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RISK-BASED FRAMEWORK USING GEOGRAPHIC INFORMATION SYSTEMS TO IDENTIFY TRANSPORTATION CORRIDORS VULNERABLE TO DEVELOPMENT

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16. Abstract

The Virginia Department of Transportation (VDOT) is increasingly involved with the land development process in evolving transportation corridors. This process includes consideration of real estate interests, rezoning and permitting approvals, site plans, public utilities, right of way, access management, and the transportation facilities themselves. Localities may compete with one another for economic development and withhold plans for developing corridors or may simply be unaware of development intentions. It is therefore important that VDOT transportation planners anticipate and proactively address future development along corridors to avoid surprise, regret, and belated action.

With many thousands of miles of undeveloped corridors across the Commonwealth, VDOT must prioritize the corridors and corridor sections most in need of immediate attention. This study developed a comprehensive approach using geographic information systems (GIS) to identify and prioritize the needs for protection strategies in countywide corridors. Over eighty GIS data layers sourced from VDOT, Fauquier County, and others were evaluated to determine appropriate factors for the analysis. Layers not available to other counties were ruled out. Layers were selected by adopting principles of risk management, asking experts about the flaws and consequences in corridor protection. Four indicator factors including lateral distance from corridors, proximity to intersection of corridors, proximity to population centers, and proximity to employment centers were used in the analysis to identify parcels with a high likelihood of development. Two constraint factors including protected parcels and economically developed parcels were used to identify very low likelihoods of development and eliminate parcels from the analysis.

Several corridor sections were identified as candidates for further study of protection strategies including early right-of-way acquisition and access management. The density of curb cuts and the average parcel values and development likelihoods were plotted against the centerline mile to suggest the opportunities and costs of risk management. The methodology aims to generate maximum insight by using a manageable number of GIS layers and is repeatable in other cities, counties, and regions of Virginia by using currently available data. The suggested training material for the GIS analysts is (1) the PowerPoint presentation initially developed for the steering committee, and (2) the sample GIS layers and associated files that were used for the Fauquier County case study. Both are available for download at www.virginia.edu/crmes/corridorprotection. The results (relative prioritization of corridor sections) are not dependent on assumptions or steps that may differ from analyst to analyst. In the future, a web- or spreadsheet-based implementation of the layer combination process could be developed for use in presentations and public meetings. The results will help VDOT make the business case for corridor protection, for example, considering cost-effectiveness, return on investment, multiple objectives and stakeholders, and/or cost-benefit ratio. The results (maps of priorities) should highlight the features that confirm and reject the intuition of the planner and analyst. Numerous examples of such insights gained in discussion of the results with Fauquier County planning staff and the steering committee are included in this report.

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NOTICE

The project that is the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

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ABSTRACT

The Virginia Department of Transportation (VDOT) is increasingly involved with the land development process in evolving transportation corridors. This process includes consideration of real estate interests, rezoning and permitting approvals, site plans, public utilities, right of way, access management, and the transportation facilities themselves. Localities may compete with one another for economic development and withhold plans for developing corridors or may simply be unaware of development intentions. It is therefore important that VDOT transportation planners anticipate and proactively address future development along corridors to avoid surprise, regret, and belated action.

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INTRODUCTION

Over 9,200 interstate and primary centerline miles form the backbone of the roadway transportation system in Virginia (Virginia Department of Transportation [VDOT], 2005). This network becomes increasingly congested each year. VDOT traffic counts indicate in the five-year period from 2002 to 2006, daily VMT on interstate and primary roads grew 7.8% from 148 million vehicle-miles to 160 million vehicle-miles. This increase, shown in Figure 1, outpaces the growth of both Virginia residents (4.8%) and licensed drivers (4.1%) indicating the population is traveling more on average per person than it did five years prior. In addition to increased travel times and trips, real estate development has affected congestion. Greenfield and infill construction create additional trip origins and attractions. Additional intersections and access points often require signalization and increase the potential for accidents. Rising real estate values have drastically increased the cost of acquiring right of way (ROW) for new construction and widening of roads. Agencies that protect transportation ROW in advance can avoid the need to later relocate residents and businesses and pay uncertain court costs (Heiner and Kockelman, 2005).

The effect of construction on transportation systems points to complexities of the relationship between transportation and land use. Federal legislation ISTEA, TEA-21, and most recently SAFETEA-LU have required states and metropolitan planning organizations (MPOs) to focus on the relationships between transportation and land use. The *Code of Virginia* requires localities to maintain a comprehensive plan and include a transportation plan that functionally classifies roads as part of the comprehensive plan (Grimes, 2006). Section 15.2-2222.1 of the *Code of Virginia* requires localities to submit comprehensive plans and comprehensive plan amendments that will substantially affect transportation on state-controlled highways to VDOT

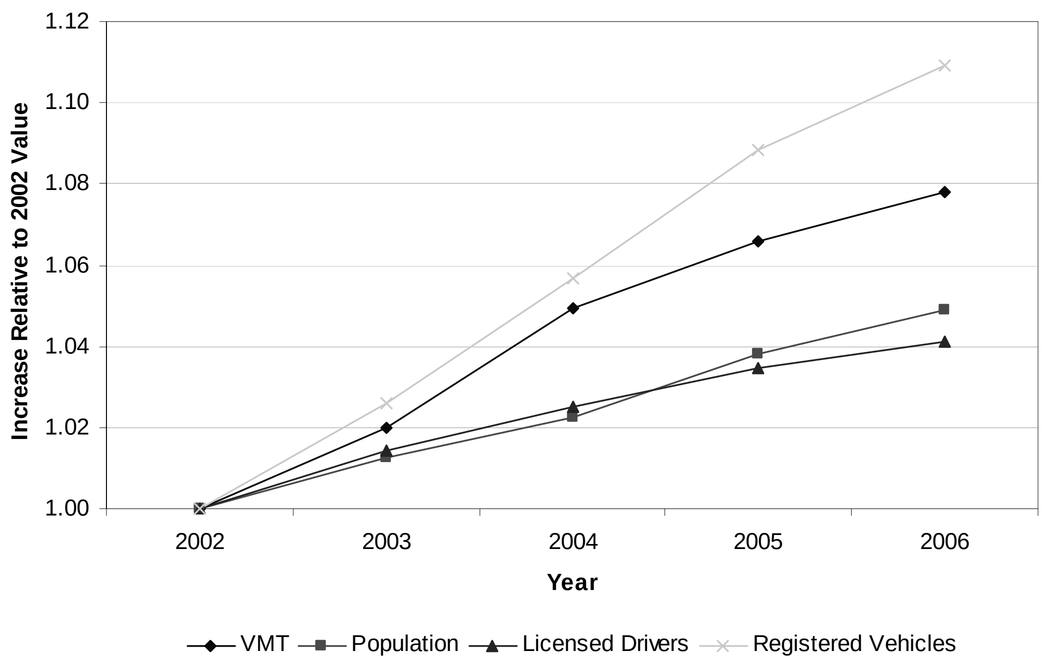

Figure 1. Rate of Change of Virginia Highway Statistics. *Source:* Virginia Department of Motor Vehicles.

in order for the agency to review and provide comments on the impact of the item submitted. This section also requires localities to submit traffic impact statements along with proposed rezonings, site plans, subdivision plats, and subdivision development plans that will substantially affect transportation on state-controlled highways to VDOT for comment by the agency. Chapter 527 of the 2006 Acts of Assembly directs VDOT to promulgate regulations for the implementation of these requirements. To ensure safety, minimize congestion, and extend the useful life of existing infrastructure, VDOT is working to establish a comprehensive access management program that includes corridor protection. At present, ROW purchases are managed in the project development process of VDOT's Six-Year Improvement Program and State Transportation Improvement Program.

Despite these attempts at integrating transportation and land use planning, comprehensive plans are not the sole determinant of development patterns. They provide a vision for communities and a basis for legally binding ordinances, but comprehensive plans themselves are not legal instruments and are subject to change. Because communities consist of diverse stakeholders with a wide range of interests, comprehensive plans are subject to changes in the form of comprehensive plan amendments. Localities differ in the quality and completeness of comprehensive plans, as well as their willingness to alter their comprehensive plans. Localities may compete with one another for economic development and withhold their intentions for developing corridors, or could simply be unaware of development intentions. Thus, from VDOT's statewide perspective there is considerable uncertainty within and among counties with respect to land use planning and control. These uncertainties surrounding growth and distribution of development present challenges to VDOT as it attempts to invest money today to protect capacity and guard against congestion in corridors in the future. Because there are over 9200 lane miles of interstate and primary roads in Virginia but limited funds to invest, efficient allocation of funds is crucial to the future of the Commonwealth's transportation system.

PURPOSE AND SCOPE

The purpose of this study was to develop and pilot-test a methodology using GIS-based technology to support the identification, prioritization, and protection of transportation corridor sections in Virginia that could face significant development in five to ten years. Principles of risk assessment and risk management were used to guide the effort.

The objectives were as follows:

- To identify factors available statewide relevant to predicting and prioritizing the future likelihood of development, a proxy for future congestion and need for corridor protection
- To base the methodology on GIS technology and factors available statewide
- To suggest quantitative and qualitative approaches to further prioritizing parcels with high likelihood of development
- To recommend protection of particular corridor sections based on risks, benefits, and costs.

METHODS

To achieve the study objectives, the project team planned and conducted seven tasks.

Task 1: Convened Project Steering Committee. The project team convened a steering committee of representatives from VDOT, regional planning bodies, localities, and other agencies (e.g., Virginia Economic Development Partnership) to guide the progress of the effort. The steering committee met three times over the course of the effort. Individual stakeholders met with the project team on several additional occasions.

Task 2: Surveyed Best Practices and Literature. The project team surveyed corridor protection best practices of other state transportation agencies and identified literature relevant to characterizing belated decisions on corridor protection as risks to quality of life, mobility and accessibility, safety, and lost opportunity. The team researched access management, ROW acquisition, and spatial analysis techniques, namely suitability analysis.

*Task 3: Acquired Traditional and Non-Traditional Data***.** The project team surveyed and acquired traditional data sources and data not traditionally used in long-range transportation planning exercises. These data were used to identify impending corridor development. The data sources included real estate transactions and assessments, aerial photographs, utility service areas, schools, parks, easements, and zoning.

Task 4: Developed a Risk-Based Methodology for Corridor Protection. The project team developed a straightforward risk-based, GIS-based methodology.

Task 5: Investigated a Multi-Objective Approach to Prioritizing Corridors. The project team integrated the above tasks in a multi-objective framework to guide further data collection and resource allocation to corridor protection strategies across yet undeveloped transportation corridors of the Commonwealth of Virginia.

Task 6: Conducted Case Study of Fauquier County. The project team performed a case study of Fauquier County, Virginia. Fauquier County was selected in consultation with the project steering committee. The candidate localities included Fauquier, Orange, Stafford, and New Kent.

Task 7: Developed Recommendations with the Project Steering Committee. The project team worked closely with the steering committee to develop conclusions and recommendations to guide VDOT’s corridor practices, policies, and procedures.

RESULTS AND DISCUSSION

Literature Review

The investigators reviewed the literature relevant to (1) corridor protection and its constituent methods and (2) the use of geographic information systems (GIS) as a tool for suitability analysis and prioritization.

Corridor Protection

Overview

A corridor is a geographic area accommodating travel in which trips tend to cluster in a general linear pattern with feeder routes linking to trunk lines which carry longer distance trips (Smith, 1999). Transportation planning has embraced corridor-based planning because project by project planning approaches insufficiently account for systemic land use decisions, multimodal and intermodal opportunities, and synergy among related projects. Jurisdictional, system-wide, or comprehensive transportation planning lack the specificity required at the local scale. Corridor studies complement these alternative approaches by focusing on specific strategies for well-defined travel markets at fine levels of detail (Meyer and Miller, 2001).

Growing congestion in metropolitan areas has been a driving force behind numerous corridor studies and research efforts, divided into several fields. Intelligent transportation systems (ITS) solutions include advanced traffic signal control systems and ramp metering techniques (Ban et al., 2007; Kazmi et al., 2002). Transportation demand management (TDM) solutions include land use planning, transit and carpooling solutions (Urban Land Institute, 2001; Zargari and Khan, 2003; Vidal, 1998). Congestion pricing solutions include fixed and variable tolling (DeCorla-Souza, 2005; Barker and Polzin, 2004; Nakamura and Kockelman, 2002). Access management solutions include control and spacing of curb cuts (Williams et al., 2006; Gluck et al., 2005; Schulte, 2004; Shadewald and Prem, 2004). Access management is considered a method of corridor protection, one of the primary subjects of this research effort.

Corridor preservation consists of a set of measures to manage access and development within the ROW of a planned transportation facility to maintain roadway safety and efficiency (Williams and Frey, 2004). Interest in corridor preservation, also referred to as corridor ‘protection’ or corridor ‘management’ to emphasize the encouragement of compatible development rather than the discouragement of all development, began decades ago (Skaer, 1988; Kussy, 1987). Perfater (1989) noted development in Virginia was occurring faster than transportation agencies could plan and build infrastructure. By the time proposed highway projects generated enough interest to be implemented, corridor alternatives had become expensive, environmentally sensitive, and politically unpopular. For these reasons the Federal government has generally supported corridor protection. In 1991 ISTEA mandated that states and metropolitan planning organizations consider the preservation of ROW for future transportation projects in the development of transportation plans and programs. Thus, to comply with federal legislation and to promote timely and cost-effective planning and construction of transportation facilities, minimize their environmental, social, and negative economic effects, and reduce the number of displacements resulting from their implementation transportation agencies engaged in studies, pilot projects, and corridor preservation plans (Maiorana, 1996; Williams and Frey, 2003). Comprehensive reviews of corridor management include Armour et al. (2002), Williams and Seggerman (2004), Maiorana (1994), AASHTO (1990), and Saito et al. (1999).

Corridor preservation activities can be considered in two categories, access management and ROW acquisition.

Access Management

Access management is a process that provides or manages access to developed land while simultaneously preserving traffic safety, mobility, and speed (Stokes et al., 1994). The 2007 Virginia General Assembly passed HB2228/SB1312 which directs the commissioner of VDOT to develop and implement access management regulations and standards with the goals of reducing traffic congestion, enhancing safety, supporting economic development, reducing the need for new highways and road widening, and preserving the public investment in new highways (VDOT, 2007).

A detailed history of access management is provided by Demosthenes (1999). Technical approaches include removal of access points by closing median openings, frontage road access for business driveways, special turning lanes to separate through vehicles from turning vehicles, and proper signing and pavement markings to communicate access points to drivers (Garber and Hoel, 2002). Transportation agencies are beginning to institute systemic access management plans that utilize regulatory, land use, and negotiating tools to prevent poor access conditions before they occur (State of Colorado, 2002; ODOT, 2007; Maze, 2000). Tools for access management include the following:

- Density credits/transfers
- Transportation impact fee credits
- Cluster development
- Setback waivers
- Interim use agreements
- Tax abatement
- Variances and waivers (Williams and Frey, 2003).

Access management plans may stand alone or be components of corridor preservation activities. Access management is reviewed thoroughly in the literature and includes guidebooks, case studies and reviews of best practices (Gattis, 2005; Access Management Manual, 2003; Stamatiadis et al., 2004; Gattis et al., 2005; Eisele and Frawley, 2005; Gluck et al., 2005; Gluck et al., 1999; Koepke and Levinson, 1992; Rose et al., 2005). The Transportation Research Board's National Conference on Access Management is in its eighth iteration.

Right-of-Way Acquisition

ROW acquisition refers to acquisition of some or all property rights to preserve ROW for new construction or road widenings. ROW acquisition is covered extensively in the literature (Stokes et al., 1994). Challenges of timing and cost estimation of ROW is reviewed as well (Heiner and Kockelman, 2005; Barnes and Watters, 2005; Kockelman et al., 2004).

Properties or parts of properties may be acquired in three ways: (1) police powers, (2) government inducements, and (3) acquisition activities (Stokes et al., 1994). Police powers involve controlling the development of private property through government regulation. This approach is largely the responsibility of local government and requires a great deal of coordination between state and local officials (Maiorana, 1996). Police powers are subject to legal interpretation and can vary from state to state (Saito et al., 2000; Mandelker and Blaesser, 1996). Police powers include the following activities:

- Exactions
  - In-kind contributions by developers
  - Monetary payments in lieu of contributions
  - Impact fees
  - Special assessments
  - Setback ordinances
- Maps of reservation
- Access control.

Government inducements provide incentives to land owners to cooperate with transportation and land use agencies and reserve ROW. Examples include the transfer of development rights and private/public joint development joint development.

Acquisition activities include gaining control of some or all rights associated with a parcel of land. Fee-simple acquisition refers to acquiring the title of the land and all property rights associated with it. Most state transportation agencies use fee-simple acquisition as a last resort for several reasons. First it erodes the local tax base and can encumber money in long-term property investments (Maiorana, 1996; Kleinburd, 1996). Second, purchase of property by fee simple title may require a great deal of capital, entail special requirements for NEPA compliance, and elicit property management concerns. Instead, property rights may be considered separate from one another, using the 'bundle of sticks' analogy (Mandelker, 2003). Individual rights may be separated from the bundle and bought and sold one by one. For example, instead of buying an entire property, a state agency may offer to buy the land owner's right to extend an access point to a highway. This right would be removed from the parcel in perpetuity, and the parcel would obtain access from an access road or an adjoining parcel. Examples of acquisition activities are as follows:

- Hardship acquisition
- Protective buying
- Option to purchase
- Development easements
- Surplus government land
- Functional replacement.

Although transportation agencies may prefer these methods, property owners are often wary of selling partial rights and often prefer selling their properties outright (Kleinburd, 1996).

With the passage of ISTEA, Congress instructed the Secretary of Transportation to compile a report of corridors requiring preservation. The report, delivered to Congress in 1994, included 1,561 corridors, 586 of which were corridors proposed by local governments, MPOs, and transportation agencies. These corridors totaled over 18,000 miles in length ("Report of the Secretary of Transportation to the United States Congress on Preservation of Transportation Corridors," 1994). (In comparison, the interstate highway system is over 46,000 miles and the

National Highway System is roughly 160,000 miles [“Interstate Highway System,” 2007; FHWA, 2007].) Based on fee-simple acquisition, the report estimated the cost of preserving the existing corridors at $3 billion and the proposed corridors at an additional $2 billion. It acknowledged these costs were likely underestimated as only 60% of the corridors had completed cost estimates. The report also noted the corridors submitted were not based on a uniform identification process as requested by Congress.

Thus the report reveals several challenges: (1) to develop a process to identify and prioritize corridors requiring protection, and (2) to investigate alternative protection methods that may be more cost effective than fee-simple acquisition. The latter has been addressed in full in the literature. The former has not been the focus of research studies. Despite the large body of literature pertaining to corridor preservation activities, there is comparably less literature about how to identify corridors in which corridor preservation activities should be implemented.

Armour et al. (2002) suggest three ways to identify corridors and provide examples of states that practice each method.

1. Idaho, Delaware, Kansas, and Minnesota identified and designate corridors through the long range planning and the statewide plan. Approaches vary from long range collaborative planning processes (Idaho, Minnesota) to a district engineer designating corridors on a District Transportation Plan (Kansas).
2. Wisconsin and Maryland selected corridors on an individual project basis. This approach requires fewer resources but obscures how corridors are selected.
3. North Carolina, Nebraska, and Iowa adopt corridors for protection under Map Acts. A transportation corridor Official Map Act allows local governments and the state to file a corridor for protection in order to preserve future ROW for priority highway projects (Armour et al., 2002).

A review of corridor preservation activities in five Florida counties note the absence of documented location selection methodologies in all but one (Williams and Frey, 2003). Indian River County identifies corridors needing protection in its long range transportation plan using a transportation demand model. Stokes et al. (1994) identify corridors based on the capacity analysis procedures in the Highway Capacity Manual. Highways currently have or are projected to have average annual daily traffic in excess of 5000 vehicles per day were considered candidates for corridor preservation programs. DelDOT identified the SR-1 corridor as a candidate for preservation using a ‘we know it when we see it’ approach (Kleinburd, 1996). What DelDOT professionals saw was (1) normal population expansion, (2) a dramatic growth in popularity of Delaware beaches as a destination, and (3) a recently constructed relief route allows traveling motorists to bypass the existing roadside commercial activities between I-95 and Dover. These factors were indicative of patterns that led to intense development along other corridors in the past.

These methods attempt to identify areas where corridor preservation will be required by identifying where congestion occurs. Traditionally, congestion occurs where development occurs (Downs, 2004). Thus, one method for identifying corridors requiring preservation is to identify corridors likely to intensely develop. Types of models used to predict land development include scenario generation and evaluation models, urban economic models, and integrated transportation and land use models (Johnston and Clay, 2004; Waddell, 2002). Several of these models are highly integrated with GIS.

GIS-Based Method for Priority Setting

GIS has greatly impacted both transportation and land use planning. Malczewski (2004) provides a detailed survey of the history, methods and techniques, and trends and challenges of GIS paying particular attention to land-use suitability analysis.

A common GIS analysis technique used to identify the most appropriate spatial pattern for future land uses according to specific requirements, preferences, and predictors is known as *suitability analysis* (Malczewski, 2004). The history of suitability analysis is reviewed by Malczewski (2004) and Collins (2001).

Suitability analysis is central to scenario generation and evaluation transportation and land use models, several of which are based on the UPLAN model (Johnston et al., 2003; Johnston and Clay, 2004). Models and methodologies based on suitability analysis trade off ease of use, cost, and transparency for the detail of predictions provided by more complex models. Waddell (2002) reviews urban economic models and integrated transportation and land use models including DRAM/EMPAL, MEPLAN and TRANUS, CUF-2, and UrbanSim. While these models may provide detailed predictions regarding the future of urban development, they may require a great deal of input data, have a steep learning curve, and are not necessarily transparent to decision makers and the public DRAM/EMPAL, MEPLAN, and TRANUS are proprietary.

