

Spatial economics and location theory – implications for modeling  
environmental impacts of future development patterns

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*Reflections of life in an empty world*

Henry James, *Washington Square* (1881) "... at the end of three or four years we'll move. That's the way to live in New York – to move every three or four years. Then you always get the last thing ... So you see we'll always have a new house; you get all the latest improvements ..."

*Reflections of life in a full world*

William Whyte, *The Last Landscape* (1968) "... we have been the most prodigal of people with land, and for years we wasted it with impunity ... no matter how much we fouled it, there was always more over the next hill, or so it seemed."

## Introduction

In *People and the Land through Time* Emily Russel writes "...past human activities have left traces on the landscape that persist to the present." Never has a civilization existed that has not had some impact on the landscape; however, these impacts are varied in not only temporal and spatial scales but also relative level of intensity and persistence. What distinguish western civilizations from those of the past are the human impacts that range beyond a mere persistence through the present day. These activities have largely been wrought for individual profit and the establishment of socially acceptable levels of quality of life. What has been ignored along the route to this standard of living are arguably some of the most significant traces ever left by human culture that will persist farther into the future than our civilization extends into the past.

These issues share a complex relationship with the way the American landscape has been settled since the time the European's invaded the continent several hundred years ago. A persistent manipulation of the environment, technological change and the quest for material accumulation and wealth, while largely recognized as causal factors of environmental degradation, threatens the very quality of life that modern civilization has worked so hard to establish. Perhaps this is most clear in our governance of the landscape and the way natural resources are utilized to placate desires for personal satisfaction. From an intergenerational equity standpoint, the over-allocation of land resources to past and current generations invalidates the potential for long-term sustainability at current living standards. Economically speaking, the inelastic demand for resources such as clean air and water, and the lack of substitution possibilities for those goods requires a precautionary approach toward the conversion of land in the perpetuation of the American dream.

Human perception of the landscape has changed over time and has reached a point where there is no longer a consistent standard that can serve as the single perspective of what is right. From a neoclassical economic perspective, land is viewed as endowed capital. Classical Ricardian theory asserts that although land does not make economic earnings, it earns rental payments. The significance of economic space was not well established until the advent of the free market system and parallel concepts of private property, governmental regulation and the ability of land owners to collect rent and legally enforce exclusion. The resulting human monopoly of the landscape has led to a misallocation of resources away from non-human consumers and caused an overall reduction in the aggregate welfare of ecosystem services, species biodiversity, and human connection to the landscape. There exists a real danger of crossing a threshold beyond which ecosystem recovery is no longer practicable. This is one of the most pressing issues currently facing society and it must be addressed through a combination of scientific and social research that lends support to the land use planning process.

The importance of economic space began to be explored in the late 18<sup>th</sup> century. Many of these ideas are relevant even today as theory attempts to understand the interactions between locational preferences and access to markets and amenities. Changing technology, especially transportation, has undoubtedly influenced the shape of settlement

patterns, impacting social and physical systems alike. Government policy and land use planning efforts attempting to ameliorate living conditions have been met with mixed results. As human population continues to increase, the empty world model is no longer a practical starting point for evaluating the impacts of human settlement patterns. Urban simulation modeling can be utilized as a valuable planning tool to test alternative policy scenarios to formulate ideas about how best to manage and accommodate future growth in relation to sustaining ecological function.

