OPTIMIZING TRANSPORTATION NETWORK BASED ON ECOLOGICAL SUITABILITY: AN INNOVATIVE NONMOTORIZED APPROACH TO INTEGRATE TRANSPORTATION WITH URBAN ECOLOGY

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN ARCHITECTURAL STUDIES

UNIVERSITY OF FLORIDA

2017

To my country and my family

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my committee chair Professor Walters for his patience, motivation and immense knowledge. His valuable guidance helped me to tear the vitals out of a subject, think beyond the appearance more comprehensively and inspired me to a broader world of both career and life.

Besides, I would like to acknowledge the rest of my thesis committee: Professor Steiner for her encouragement, insightful comments on specific research directions, and professor Volk, for his enthusiasm, continuous support, and professional guidance in all the time of the research and writing of my thesis.

I would also like to thank Professor Latimer for his patience and technical support that contribute to the analysis part of my research.

Finally, I must express my profound gratitude to my family and friends for providing me with unfailing support and continuous encouragement throughout my study.

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LIST OF ABBREVIATIONS

ESM	ESM refers to ecological suitability map, which is produced based on multiple indicators that impact on ecological suitability, and then calculated the overall value of each cell with weightings as a suitability map.
ETN	ETN refers to the existing transportation network that consists both road network and trails and cycling lanes that connected to the road network. The ETN was the existing condition for comparison.
OTN	The Optimized transportation network consists of two parts: one is existing road network that is the same as in the ETN, the other part is generated based on ecological suitability and screening criteria. Both parts were integrated together as optimized transportation network and assess the extent of improvement.

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for Degree of Master of Science in Architectural Studies

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July 2017

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Major: Architecture

With the increasing conflictions between development and ecology, sustainable development has been widely applied to multiple actions. However, only very few research focus on integrating transportation with ecology, where the nonmotorized approaches to address this issue have long been a research gap.

This research was conducted to generate an optimized transportation network that consists of both nonmotorized routes based on ecological suitability and existing road network to make transportation network both efficient and environmentally friendly. Multiple transportation assessment approaches, such as topological analysis, ecological impact analysis, and network analysis, were then applied to test its service efficiency based on GIS and Space Syntax. The result shows that the ecologically based transportation network can improve the existing one topologically and satisfyingly serve travel demands in study area efficiently.

CHAPTER 1
INTRODUCTION

With the concept of sustainable development becoming extensively acknowledged and commonly applied to practical experience, natural area conservation gains increasing concern. However, we are so cautious about the preservation that most of the conservations were passively done by avoiding construction and development in such area. Such passive attitude is tolerable in rural areas where natural landscape is dominating, while in urban areas, admittedly, natural patches such as preserves and wetlands play important roles that benefit both ecosystem and human health. Such areas leave unincorporated holes in built environment that result in inconvenience for urban life and threaten to vulnerable urban ecology.

Fig. 1 The Hogtown Creek is cut off by two major roads

Fig. 2 The I-75 run across Paynes Prairie Preserve

Such confliction is particularly prominent when comes down to the transportation network. Optimistically, road network planning, or most of the network plan, such as route selection, is designed to avoid natural areas to mitigate environmental impact considering patch size and human impact. On the one hand, natural areas contain the essential ecological values to alleviate the heat island effect, purify air quality, conserve water, as well as provide accessible places to interact with nature and have recreational activities. On the other hand, the lack of accessibility and the ineffective of walkability (mainly results from its large size and long distance) make it hard for urban natural areas to function well as it could be. However, when facing the confliction with development, the ecological health always has to compromise to human development (Fig. 1) or regional connection (Fig. 2).

Various kinds of efforts are being taken to minimized ecological impact, such as expand the width of wetland by adding space for creek branches to protect its moisture holding capacity (e.g. the Road Ecology Program) and makes great functions of wildlife crossings as environmental mitigation infrastructure (e.g. ARC Wildlife Crossing Competition). Nevertheless, these actions are mostly done by related professions, such as designers, ecologists, and civil engineers, while very few of the public would concern about certain issues. To the most basic reason, people only care what matters to them based on acquired knowledge, thus to make urban natural area visible is essential to let human aware of the importance of protection and conservation through tourism, education, and participation, where transportation network lays the foundation for all the above actions. Hence, it is urgent and necessary to optimize urban transportation network with limited ecological impact.