UPlan, on the other hand, is a free download (although it requires ArcGIS and the ArcGIS Spatial Analyst extension) and can be applied in a few weeks by a GIS staff member. UPlan projects several land types including three residential densities, two commercial densities, and one industrial density in grid cells that roughly match parcel sizes. The model is not calibrated because it is intended for long-range scenario testing. Based on a series of inputs, an attraction grid is combined with an exclusion grid to create a suitability grid. The suitability grid becomes the template for the allocation of future land consumption by type, guided by a layer of representing future land use of a comprehensive plan (Johnston et al., 2003). The UPlan tools were used in other efforts including the Merced County Partnership for Integrated Planning (PIP) sponsored by the Federal Highway Administration, U.S. Environmental Protection Agency, and the California Department of Transportation (McCoy and Steelman, 2005) and an effort to forecasting exurban development to evaluate the influence of land use policies on wildland and farmland conservation (Merenlender et al., 2005).

Several terms are useful to describe core suitability analysis functions (Pease and Coughlin, 1996):

- Factors are attributes that contribute toward the suitability of a parcel of land
- Scaling refers to the way points are assigned to a factor (an example is to assign scores of 0 to 100 for each factor)

- Factor rating refers to the particular score assigned to a factor
- Weighting refers to a weight applied to each factor to recognize its relative importance
- Weighted factor rating denotes the factor rating after a weight has been applied
- Score is the total of all weighted factor ratings
- Ranking is the relative importance of a site compared to other sites.

Because the literature contains a wide variety of applications of suitability analysis, there are many potential factors that have been used. The factors used depend on the application, scale of study area, and availability of data. A study to evaluate potential residential sites in a small region of rural Switzerland used the following factors:

- Impacts on a nature reserve, landscape, and/or water table
- Air pollution coming from a waste water treatment plan, dumps, and highways
- Proximity to noise from highway traffic
- Commute time to employment centers
- Local climate including sunshine, temperature, and fog
- Risk of landslide
- Distance to localities and public facilities such as water supply and electricity
- Viewshed quality (Joerin et al., 2001)

Another effort that identifies of rural residential development sites uses the following factors:

- Capacity of soil to support onsite wastewater disposal systems
- Accessibility from transportation infrastructure
- Commuting times
- Proximity to existing development
- Slope
- Erosion hazard
- Soil shrink and swell
- Airport noise (Pease and Coughlin, 1996).

Several studies characterizing the inventory of developable land use the following factors:

- Vacant land
- Environmentally constrained land
- Land needed for public services
- Land that is underdeveloped
- Land served by utilities
- Improvement-to-land ratio (Landis, 2001; Moudon, 2001; Knaap and Moore, 2000).

A criticism of suitability analysis is the difficulty in choosing appropriate factors, scales, and weights. Miller et al. (1998) employ expert opinion, send out surveys to the town council and town employees, interpret published materials, and obtain advice from local professionals, scientists, and wildlife managers to obtain ratings and weights for factors. Other efforts have employed more strictly defined techniques such as AHP (Eastman et al., 1993; Banai, 1993; Banai-Kashani, 1989), and the Delphi approach (Dobson, 1979; Pease and Coughlin, 1996).

As noted in the historical reviews (Malczewski, 2004; Collins et al., 2001) GIS and suitability analysis capabilities have evolved considerably over time. Raster analysis in particular allows analysts to easily scale, weight, and combine datasets (Star and Estes, 1990; Miller et al., 1998). From 1990 to 2004 Malczewski (2006) finds 300 articles related to GIS-based multicriteria decision analysis. One such example is provided by Pereira and Duckstein (1993). Multicriteria decision making (MCDM) is also combined with suitability analysis (Jankowski, 1995; Malczewski, 1996; Prakash, 2003). Cromley and Hanink (1999) and Hanink and Cromley (1998) formulate their raster suitability analysis as a linear optimization problem. Further strides have been made to integrate artificial intelligence methods including fuzzy logic techniques, neural networks, genetic algorithms, and cellular automata (Malczewski, 1996).

Thus the literature demonstrates GIS-based suitability analysis is an approach that is accepted not only in the field of transportation and land use planning, but many other disciplines. It has been developed and refined over the last 50 years for a wide variety of spatial applications consistent with that of a risk-based approach to selecting road segments requiring corridor protection.

Developed GIS Methodology and Case Study

A seven-step GIS-based technology to support the identification, prioritization, and protection of transportation corridor sections in Virginia that could face significant development in five to ten years was developed in this study. The steps of this methodology are as follows:

Step 1: Define the problem.
Step 2: Investigate data sources and collect data.
Step 3: Identify relevant factors.
Step 4: Derive factors from collected data.
Step 5: Scale the factors.
Step 6: Weight and combine the factors into a final output dataset.
Step 7: Interpretation of results.

The methodology was applied to a case study of Fauquier County, Virginia. Appendix A provides a technical explanation of the steps, and Appendix B describes the steps in further technical detail.

Step 1: Define the Problem

Answering several questions helped to focus the research effort and shape the remainder of the steps in the methodology. These questions are as follows:

- What is the analysis trying to determine/identify?
- Who are the stakeholders and what are their interests?
- What is the geographical scale and study area?

- How will the results be represented?
- How will the results be analyzed?
- How will the analysis be used to address the original problem?

Applied to the Fauquier County case study, Step 1 defines the problem and introduces the study area.

VDOT's Transportation and Mobility Planning Division (TMPD) wished to investigate the potential for corridor preservation strategies in areas not yet intensely developed but those expected to experience pressure to develop within the next ten to twenty years. From a short list of candidates including Fauquier, Orange, Stafford, and New Kent counties, Fauquier County was selected as an ideal candidate for a corridor preservation case study due to (1) its proximity to the Washington, D.C., Metropolitan Area, (2) the county's interest in access management and corridor preservation, and (3) pledged cooperation of officials of both Fauquier County and the Rappahannock Rapidan Regional Commission (RRRC), the regional commission to which Fauquier County belongs.

One of the first steps taken was to convene a steering committee consisting of representatives from the following stakeholder groups:

- Fauquier County government
- Departments of Community Development
- Department of Economic Development
- VDOT TMPD
- Fauquier Chamber of Commerce
- RRRC.

These stakeholders were instructed (1) to guide the research effort, and (2) to voice opinions, concerns, and questions of interest. Together, the research team and the stakeholders formulated an appropriate problem definition for the case study.

This case study would assess relative likelihoods of development of parcels in Fauquier County and associate priority development areas to corridor sections. Thus it would identify which corridor sections are expected to develop prior to other corridor sections. Results in the forms of maps, tables, and graphs would focus Fauquier County's and VDOT's attention on corridor sections of high priority for corridor preservation activities. A written report would provide instructions for Fauquier County, VDOT, and RRRC to repeat and customize the methodology as they see fit.

Fauquier County is located in Northern Virginia, 40 miles southwest of Washington, D.C. It occupies approximately 660 square miles and, as shown in Figure 2, is bounded to the west by Culpeper and Rappahannock counties; to the south by Stafford County; to the north by Loudoun, Warren, and Clarke counties; and to the east by Prince William County. Fauquier is currently only several miles beyond the advancing exurban fringes of development in Loudon and Prince

Figure 2. Fauquier and Surrounding Counties. The polygons within Fauquier County represent service districts.

William counties. The Fauquier County Comprehensive plan identifies six primary and interstate corridors that provide access to adjoining counties (Fauquier County Comprehensive Plan, 1992). These corridors are U.S. Routes 29, 17, and 211; Virginia Routes 28 and 55; and I-66; they were chosen as the major corridors of interest for the study based on their specific mention in the comprehensive plan. These corridors total roughly 165 miles in length. The county contains approximately 32,000 parcels. The Fauquier County Comprehensive Plan designates nine 'service districts' in which it desires to concentrate development while preserving the scenic and agricultural natures of the remaining rural areas. The service districts comprise 36 square miles, about 5.5% of the county's total land area. Fauquier uses several planning and conservation tools to encourage development in the service districts and discourage development in the rural areas, including (1) clustering and large-lot zoning to restrict residential development in rural areas, and (2) federal, state, and local parks; agricultural and forestal districts; and conservation easements, i.e., voluntary controls to prevent or restrict development on designated parcels. Over 40% of the county's acreage is under voluntary control ("Growth Management: Fauquier County, Virginia," 2007). The population of Fauquier County is roughly 66,000, about one-eighth of which lives in or near Warrenton, the county seat (American Factfinder, 2006). As of the 2000 Census, about 38% of the county's population lived in an urban area.

Step 2: Investigate Data Sources and Collect Data

Step 2 in the methodology is to investigate data sources and collect data. Any and all data sources should be considered as potential inputs for risk-based suitability analysis. Transportation systems interact with a variety of natural and manmade systems including public and private utilities, recreational facilities, schools and parks, national parks and wild lands, and all types of development. Some states maintain online clearinghouses for spatial datasets from a variety of stakeholders. The factors identified as relevant in Step 2 will depend on what data are available, so the two steps may be conducted concurrently or iteratively.

For the Fauquier County case study, this step was conducted along with Step 3 in an iterative fashion. Step 2 informed Step 3 as to what factors were available, and Step 3 informed Step 2 as to what factors were desired. Virginia's spatial data clearinghouse, Virginia Geographic Information Network (VGIN), is under development, thus the two predominant sources of spatial data for this effort were VDOT's TMPD Planning Systems group, and Fauquier County's GIS Department. Both VDOT and Fauquier County had previously obtained much of their spatial data from other Virginia agencies. These primary sources are noted in the dataset inventory matrix shown in Table 1. The inventory matrix displays information for each factor collected including a dataset ID, name/description, project source, primary source (if different than the project source) and expected statewide availability.

Step 3: Identify Relevant Factors

Step 3 is to identify factors relevant to the problem as it is defined should be identified by several sources. The literature review highlights factors used in previous research efforts. Expert opinion from the perspective of each stakeholder group should be solicited. Problem scope and data availability (explored in Step 2) influence what factors may be used for the current effort. Factors that may be relevant but are not yet available should be noted in the final report to inform future efforts.

For the Fauquier County case study, review of the literature and several meetings with stakeholders and experts listed above led to identification of several categories of factors relevant to predicting land development at a county scale. *Constraint* factors decrease a parcel's likelihood of development, while *indicator* factors indicate a higher likelihood of development. The identified factors are as follows:

- *Constraint* factors
  - — Parcels under restriction
  - — Parcels economically unsuitable for development

Table 1. Inventory of Traditional and Non-Traditional Data Collected for Corridor Protection Project

ID	Dataset	Project Source	Primary Source (if other)	Available Statewide
D01	5' Topo Contours	FCDCD		Yes
D02	Easements: BOS Commitment	FCDCD		No
D03	Easements: BOS Openspace	FCDCD		No
D04	Easements: Historic Resources	FCDCD		Yes
D05	Easements: Land Trust of Virginia (LTV)	FCDCD	Land Trust of Virginia	Yes
D06	Easements: Marsh Resources, Inc.	FCDCD	Marsh Resources, Inc.	No
D07	Easements: Nature Conservancy	FCDCD	The Nature Conservancy	Yes
D08	Easements: Purchase of Development Rights (PDR)	FCDCD		No
D09	Easements: Piedmont Environmental Council (PEC)	FCDCD	Piedmont Environmental Council	Yes
D10	Easements: Virginia Outdoors Foundation (VOF) Openspace	FCDCD	Virginia Outdoors Foundation	Yes
D11	Easements: Virginia Outdoors Foundation (VOF) Owned	FCDCD	Virginia Outdoors Foundation	Yes
D12	Parks and Schools: Community Centers	FCDCD		Yes
D13	Parks and Schools: Schools	FCDCD		Yes
D14	Parks and Schools: Sports Complexes	FCDCD		Yes
D15	Parks and Schools: County Parks	FCDCD		Yes
D16	Parks and Schools: Natural Areas	FCDCD		Yes
D17	Parks and Schools: State Parks	FCDCD		Yes
D18	Agriculture and Forestal Districts: Cobbler Mountain	FCDCD		No
D19	Agriculture and Forestal Districts: Fiery Run	FCDCD		No
D20	Agriculture and Forestal Districts: Marshall Warrenton	FCDCD		No
D21	Agriculture and Forestal Districts: Middleburg Marshall	FCDCD		No
D22	Agriculture and Forestal Districts: Orlean Hume	FCDCD		No
D23	Agriculture and Forestal Districts: Paris Valley	FCDCD		No
D24	Agriculture and Forestal Districts: Routts Hill	FCDCD		No
D25	Agriculture and Forestal Districts: Southern Fauquier	FCDCD		No
D26	Agriculture and Forestal Districts: Springs Valley	FCDCD		No
D27	Agriculture and Forestal Districts: The Plains	FCDCD		No
D28	Agriculture and Forestal Districts: Thumb Run	FCDCD		No
D29	Agriculture and Forestal Districts: Trumbo Hollow	FCDCD		No
D30	Agriculture and Forestal Districts: Upperville	FCDCD		No
D31	Service Districts: Bealeton	FCDCD		No
D32	Service Districts: Calverton	FCDCD		No
D33	Service Districts: Catlett	FCDCD		No
D34	Service Districts: Marshall	FCDCD		No
D35	Service Districts: Midland	FCDCD		No
D36	Service Districts: New Baltimore	FCDCD		No
D37	Service Districts: Opal	FCDCD		No
D38	Service Districts: Remington	FCDCD		No
D39	Service Districts: Warrenton	FCDCD		No
D40	Flood Areas	FCDCD		Yes

ID	Dataset	Project Source	Primary Source (if other)	Available Statewide
D41	National Heritage Resources	FCDCD	VDCR	Yes
D42	Urban Clusters	FCDCD		Yes
D43	Parcels	FCDCD		No
D44	Zoning	FCDCD		No
D45	Water	FCDCD		No
D46	Sewer	FCDCD	Fauquier Water and Sewer Authority	No
D47	Property and Land Assessment Values	FCCR		No
D48	Functionally Classified Roads	VDOT TMPD		Yes
D49	Hazardous Waste Sites	VDOT TMPD	US EPA	Yes
D50	Superfund Sites	VDOT TMPD	US EPA	Yes
D51	Toxic Release Inventory	VDOT TMPD	US EPA	Yes
D52	National Wetlands Inventory	VDOT TMPD	US Fish and Wildlife Service	Yes
D53	Employers	VDOT TMPD	VA Employment Commission	Yes
D54	Easements held by The Nature Conservancy	VDOT TMPD	The Nature Conservancy	Yes
D55	Virginia Conserved Land: Conservation Easement	VDOT TMPD	Fauquier County	Yes
D56	Virginia Conserved Land: Local Park	VDOT TMPD	Fauquier County	Yes
D57	Virginia Conserved Land: Military Installation	VDOT TMPD	Navy, Army, Dept of Defense	Yes
D58	Virginia Conserved Land: NPS Holding	VDOT TMPD	National Park Service	Yes
D59	Virginia Conserved Land: NPS Scenic Easement	VDOT TMPD	National Park Service	Yes
D60	Virginia Conserved Land: Non-Profit Conservation Easement	VDOT TMPD	Northern VA Conservation Trust	Yes
D61	Virginia Conserved Land: State Forest	VDOT TMPD	VA Dept of Forestry	Yes
D62	Virginia Conserved Land: State Natural Area Preserve	VDOT TMPD	VAOutdoors Foundation	Yes
D63	Virginia Conserved Land: State Park	VDOT TMPD	VDCR	Yes
D64	Virginia Conserved Land: State Public Fishing Lake	VDOT TMPD	VA Dept of Game and Inland Fisheries	Yes
D65	Virginia Conserved Land: State Scenic Holding	VDOT TMPD	Commonwealth of Virginia	Yes
D66	Virginia Conserved Land: State Wildlife Management Area	VDOT TMPD	VA Dept of Game and Inland Fisheries	Yes
D67	Virginia Conserved Land: USFS Scenic Easement	VDOT TMPD	National Park Service	Yes
D68	Virginia Conserved Land: VOF Open Space Easement	VDOT TMPD	Virginia Outdoors Foundation	Yes
D69	Virginia Conserved Land: VOF Property	VDOT TMPD	Virginia Outdoors Foundation	Yes
D70	Scenic Rivers	VDOT TMPD		Yes
D71	MPO Boundaries*	VDOT TMPD		Yes
D72	Scenic Roads	VDOT TMPD		Yes
D73	Six-Year Improvement Plan Projects	VDOT TMPD		Yes
D74	Urban Clusters	VDOT TMPD		Yes
D75	Urbanized Areas	VDOT TMPD		Yes
D76	Virginia State	2000 Census		Yes
D77	Virginia Counties	2000 Census		Yes
D78	Virginia Tracts	2000 Census		Yes
D79	Virginia Block Groups	2000 Census		Yes
D80	Block Populations	2000 Census		Yes

FCDCD - Fauquier County Community Development

FCCR - Fauquier County Commissioner of Revenue

VDOT - Virginia Dept of Transportation Transportation and Mobility Planning Division

VDCR - Virginia Dept of Conservation and Recreation

* Fauquier County is not part of an MPO

- *Indicator* factors
  — Parcels near major corridors
  — Parcels near intersections of major corridors
  — Parcels near population centers
  — Parcels near employment centers.

Use of zoning data, often a major determinant of development, was considered for inclusion in the analysis but was omitted for several reasons. First, zoning layers are not uniformly available statewide. One of the central goals of this research was to develop a general methodology based on data available in all counties statewide so that it would easily be repeatable. More specific variations of the methodology could be created in subsequent iterations. Second, zoning districts vary considerably from county to county statewide. It was not clear that results of the Fauquier County case study would be transferable to each county. Third, zoning reflects the desires and interests of a variety of stakeholders and is subject to change. In contrast, the chosen factors for the first iteration of this methodology were based on objective existing conditions. For example, sizes and locations of activity centers are not subject to a political process. Thus zoning was excluded for the present effort with the intention of exploring it in future work.

Constraint Factors

Parcels Under Restriction. Parcels under voluntary restriction (including conservation easements; agricultural and forestal districts), held in the public trust (federal, state, and county parks; schools and recreational facilities), and historic sites have very low likelihood of development (Fauquier County Comprehensive Plan, 1992).

Parcels Economically Unsuitable for Development. Economics and financial expectations dictate which parcels will generate favorable returns. Though development prospects depend most on the health of the local real estate market or neighborhood expectations, individual parcel characteristics are also useful. An improvement value to land value ratio may be used to examine the utilization of a parcel. Parcels with ratios less than a threshold amount are judged economically underutilized and therefore are candidates for development (Landis, 2001). That is, a high improvement-value to land-value ratio suggests a parcel is unsuitable for further development.

Indicator Factors

Parcels Near Major Corridors. Parcels near major corridors have greater access to activity centers (or potential-customer passers-by) than do parcels farther away, and thus are likely to develop before parcels that are farther away (Marshall, 2001). The steering committee suggested development within one quarter-mile has significant impact on the functionality of a countywide corridor, while development within one mile has some impact.

Parcels Near Intersections of Major Corridors. Parcels near corridor intersections have immediate access to activity centers in multiple directions. These parcels have superior accessibility compared with parcels that are located on a single corridor. Thus parcels near intersections have a relatively higher likelihood of development (Garreau, 1992).

Parcels Near Population Centers. Parcels near existing and future population centers are more likely to develop than parcels farther away for a variety of reasons. Public utilities, schools, and retail activity centers are likely present or nearby. If retail and commercial is not nearby, market opportunities exist to provide these to existing residents. Thus parcels near population centers have a higher likelihood of development (Christaller, 1966).

Parcels Near Employment Centers. Similarly, parcels near existing and future employment centers are more likely to develop than parcels farther away for a variety of reasons. Existing public utilities and supporting retail can prompt further commercial development. Opportunities exist to provide residential development nearby to lessen employee commutes. Thus parcels near population centers have a higher likelihood of development (Christaller, 1966).

Step 4: Derive Factors from Collected Data

Step 4 derives factors identified in Step 3 from available data. Most factors identified need to be derived from collected data before they may be used as inputs for suitability analysis. Derivation involves performing a number of basic (or fundamental) GIS functions on a collected dataset to obtain a factor relevant to the problem as it is defined (Malczewski, 2004). For example, to derive distance from a population center, population centers must be identified using census data and distances from those population centers must be calculated using the road network. Derivation of factors from the datasets for the case study is explained in the remainder of this section. Factors are related to their constituent datasets in Table 2. Both vector and raster analyses were used. The advantages and disadvantages of both methods are as follows:

- Vector advantages
  - — Stores data at a high resolution
  - — Represents linear features explicitly
  - — Efficiently stores sparse data
- Vector disadvantages
  - — Manipulations require sophisticated algorithms
  - — Processing can require lots of computer time
  - — Inefficient storage of dense data
- Raster advantages
  - — Easy to overlay data
  - — Efficient storage for dense, heterogeneous data
- Raster disadvantages
  - — Requires large amounts of storage space
  - — Inefficient when data are sparse or homogeneous
  - — Deals poorly with linear features (Star and Estes, 1990).

Raster analysis was used primarily for overlaying and combining data between multiple data layers. Vector methods for doing so would have been computationally prohibitive. Further, use of the raster format allows the use of powerful techniques such as raster algebra and density

Table 2. Identified Factors and the Datasets From Which They Are Derived. Refer to Table 4.1 for IDs

Factor Type	Identified Factor	Constituent Datasets
Constraint	CF1 - Parcels under Restriction	D02-30, D40, D41, D43, D49-52, D54-69
	CF2 - Parcels Economically Suitable for Development	D43, D47
Indicator	IF1 - Parcels near Major Corridors	D43, D48
	IF2 - Parcels near Intersections of Major Corridors	D43, D48
	IF3 - Parcels near Population Centers	D43, D48, D80
	IF4 - Parcels near Employment Centers	D43, D48, D53

analysis. All derived factors were stored as raster images with cells having height and width of 1/128 miles (41.25 feet). This extremely fine granularity allowed the project team to distinguish individual parcel boundaries in the raster files.