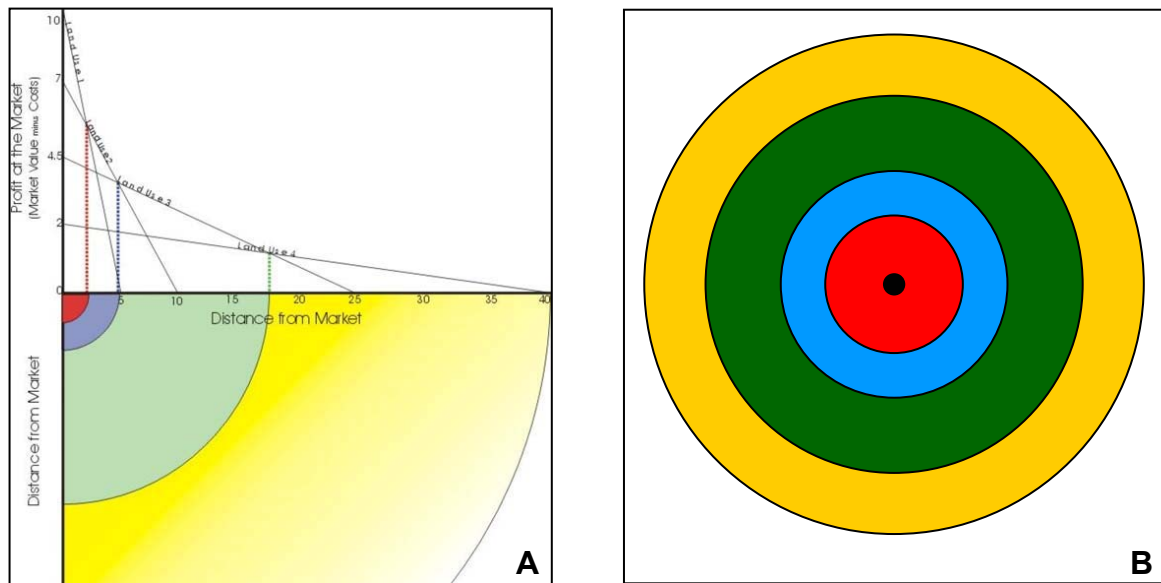
## **A history of spatial economics**

The development of early cities was dependent on the existence of surplus agricultural goods (O'Sullivan, 2000), made possible through the domestication of grains, technological advancements in the farm equipment and the creation of water transfer and irrigation systems. The central market place became the primary location for the distribution of these goods and afforded non-farm workers the opportunity to ply other trades in exchange for surplus agricultural goods. Since the time of these early settlements, the nature and scale of human development has changed considerably. Some of the earliest ideas regarding the importance of economic space date back to the late 18<sup>th</sup> century. Portions of these ideas coalesce to form the basis of William Alonso's theories published in his 1964 book *Location and Land Use* and continue to be applied today.

### ***Classic models of land use and central place***

Among the early ideas of the relevance of location was David Ricardo's (1772 – 1823) theory of differential rent. Although his theory did not specifically address economic space, the crux of his theory seems dependent on variable location for the production of agricultural goods. His idea involved the quality of land fertility in relation to the amount of land under cultivation. As population grew, an increasing amount of land would fall under cultivation, including land less suitable for agriculture. As a result, the return on investment from these less productive lands would decrease, thereby making them less attractive to renters. The real benefit would be derived by landowners as farmers would bid rent up in an attempt to gain access to the more fertile parcels. Ricardo's writing established the conflict between land owners and tenants, and his ideas proved influential in Karl Marx's writings regarding adversarial class relations.

Johann-Heinrich von Thünen (1780 - 1850) published an early model of land development that was based on a central market place with varying land uses radiating outward from a central location (see Figure 1). His model is most appropriate for agrarian society because it was developed prior to large-scale industrialization with no major routes of transportation for moving goods to the market place. His classic work entitled *The Isolated State* (1826) established a model of development based on the assumptions that there was a self-sufficient central market place (the "Isolated State") not subject to external influences. This central market offers the same price for goods to all producers, and the yield per acre is the same everywhere. The latter assumption is justified through the assumption of the central market surrounded by a homogenous landscape of unoccupied land. Finally, since major transportation routes do not exist, producers transport their goods to the market by whatever means necessary, and the price of goods in the market will influence the location of production (Crosier, 2003).

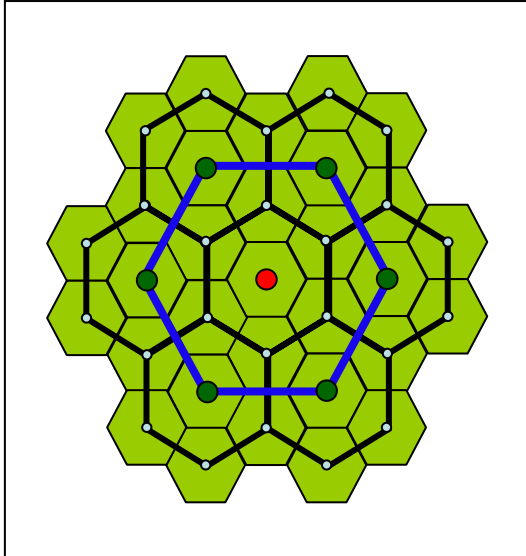


**Figure 1: A) Locational rent function graph based on von Thünen's theory of the isolated state. The figure on the left represents profit at the market on the positive y-axis and the distance to the market on the x-axis. The slope of the line is the cost of transporting goods per unit distance. B) The distribution of various land uses around the central market place (black dot).**

Based on these assumptions, von Thünen established a hierarchy of land uses surrounding the central market (see Figure 1B). Products that proved difficult to transport or offered the highest rate of profitability were developed closest to the market place. As a result, the price of land decreased with increasing distance to the market. Net profit to the producer is determined by the market value of the good minus the incurred cost of transporting goods to the central market place.

Other 19<sup>th</sup> century contributions to location theory came primarily from German and French railway engineers who, although positioned outside the field of economics, made valuable contributions nonetheless, including theories of optimal space pricing, optimal bounds of the spatial market, and industrial location. From a transportation perspective, it seems intuitive that employees within the rail industry would recognize the potential transformation of the production process given increased ability to mobilize goods to markets over greater distances. The increasing availability of rail access affected industrial location decisions because of: a) the reduction in transport costs of goods to the market place, b) the expansion of the market into previously inaccessible areas (significant in terms of access to more employees or consumers), and c) the ability to locate industry where land rents were significantly low enough to offset the transportation costs associated with increasing distances to one or more market places.

