150
0.151 - 0.224
0.225 - 0.310
0.311 - 0.470
0.471 - 0.702
IRI as Independent Variable
tx_pay
PARM_2
-46.706 - -25.297
-25.296 - -7.312
-7.311 - 22.009
22.010 - 62.668
62.669 - 108.672
ABC as Independent Variable
tx_pay
PARM_3
-1013.500 - 33.724
33.725 - 626.456
626.457 - 1434.860
1434.861 - 1983.290
1983.291 - 3098.430