In order to cope with such issue, this study selects non-motorized network as a probe to integrate transportation with urban ecology, explore implicit relationships between these two systems and try to find a potential solution for a better transportation network. **Error! Reference source not found.** Fig. 3 shows the road map of this thesis, which can split into five chapters. The Literature review gives an overview of research gap and referenceable precedent research on suitability identification and transportation network assessment. The Methodology chapter explains deliberately on adaptive methods for identifying ecological suitability, select potential transportation routes, and assess optimized transportation network, as well as each transitional step that is connecting these parts, such as how to select potential routes for an optimized network and how to make the optimized routes implementable. Data and resources are also components for this part. While the fourth chapter elaborates research process and related results, which has detailed explaination in the next paragraph. The last chapter is discussion and conclusion based on the forehead four chapters and explains future

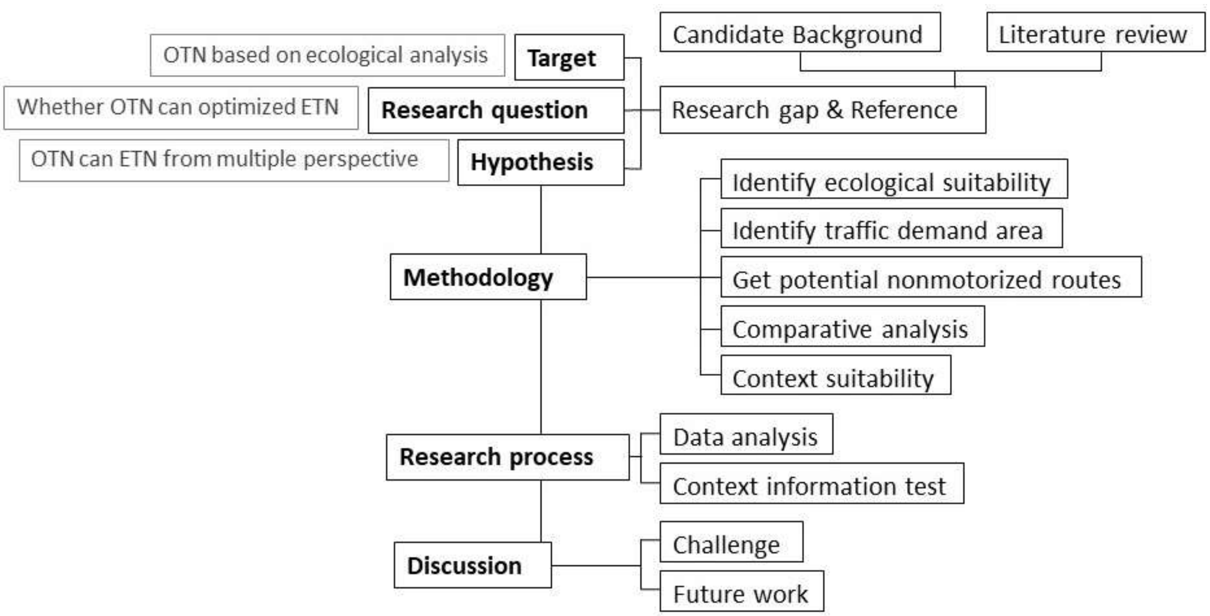


Fig. 3 Roadmap for this research

works.

The research process consists of two sessions. The first part was oriented to analyze and identify two major clues, respectively were ecological priority and transportation priority, working simultaneously. The ecological identification result formed up an ecological priority map based on Geographic Information System (GIS), using multiple resources of statistic data to find potential areas with less ecological conservation priority for nonmotorized routes construction. While the transportation priority identified transportation demand and selected potential corridors for optimizing existing transportation network, which could then represented as transportation demand priority maps at both regional scale (Alachua County) and city scale (City of Gainesville). Then overlay the two maps with screening criteria to get nonmotorized corridors as the basis for the optimized plan. The second session focused on assessing both existing transportation network and optimized transportation network to evaluate the extent of how much the transportation network was improved as well as the suitability to the contextual condition. This study also adapted multiple indices and criteria for assessment from thr previous research and projects. Based on these supports, this study offers several suggestions for future work.

The efforts taken in this research was trying to figure out whether the nonmotorized routes that identified from ecological sensitivity can improve the existing transportation network while adaptive to contextual condition and how this could be helpful and referenceable for the future planning.