In contrast to the land use model of von Thünen, Walter Christaller (1893 – 1969) developed a theory of location based on the economic functions of central locations. Central places form a hierarchical structure of locations that are ranked according to their



**Figure 2: Hierarchical pattern of hexagons that define the locations in Christaller's theory of central place. The conurbation is the location with the largest service area, denoted here with the red dot and a service area defined by the blue hexagon. Next in line are cities (green dots), towns (blue dots), and villages which occur at the vertices of the smallest order hexagons.**

central functions (Pinto, 1997). Christaller's theory assumes a homogenous area of location, heterogeneous production that captures the efficiencies of economies of scale, and exogenous transport cost and supply center locations. The distance between central locations corresponds to maximum practical travel distance from outlying area to the market, or vice versa. His early calculations of distance between central places were based on a series of hexagonal polygons (see Figure 2) that arranged market locations at the vertices of equilateral triangles. An array of larger hexagons can then be placed on top of the smaller set to denote the service areas of the next size order (which Christaller calculated to be  $\sqrt{3}$  times larger than the smaller center), and from this an orderly hierarchical pattern emerges where goods are exported from higher order places to lower order places. One of Christaller's contemporaries, August Lösch, differed in his theory of

central place by including in his assumptions multiple transportation opportunities, an evenly distributed population and the ability of lower order markets to serve higher order markets.

Returning to von Thünen's theory of agricultural land use, William Alonso (1933 – 1999) developed a monocentric model of the city to analyze utilization of urban land and its values (Polimeni, 2002). Alonso's model includes factors of production, transportation and residential location, and assumes a featureless plain, where land is bought and sold without institutional constraints and is readily available for development. Additionally, the buyers and sellers have perfect knowledge of the market, and while the seller is looking to maximize revenue, the buyer is attempting to maximize satisfaction based on individual preferences. These preferences are determined as the intersection between a surface representation of all the opportunities open to a consumer at a particular income level, called the locus of opportunities, and an indifference surface mapped as a set of combinations of land quantity, composite good and distance to the central city such that any combination is equally satisfying to the individual. The intersection of these two planes represents an individual equilibrium that yields the greatest level of individual satisfaction (Alonso, 1964).

A bid-rent function is used to establish a variable distance from the central city at which an individual, farmer or business is able to remain on the same indifference curve. A steeper bid-rent function exists for commercial activity versus other land uses, resulting in the central location of employment. Transportation improvements (automobile

ownership and road improvements) are suggested as a causal factor for increasing land prices at the periphery of the city. Based on his model, these transportation improvements extend the opportunity for settlement away from the central city, assuming the individual has access to personal transportation.

What the classical growth models seem incapable of capturing is the space required to accommodate changing technology; most notably technology associated with transportation improvements. The technological changes of the past century (let alone since von Thünen first proposed his early theory of land use) have forced profound impacts on the function of culture, the role of class, and the nature of place. Human development patterns are now more than ever influenced by not just desires, but the ability to make these desires real. Affordable automobile travel and an extensive road network have combined to assert individual control over daily interactions within the social and commercial networks that define modern society. Air travel has effectively limited the size of the globe for commercial and recreational purposes, and the decentralization of historic urban cores and central places are resulting in far-reaching social, economic and environmental consequences.

#### *Human settlement patterns – from the central city to the suburban enclave*

At one time the location of human settlements were dictated by their proximity to the central market and the reliance of the village on the surrounding features of the landscape to provide them with adequate sustenance through some combination of farming, hunting and fishing. Settlement locations sought to minimize travel time (cost) among work, home and market place locations. O’Sullivan (2000) suggests that as a rule of thumb, travel from the edge of the city to its center should be possible in less than one hour. Considered in the context of a pedestrian population, this implies that the radius of the city extend less than two miles. Technological innovation in terms of transportation has loosened this restriction, and has expanded the market of potentially developable lands. Reductions in travel times to cover greater distances corresponds with a commensurate reduction in transport costs associated with delivering goods to the market place or traveling to places of employment. Although urban form has undergone horizontal expansion as population increased, the automobile has accelerated this transformation more rapidly than any other form of transportation technology.

Prior to the 1840s, the development of cities, and by default commercial activity, was reliant on adjacent waterways as a primary means of transportation. Progressing through the late 19<sup>th</sup> century, the advent of rail transport increased the profitability of interior lands not connected to major water bodies and extended development across the plains and into the west. Rail transport alleviated many of the past problems of intra-urban commerce since it was more efficient than horse-drawn carriage and not so easily influenced (or complicated) by weather. Ports and rail terminals provided favorable conditions for manufacturing centers as they granted easy access for distribution of goods. A parallel development was the establishment of residential areas around these industrial sectors to provide an employment base.

During this period, human transport evolved from pedestrian and horse-drawn carriage (pre 1850) to horse-drawn and electric streetcar (1850 – 1900), and eventually to subways

in the larger cities. Residential location followed according to the primary mode of transport. In the earliest period, the wealthy residents outbid the poor for the most centralized locations and an income gradient was established with decreasing wealth based on distance to the central city. Transportation improvements (travel time and mode) saw the beginning of outward migration of the upper and middle income classes, and the 19<sup>th</sup> century city was born, consisting of a compact core surrounded by residences concentrated around spokes of mass transport (Anas, 1998). In the coming decades (1910 – 1920), the truck and telephone replaced the horse and messenger, facilitating an outward spread of business activity seeking cheaper land prices and a physical linkage to the city through railheads. At the same time increasing automobile ownership facilitated development of the areas between the streetcar lines as residents were no longer reliant on mass transit as their primary mode of transportation to the central city. These factors combined to entice the upper middle class and wealthy residents to relocate on the periphery of the central city, effectively reversing the income gradient of earlier decades. In exchange for more space and cheaper land rents, suburban residents proffered increased travel times to work and the central market and a voluntary segregation from lower income classes that did not have the same access to private transportation options.