Constraint Factors

Parcels Under Restriction. All parcels under development restriction including agricultural and forestal districts, parcels under conservation easement, wetlands, public infrastructure, contaminated sites, and federal, state, and county parks were combined into a single data layer. Figure 3 visualizes the resulting data layer.

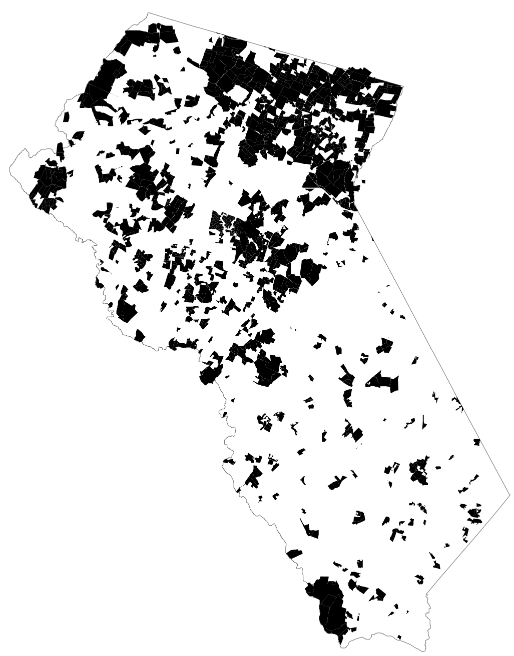

Figure 3. Fauquier County Parcels Currently Protected From Development

Parcels Economically Suitable for Development. A ratio of improvement-to-land assessment values was generated for each parcel within one-mile of the centerline of the major corridors. Various thresholds of improvement-to-land assessment ratio were tested and compared with expert knowledge of Fauquier County. Parcels having a ratio greater than 0.90 were eventually deemed economically unsuitable for development due to demolition and development costs relative to the cost of the land. Parcels having a ratio less-than-or-equal to 0.90 were deemed economically suitable for development. Figure 4 depicts the economic suitability within Fauquier County.

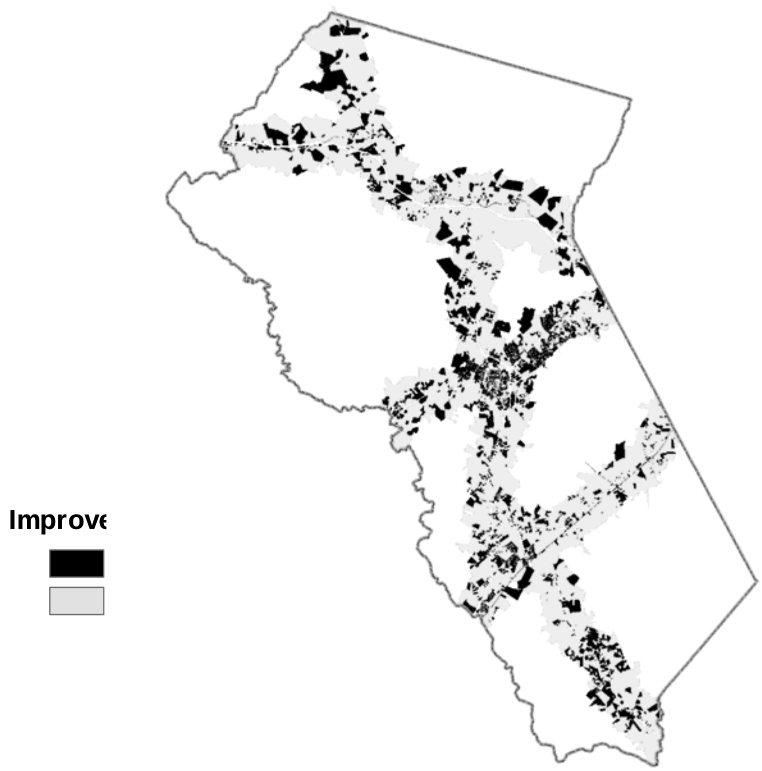

Figure 4. Economically Suitable and Unsuitable Parcels Based on Improvement-to-Land Ratio

Indicator Factors

Parcels Near Major Corridors. Quarter-mile and one-mile straight-line buffers were generated based on the centerlines of the major corridors. Straight-line buffers were chosen over network buffers because development may alter a parcels access to the road network. The buffers were used to isolate all the parcels within a quarter-mile and one mile, respectively. As I-66 is a limited access facility, only those parcels within a quarter-mile and one mile of the entrance ramps were considered for the analysis. The two buffer categories are mutually exclusive. Parcels within a quarter-mile are not also included in the set of parcels within one mile. Figure 5 depicts the resulting data layer.

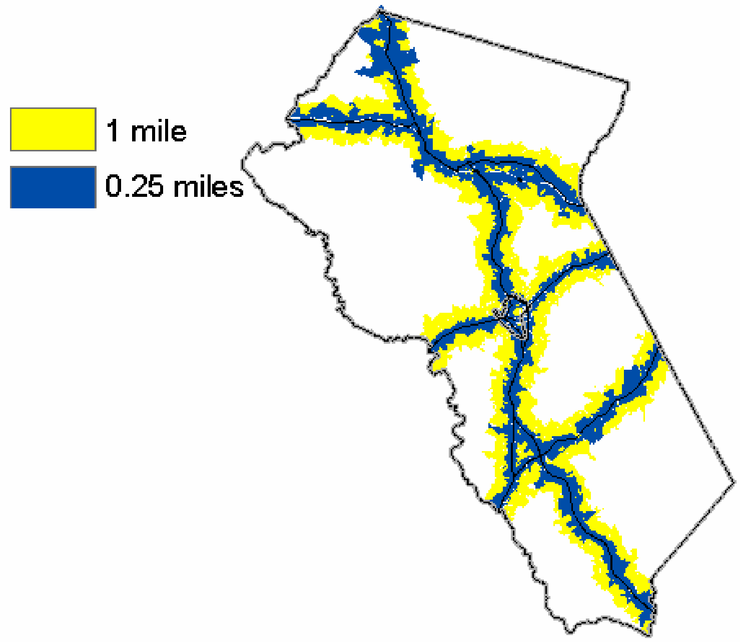

Figure 5. Parcels Within 0.25 and 1.0 Mile of Major Corridor Centerlines

Parcels Near Intersections of Major Corridors. Parcels within a quarter-mile and one mile were extracted for each of the six corridors and represented as raster images. These individual raster images were combined using raster algebra to determine which parcels were within a mile of corridor intersections. Parcels were categorized as either near the intersection of two or three corridors or along a single corridor (no intersections). Figure 6 represents the resulting data layer.

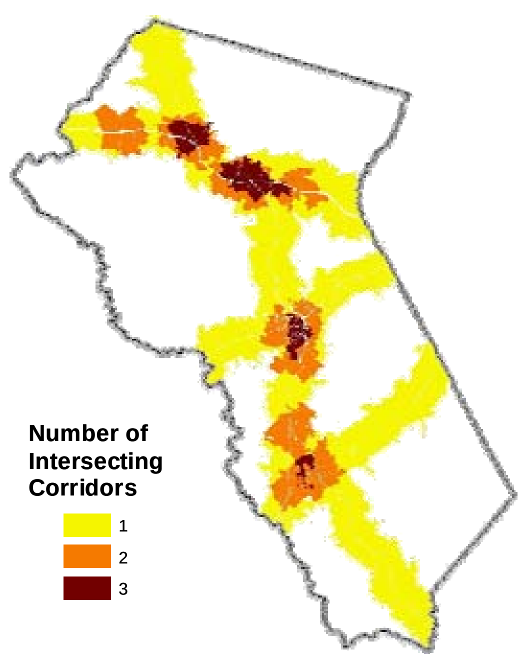

Figure 6. Parcels Near Intersections of One or More Major Corridors

Parcels Near Population Centers. Identifying likelihood of development of parcels near population centers required several sub-steps. These steps are similar in concept to a transportation gravity model.

First, because people often cross county borders to travel home, a place of employment, or a store, the study area was expanded to include Fauquier and the immediate surrounding counties including Clarke, Loudoun, Prince William, Stafford, Culpeper, Rappahannock, and Warren Counties. The expanded study area was previously shown in Figure 2.

Second, a raster population density gradient was generated using block populations from the 2000 Census. Various threshold populations were tested to identify the location and size of population sizes. The threshold of the entire study area was adjusted to reflect the location and boundaries of population centers in Fauquier County. A threshold of 300 persons per square mile was found to roughly reflect the location and size of population centers. The resulting map, shown in Figure 7, resulted in 18 population centers that were verified by representatives of the Fauquier County Department of Community Planning.

Third, the geometric centroids of the population centers were calculated and associated with the nearest point on the road network. This network included all interstate and primary roads in the eight-county study area. The network was then used to calculate driving distances of 5, 10, 25, and 40 miles from each of the 18 population centers. Figure 8 shows network buffers for two of the population centers. These driving distances, or network buffers, were stored as raster images. Raster cells were assigned values depending on their distance from the population

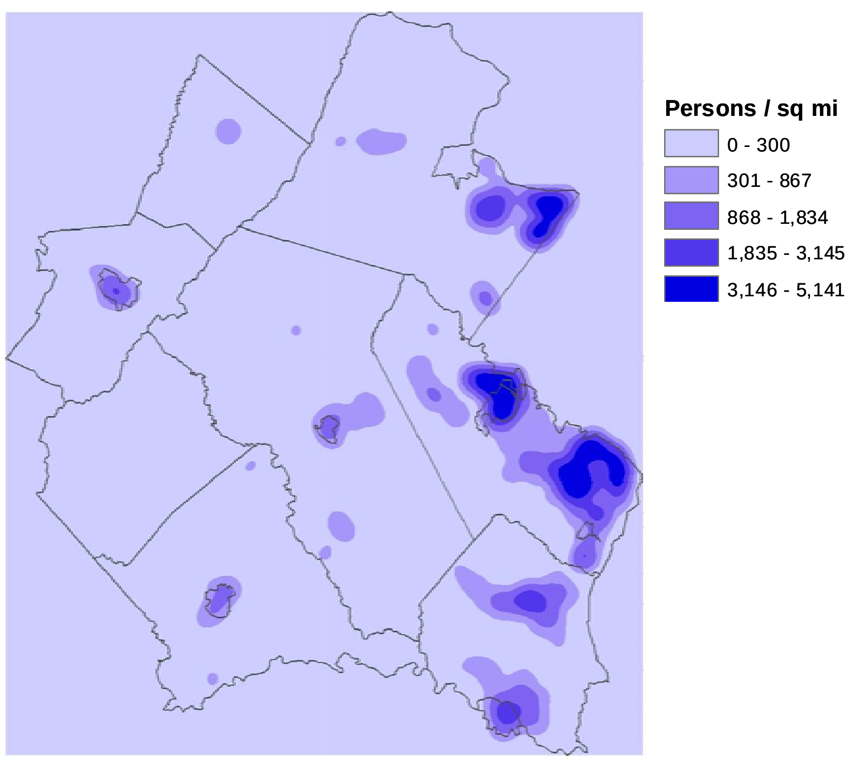

Figure 7. Population Density Gradient Displaying Population Centers in Fauquier County Study Area

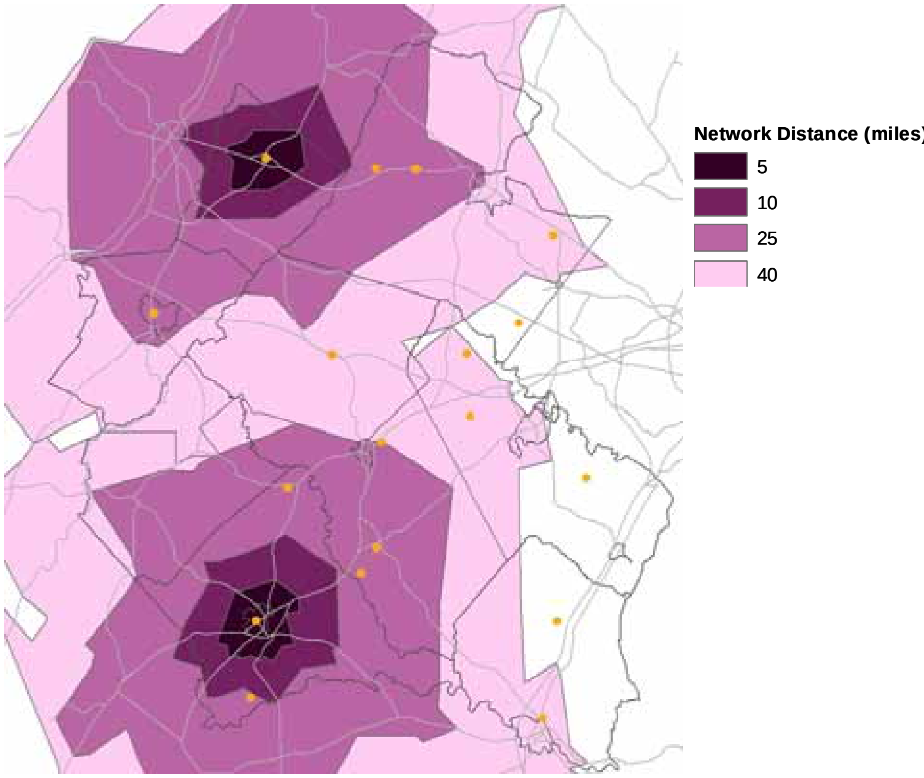

Figure 8. Sample Network Buffers Representing Driving Distances From Winchester (top) and Culpeper (bottom)

Fourth, the values associated with the network buffer raster images were weighted to reflect that larger population centers are more likely to attract development than smaller population centers. The relative size of each population center was determined by dividing the population size of each population center by the population size of the largest population center, in this case, Manassas in Prince William County. The weight for each population center was multiplied to the raster values associated for that population center.

Fifth, the 18 weighted raster images were added using raster algebra to account for both the distance to population centers and the number of nearby population centers. Figure 9 shows the resulting likelihood of development based on proximity to population centers.

Parcels Near Employment Centers. Identifying likelihood of development of parcels near employment centers followed a process similar to the population center analysis and required several sub-steps. These steps are similar in concept to a transportation gravity model.

First, because people often cross county borders to travel home, a place of employment, or a store, the study area was expanded to include Fauquier and immediately surrounding counties.

Second, a raster employment density gradient was generated using employment data VDOT obtained from the Virginia Employment Commission. Various thresholds of employee

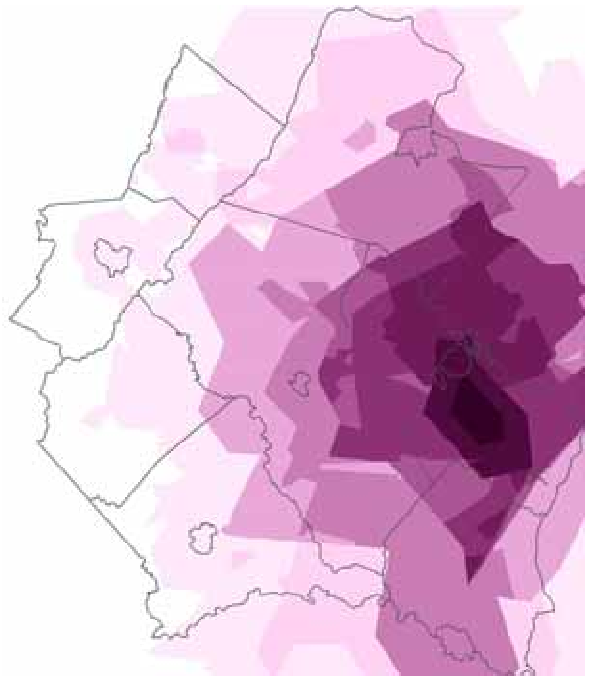

Figure 9. Likelihood of Development Based on Distance from Population Centers. Dark regions represent higher likelihood.

densities were tested to identify the location and size of employment centers. The threshold of the entire study area was adjusted to reflect the location and boundaries of employment centers in Fauquier County. A threshold of 300 persons per square mile was found to roughly reflect the location and size of employment centers in. The size and location of the 17 employment centers was validated by Fauquier County planners.

Third, the geometric centroids of the employment centers were calculated and associated with the nearest point on the road network. This network included all interstate and primary roads in the eight-county study area. The network was then used to calculate driving distances of 5, 10, 25, and 40 miles from each of the 17 employment centers. These driving distances, or network buffers, were stored as raster images. Raster cells were assigned values depending on their distance from the employment center to reflect relative likelihood of development. Cells more than 40 miles away were assigned a value of 0. Cells between 25 and 40 miles away were assigned a value of 1. Cells between 10 and 25 miles away were assigned a value of 2. Cells between 5 and 10 miles away were assigned a value of 3. Cells less than 5 miles away were assigned a value of 4.

Fourth, the values associated with the network buffer raster images were weighted to reflect that larger employment centers are more likely to attract development than smaller employment centers. The relative size of each employment center was determined by dividing the employment sizes of the employment centers by the employment sizes of the largest employment center, in this case, near the Dulles Toll Road in Loudoun County. The weight for each employment center was multiplied to the raster values associated for that employment center.

Fifth, the 17 weighted network buffer raster images were added using raster algebra to consider the both the proximity to employment centers and the inherent advantages of being near multiple employment centers. Figure 10 reveals the resulting likelihood of development based on proximity to employment centers.

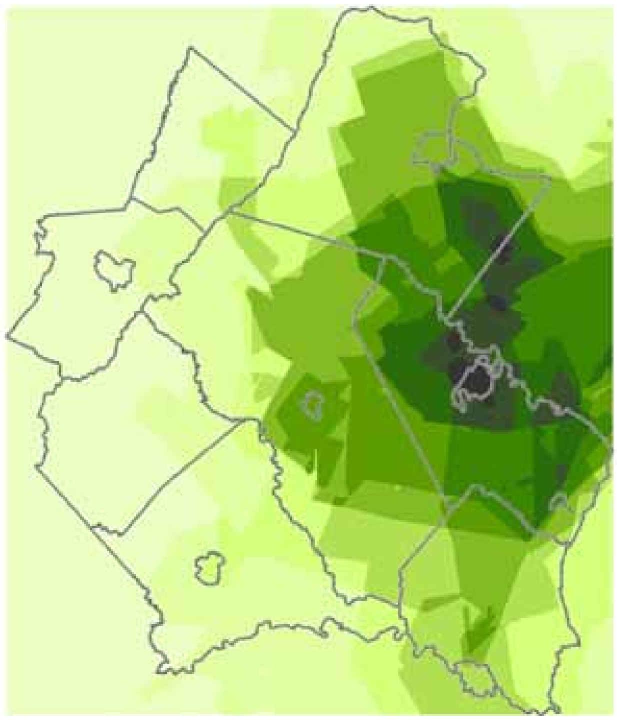

Figure 10. Likelihood of Development Based on Distance From Employment Centers. Dark regions represent higher likelihood.

Step 5: Scale the Factors

Step 5 is to adjust each of the six factors to a common scale. Multiple factors having values of different scales cannot directly be combined, nor can factors having cardinal values be directly combined with factors having ordinal scales (Miller et al., 1998; Hopkins, 1977, 1980). To work around these issues, values for each factor should be adjusted to a unitless scale common to all factors. For example, values for each factor may be mapped to a unitless scale between 1 and 100.

The six factors in the Fauquier County case study had non-commensurate units. Distance from major corridors and number of intersections were cardinal numbers, while distance from population and employment centers were ordinal numbers. The factors had to be transformed to a common scale so they may be combined. For this effort, the values for the factors were scaled from one to ten. Restricted parcels and economically suitable parcels were scaled as well; however, for reasons explained in Step 6, raster images for these factors were transformed to binary variables. Table 3 summarizes the values of the scaling operation.

Table 3. Values Used to Scale Factors to Common Scale of 1 to 10 (0 or 1 for Binary Factors)

Factor Type	Identified Factor	Original Value	Scaled Value
Constraint	Parcels under Restriction	Unrestricted parcels	1
		Restricted parcels	0
	Parcels Economically Suitable for Development	Economically suitable	1
		Economically unsuitable	0
Indicator	Parcels near Major Corridors	1/4 mile	10
		1 mile	5
	Parcels near Intersections of Major Corridors	3 corridors	10
		2 corridors	6
		1 corridor (no intersection)	3
	Parcels near Population Centers	Lowest to highest likelihood, equal intervals 1-10	1-10
	Parcels near Employment Centers	Lowest to highest likelihood, equal intervals 1-10	1-10

Step 6: Weight and Combine the Factors into a Final Output Dataset

Step 6 is to weight and combine the factors. Expert opinions should be solicited as to the relative importance of the factors. For example, 'distance from a population center' may be relatively more or less important to predicting where development will occur than 'distance from an employment center.' Raster algebra may then be used to combine the factors into a final output dataset. The weighting and combination procedure is similar to Hanink and Cromley (1998):

$$S_{ij} = \sum_{k=1}^{p_j} w_{ijk} A_{ijk}$$

p_j – number of factors for the jth land use

w_{ijk} – weight of the kth factor with respect to the jth land use for the ith cell

A_{ijk} – suitability scalar of the ith cell for the jth land use with respect to the kth factor

For the Fauquier County case study, the project team did not distinguish among land uses, thus the *j*th land use in the above equations represent the generalized case. Factors were given equal weights for the case study (though expert opinion may be solicited as to the relative importance of the factors), and raster algebra was used to weight and sum the values together. The maximum value for each cell within a raster was ten, and the maximum value for each cell in the resulting summation was forty. The raster images of the binary factors were multiplied to the result of the summed non-binary factors. This assigned values of zero to all restricted and economically unsuitable cells, effectively assigning these cells the lowest likelihood of development possible. Figure 11 illustrates the weighting and combination process.