The first decade of the 20<sup>th</sup> century was characterized by rapid growth of metropolitan areas in the central city. The following decade saw increased development within a five-mile ring around the edges of the central city. Development through the 1950s continued its horizontal expansion, covering an area defined by a 10-mile radius surrounding the central city. A combination of government financed road projects coupled with the speed and privacy of personal transportation allowed the automobile to compete with mass transit, while inter-city trucking (facilitated by the construction of the interstate highway system) weakened the link between business and rail location. At this point, central cities began the transition from manufacturing centers to service and office centers (Anas, 1998). By 1956 the outward tendency had expanded to the point that more than  $\frac{3}{4}$  new dwelling units for major metropolitan areas were scheduled for development outside the central city (Vernon, 1959).

Cities have been expanding for more than two centuries, but recent decentralization of the city form has resulted in a polycentric structure of employment centers that have influenced the distribution of employment opportunities and residential locations (Anas, et al, 1998). In 1950 almost 70 percent of the population of the 168 metropolitan areas lived in the cities, while in 2000, nearly 60 percent of the 331 metropolitan area populations lived in the suburbs (Rusk, 2003). This trend reflects not only a growing population, but an increasing number of non-traditional settlements defined by segregated land uses, limited residential accommodation in the central city and the horizontal expansion of older cities. Employment patterns have followed this transition, rendering the suburban bedroom communities of decades past the employment centers of the present. Anas (1998) argues that these central locations were either the central cities of a previous era that have been subsumed by expanding growth of larger urban centers or newly formed cities at intersections of critical transportation nodes. Joel Garreau (1991) referred to the latter as edge cities. Part government subsidy, part advertising genius, the redefined American dream (Rusk, 2003) of home ownership and a piece of land was a



deal too good to be true. The combination of personal transportation made practical by federally subsidized highways, constant economic growth driving the employment sector and affordable home mortgages converted the central city into a place from which to escape as families traded the marginal utility of central city locations for a slice of paradise in the suburban United States.

William Alonso (1964) defined suburbanization of the city as both an increase in the size of the urban area beyond its original boundary, as well as, a change to lower density characteristics of human settlement. He hypothesized that population growth without increasing per capita income or transportation efficiency would lead to higher densities in the city center resulting from an increased demand for land without a corresponding increase in supply, while an increase in income or transportation improvements, without a corresponding population increase, would lead to more rapid suburbanization.

One difference between the central city and the suburb noted by Vernon (1959) is that suburban development can be dominated by a relatively few businesses that offer high wages to employees. At the same time, however, there exist manufacturing plants whose existence is reliant on large numbers of available workers that are desperate for employment at any level and therefore are willing to work at levels below the prevailing wage. Chicago is an example of the former, while Philadelphia and New York could be listed as examples of the latter. Price differential in land value is significant to the extent that newly establishing plants are more likely to locate outside the central city in an attempt to reap substantial land rent discounts compared to the available rents of the central city. Vernon recognized as early as the (1950s) that larger firms were tending to develop on the edge of the city as a means of maintaining or developing a competitive advantage over rival industries. Through cost internalization of functions that smaller firms needed to rely on external services for, the size and complexity of factories dictated larger land areas for siting plants, pushing them further away from the central cities' congested land use patterns and inflated rents. Smaller firms on the other hand agglomerated in the industrial sectors of the central city contributing to the local tax base in exchange for essential services and the proximity of cooperating industries.

The decline in America's industrial workforce as a result of global competition and technological change has also had an impact on where people live. Originally drawn in to the central city at the start of WWII because of increased manufacturing opportunities, many of these jobs are likely to have relocated to suburban sites. Cheaper land, changing manufacturing processes requiring more space, and decreasing transportation costs have made it not only economically feasible, but fiscally prudent to relocate outside the city center. The trouble with this model is that negative externalities such as environmental degradation are not measured as part of overall business performance, regardless of their toll on the natural and social systems upon which they are reliant. Since World War II, transportation improvements (technological and infrastructure) coupled with increases in per capita income and population have led to sprawling development patterns that clutter the once fertile agricultural peripheries that enveloped city life. Loosely phrased, sprawl takes on the form of leap-frog style development consisting of low-density, non-contiguous land patterns heavily reliant on personal transportation. Increased automobile

ownership has not only facilitated in-filling between trolley and train lines, it has led to the horizontal expansion of city boundaries as greater numbers of individuals possess the flexibility to transport themselves further to work, shop and recreate.

The 157 urbanized areas in 1950 contained approximately 69 million people and covered 12,715 square miles. In 2000, those same 157 urbanized areas were home to 155 million residents, but covered 52,388 square miles. The net result is slightly more than twice the population with more than four times the land area (Rusk, 2003). Population density decreased in 147 of the 157 urbanized areas during this time. The only notable exceptions were cities with high influxes of immigrants such as Miami and Los Angeles. While Smart Growth America (2000) found that 78% of Americans desire government intervention as a means to control sprawl, efforts to curb this development trend through land use planning and environmental regulation have been met with stiff resistance from property rights advocates that argue for the sovereignty of the individual over public process and consensus decision making.

### **Factors of influence for residential location**

The formation of urban centers was once dependent on a local agricultural surplus; however, technological innovations in the areas of transportation and farming have presented the population with opportunities to reside in locations that previously were not practical. Nationwide the number of farms fell by more than 58% from 1953 to 1993, while the average farm size increased by more than 95% (Ilg, 1995). The result is that fewer farms produce more food to be distributed over larger areas, and central cities, who increasingly import agricultural goods from distant locations, are no longer surrounded by an agricultural periphery but a sparsely populated residential morass of cul-de-sacs and cookie cutter subdivisions. While the transport of goods is of paramount importance, so too is the ability of individuals to travel greater distances in less time. It is equally salient to consider the role of government policy, economic opportunity and the underlying system of social values when evaluating the dimensions and characteristics of modern urban form.

#### *Technological change*

The obsolescence of yesterday's technology is readily apparent when applied to computers or VCRs, but what is not considered is how a changing standard of living has rendered early city form incapable of coping with certain elements of the modern lifestyle, namely personal transportation choices. Vernon (1959) suggested that a changing standard of living has left everything from housing to the delivery of water and the handling of sewage obsolete over time. Historic cities developed with transportation networks that were designed prior to high levels of personal automobile use (Boston, New York, Washington DC), are inefficient in their efforts to accommodate current levels of automobile utilization. But where is the efficiency in the city designed for the automobile (Houston, Phoenix) when considering that many of these places suffer from the same basic problem, congestion? It could be argued that modern cities suffer from the problem of congested transportation routes because too much significance has been placed on a solving the single mode transportation problem (automobiles), instead of

implementing alternatives. However, this in turn ignores the underlying social values that govern personal consumption and transportation choices.

Transportation options also influence business decisions which in turn influence residential locations. Garreau's (1991) edge cities formed at intersections of prominent transportation lines. Largely based on the interstate highway system these locations serve as transit and manufacturing hubs whose locational efficiencies for transporting goods to central market places around the world mirror Christaller's ideas of central place on a much grander scale. Transportation costs for both inputs and outputs have declined to the extent that industries heavily reliant on resource inputs are able to locate in resource-deficient areas where the low cost of transport and inexpensive labor more than offset the increased distance to central markets. Whether transporting raw materials or finished goods, the universal characteristic of these edge cities is the attraction of employers and employees, the conversion of land from rural to urban uses and low density settlement patterns heavily reliant on automobile transport.

### *Socio-economic values*

Anderson (1962) included in his list of factors for residential location population concentration, competition for land, social interaction preferences. These preferences are manifested in the form of social rivalries which lend support to the economic theory of segregation based on economic status. Richard Sennett (1970), in his book *The Uses of Disorder*, described this motivation as voluntary segregation, suggesting that increased congestion (disorder) of the central city led upper middle class residents to relocate to suburban locations comprised mainly of homogenous racial, social and economic groups (thereby providing order). Ahmad (1991) found residential segregation along ethnic lines resulted in increased ethnic disturbance, outward extension of city limits and a corresponding increase in per capita cost for service provision, and Rusk (2003) suggested that "white flight" is partially the result of discriminatory public policy and racial prejudice (Rusk, 2003).

As middle class residents abandon the central city, these locations were taken over by the lower social classes. The result then is a time lag distribution of the lower income classes mimicking those of their predecessors, with the lowest of the lower social classes unable to afford home ownership or improved living conditions. While this flight from the urban cores may be the result of a skewed system of social values, a vital component of city life may rest in what has been left behind in the form of the public and private capital that still contains economically viable utility. What further complicates this issue is how to finance infrastructure and social services for newly urbanizing areas without allowing the existing infrastructure of the central city to degrade below functional levels. These existing and emerging problems present unique challenges to planning professionals in their efforts to revitalize urban centers and plan suburban development to accommodate an increasing population.

### *Land use planning*

Land use planning originated in the 1920s as a means to protect human health and welfare from a mix of incompatible development types. These organizational rules adopted by municipalities were intended to proscribe an arrangement of land uses that

would protect the well-being of the populace. More recently, planning has been useful for developing a coordinated decision-making processes for regional development. Left unchecked, cumulative impacts of individual development decisions may surpass the natural systems' ability to accommodate unintended consequences in the form of non-point source pollution, habitat fragmentation or interruption of natural processes. The threat of countless individual decisions can accumulate into serious threats to social and environmental quality, which in turn jeopardizes the economic base of communities reliant on natural amenities to drive the local economy (Erickson, et al, forthcoming). Ironically, however, some of the modern problems of development are intrinsically linked to the institutionalization of human settlement patterns as established in land use planning efforts.