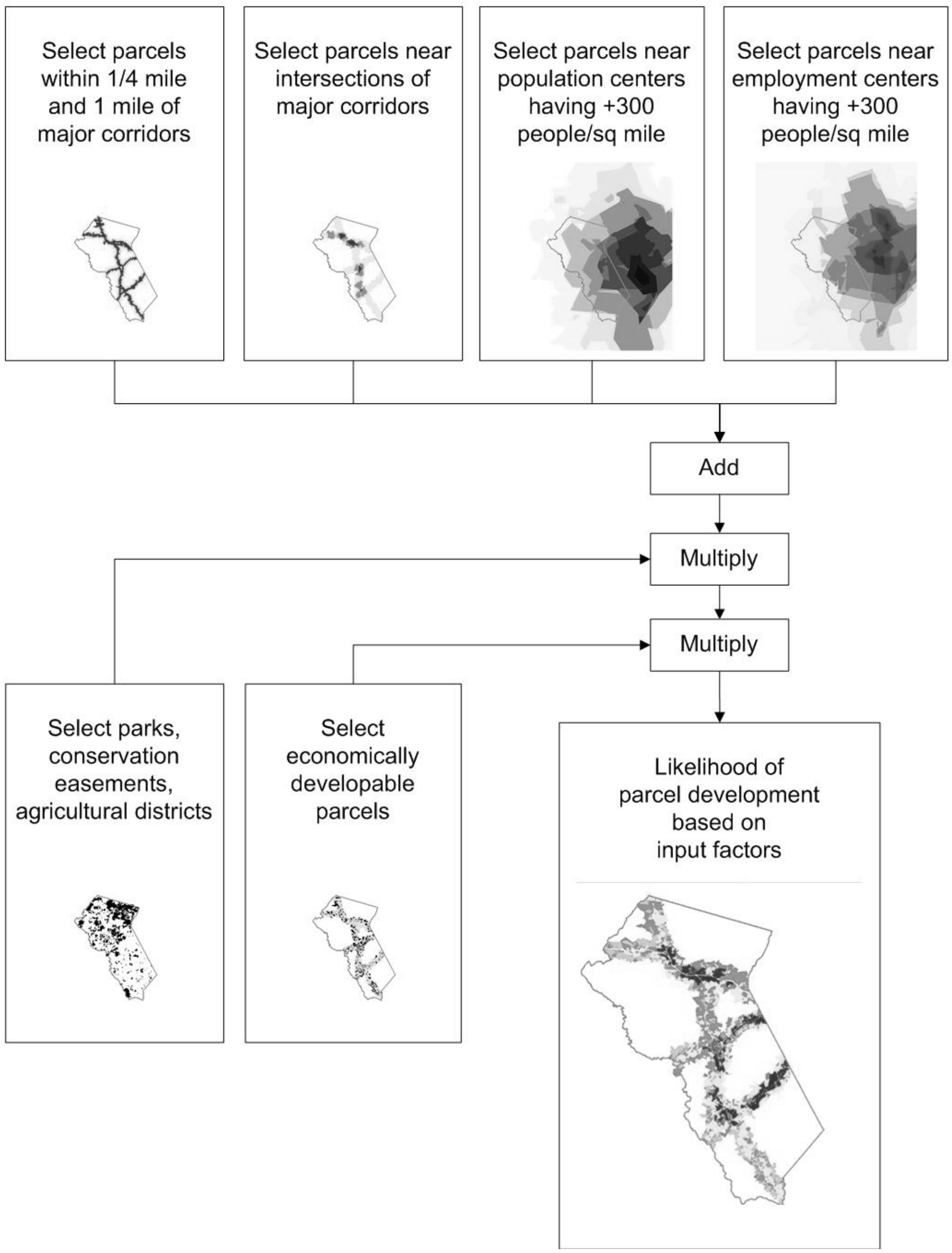

Figure 11. Overview of Combination of Factors to Identify Likelihood of Development of Parcels in Fauquier County

The resulting raster image was converted back to a vector representation of the parcel using the zonal analysis raster function in GIS. Each parcel was assigned the score of the cell within its border having the maximum value. Figure 12 shows the resulting map depicting the relative likelihood of development of parcels near major corridors in Fauquier County. In addition, Figure 13 represents all corridors individually. Parcels are categorized as having Very Low, Low, Medium, or High likelihood of development relative to other parcels in the study area. Parcels were categorized using the quantile classification method by which the likelihood classes are sized to contain the same number of parcels.

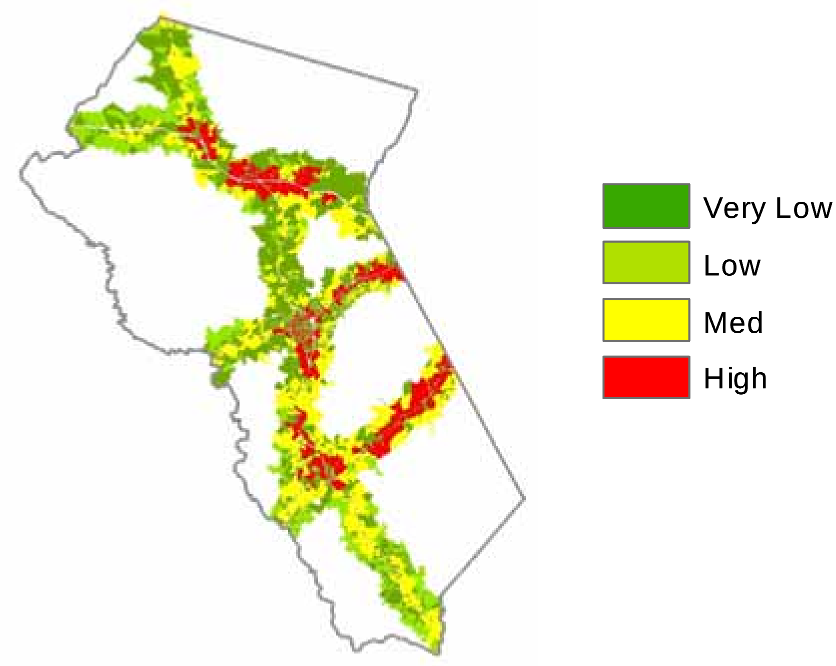

Figure 12. Likelihood of Development in Countywide Corridors Based on Six Indicator and Constraint Factors.

Step 7: Interpretation of Results

The results of the Fauquier County case study were analyzed from a variety of perspectives. The entire road system or individual corridors were investigated visually on maps, summarized with respect to length, land value, area, and other available characteristics tabularly and on graphs. Corridors were inspected in their entirety as well as in discrete sections.

Results of Corridor-to-Corridor Comparisons

Relative likelihoods of development were visually inspected for the entire corridor network. This revealed several interesting findings.

First, the model predicted intense development is most likely to occur in corridor sections in eastern Fauquier County. This was due to the magnitude and number of activity centers comprising the Washington, D.C., Metropolitan Area.

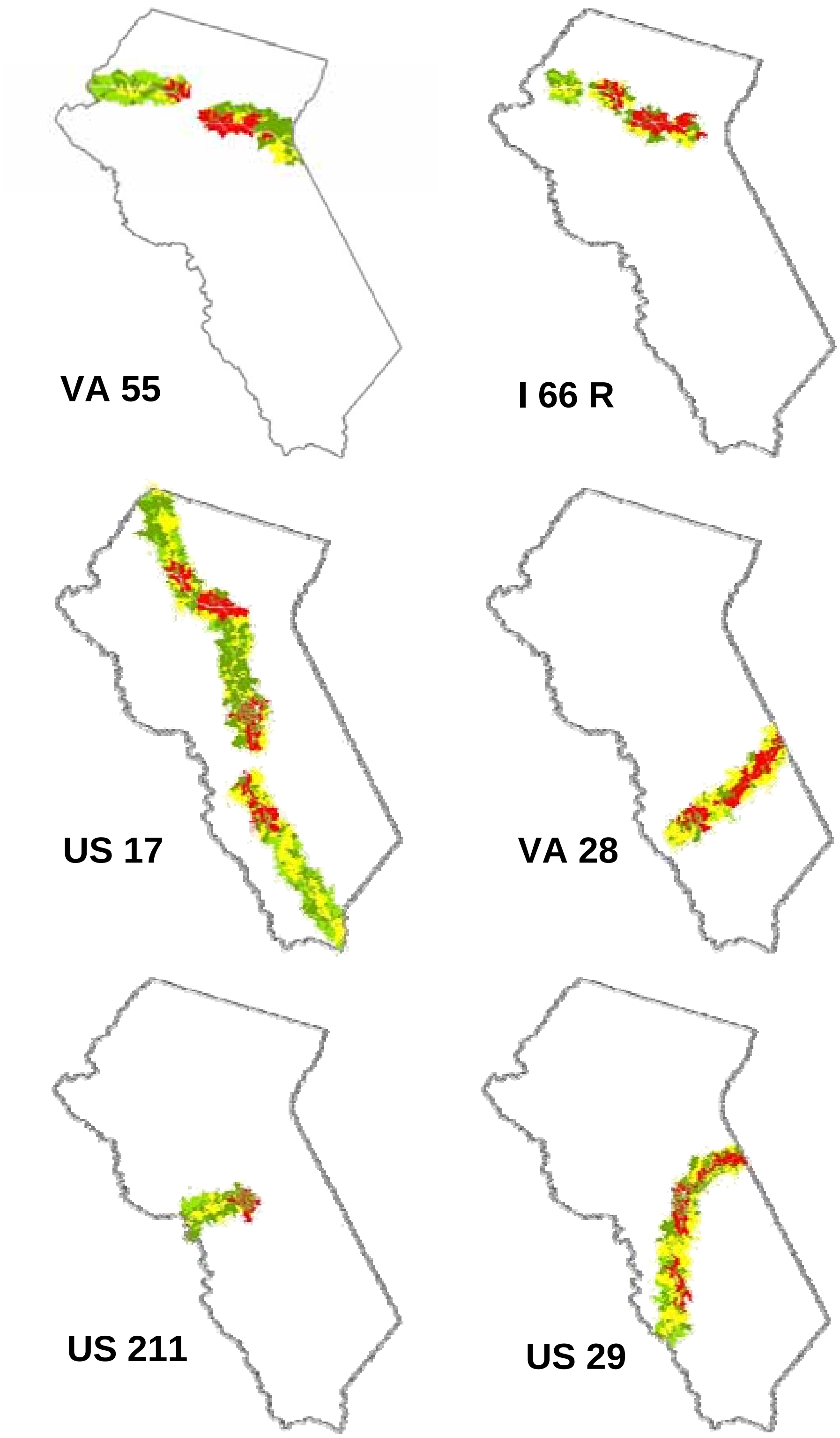

Figure 13. Likelihood of Development in Countywide Corridors, by Corridor

Second, the model anticipated likely development at the corridor intersections, especially those common to I-66, U.S. 17, and VA 55. Another high likelihood area is Bealeton, where U.S. 29, VA 28, and U.S. 17 intersect.

Third, an additional run of the model without the economic suitability factor, represented in Figure 14, resulted in different likelihoods. A comparison of Figures 12 and 14 shows the corridors relatively more developed than others. Thus the comparison distinguishes between opportunities for corridor protection in undeveloped areas and situations requiring retrofitting in already developed areas. For example, Figure 14 shows considerably fewer ‘Very Low’ priority parcels on U.S. 29 than does Figure 12; therefore, U.S. 29 has a notable number of parcels that are economically unsuitable for further development. Thus, U.S. 29 may require retrofitting, while other corridors, especially VA 28, may be opportunities for systemic corridor protection plans in advance of intense development.

Fourth, the individual corridors may be summarized with respect to length, land value, area, and assessment characteristics and explored in a table. By doing so, Table 4 reveals several interesting observations.

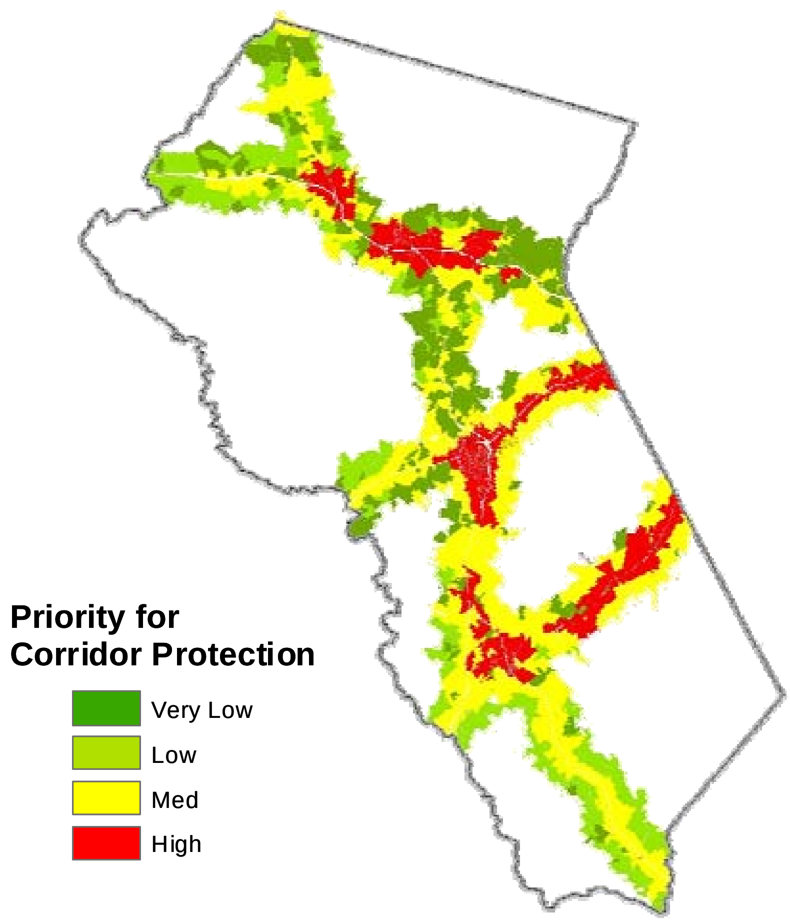

Figure 14. Likelihood of Development Without Consideration of Economic Suitability Factor

Table 4. Tabular Statistics Calculated From Results of GIS-Based, Risk-Based Methodology

I 66 Ramps - 5.6 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	536	5.9	30	103	193	17
Low	30	1.9	10	16	521	8
Med	153	4.7	24	65	428	14
High	667	7.1	36	218	326	31
	1,386	19.6	100	402	290	20

US 211 - 7.0 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	2,649	5.7	50	510	193	89
Low	70	1.9	16	25	354	13
Med	167	2.5	22	54	326	22
High	1,196	1.2	11	308	258	250
	4,082	11.3	100	897	220	79

VA 55 - 18.0 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	783	12.0	39	167	213	14
Low	239	6.8	22	79	332	12
Med	463	5.5	18	125	271	23
High	653	6.4	21	209	320	33
	2,138	30.8	100	580	271	19

VA 28 - 13.7 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	1,670	4.1	19	225	135	55
Low	9	0.5	2	6	669	11
Med	737	10.1	46	128	174	13
High	539	7.2	33	131	244	18
	2,955	22.0	100	491	166	22

US 17 - 53.8 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	6,725	27.0	38	1,226	182	45
Low	379	11.1	16	126	332	11
Med	1,182	21.5	30	348	294	16
High	2,218	11.0	16	663	299	60
	10,504	70.6	100	2,362	225	33

US 29 - 22.2 miles

Development Likelihood	Parcels	Acres (K)	Acres (%)	Land Val ($M)	Avg Val per Parcel ($K)	Avg Val per Acre ($K)
Very Low	5,515	9.7	32	893	162	92
Low	371	2.5	8	42	112	16
Med	1,088	11.9	39	266	244	22
High	1,323	6.2	20	432	326	70
	8,297	30.4	100	1,632	197	54

- U.S. 17 has the largest number of parcels and contains the most acreage.

- The I-66 ramps are surrounded by the smallest number of parcels by far, but the area of these parcels is comparable in size to the area of parcels surrounding U.S. 29. The acreage is particularly exaggerated for I-66 relative to its modest centerline length of 5.8 miles because the quarter-mile and one-mile buffers capture a proportionally larger land area at the ends of the ramps than the buffers do for the longer corridors.

- U.S. 29 has two times as many parcels in the same size acreage as the I-66 ramps. Thus it demonstrates the land surrounding U.S. 29 has been subdivided a great deal to accommodate residential and commercial development.

- The average land values per parcel are roughly the same magnitude, between $166,000 and $290,000 dollars, for all the corridors. That being said, the VA 28 corridor has the lowest per-parcel average and modest land-value-per-acres average as well. Land values are depressed due to lack of public sewer and water services and presence of “black jack soils,” Given the VA 28 corridor is the primary access route to and from a rapidly growing Prince William County, utility infrastructure may one day be expanded and stimulate development of the land. Without utility improvements, however, low land prices may provide opportunities for acquisition and access management options in this corridor.

- The U.S. 211 corridor presents a striking anomaly. Average land value per acre for the high risk parcels is not only a magnitude larger than other likelihood categories in the same corridor, but all likelihood categories for all the corridors. Inspection of the map reveals all high likelihood parcels in this corridor are in Warrenton, thus there are no rural parcels to depress the average land value for this category of likelihood. That the per-parcel and per-acre land values are similar demonstrates Warrenton is already a highly developed area consisting of residential and commercial uses.

A fifth analysis technique graphed select tabular results as bar charts. Figure 15 displays the number of acres in each priority category by corridor.

U.S. 17 is the largest corridor by far and contains the largest number of acres in all four priority categories. The I-66 ramps, VA 55, VA 28, and U.S. 29 have similar acreage of high priority land, while VA 28 and U.S. 29 have significantly larger quantities of medium priority land. Because some corridors, such as U.S. 17, are geographically larger, they are predisposed to having larger number of acres within the four priority categories.

Figure 16 attempts to consider the lengths of the corridors by normalizing the acreage by the lengths of the centerlines. This has two notable results. First, the I-66 ramps have the largest high priority acreage relative to their centerline miles by far. The reason for this is the quarter-mile and one-mile buffers capture a proportionally larger land area at the ends of the ramps than the buffers do for the longer corridors. Second, VA 28 has the second largest amount of both high and medium priority acres relative to its centerline distance.

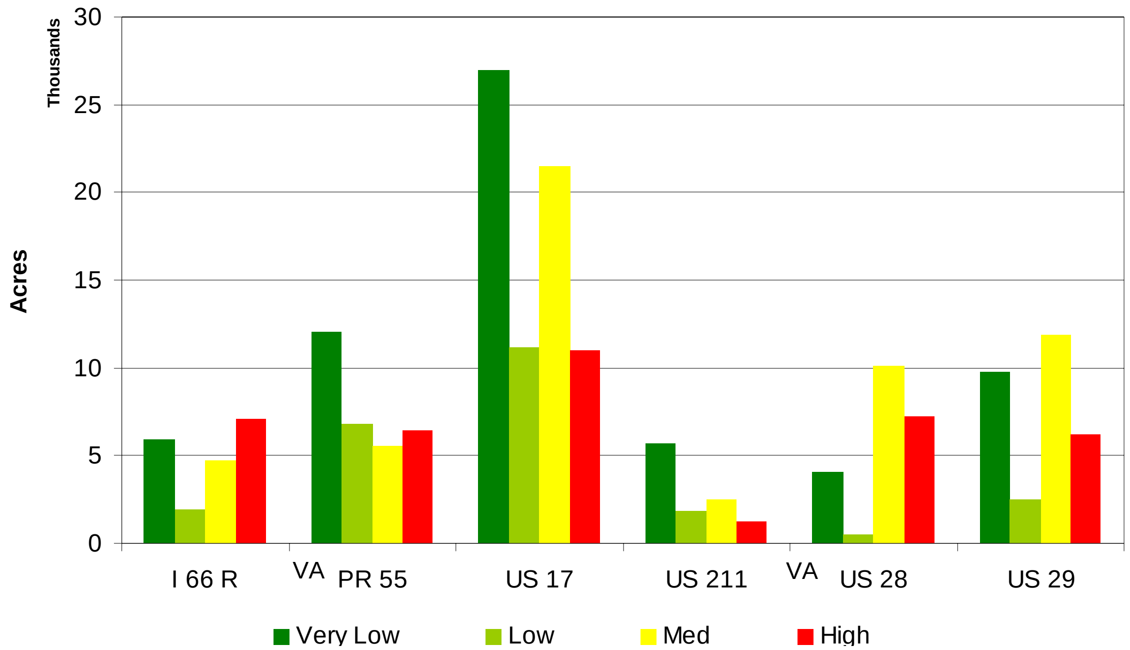

Figure 15. Number of Acres in Each Priority Category, by Corridor

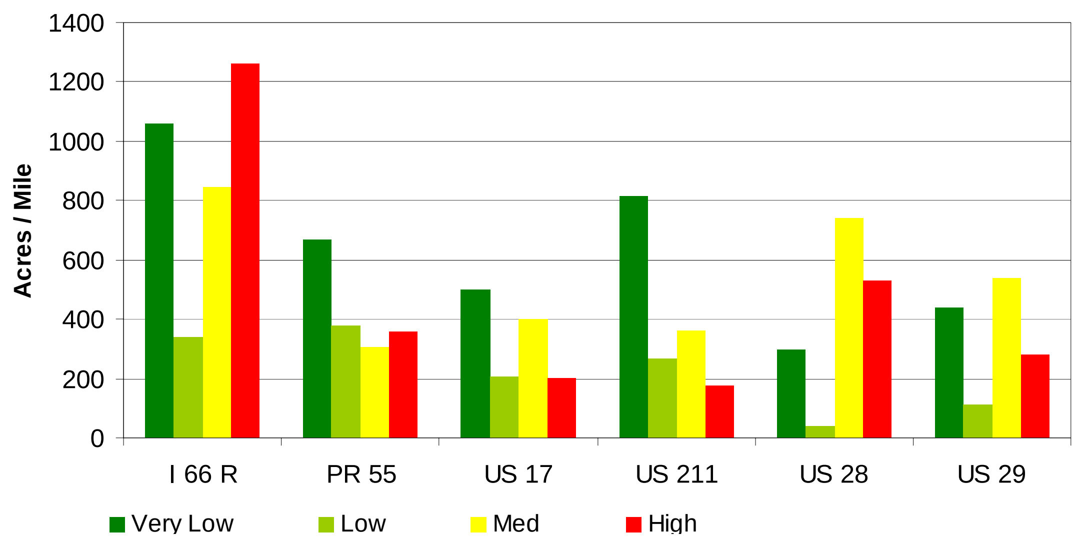

Figure 16. Number of Acres Normalized by Corridor Length in Each Priority Category, by Corridor

Figure 17 displays the number of parcels (rather than acres) by priority category for each corridor. U.S. 17 and U.S. 29 have the largest number of very low priority parcels, a combination of both long centerline lengths and collocation with Warrenton, Fauquier County's primary population and employment center. The number of parcels is an indicator of the number of stakeholders that will be involved in a corridor protection program.