Anas (1998) notes that land use controls and the provision of transportation infrastructure play a significant role in development of spatial patterns on the landscape. Government programs contribute significant funding for road building (FY 2001 federal highway funds = \$26.4 billion) and other grant programs such as water and sewer lines (FY2001 grants = \$3.6 billion). These monies function as development subsidies, encouraging new growth in previously undeveloped areas. Other government policies, such as the National Flood Insurance Program (NFIP), or agencies, such as the US Army Corps of Engineers, have unintentionally minimized the risk of development in naturally hazardous or environmentally sensitive areas by distributing these costs to taxpayers. Along the ocean coast, a combination of federally funded coastal engineering projects designed to "stabilize" estuary entrances and shorelines and the provision of low cost flood insurance through the NFIP have resulted in billions of dollars of private development occurring on fragile coastal margins, placing not only human life and property at risk, but severely degrading the ability of coastal ecosystems to respond (and recover) from large and small scale natural disturbances and that have dictated coastal land forms form millennia.

More recently, open space planning has produced mixed results as a tool to curb sprawling development and encourage migration back to the central city. Open space provides utility in the form of recreational opportunities, but also affords measures of privacy that may not be possible to achieve in a densely developed urban environment. Wu and Plantinga (2002) examined the role of open space on urban land use patterns to assess impacts on residential location choices and the potential to attract new residents to the city. Their research found that the utility provided by open space is a function of its size, configuration and distance from individual parcels. Open space can be configured as either areal (community parks or conserved land) or linear (greenbelts, riverfront parks, or wildlife corridors) features on the landscape, and this configuration can influence adjacent development patterns (Lee and Fujita, 1997).

Lee and Fujita (1997) found that designating open space outside of the city boundary may expand total city size or influence leapfrog development. The former is more likely if the open space is closer to the central city as development will extend to encompass it, whereas the latter was more prevalent when open space was located a sufficient distance from the central city where increased travel time may be offset by improved access to open space amenities. Wu and Plantinga (2002) found that the distribution of open space

amenities could influence the location of residential development. Brueckner, et al (1999) developed similar conclusions in their assessment of the effect of amenities such as open space on attracting wealthier households to the central city. However, Yang and Fujita (1983) found that wealthier households tended to develop further away from the central city regardless of open space configuration in the central city. Within the developed urban area, analysis of housing price reveals an inverse relationship between proximity to a natural amenity and housing price (Wu and Plantinga, 2002), that is not necessarily based on the proximity of residential location to the central city (Yang and Fujita, 1983).

The problems with land use planning and the efforts to minimize human impacts through coordinated decision making reflect the complexity of Peter Senge's principles of systems thinking included in his book *The Fifth Discipline* (1990). In particular the first principle which states "Today's problems come from yesterday's solutions" and the fifth principle 5 "The cure can be worse than the disease" are indicative of the struggle faced by modern planning professionals. The difficulty of planning lies in looking toward the future as the interests of individuals vying for competitive exclusion of private property are balanced with the rights of the public to access common pool resources such as clean air and water.

This is not intended to suggest that land use planning efforts should be abandoned. On the contrary, it is important to consider the context of historical development patterns within the framework of modern technology to develop an understanding of current and future growth trends, and to consider the implications of such knowledge from an interdisciplinary standpoint. Government policies, advancing technology and social values are a few of the factors that influence decisions regarding residential location. How these factors combine to form individual preferences is not easily discerned, if possible at all. Our ability to predict future growth is only as good as our understanding of past patterns and processes. The development and application of computer simulation models that integrate land use, transportation and environmental planning toward understanding future growth patterns is a promising method for testing hypotheses of location theory and evaluating the consequences of alternative land use policies aimed at protecting environmental resources, natural capital and ecosystem services.

## **Modeling urban development**

Human domination of the landscape has rendered a complex mosaic of land use patches that affect and influence the natural and social environments that serve as the core of the economic system. Advances in computer technology, data collection, and human understanding of natural systems have enabled the development of modeling tools to assist and inform the land use, transportation and environmental planning efforts. However, the complexity of interactions between human and natural systems presents formidable challenges for modeling with many unknowns and significant levels of uncertainty. Additionally, the integration of varying temporal and spatial effects of emerging land use patterns is critical when considering long-term natural resource management objectives.

Decisions on model type, the establishment of rules that influence change and data availability can all affect outcomes of urban simulation modeling. Oversimplification of model parameters may result in output that does not accurately reflect reality, and is therefore of limited utility in a planning context. However, at some level, all models are simplified versions of a complex reality, and therefore result in uncertainty and error. In terms of data, coarse spatial scales may prove so general that results do not depict levels of detail specific enough to test policy alternatives capable of influencing patterns of development, while high resolution data intense models may exceed current computational ability (in relation to cost) and overstate confidence in our understanding of human systems, natural environments, and the interaction between the two.

The following sections discuss the applicability of geographic information systems (GIS) for assembling and organizing data, as well as modeling urban growth and the complex interactions of human and natural systems in order to test hypotheses of economic drivers on residential location, policy alternatives to mitigate impacts to natural systems, and the role of land use planning for maintaining viable economic and social systems at the core of sustainable human communities.