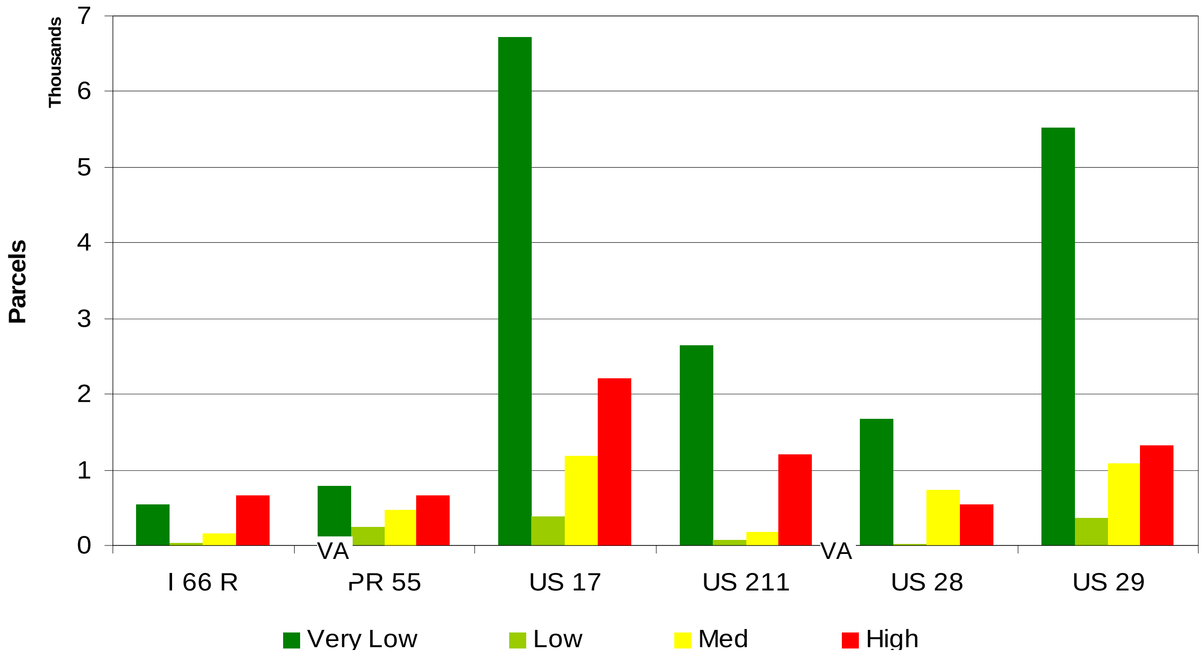

Figure 17. Number of Parcels in Each Priority Category, by Corridor

Results of Section-to-Section Analyses

The corridors were analyzed in half-mile segments from two perspectives.

First, curb cut densities were compared to the likelihoods of development of the parcels. This was done by counting the number of high and low volume curb cuts intersecting each half-mile segment and comparing those figures with the average likelihood rating (0 for *very low*, 1 for *low*, 2 for *medium*, and 3 for *high*) of parcels within the segment. High volume curb cuts are those that cross the median or provide access to a primary, secondary, interstate, or shopping center. Low volume curb cuts are those that provide access to a driveway, farm road, or U-turn-only median crossing. Only parcels within 250 feet of the centerline were considered. Figure 18 shows several interesting results for the VA 28 corridor. In most cases the number of high volume curb cuts is correlated with activity centers along the corridor. The primary finding from a graph such as this can be seen just east of Calverton where the priority score peaks and the density of access points troughs. Because there are very few access points, it is likely the land is not yet heavily developed. But the high priority score indicates a high likelihood of development. Thus this would be an effective place to focus access management strategies before development takes place.

Second, average assessed land and improvement values per acre along the corridors were compared with the average likelihood rating. This comparison is shown in Figure 19. The comparison highlights those parcels, particularly those between Calverton and Catlett and east of Catlett, that have *high* likelihoods of development but are assessed at relatively low values. As described earlier, this low valuation is a result of poor soil quality. These parcels may be good targets for early ROW acquisition, prior to construction of water and sewer utilities that may stimulate land development.

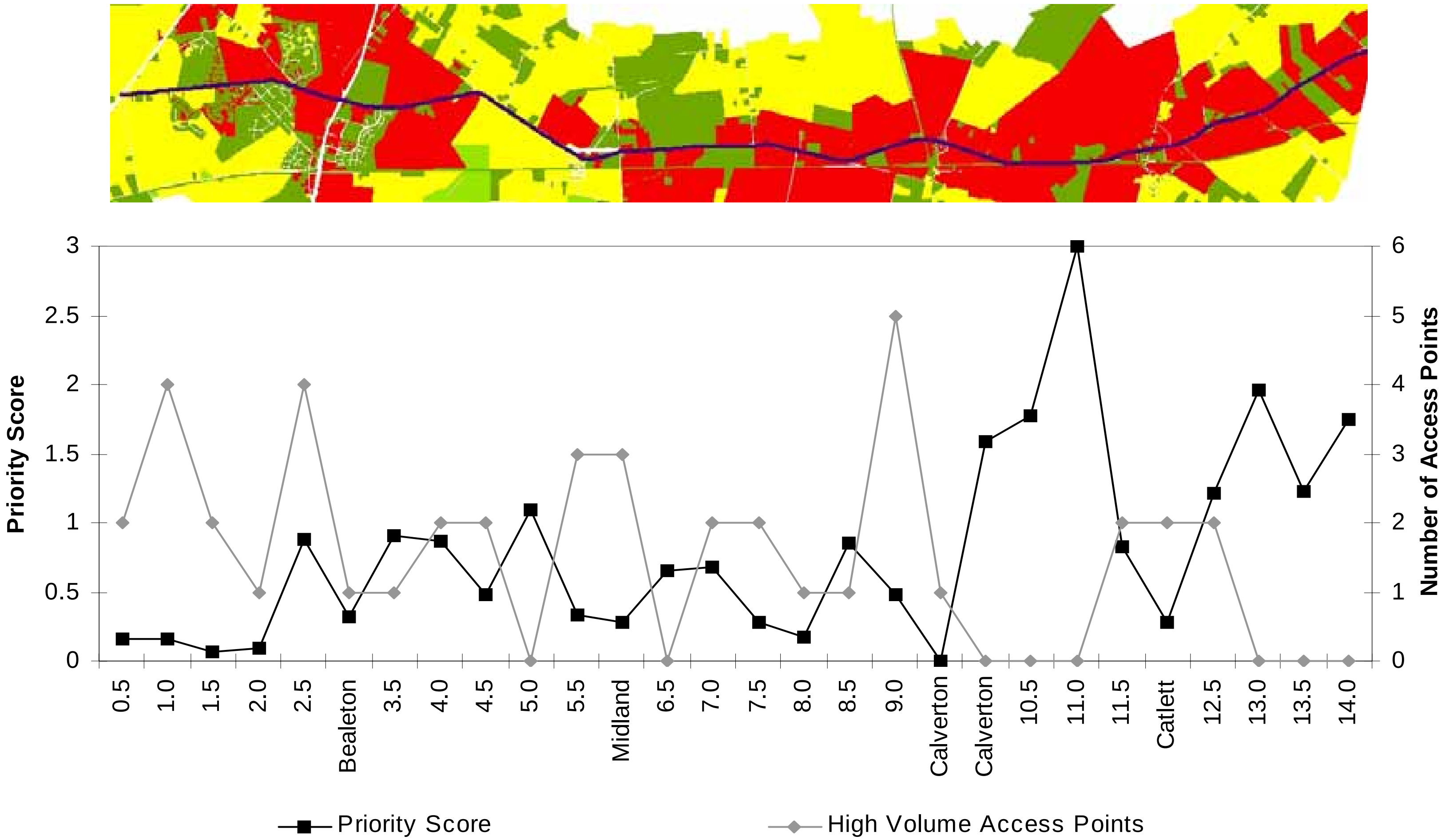

Figure 18. Comparison of Development Likelihood Along VA 28 With Number of High Volume Curb Cuts in 0.5-Mile Corridor Sections

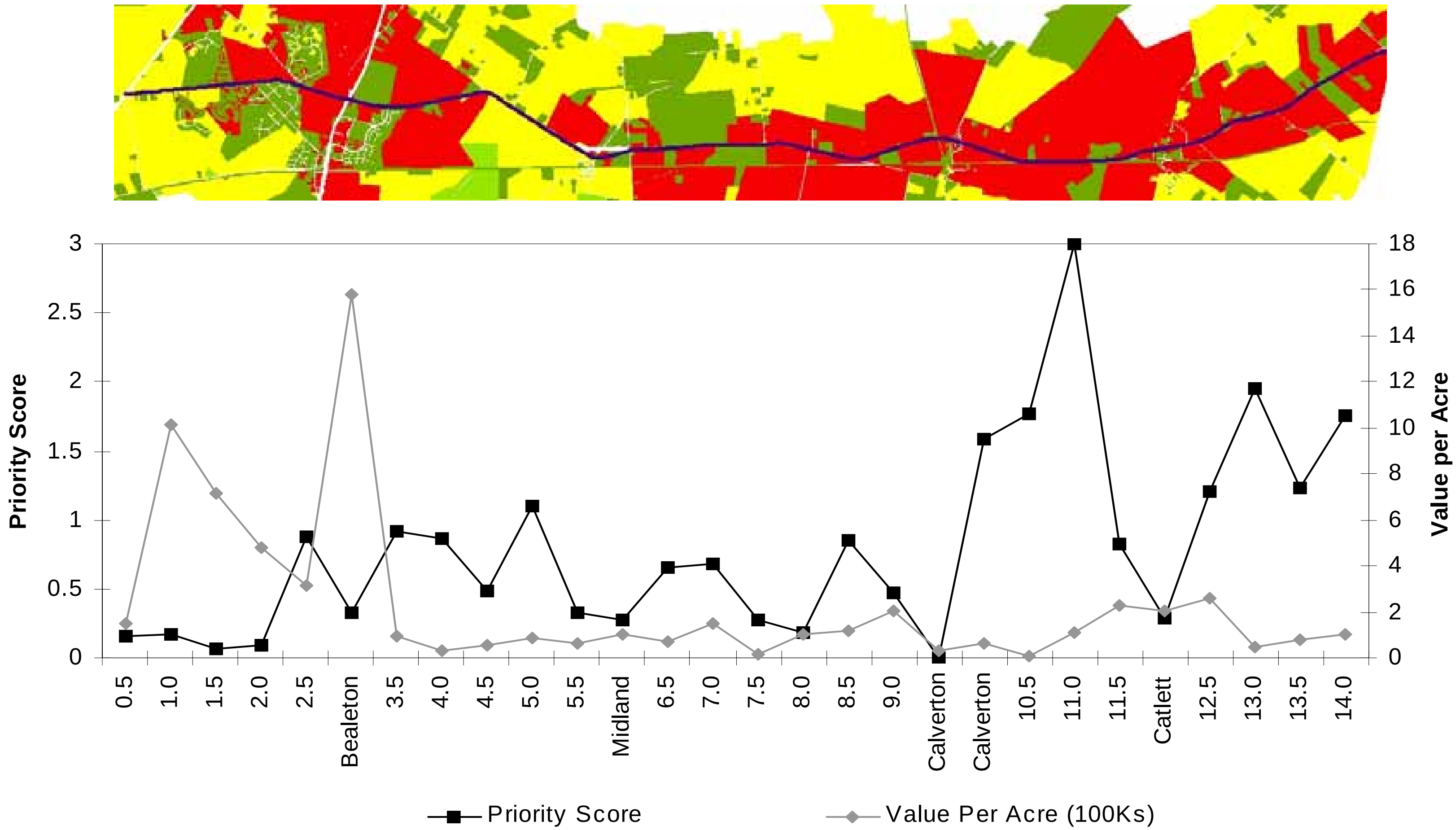

Figure 19. Comparison of Development Likelihood Along VA 28 With Average Assessment Value per Acre in 0.5-Mile Corridor Sections

Key Points

First, while this study has demonstrated a risk-based, GIS-based suitability methodology at the county scale, there are 134 counties and independent cities in Virginia. VDOT may require a statewide methodology to identify those counties or planning districts most in need of corridor protection. Such a methodology could also be based on suitability analysis using a different set of factors. In addition, this methodology may be transferred to state, regional, and local planners via this report and the accompanying slide show presentation. The visual nature of this methodology lends itself particularly well to slide presentation. The most recent slide show presentation is available at www.virginia.edu/crmes/corridorprotection.

Second, the results of this study (i.e., *what* corridor sections should be protected) should be followed by addressing *how* corridor sections will be protected. This subject is reviewed in general in the "Literature Review," and individual corridor sections that differ in size and character need to be addressed independently. Furthermore, enabling laws differ from state to state, and the corridor protection strategies available in other states may not be available in Virginia. A future research effort must examine the corridor protection options legally available to VDOT and municipalities. Such an effort may also suggest additional legislation that would help achieve the goals of corridor protection.

Third, this research highlights opportunities for collaboration among transportation and land use authorities as well as various government agencies. Sharing data, seeking opinion and comment from other agencies, harmonizing long range plans of various agencies, and seeking policies that favor the interests of multiple agencies are some activities that further collaboration. Particular synergies may exist between corridor protection and resource protection activities. In the Fauquier case study, the US 17 corridor north of Warrenton and the VA 55 corridor in the east of the county are already protected by a wide variety of conservation easements and agricultural and forestal districts. There are significant benefits to conserving contiguous parcels of land (Debinski and Holt, 2000; Virginia Outdoors Foundation, 2007), thus additional adjacent conservation easements may be highly cost effective here by serving both access management and environmental conservation purposes.

Fourth, the methodology demonstrated how GIS data sets could be used to analyze corridor protection. The following improvements have been identified to strengthen subsequent iterations:

- *Incorporate additional factors in the analysis*. Subsequent iterations of this methodology may incorporate additional factors used to identify likelihood of development. These factors include land use and zoning, functional classification of corridors, green infrastructure available from the Virginia Department of Conservation and Recreation (VDCR), transportation infrastructure of additional modes such as bike and pedestrian, rail, bus, and air, parcels owned by non-resident owners, locations of water and sewer infrastructure, and soil quality.

- *Incorporate a dependent variable, such as building permits, to calibrate the model.* The methodology as developed in this report does not have a calibration mechanism other than the expert review of stakeholders having intimate knowledge of the study area. Because calibration data were not available, threshold values were selected not for the purposes of increasing prediction accuracy. Instead, prediction values were selected in order to provide the appropriate level of discriminatory power for the model. Obtaining a dependent variable, such as building permits, would allow for a quantitative approach to calibrating the model by choosing and weighting factors appropriately.

- *Consider time rather than distance as a cost of travel to and from population and employment centers*. Time is a more appropriate measure for proximity than mileage for the population/employment centers because developers are often interested in the market area within a certain travel time.

- *Expand the study area for the factors considering population and employment centers*. Because network distances up to 40 miles are being used, the analysis should included all geographic areas within 40 miles of one of the borders of the county in question. As discussed previously, the mileage buffers can be updated to travel time buffers.

- *Consider the population and employment centers as they are defined by their entire areas rather than by their centroids.* Some of the activity centers are very large spatially while others are significantly smaller. Measuring distances from the centroid may discount the reach of the large urban/employment centers somewhat since some of the distance measured will be occurring within the actual employment or population center. Thus travel times should be considered from the border of the activity centers rather than the centroids.

- *Conduct further sensitivity analysis.* Though results were generated without the improvement-to-land factor, additional combinations of factors and weights of factors could be modeled. Codifying the methodology into a computer application could facilitate this.

- *Identify future population and employment centers*. The methodology developed in this report relies on reported population and employment statistics. Use of projected population and employment statistics will help predict the size and relative scale of future activity centers.

- *Code the suitability analysis into an automated, repeatable process*. A web-interactive or otherwise portable tool could be used during meetings with stakeholders to project a variety of future scenarios based on different combinations or weights of features. An application would also enable the rapid use and reuse of the methodology in multiple counties and at multiple scales.

CONCLUSIONS

The GIS-based methodology developed in this study has several strengths and shortcomings.

Strengths include the following:

- *The methodology is intuitive and is easily communicated through pictures and words.* Given that suitability analysis is based on spatial factors, the process may be depicted through a series of pictures that are intuitive to non-planners.

- *The data used in this methodology are largely available in a digital format throughout the Commonwealth.* As the popularity of GIS increases for spatial data storage, analysis, and communication, more and more datasets are digitized. Most of the factors used in this research effort are available statewide, with the exception of parcel data. While the number of counties digitizing their parcel data increases, the extent of development within corridors can still be investigated without this dataset.

- *The methodology is transferable to a variety of applications and scale of study areas.* As noted in the literature, suitability analysis can be used to study transportation, land use, wildlife habitats, agriculture, water resources, and green infrastructure. It can also be used at a variety of scales including neighborhood, municipality, county, state, region, nation, or even worldwide. While the framework of the analysis remains the same, the factors chosen for each type and scale of study would vary.

Potential shortcomings include the following:

- *Identification of threshold and scaling values is challenging.* Threshold values that determine size and location of population and employment centers, economic suitability, and distances are difficult to determine in an absolute sense; however, values chosen for this analysis were done so through careful consultation with the project steering committee consisting of experts familiar with the study area. These values were confirmed by the steering committee to be reasonable, particularly in a relative sense. For example, it is reasonable the parcels farther away from activity centers are less likely to develop, all other things being equal. A calibrating mechanism in future efforts will help address this challenge.

- *The final likelihood score for each parcel is unitless.* The scores represent the translation of both cardinal and ordinal numbers to unitless scores. These scores have little meaning by themselves but are used effectively to show differing likelihoods of development among parcels.

- *Causality of constraints and indicators needs to be better understood.* This methodology uses constraints and indicators to identify where development will occur, but often development also influences the indicators and constraints as well. For example, the presence of utilities may entice development in a particular area, but development in an area may result in expansion of those utilities. This issue arises not only for this methodology, but for any planning exercise.

RECOMMENDATIONS

1. *Local planners should use the methodology to communicate with Boards of Supervisors and Planning Commissions.* For example, in the case of Fauquier, the methodology should be used to accomplish the following tasks:

   - Corroborate the needs in implementing the VDOT Safety Improvement Plan for Crossovers along US 15/29 for Fauquier County by continuing to close unsafe median cuts and restricting access along this major federal highway.
   - Improve linkage with land use/transportation planning and the land development process along Fauquier County's major primary road corridors.
   - Assist in better understanding adjoining jurisdiction impacts on Fauquier County transportation network.
   - Identify areas where increased land use management controls should restrict future access.
   - Provide an additional perspective for adjusting service district or urban development area boundaries in the Fauquier County Comprehensive Plan.

2. *Local planners should use the methodology to depict and enable analysis of areas where creative solutions might be warranted.* For example, VA 28 from Prince William County to US 17 is shown to have a high likelihood of development. Development in this location is already constrained due to the lack of public sewer and water services and "black jack soils", and the primary land use is agriculture. Here the case study results could be used to recommend that active farms along this regional corridor be given a higher Board of Supervisors priority in Fauquier County's Purchase of Development Rights (PDR) program. Whether development rights should be purchased for land that may already be protected by a growth management tool is a reasonable question; however, this study assumes that political and economic forces vary among counties and that growth management efforts are potentially subject to these forces. Particularly low land values today present an opportunity to protect the corridor before the development pressure exceeds the desire to protect an area of land. Thus development rights for these properties could methodically be acquired and extinguished through recorded easements along this key corridor, reducing demand for access and making it easier to acquire future right of way when primary road expansions or safety improvements are required. This is an example of how results of the methodology can be used to help make the business case for corridor protection by considering cost effectiveness, return on investment, and/or cost-benefit ratio.

3. *Localities of the Commonwealth should adopt the methodology in meeting and taking advantage of the provisions of House Bill (HB) 3202, enacted on July 1, 2007.* It can serve as a preliminary analytical tool to identify specific locations where designated urban

development areas may be suitable. It may be used to assist in the preliminary development of locations needing consideration as a Traffic Impact Fee Service Area.

4. *Planning district commissions should employ the methodology at the regional level, insuring a more consistent, coordinated approach among member jurisdictions in land use and transportation planning.* Doing so will provide this GIS-based analysis to member jurisdictions that do not have the staffing capabilities to develop studies of their own. Furthermore the regional application will coordinate a unified presentation of network improvements, including, road, bus/rail transit, and pedestrian elements. Members of the committee recommend VDOT consider grants to interested Regional Commissions to use this model and adjust it to fit their local environment and needs.

5. *Local planners should consider how to include additional data layers including land use and zoning, functional classification of corridors, green infrastructure (compiled by the Virginia Department of Conservation Resources) and transportation infrastructure of additional modes such as bike and pedestrian, rail, bus, and air.* Many data were not included in the study because they are not available or consistent statewide, though the methodology is flexible and can accommodate any data representative of a defined study area. Future efforts may use fewer or more factors, or different factors, depending on the location and size of the study area and application of the study.