### *Geographic Information Systems*

GIS is uniquely suited as a tool for inventorying, characterizing and documenting human development patterns over time. The spatial nature of urban change data is best organized in a GIS database because of its abilities to rapidly query and display results, integrate multiple layers of information from a variety of disciplines, and develop mapped output as a means of communicating results with non-technical users. Federal, state and many local government organizations maintain geospatial data describing physical and environmental conditions, property ownership boundaries and public infrastructure investment. Additional data, such as employment figures or survey responses, can be registered to spatial locations through unique identifiers such as parcel identification numbers, business licenses or permit applications. Data can be stored and analyzed at multiple spatial and temporal scales, allowing for the analysis of time series data, as well as comparisons of local, regional and national data.

Of particular interest to modeling urban change are satellite imagery and aerial photography that facilitate quantification of land conversion and changes in impervious surface. Analysis can also determine the amount of undeveloped land that exists for different types of zoning, providing an indication of availability of suitable land for future development. Finally, GIS can be used to format data for inclusion in modeling software, and import model output to develop 2 and 3-dimensional displays of projected future conditions. This last step is crucial for involving non-technical parties in the planning process. By providing mapped output for public consumption, the array of interested stakeholder groups are able to maintain an active role in the planning process, thereby increasing the chances for successful adoption and implementation of planning recommendations.

### *Model types*

Agent-based and cellular automata are two model approaches to predicting changes in urban development. Agent-based urban change models seek to represent individual

behavior within a larger system. Individual actors interact with one another and the overall economic system (Ceroni, *in press*). The model design applies specific social and economic characteristics to each of the actors based on population and employment data (among other things). The model is defined over a spatially explicit region, and is used to test agent mobility and interaction, and from these simulations of interaction aggregated macro-scale behavioral patterns emerge.

Cellular automata models utilize a tessellation of cells covering a specified spatial extent. The specific characteristics of a given location are generalized to the cell level to define the initial conditions of the model. A series of transition rules are developed to govern changes in the grid condition, and a recursive application of these rules is applied to the modeling space (Clarke and Hoppen, 1997). Self-modifying cellular automata models will alter their transition rules based on threshold levels for specific conditions. For example, if a certain level of build out is reached in the model, zoning restrictions may become more flexible to allow for continued construction at higher densities. Cellular automata models vary from the agent-based approach in that they do not try to characterize individual actors, rather to observe and identify complex, self-organizing behavior resulting from a limited matrix of transition rules (Ceroni, *in press*).

#### *Modeling urbanization in northern Vermont using UrbanSim*

Past economic models have focused primarily on the maximization of human benefit based on perfect knowledge and the assumption of establishing personal gains as an individual's highest priority. These models assume that maximization of economic wealth is a common goal for the economic man represented in their modeling framework. Other simplifications have included homogenous landscapes (Christaller) or closed systems (von Thünen) neither of which accurately portray the spatial variability of the landscape or the high level of mobilization that 21<sup>st</sup> century living affords.

More recent modeling efforts have sought to integrate individual actors functioning within given transportation and economic constraints across a grid of land use characteristics. UrbanSim is one such model currently under development at the University of Washington's Department of Urban Design and Planning. The model is based on a dynamic disequilibrium approach that represents systemic changes occurring at different temporal scales (Waddell, 2003), and combines elements of both the cellular automata and agent-based approaches. Physical characteristics of the landscape are aggregated at the cellular level, while individual actors make decisions regarding employment and housing location.

The model is comprised of a suite of tools that simulate economic and demographic transitions, household and employment mobility and location, land rent and real estate development, and accessibility of households to community services and amenities. The individual modeling tools communicate through a common data storage site (database), where the outputs from one component can serve as the inputs for one or more of the others. Exogenous inputs to the model include macroeconomic indicators of employment conditions and real estate transactions, outputs from an independent travel demand model and user specified conditions regarding land use policy or scheduled events. The scheduled events represent significant changes to the initial conditions resulting from

changing land use policies, new employment opportunities such as an influx of jobs associated with the opening of a new manufacturing plant, or changes to the transportation network. Based on user specifications it is possible to test alternative growth scenarios resulting from placing additional parcels under conservation easements, increasing or decreasing residential development densities, establishing urban growth boundaries or other policy modifiers that may influence the location of new development.

User specifications include the size of the grid, time extent for the model steps and the duration of the model run. Previous applications of the model in Eugene, OR and Honolulu, HI have utilized a 150 meter grid with annual time steps for each of the components except for the transportation model. Generally speaking, the transportation model is only run for the initial time step or when significant changes have been made to the transportation network, such as the addition of new interstate highway or interchanges. The other model components are typically run on an annual time step simulating partial equilibration as actors adjust to the rate of change of fluxes within the economic system or the housing market. The annual time step simulates the evolution of the household and employment locations at the individual level and the evolution of the real estate market at the grid cell level (Waddell, 2003). Where required data does not exist for a municipality, the model architecture allows the user to disable model components. Model outputs can be imported into GIS for graphical display and further analysis. Specific model outputs include future land use patterns, employment opportunities, business locations and land values.

An effort is currently underway to model urban change in Chittenden County, VT. The model will be calibrated for the time period 1990 – 2003, and predictive model runs will explore change through 2015. Based on the results of the modeling effort for Chittenden County, Addison and Lamoille Counties may also be included in subsequent model runs. Data collection is complete and processing is ongoing to prepare geospatial information for inclusion in the model. The initial calibration effort will utilize a 150 meter grid and annual time steps for each of the model components. Following calibration, adjustments to the grid size will test for variation in model output (sensitivity analysis), and different scenarios for the completion of the circular highway will alter the number of times the transportation model is run.