6. *Local planners should engage in a qualitative validation of the results, such as Fauquier County planners checked for correlation with the service districts and with water and sewer service areas, and seeking a relationship to the access points (curb cuts).* The methodology generated results that confirmed and surprised the intuition of VDOT and Fauquier County planners, generating critical thought of both qualitative and quantitative characteristics of the study area and rich discussion. The steering committee agreed that the overall results of the model were highly correlated with the service districts and the water and sewer coverage areas (with the exception of the westernmost intersection of Interstate 66, US 17, and VA 55 where development is constrained for environmental reasons). Another suggestion was to conduct the suitability analysis using data from 20 years ago, however this data is not currently digitally geo-coded, nor is it detailed enough to conduct a countywide study. A future effort may attempt to validate the results using issuance of building permits.

7. *Local planners should consider in the qualitative validation the extent to which high, medium, and low "likelihood" could represent a "near-term priority," "mid-term priority," and "long-term priority."* Thus the methodology would help the localities to be proactive in addressing those corridor sections that are most vulnerable to development in the near term. In addition, the committee discussed the linear sequential nature of development emanating from current activity centers. It was expected linear expansion would show up stronger in the results. This phenomenon did in fact show up in the results as the parcels in the eastern corridors were generally more likely to develop than those on the west. This is reflective of the importance of regional activity centers compared with the importance of smaller activity centers in Fauquier County. To increase the significance of linear development, the weight assigned to the activity center factors may be increased.

8. *VDOT's Transportation and Mobility Planning Division (TMPD) should make slideshow presentations and GIS files used in the analysis available to local planners as training materials.* Both materials are currently available for download at www.virginia.edu/crmes/corridorprotection. The presentation and files are a highly effective means of transferring the technology as they are visual and allow GIS specialists to recreate the analysis in the way they best see fit. As GIS applications evolve the presentation flowcharts, and intermediate and final results will still be effective to describe what was done.

9. *VDOT's TMPD and local planners should consider how the methodology could be most useful to evolving access management and corridor protection initiatives and programs across the Commonwealth.* Strategies and resources discussing access management and corridor protection are provided in the "Literature Review."

COSTS AND BENEFITS ASSESSMENT

The results of the research effort will benefit accessibility, mobility, economic development, and safety for transportation corridors that are facing significant development in five to ten years. The developed tools and methodology will enable VDOT planners to more effectively identify needs for corridor protection across many thousands of miles of roadway. The effort will be unique to address the problem of corridor protection with a risk-based approach.

Further benefits include the following:

- *Integration of a wide variety of non-traditional considerations into the long-term transportation planning process*. Several trends including environmental streamlining, context sensitive solutions, and performance-based planning tout the benefits of transportation and land use planning and interagency cooperation. Along these lines, the effort described in this report engages a wide variety of stakeholders, acquires and combines non-traditional datasets, and furthers interagency cooperation and collaboration. The quantitative benefit, that is, the value of this information to decision-makers, would be difficult to estimate.

- *Reduction in disturbances of the built environment*. The study outlined in the report allows agencies to appropriately protect transportation right of way in advance. Doing so obviates the need to later relocate residents and businesses and pay uncertain court costs (Heiner and Kockelman, 2005). A systemic corridor preservation plan will likely take advantage of local municipality police powers, thus saving money that might have otherwise been allocated for fee simple transactions.

- *Extension to a variety of applications*. As demonstrated in the literature review, suitability analysis can be used for a wide variety of applications. Conducting an analysis for purposes of corridor protection provides practice for analysts and decision makers so that they may be prepared to apply the methodology for problems such as protecting infrastructure from natural disasters, lighting and guardrail studies, or prioritization of transportation investments.

Costs include the following:

- *GIS software, GIS-trained personnel*. Many transportation and planning agencies already have GIS software and trained personnel, and many others are planning to acquire these resources for a variety of uses in addition to conducting suitability analyses.

- *Time spent conducting the analysis*. This will vary depending on the quality of the input data, the complexity of the analysis, the proficiency of the GIS-trained personnel, and the quality of the computer hardware. A relatively quick, simple analysis may be completed in a few days, while a more complex analysis such as the Fauquier County case study presented in this report may take anywhere from a few weeks to a few months. A transportation or planning agency may wish to start with a simple version and iterate, adding more complexity with each iteration. Doing so will hone the GIS resources skills. The effort documented in this report was the result of four iterations.

- *Interpretations of the results at meetings attended by a wide variety of stakeholders.* Meetings with stakeholders require expert preparation and organization of the interpretation of the technical results of the methodology, in posters and slides and edited handout materials.

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APPENDIX A: ROADMAP OF METHODOLOGY

Figure A.1 provides a roadmap of the methodology using GIS to prioritize sections of roadway for corridor protection.

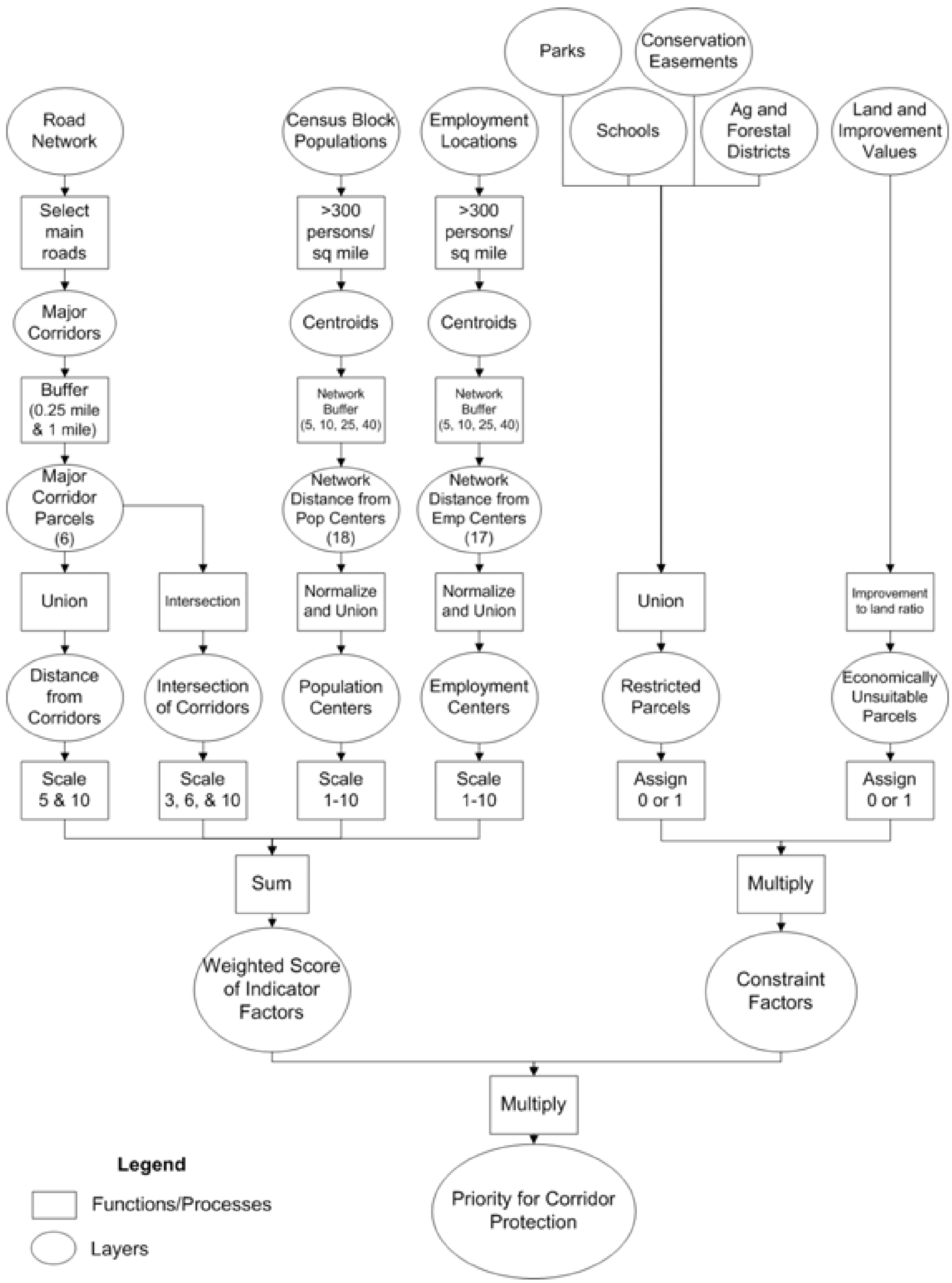

Figure A.1. Roadmap of GIS-Based Methodology to Prioritize Roadway Sections for Corridor Protection

APPENDIX B: TRAINING MANUAL, VERSION 2.0

RISK-BASED FRAMEWORK USING GEOGRAPHIC INFORMATION SYSTEMS TO IDENTIFY TRANSPORTATION CORRIDORS VULNERABLE TO DEVELOPMENT

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Training Manual, Version 2.0

Table of Contents

1.0 Overview
For an overview, the reader is advised to review the slide presentation available for download at www.virginia.edu/crmes/corridorprotection.

This training manual describes the technical steps in implementation of a method to prioritize corridor sections according to their potential for land development. It utilizes both vector and raster analysis using ESRI's ArcGIS application suite. Functions and terms native to the ESRI software are identified by *italics*.

The remainder of Section 1.0 (i) reviews the concepts of the methodology and (ii) describes important technical considerations to be made prior to beginning the methodology. Section 2 derives constraint factors from constituent datasets. Section 3 derives indicator factors from constituent datasets. Section 4 scales indicator factors. Section 5 combines constraint and indicator factors to create a dataset describing likelihood of land development. Section 6 derives management indicators and apply those indicators to investigate trade-offs among corridor sections.

A locality desiring to get started to implement the methodology will need to obtain the following GIS data layers for their locality and the immediately surrounding counties (* denotes data layers available from VDOT's Statewide Planning System):

Constraint factors (used to rule out potential development at the corridor section)

a. Restricted Parcels
    - Conservation Easements:
        1. BOS 8-year
        2. BOS Openspace
        3. Historic Resources
        4. Land Trust of VA
        5. Marsh Resources
        6. Nature Conservancy
        7. PEC
        8. PDR Program
        9. VOF Openspace
        10. VOF Owned
    - Parks and Schools:
        1. Community Centers
        2. County Parks
        3. Natural Areas
        4. Schools
        5. Sports Complex
        6. State Parks
    - Agricultural & Forestal Districts:
b. Economically Unsuitable Parcels
    - Property Shape: Real Estate Parcel Land Values and Improvement Values

Indicator factors (used to indicate the degree of concern for development at the corridor section)

c. Major Corridors
    - Street Shape
d. Employment Data*
    - VA Employ
e. Population Data*
    - U.S. Census block-level population data

Management factors (used to suggest the opportunities for access management based on existing densities of curb cuts and land values) [the *management factors* data and analysis should be considered optional]

f. Access point densities
    - Access points along the corridor
g. Parcel real estate land and improvement values
    - [identified above with the constraint factors]
h. Utilities
    - Existing and planned water/sewer services

1.1 Review of concepts

The method uses GIS data layers to derive three types of factors as shown in Figure B.1. Constraint factors highlight land unlikely to develop. Indicator factors highlight land likely to develop. These factors are combined as shown in Figure B.2 to highlight parcels of land that have a high likelihood of development. Management factors such as curb cut density, shown in Figure B.3, help identify corridor protection trade-offs among corridor sections adjoining high likelihood parcels.

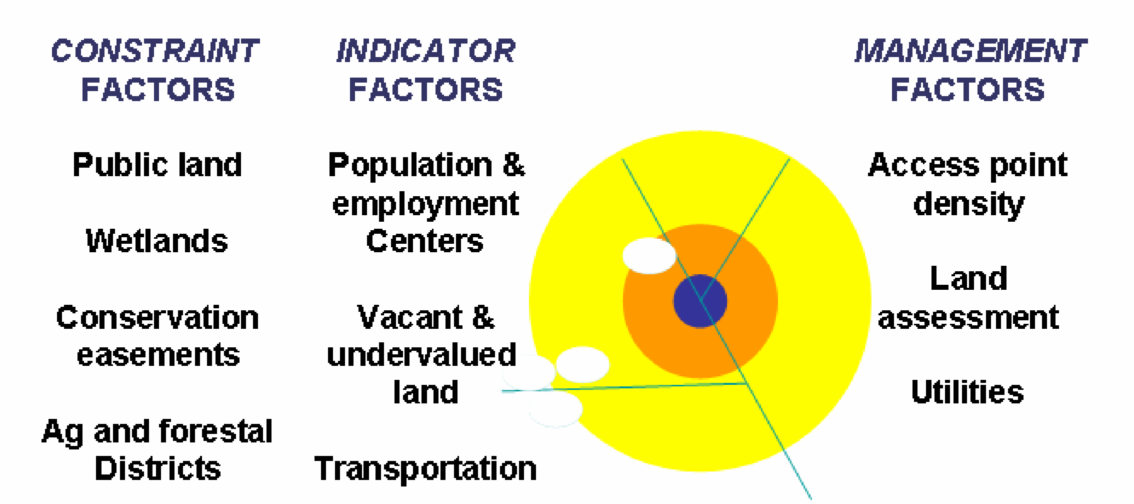

Figure B.1. Three Types of Factors Useful in Prioritizing Corridor Sections Vulnerable to Land Development

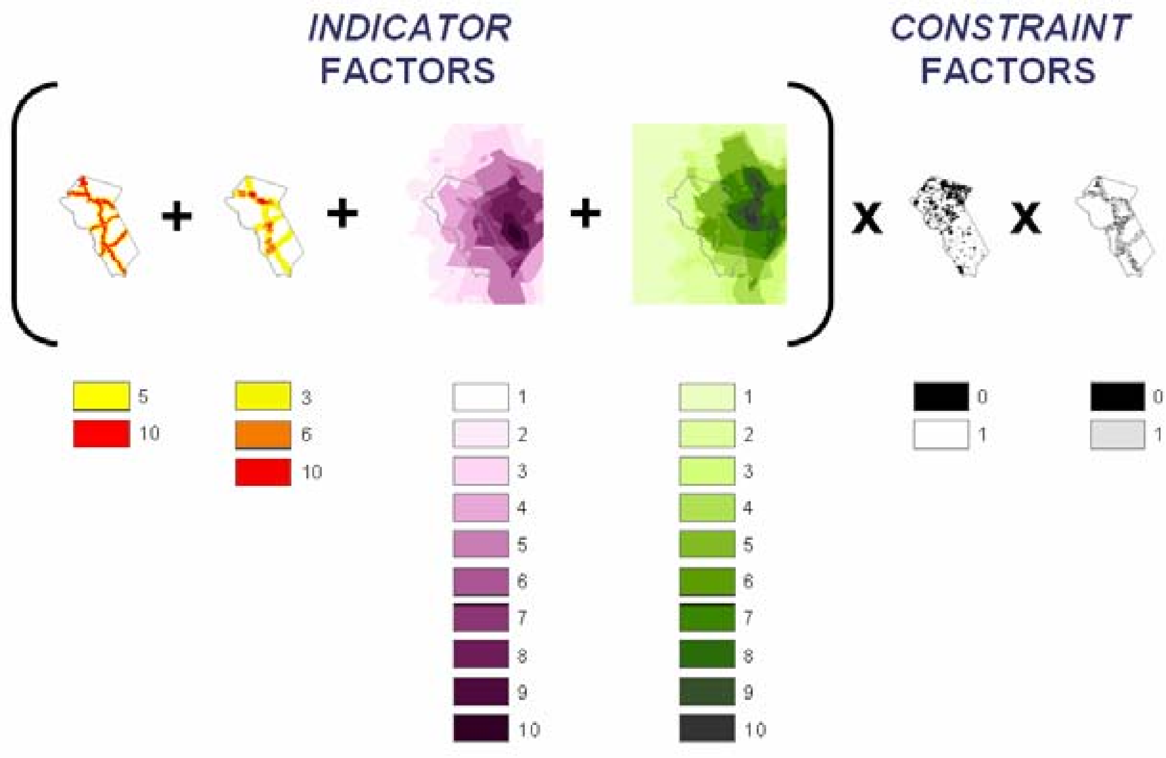

Figure B.2. Combination of Indicator and Constraint Factors

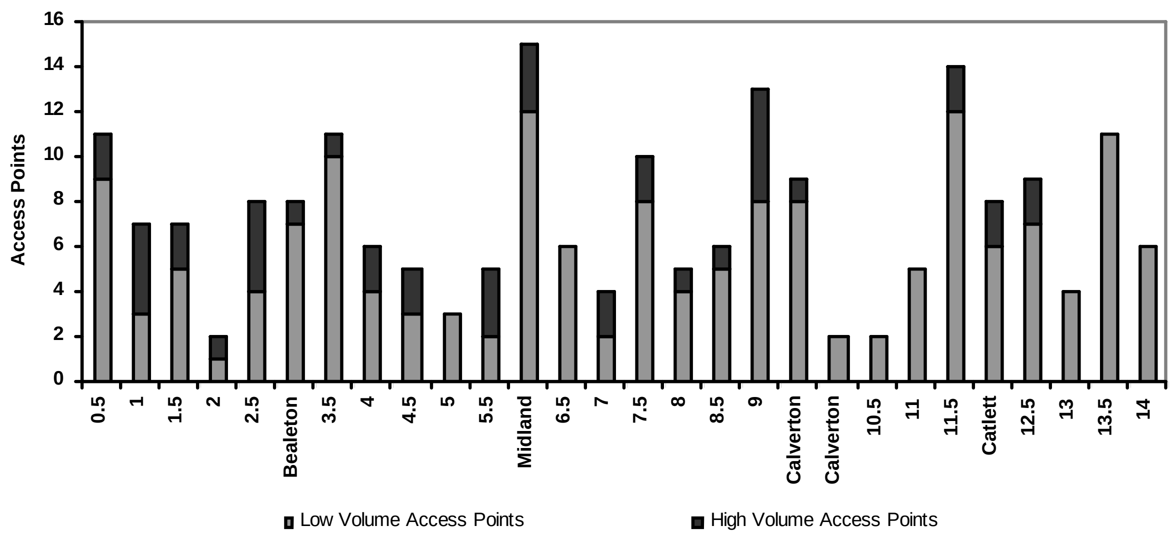

Figure B.3. Number of Curb Cuts per Half-Mile Corridor Segment Along U.S. 28 Is Example of Management Factor

1.2 Technical considerations

This section introduces several technical considerations to be made prior to repeating this methodology. Consideration of these items will save time and effort at later stages.

First, consider and determine the size and location of the study area. These factors will help determine the appropriate *coordinate system* and *projection*. GIS specialists with local knowledge of the study area will know what coordinate system to use. This Training Manual uses the 1983 State Plane Virginia North projection for the study area of Fauquier County in Northern Virginia.

Second, though optional, consider the use of a *personal geodatabase* to organize constituent *shapefiles*, intermediate results, and derived factors. Attempt to develop a systematic, consistent, and intuitive naming system to facilitate organization of the constituent *shapefiles* and intermediate results. Begin all names of *shapefiles* with letters (avoid numbers or special characters as the first character of a filename) and substitute underscores ('_') for spaces (' ') between words in filenames.

Raster analysis is used for many of the steps. Use of the *Spatial Analyst* extension is required. Care must be taken in selecting the appropriate *cell size* for the raster analysis. Smaller cell sizes provide greater accuracy but larger filesizes and longer processing times. Larger cell sizes provide less accuracy but smaller filesizes and shorter processing times. Choose the largest cell size that will still accurately represent the boundaries the parcels. Test this out by converting a few of the smallest 5% to 10% of the parcels to rasters using the *Spatial Analyst Convert Features to Raster* technique.

Furthermore, all rasters created should be *snapped* so that the raster cells line up exactly. This is done by creating an *analysis mask* of the study area. The *mask* should have the desired cell size. This mask can be used by snapping to resulting raster outputs to it. Using the *Spatial Analyst Options* feature.

2.0 Derive constraint factors

Constraint factors are used to rule out potential development. This section derives two constraint factors from constituent shapefiles, (i) protected parcels and (ii) economically unsuitable parcels.

2.1 Protected parcels

Required Data: Shapefiles for each type of protected parcel. Examples are shown in Figure B.4.

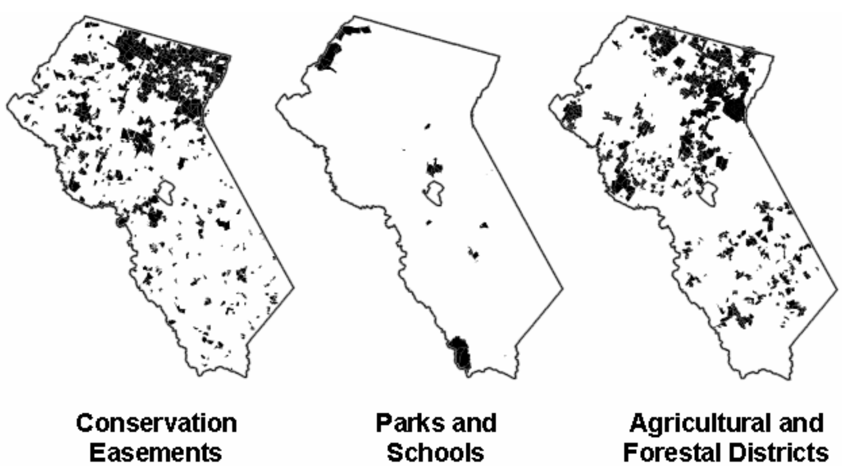

Figure B.4. Spatial Datasets Showing Protected Parcel

Step 1. Combine all shapefiles containing protected using the *Merge* tool. This will result in a shapefile resembling Figure B.5.

Figure B.5. Protected Parcels

Step 2. Use the *Spatial Analyst Convert Features to Raster* function to convert the protected parcels to a raster. Use the *analysis mask* as described in Section 1.2 to *snap* the *extent* and the *cell size*. During the conversion process assign raster cells a value of 0 if they are within protected parcels. Assign raster cells a value of 1 if they are not within a protected parcel.