### *Summary of modeling tools*

It is important to note that the implementation of UrbanSim model is just the first step in quantifying the impacts of future growth. Model outputs provide possible templates of future growth patterns but reveal little in terms of changes to environmental quality. Additional efforts are underway to couple outputs from UrbanSim with environmental quality and ecosystem services research to assess the impacts of urban growth and rural land conversion on habitat fragmentation and species biodiversity. Model outputs can also inform the land use planning process, especially for the development of regional planning measures. Successful modeling efforts will necessarily be reliant on interdisciplinary cooperation of natural, social and computer sciences and the application of this integrated research toward testing hypotheses of policy alternatives. Finally, advances in modeling will continue to rely on the improvement of model design, variable selection, data quality, and unit of analysis (Allen, et al, 2003).



## Conclusions

Agricultural surplus as an independent factor in human settlement has taken a back seat to technology as evidenced by the decline in the number of farms coupled with the increase in average farm size and productivity. Whereas historical landscapes were dotted with settlements developed out of necessity (defense, limited transportation options, etc), the modern landscape reflects the human ability to alter environmental conditions and utilize technology to limit the relevance of proximity to commercial markets and central cities. Development patterns of urban areas over the past several decades have resulted in declining population densities spreading residents over larger areas of the landscape. Market failures in the form of government subsidized growth have minimized the risk of development in naturally hazardous and environmentally sensitive areas between the hurricane and erosion prone coastal margin of the east to the low-lying floodplains of the midwest to forested landscapes of the western ranges better typified by their propensity to burn than their ability to raise a family of four with two cars and a mortgage. What is clearly important is the identification of thresholds levels beyond which irreparable environmental damages will result. A conservative balance must be sought through a combination of scientific research, coordinated decision making and the establishment of values system that respects intergenerational equity regarding social and natural capital stocks.

The beginning of the 20<sup>th</sup> century saw the trolley and suburban railway. By the 1930s technological change brought the automobile in to the home and the bus as the mode of public transport. Modern transport options include personal jets that mock historic trans-oceanic travel with in-flight movies and five course catered meals. While it may be true that fuel cells will one day replace the traditional combustion engine, automobile emissions are only one part of the problem. The real challenge lies in consolidating human development before it consumes the remaining open spaces that support ecosystem functions and provide habitat to sustain species biodiversity. Increased opportunities for personal transportation over time have proven the single most influential aspect of residential settlement patterns.

Residential location is necessarily driven by a combination of social choice, technological innovation and the economic opportunities necessary to facilitate inclusion in the market system. What the classic spatial economic models do not necessarily capture is the underlying value system inherently connected to the individual desire for owning a piece of the ever-changing American dream, and where that home is located may have much more to do with social realities than access to services and the marginal utility of land rent. These social factors may represent remnants of the frontier mentality that stubbornly settled the country in the face of conflict and hardship, or they may simply reflect the desire for space, a place to call home, and the misnomer of struggle within a climate controlled shelter fully equipped with cable television, modern appliances and a method of transport for returning to civilization when the going gets tough.

The boundary between city and country, urban and rural has been dissolved (or at least marginalized) one decision at a time, resulting in environmental degradation in the form of increased pollution and run-off, impaired water quality and ecosystem function, and

the eventual degradation of social capital, representing outcomes that can not be appreciated at the individual level at the time of decision making (Erickson, et al, forthcoming). The tyranny of these small decisions (Kahn, 1966) accumulates to influence change orders of magnitude beyond the initial scope of the decision and in many cases unbeknownst to the individual decision maker. In the quest to maximize self-interest, the decision maker selects personal satisfaction over public well-being at the expense of environmental quality.

Land use planning efforts should necessarily include integrated modeling effort aimed at understanding human development patterns in the context of social desires, economic opportunity and available technology. To that end, UrbanSim should prove a valuable tool for exploring past and future changes in residential and commercial development patterns in northern Vermont. Additionally, the Baltimore Ecosystem Study may also prove a valuable research arena for other modeling exercises. The wealth of geospatial data for the Baltimore Metropolitan Area will facilitate the exploration of the role of open space on influencing residential development patterns and real estate values and could lead to another opportunity to apply UrbanSim. Finally efforts to utilize urban simulation modeling to test the impact of alternative policy scenarios should prove useful for developing land use strategies aimed at managing environmental resources and preserving ecosystem integrity. Future research questions include:

- How will modified policy scenarios affect UrbanSim model output, and what are the implications for future land use planning efforts?
- Can UrbanSim model outputs successfully be integrated with ecosystem modeling efforts to quantify impacts of land conversion and habitat fragmentation?
- Is it possible to develop an intergenerational Pareto efficient allocation of land resources as they relate to the provision of sustainable ecosystem services?
- If zoning is, in effect, the establishment of the rules of the game, how can this process be most effectively applied to ensure resource productivity while balancing an individuals “right” to claim sole ownership over common pool resources?
- What level of spatial resolution is best for analyzing locational phenomena? (Anas, 1998)

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