2.2 Economically unsuitable parcels

Required Data: Parcel shapefile with unique parcel identification number; improvement and assessment values with unique parcel identification number (if this information is not already included in the parcel shapefile).

Step 1. If improvement and land assessment values are not included in the parcel shapefile, join the parcel shapefile to the improvement and parcel values using an attribute-style *join* based on parcel identification number.

Step 2. Calculate improvement-to-land ratio by *creating a new field* in the *attribute* table of the joined parcel and assessment data. *Calculate* values for the new field by dividing the land value by the improvement value.

Step 3. Use the *Spatial Analyst Convert Features to Raste*r function to convert the economically unsuitable parcels to a raster. Use the *analysis mask* as described in Section 1.2 to *snap* the *extent* and the *cell size*. During the conversion process assign raster cells a value of 0 if the calculated improvement-to-land ratio is greater than or equal to 0.9. Assign raster cells a value of 1 if the calculated improvement-to-land ratio is less than 0.9. The resulting shapefile will resemble Figure B.6. (*Note:* Figure B.6 shows only those parcels within one mile of the corridor centerlines. It is not necessary to limit the parcels in this way for this step.)

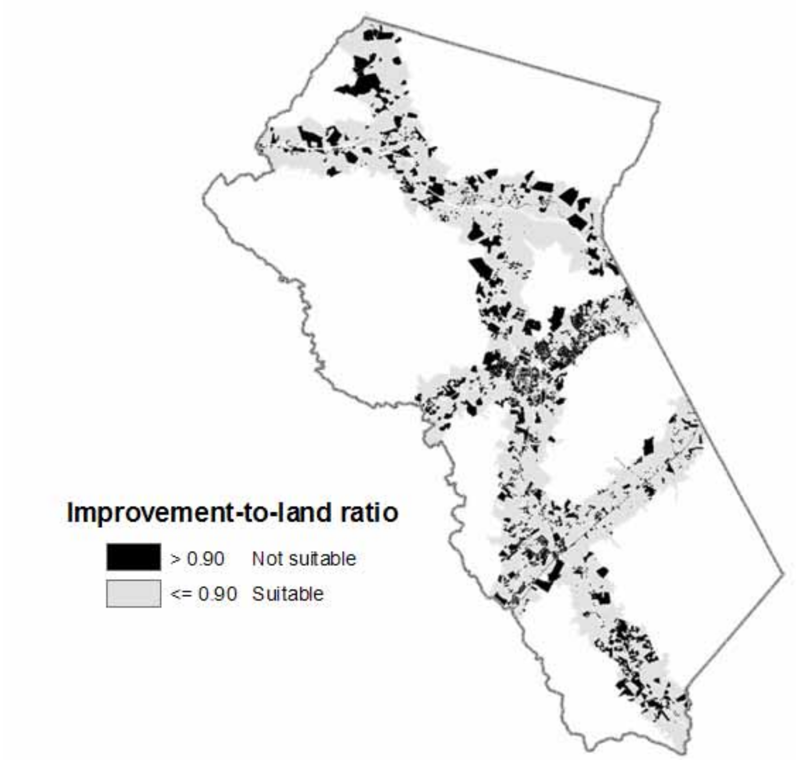

Figure B.6. Economically Unsuitable Parcels

3.0 Indicators of potential development
Indicator factors are used to highlight parcels with greater than very low likelihood of development. This section derives four indicator factors from their constituent datasets: (i) lateral proximity to major corridors, (ii) proximity to corridor intersection, (iii) proximity to population centers, and (iv) proximity to population centers.

3.1 Lateral proximity to major corridors
Required Data: corridor centerlines, parcels

Step 1. For each corridor, create quarter-mile and whole-mile buffers around the corridor centerline using the *create buffer* tool. Set the *dissolve* option to 'all.'

Step 2. For each corridor, select all parcels that intersect the whole-mile buffer using a *spatial join*. *Export* the selected parcels as a new shapefile.

Step 3. For each corridor, *create a new field* in the *attribute table* of the new parcels shapefile. Create a spatial join between the new shapefile and the quarter-mile buffer. *Calculate* a value of 1 in the new field of all selected parcels. *Switch the selection* and assign a value of 0 to all selected parcels.

Step 4. For each corridor, use the *Spatial Analyst Convert Features to Raste*r function to convert the laterally proximate parcels to a raster. Use the *analysis mask* as described in Section 1.2 to *snap* the *extent* and the *cell size*. During the conversion process assign raster cells a value of 1 if the parcel is within a quarter-mile. Assign raster cells a value of 0 if the parcel is within a whole-mile but not a quarter-mile.

Step 5. Use the *raster calculator* to combine all the individual corridor rasters. Set the resulting raster cell values to equal the maximum value all the individual corridor rasters. The resulting shapefile will resemble Figure B.7.

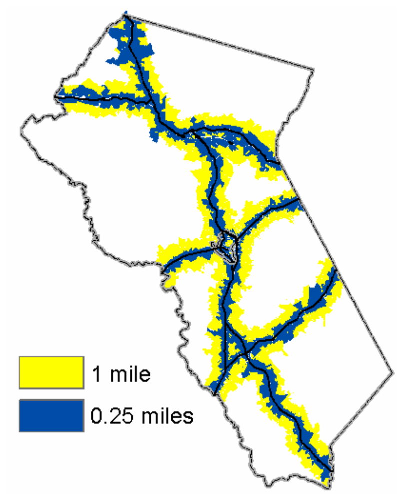

Figure B.7. Lateral Proximity to Corridors

3.2 Proximity to corridor intersections

Required Data: individual corridor rasters created in Step 4 of 3.1.

Step 1. Using the *Spatial Analyst Reclassify* function, create a new raster for each individual corridor raster created in Step 4 of 3.1. Reclassify the values of all the raster cells to 1.

Step 2. Using the *raster calculator*, add the values of the newly created, reclassified corridor rasters. The resulting shapefile will resemble Figure B.8.

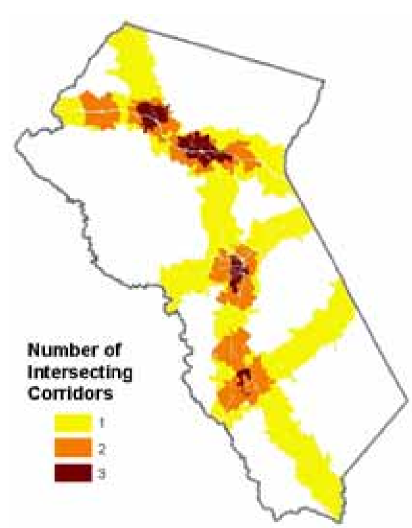

Figure B.8. Proximity to Corridor Intersections

3.3 Proximity to population centers
Derivation of this step is divided into several substeps: (i) identify population centers, (ii) create the road network, (iii) create driving distance buffers, (iv) combine driving distance buffers.

3.3.1 Identify population centers
Required Data: counties included in commute shed (expanded study area), population polygon or point shapefile for expanded study area.

Step 1. Map the population data in the study area. Use the *Spatial Analyst Density* function to create a population density gradient. Set the cell size to the same cell size of the analysis mask created in Section 1.2.

Step 2. Alter the *symbology* of the resulting raster population density gradient to differentiate between cells above and below a population density threshold. Set the threshold so that there are roughly 10 to 20 contiguous areas above the population density threshold. These areas represent 'population centers.' Check with local planners to make sure these population centers reflect reality. A threshold of 300 persons per square mile was chosen for the population density gradient shown in Figure B.9.

Step 3. Reclassify the population density gradient so that values greater than or equal to the chosen threshold are assigned a value of one, and those below the chosen threshold are assigned a value of zero. This will create a new raster of the population centers.

Step 4. Using the Spatial Analyst Convert Raster to Features function on the new population center raster, create polygons for each of the population centers.

Step 5. Create two new fields in the *attribute table* of the population center polygons. Name them 'XCent' and 'YCent,' respectively. Use the *Calculate Geometry* on the XCent field to calculate the x-coordinates of the *centroid* each of the population center polygons. Use the *Calculate Geometry* on the YCent field to calculate the y-coordinates of the *centroid* each of the population center polygons.

Step 6. Use the *Add XY Data function* to create a point shapefile of the centroids of each of the polygon population centers. *Create a new field* in the *attribute table* of the resulting point shapefile. Name the field 'Population.' *Create a new field* in the *attribute table* of the resulting point shapefile. Name the field 'Pop_Weight.' Open the *Editor toolbar* and choose the function *Start Editing*. Choose the folder or database to edit from that allows the new point shapefile to be edited. Set the toolbar so that the *target* shapefile is the new point shapefile.

Step 7. For each polygon population center, select the polygon population center. *Join by location* the selected polygon population center to the population points or polygons. *Export* the selected population points or polygons to a new shapefile. Open the attribute table of the new shapefile. Perform the *Statistics* function and make note of the value of the *Sum*. In the new point shapefile (created in Step 7), identify the centroid corresponding to the selected polygon population center. Enter the calculated sum into the 'Population' field of the corresponding centroid in the new point shapefile. Thus the population of each population center is associated with the centroid of that population center. *Save edits* and close the editor toolbar.

Step 8. In the attribute table of the new point shapefile, identify the maximum population of all the population centers. Calculate values for the 'Pop_Weight' field to be the population of each individual population center divided by the size of the maximum population center. Thus the size of each population center relative to that of the largest population center is associated with the population center centroids.

3.3.2 Create the road network

Required Data: expanded study area (from 3.3.1), interstate and primary roads included in that commute shed

Step 1. Creating a *buffer* of 15 miles around the expanded study area. This buffer includes all the area within the study area as well as that area within 15 miles.

Step 2. Use the *Geoprocessing clip* tool to *clip* the interstate and primary roads based on the buffer. Save the clipped roads in a *personal geodatabase* in a *Feature Dataset*. Close *ArcMap*.

Step 3. Open *ArcCatalog*. Open the *Feature Dataset* in which the clipped roads shapefile was saved. Right-click and choose *New Network Dataset*. Follow the steps to create a *network dataset*. Create a cost attribute based on the length field in the clipped roads shapefile. Identify the units of this field. If the units of the length field are miles, name the cost attribute LENGTH_MI. If the units are something other than miles, name the attribute appropriately. *Close ArcCatalog*.

3.3.3 Create driving distance buffers

Required Data: network dataset (from 3.3.2), point shapefile of population center centroids

Step 1. Open ArcMap. Open the *Network Analyst toolbar*. Insert the network dataset into the map. Choose *New Service Area*. Right-click on *Facilities*. Choose *Load locations* and load the centroids of the population centers from 3.3.1 as the facilities. Under the *Analysis Settings* tab of the *Layer Properties* of the *Service Area*, set the *impedance* to LENTH_MI, the *default breaks* to the desired driving distances, the direction to *away from facilities*, allow u-turns *everywhere*, and check *ignore invalid locations*. Under the *Polygon Generation* tab, check *Generate Polygons*, and choose *generalized*-, *overlapping*-, *ring*-type polygons. Click the *Network Analyst Solve* button.

Step 2. Open the *attribute table* of the *Service Area Polygons*. Select the ring polygons associated with each unique Facility ID. For example if there were four default breaks, there will be four ring polygons associated with each service ID. Export these into a new shapefile. Perform this export for each Facility ID.

Step 3. For each resulting shapefile of ring polygons, use the *Spatial Analyst Convert Features to Raste*r function to create a raster. Set the *extent* to include the expanded study area (originally used in 3.3.1). Use the 'ToBreak' field of the polygons to assign values to the raster cells. For the polygon with the smallest 'ToBreak' assign the value of the number of default breaks chosen in Step 1. For the next largest 'ToBreak' assign the value of the number of default breaks minus one. For the next largest 'ToBreak' assign the value of raster cells the number of the default breaks minus two. And so on.

Step 4. For each of the resulting driving distance rasters, use the *Spatial Analyst Reclassify* function to assign values of zero where the values are 'No Data.'

3.3.4 Combine driving distance buffers

Step 1. Use the *Spatial Analyst Raster Calculator* to combine the driving distance buffers as defined in the raster files created in Step 4 of 3.3.3. For each population center, multiply the Pop_Weight by the raster values that characterize the driving distances from that population center as shown in Figure B.9. The resulting raster will resemble Figure B.10.

3.4 Proximity to employment centers

Derivation of this step is divided into several substeps: (i) identify employment centers, (ii) create the road network, (iii) create driving distance buffers, (iv) combine driving distance buffers.

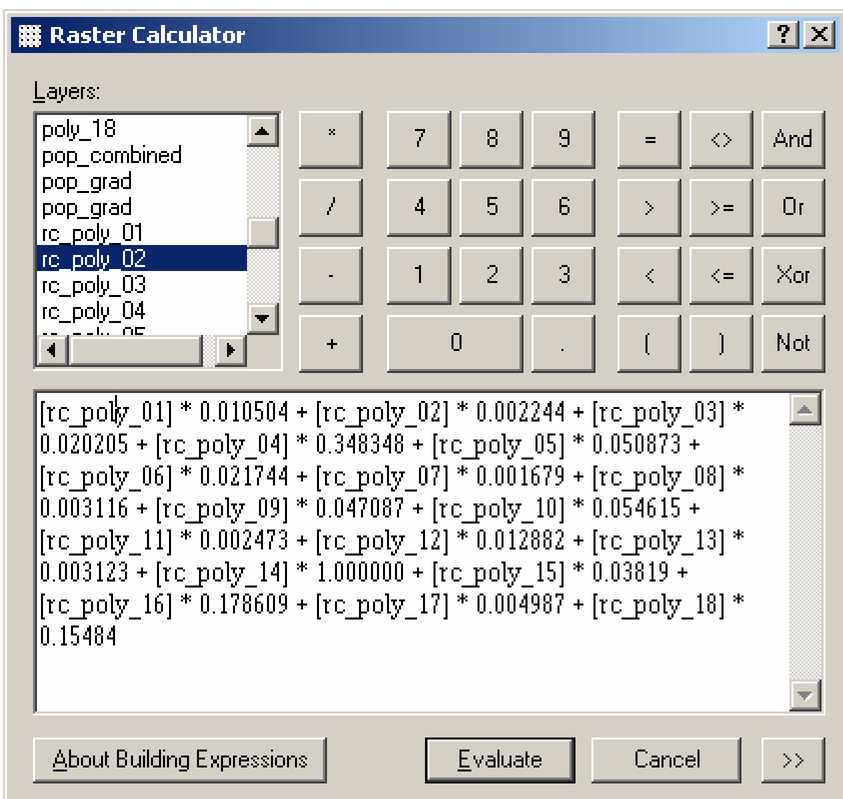

Figure B.9. Raster Calculation to Combine Driving Distance Rasters

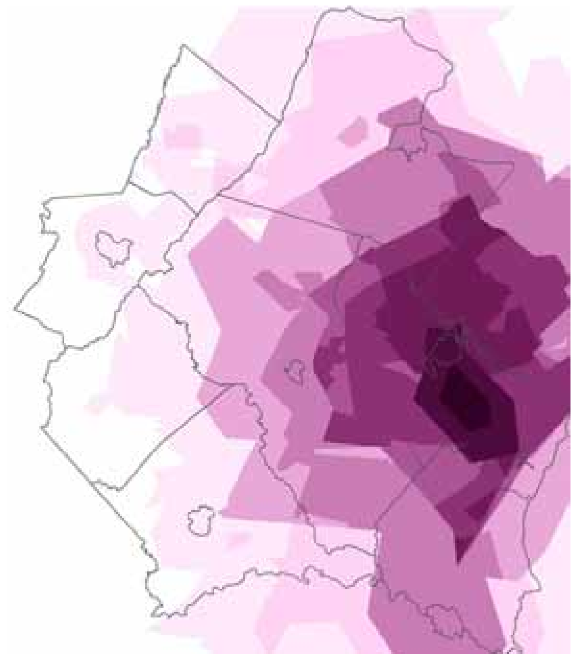

Figure B.10. Proximity to Population Centers

3.4.1 Identify employment centers

Required Data: counties included in commute shed (expanded study area), employment polygon or point shapefile for expanded study area.

Step 1. Map the employment data in the study area. Use the *Spatial Analyst Density* function to create a employment density gradient. Set the cell size to the same cell size of the analysis mask created in Section 1.2.

Step 2. Alter the *symbology* of the resulting raster employment density gradient to differentiate between cells above and below an employment density threshold. Set the threshold so that there are roughly 10 to 20 contiguous areas above the employment density threshold. These areas represent 'employment centers.' Check with local planners to make sure these employment centers reflect reality. A threshold of 300 persons per square mile was chosen for the employment density gradient.

Step 3. Reclassify the employment density gradient so that values greater than or equal to the chosen threshold are assigned a value of one, and those below the chosen threshold are assigned a value of zero. This will create a new raster of the employment centers.

Step 4. Using the Spatial Analyst Convert Raster to Features function on the new employment center raster, create polygons for each of the employment centers.

Step 5. Create two new fields in the *attribute table* of the employment center polygons. Name them 'XCent' and 'YCent,' respectively. Use the *Calculate Geometry* on the XCent field to calculate the x-coordinates of the *centroid* each of the employment center polygons. Use the

Calculate Geometry on the YCent field to calculate the y-coordinates of the *centroid* each of the employment center polygons.

Step 6. Use the *Add XY Data function* to create a point shapefile of the centroids of each of the polygon employment centers. *Create a new field* in the *attribute table* of the resulting point shapefile. Name the field 'Employment.' *Create a new field* in the *attribute table* of the resulting point shapefile. Name the field 'Emp_Weight.' Open the *Editor toolbar* and choose the function *Start Editing*. Choose the folder or database to edit from that allows the new point shapefile to be edited. Set the toolbar so that the *target* shapefile is the new point shapefile.

Step 7. For each polygon employment center, select the polygon employment center. *Join by location* the selected polygon employment center to the employment points or polygons. *Export* the selected employment points or polygons to a new shapefile. Open the attribute table of the new shapefile. Perform the *Statistics* function and make note of the value of the *Sum*. In the new point shapefile (created in Step 7), identify the centroid corresponding to the selected polygon employment center. Enter the calculated sum into the 'Employment' field of the corresponding centroid in the new point shapefile. Thus the employment of each employment center is associated with the centroid of that employment center. *Save edits* and close the editor toolbar.

Step 8. In the attribute table of the new point shapefile, identify the maximum employment of all the employment centers. Calculate values for the 'Emp_Weight' field to be the employment of each individual employment center divided by the size of the maximum employment center. Thus the size of each employment center relative to that of the largest employment center is associated with the employment center centroids.

3.4.2 Create the road network

Required Data: expanded study area (from 3.3.1), interstate and primary roads included in that commute shed

Step 1. Creating a *buffer* of 15 miles around the expanded study area. This buffer includes all the area within the study area as well as that area within 15 miles.

Step 2. Use the *Geoprocessing clip* tool to *clip* the interstate and primary roads based on the buffer. Save the clipped roads in a *personal geodatabase* in a *Feature Dataset*. Close *ArcMap*.

Step 3. Open *ArcCatalog*. Open the *Feature Dataset* in which the clipped roads shapefile was saved. Right-click and choose *New Network Dataset*. Follow the steps to create a *network dataset*. Create a cost attribute based on the length field in the clipped roads shapefile. Identify the units of this field. If the units of the length field are miles, name the cost attribute LENGTH_MI. If the units are something other than miles, name the attribute appropriately. *Close ArcCatalog*.

3.4.3 Create driving distance buffers

Required Data: network dataset (from 3.3.2), point shapefile of employment center centroids

Step 1. Open ArcMap. Open the *Network Analyst toolbar*. Insert the network dataset into the map. Choose *New Service Area*. Right-click on *Facilities*. Choose *Load locations* and load the centroids of the employment centers from 3.3.1 as the facilities. Under the *Analysis Settings* tab of the *Layer Properties* of the *Service Area*, set the *impedance* to LENTH_MI, the *default breaks* to the desired driving distances, the direction to *away from facilities*, allow u-turns *everywhere*, and check *ignore invalid locations*. Under the *Polygon Generation* tab, check *Generate Polygons*, and choose *generalized*-, *overlapping*-, *ring*-type polygons. Click the *Network Analyst Solve* button.

Step 2. Open the *attribute table* of the *Service Area Polygons*. Select the ring polygons associated with each unique Facility ID. For example if there were four default breaks, there will be four ring polygons associated with each service ID. Export these into a new shapefile. Perform this export for each Facility ID.

Step 3. For each resulting shapefile of ring polygons, use the *Spatial Analyst Convert Features to Raste*r function to create a raster. Set the *extent* to include the expanded study area (originally used in 3.3.1). Use the 'ToBreak' field of the polygons to assign values to the raster cells. For the polygon with the smallest 'ToBreak' assign the value of the number of default breaks chosen in Step 1. For the next largest 'ToBreak' assign the value of the number of default breaks minus one. For the next largest 'ToBreak' assign the value of raster cells the number of the default breaks minus two. And so on.

Step 4. For each of the resulting driving distance rasters, use the *Spatial Analyst Reclassify* function to assign values of zero where the values are 'No Data.'

3.4.4 Combine driving distance buffers

Step 1. Use the *Spatial Analyst Raster Calculator* to combine the driving distance buffers as defined in the raster files created in Step 4 of 3.3.3. For each employment center, multiply the Emp_Weight by the raster values that characterize the driving distances from that employment center as shown in Figure B.11. The resulting raster will resemble Figure B.12.

4.0 Scale indicator factors

Required Data: Raster representations of (i) lateral proximity to corridors, (ii) proximity to corridor intersections, (iii) proximity to population centers, (iv) proximity to employment centers.

Step 1. Use the *Spatial Analyst Reclassify* function to reclassify the values of the indicator factor rasters to values of 1 to 10.

5.0 Combine constraint and indicator factors

Required Data: Raster representations of (i) protected parcels, (ii) economically unsuitable parcels, (iii) lateral proximity to corridors, (iv) proximity to corridor intersections, (v) proximity to population centers, (vi) proximity to employment centers.

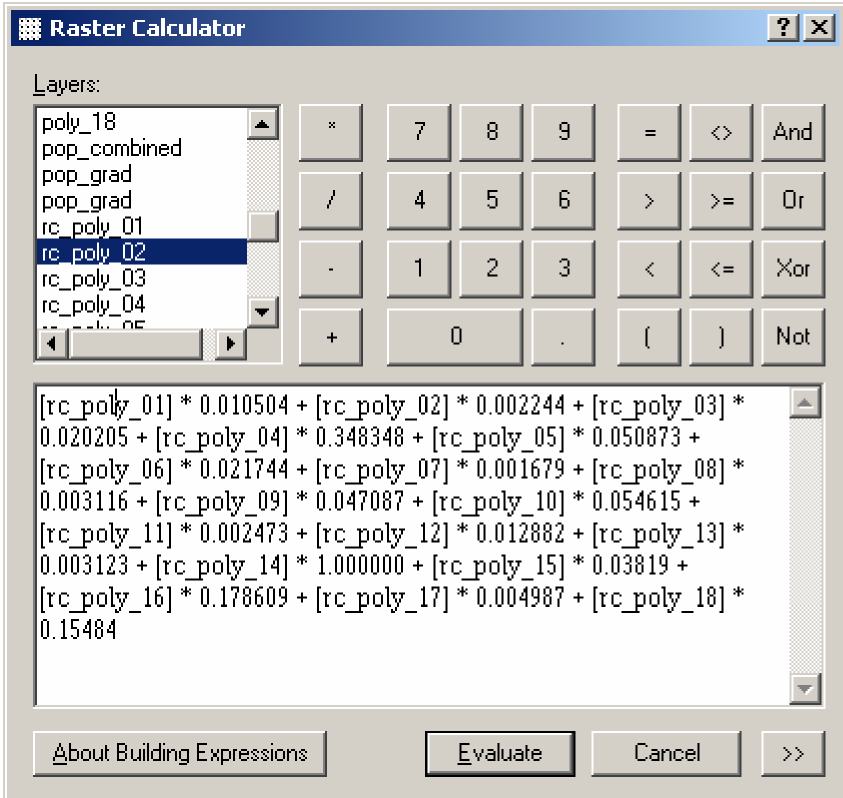

Figure B.11. Raster Calculation to Combine Driving Distance Rasters

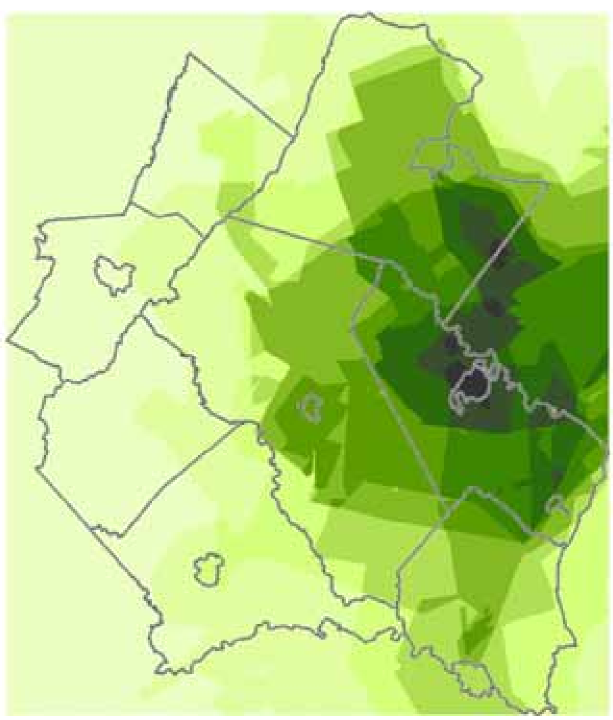

Figure B.12. Proximity to Employment Centers

Step 1. Use the *Spatial Analyst Raster Calculator* to add together the values from rasters (iii) through (iv) and multiply the results by the values from the (i) and (ii) rasters.

Step 2. Use the *Spatial Analyst Zonal Statistics* function to aggregate the raster cell values to the parcel vector layer. Assign the majority value of the raster cells within a parcel to that parcel.

Step 3. Use the *Symbology* of the resulting parcel layer to show very low, low, medium, or high likelihoods. Click the *classify* button, choose four classes, and use the *quantile* break method. The resulting parcel layer will be similar to that shown in Figure B.13.

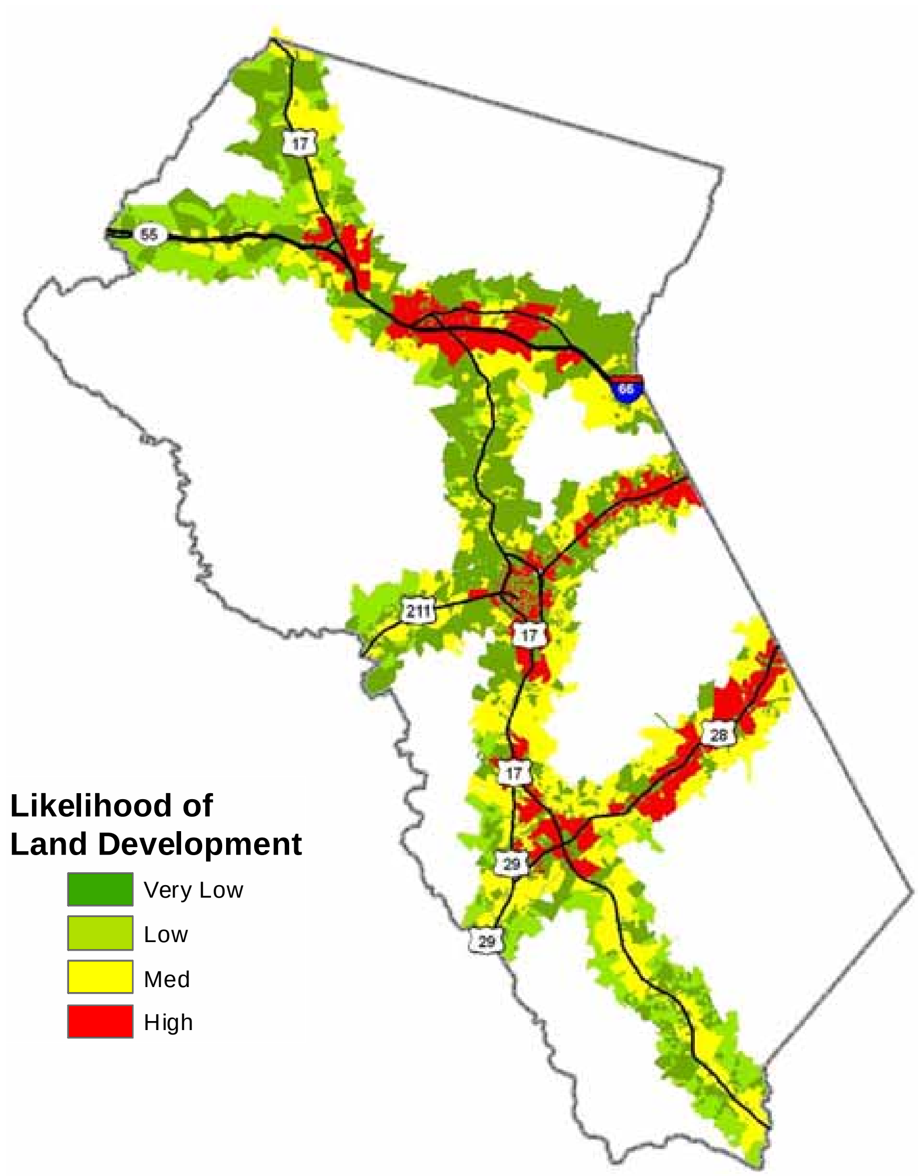

Figure B.13. Relative Likelihoods of Land Development Along Primary Corridors of Fauquier County

6.0 Derive and apply management indicators
Required Data: Parcel likelihood scores, parcel land and improvement assessments, and access points layer.

The parcel layer is usually available from the county. It is a shapefile containing all of the property parcels in the county. Generally the attribute table of this shapefile contains many values pertaining to the parcel. This analysis only requires the attribute table to contain the area of the parcel and both the un-depreciated value of the parcel along with the value of its improvements.

The curb cut layer is currently not available without creating it. To create this shapefile it is necessary to examine the aerial photographs of the road under study. While viewing this photo in ArcGIS in Edit mode, a new shapefile of points should be created by indicating where along the road there is a curb cut. Additionally the attribute table of this new layer should contain a column indicating whether the curb cut is high or low priority. Curb cuts may be prioritized as high priority or low priority. High priority access points are roads with more than 5 or more houses, intersections with major roads, and roads to major establishments such as Wal-Mart, McDonald's, gas stations, etc. The low priority access points include all other roads.

The number in parentheses next to the priority indicates how to designate this priority in the attribute table; that is, in the curb priority column, high priority curb cuts contain a '1' while low priority curb cuts contain a '0.'

Step 1. In the *attribute table* of the parcel data, add a new column to store the average value per acre. This column is calculated by adding the un-depreciated land value to the improvement value and dividing by acreage as described below:

$$\frac{undepreciatedvalue + improvementvalue}{acreage}$$

Step 2. Divide the road centerline into half mile sections using the *proportion* tool in the *Coordinate Geometry (COGO) toolkit*.

Step 3. Create a *buffer* of this layer of half mile segments to ensure that the road touches its nearest parcels. A recommended buffer radius is 250 feet. The buffer should have flat rather than rounded ends to avoid including extraneous parcels for a particular segment.

Step 4. Perform a spatial join of this buffered road layer with both the priority score layer and the parcel layers using the priority score and the total value per acre (calculated above), respectively. The resulting attribute table of the road segment buffers contains both the average priority score of the parcels touching it and the average value per acre of the parcels touching it.

Step 5. Export the results of the above calculations to Excel to create graphs such as those shown in Figures B.14, B.15, and B.16. The maps above the graphs were taken from the parcel map shown in Figure B.13.

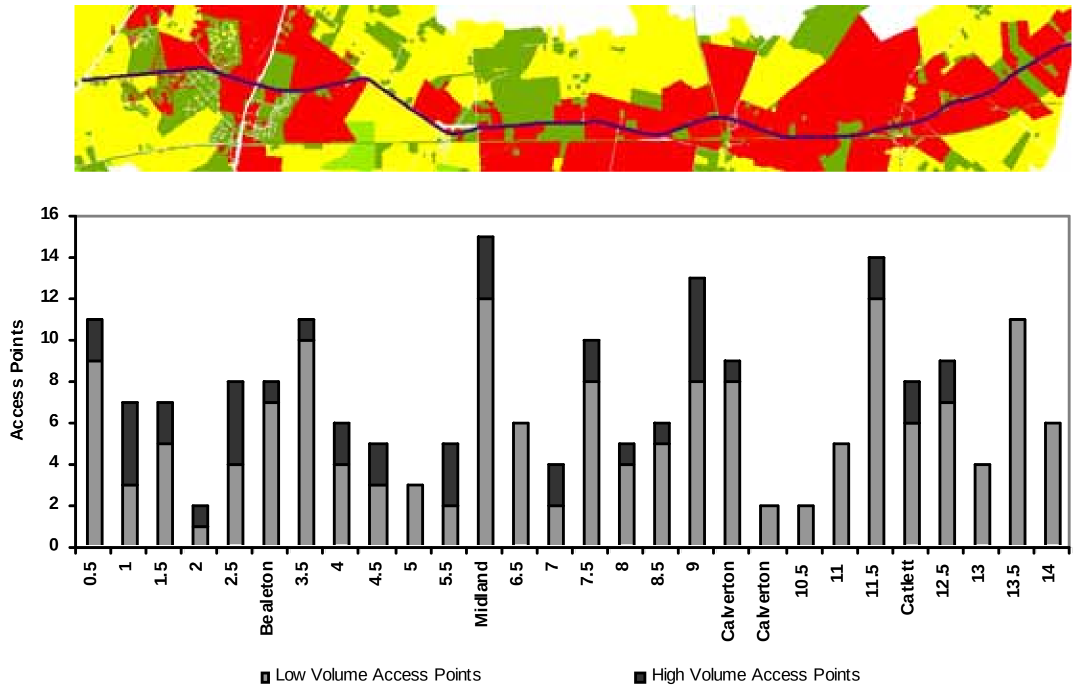

Figure B.14. High and Low Volume Access Points by Half-Mile Road Segments

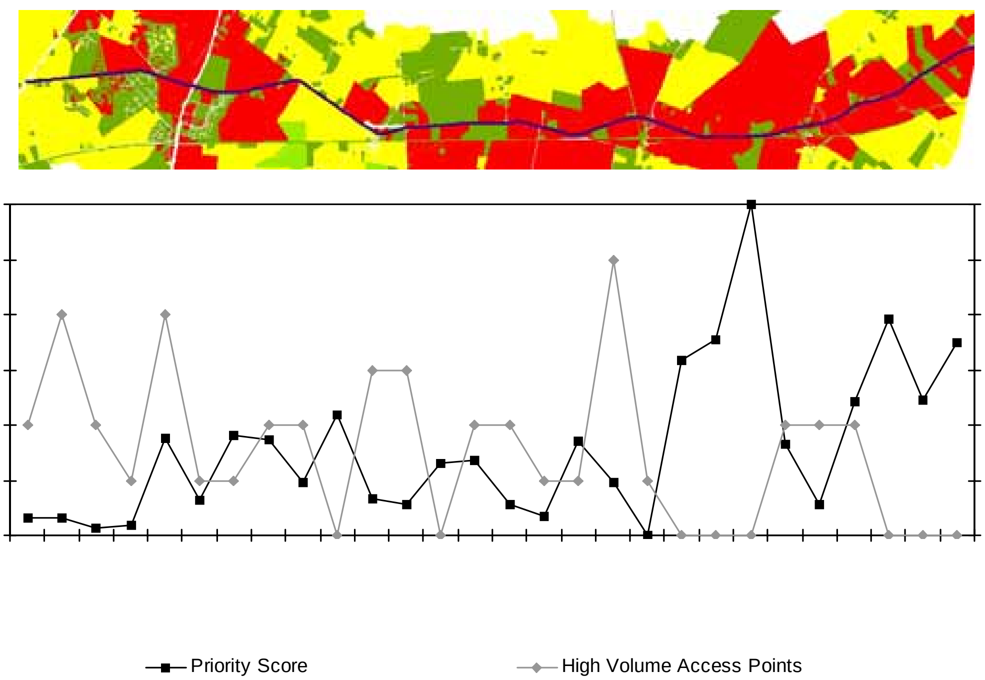

Figure B.15. High Volume Access Points Compared With Development Likelihood Scores

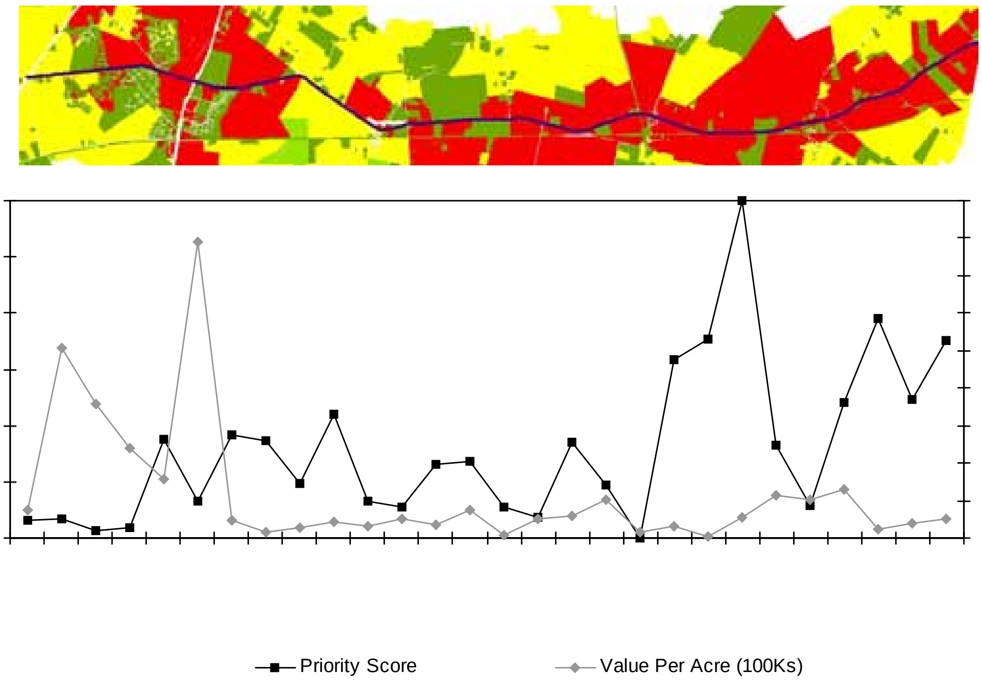

Figure B.16. Value per Acre Compared with Development Likelihood Scores

7.0. Explore various uses of the results

There are various potential uses of the results of the methodology as follows.

First, the methodology can serve as a tool to communicate among planners and the county and regional planning authorities. It can be used to accomplish the following tasks:

- Improve linkage with land use/transportation planning and the land development process along major primary road corridors;
- Assist in better understanding adjoining jurisdiction impacts on the locality's transportation network;
- Identify areas where increased land use management controls should restrict future access;
- Provide an additional perspective for adjusting service district or urban development area boundaries in the locality comprehensive plans; and
- Provide a means to implement plans such as the VDOT Safety Improvement Plan for Crossovers along primary corridors by continuing to close unsafe median cuts and restricting access.

Second, the methodology can identify areas where creative solutions could be warranted. The U.S. 28VA 28 from Prince William County to U.S. 17 is shown in the Fauquier case study to have a high likelihood of development. Development in this location is already constrained due to the lack of public sewer and water services and black jack soils, and the primary land use is agriculture. Here the case study results could be used to recommend that active farms along this regional corridor be given a higher Board of Supervisors priority in Fauquier County's Purchase of Development Rights (PDR) program. Whether development rights should be purchased for land that may already be protected by a growth management tool is a reasonable question; however, this study assumes that political and economic forces vary among counties and that growth management efforts are potentially subject to these forces. Particularly low land values today present an opportunity to protect the corridor before the development pressure exceeds the desire to protect an area of land. Thus, development rights for these properties could methodically be acquired and extinguished through recorded easements along this key corridor, reducing demand for access and making it easier to acquire future right of way when primary road expansions or safety improvements are required. This is an example of how results of the methodology can be used to help make the business case for corridor protection by considering cost effectiveness, return on investment, and/or cost-benefit ratio.

Third, the methodology can assist counties and towns in the Commonwealth in meeting and taking advantage of the provisions of House Bill (HB) 3202, enacted on July 1, 2007. It can serve as a preliminary analytical tool to identify specific locations where designated urban development areas may be suitable. It may be used to assist in the preliminary development of locations needing consideration as a Traffic Impact Fee Service Area.

Fourth, the methodology can be applied at a regional level by regional commissions, insuring a consistent, coordinated approach among member jurisdictions in land use and transportation planning. Doing so will provide the methodology to member jurisdictions that do not have the staffing capabilities to develop studies of their own. Furthermore the regional application will coordinate a unified presentation of network improvements, including, road, bus/rail transit, and pedestrian elements.

Fifth, the methodology can be adapted by a locality to incorporate additional data including land use and zoning, functional classification of corridors, green infrastructure (compiled by the Virginia Department of Conservation Resources) and transportation infrastructure of additional modes such as bike and pedestrian, rail, bus, and air. Many data were not included in the study because they were not available or consistent statewide in early 2007, though the methodology can accommodate additional data potentially relevant to the potential for land development. Future efforts may use fewer or more factors, or different factors, depending on the location and size of the study area and application of the study.

Sixth, the results of the methodology can be correlated to other sources of information. For example, can high likelihood areas be compared with the existing service districts in Fauquier County to validate the accuracy of the methodology? Or did the prior existence of the service districts shape growth in the region and contribute to the results of the methodology? The answer is likely to be *both*, however strict causality cannot be determined. In the absence of quantitative validation, qualitative validation has included confidence-checks with Fauquier planning staff, checking for correlation with the service districts and with water and sewer service areas, and seeking a relationship to the access points (curb cuts). The methodology generated results that confirmed and surprised the intuition of VDOT and Fauquier County planners, generating critical thought of both qualitative and quantitative characteristics of the study area and rich discussion. The steering committee agreed that the overall results of the model were highly correlated with the service districts and the water and sewer coverage areas (with the exception of the westernmost intersection of I-66, U.S. 17, and PR 55VA 55 where development is constrained for environmental reasons). Future effort may attempt to validate the results using historical issuance of building permits.

Seventh, the results can be interpreted to reflect the temporal dimension. The interpretation of results should consider that a related terminology for low, medium, and high "likelihood" is "near-term priority," "mid-term priority," and "long-term priority." Thus the methodology would help the locality and VDOT be proactive in addressing corridor sections that are most vulnerable to development in the near term. In addition, the committee discussed the linear sequential nature of development emanating from current activity centers. It was expected linear expansion would show up stronger in the results. This phenomenon did in fact show up in the Fauquier results as the parcels in the eastern corridors were generally more likely to develop than those on the west. This is reflective of the importance of regional activity centers compared with the importance of smaller activity centers in Fauquier County.

Eighth, the methodology can evolve with technology and available data. The slide presentation (www.virginia.edu/crmes/corridorprotection) is an effective means of transferring the technology as they are visual and allow GIS specialists to recreate the analysis in the way they best see fit. As GIS applications evolve, the presentation flowcharts and intermediate and final results will continue to be effective to describe the concepts.

The identification of high-likelihood development areas is a foundation for further steps. Once high likelihood areas are identified, appropriate strategies for protection of the corridors should be evaluated. Resources and strategies for this topic are reviewed in the "Literature Review" in this report.