CHAPTER 2
LITERATURE REVIEW

This study researches on the implicit interrelationship between urban ecology network and transportation network, based on the suitable area identification that with both least impact on ecology and most potential for construction in order to add in non-motorized routes to existing transportation network, and find out the possible optimization for the future transport construction and the innovative development direction for nonmotorized transportation. The objective focuses on dealing with ecological issues in urban transportation and integrates both networks towards sustainability.

This chapter was conducted following the roadmap of research design: the ecology analysis and conservation priority identification as the basis for the selection of nonmotorized transportation routes, and then apply comprehensive indicators to a comparative research among existing transportation network and optimized transportation network for potential ecology-transportation integration and better urban nonmotorized network.

Identification Ecological Priority

Ecological priority research

Urban ecology issues have been heated discussed for decades (Zapparoli, 1997) (Guntenspergen, 1997) (Sukopp, 1998) either from investigating ecological patterns or from the ecosystem perspective. This results from the following reasons which were supported by different field of research such as cooperating urban development based on the high concordance between biodiversity conservation priority and ecosystem service value (Turner et al., 2007), contributing to spatial eco-balance (Lenz & Beuttler, 2003), and optimizing the spatial connections to better utilize activity diversity and travel options (Neutens, Versichele, & Schwanen, 2010).

Identifying ecological priority is considered as a common basis for different purposes among a diverse field of research, which was summarized into three major objectives: for a better future development, for the regional ecological network, and for vulnerable area conservation.

Modeling and scenario planning are two common approaches to address future development based on large datasets and multidisciplinary cooperation. One kind of major practical attempt is the oriented precautionary actions by simulating development (Stevens, Dragicevic, & Rothley, 2007), supporting zoning optimization (Geneletti & van Duren, 2008), and predicting trends and visions for precautionary actions (Florida, 2005). Another is to fight against ecological issues that come along with urban development. The expansion-caused deforestation (Soares-Filho et al., 2006), agricultural-impacted potential pollutants (Behera & Panda, 2006) as well as corresponding measures such as green infrastructure design (Snall, Lehtomaki, Arponen, Elith, & Moilanen, 2016) are three typical examples. Also, land suitability analysis is another essential approach to assess the environmental impact (Shen, Xiao, Zhou, & Bao, 2005; Wu, Jelinski, Luck, & Tueller, 2000) and to improve built environment (MENG & FAN, 2011). Such studies provide diverse possibilities for future development, where the research direction is promising and widely discussed but lack or transportation related concerns and explorations.

The regional ecological network is usually classified either by large scale programs or existing boundaries. Greenway has been considered as an effective ecological carrier as a program or project for regional network since the Greenway movement initiated by Olmsted in 1980s and 1990s (Little, 1995) (Jongman, 1995), and widely applied to Europe (Jongman, Külvik, & Kristiansen, 2004) and the United States (Fabos, 2004). For instance, Florida has engaged in such efforts since 1998 and was adaptive to current and future development (Florida Department of Transportation, 2017). While biodiversity is one of the essential indicators to identify the priority for conservation (Groves et al., 2002) and represent as science-based prove for conservation planning (Ferrier, Biology, & Apr, 2007). Meanwhile, the watershed is also commonly used as analysis boundary to identify soil and water condition (Biswas, Sudhakar, & Desai, 2002) and support land planning (Randhir, O'Connor, Penner, & Goodwin, 2001).These objectives are incorporative to regional planning considering connectivity (Gurrutxaga, Lozano, & del Barrio, 2010), biodiversity (Groves et al., 2002). The regional perspective makes up for traditional development, using ecological units rather than political management boundaries, to facilitate regional cooperation while taking care of ecological health. This worldwide trend to facilitate regional cooperation implies potential opportunities for transportation to go green and sustainable to connect multiple urban areas, where nonmotorized routes gradually play an essential role to incorporate transportation with ecology.

To protect conservation area, various perspectives and multiple approaches have been applied to the planning process to identify suitability. Zhang emphasizes the importance of balance ecosystem service (Zhang, Fu, Lü, & Zeng, 2015), Geneletti promote the sub-zoning method to preserve conservation area (Geneletti & van Duren, 2008), Austin contributes to urban ecology by science-based modeling for species distribution (Austin, 2007), Lopez team promote a context-based model from landscape approach (López Arévalo, Gallina, Landgrave, Martínez Meyer, & Muñoz-Villers, 2011). Other researchers choose to protect vulnerable areas by investigating specific species to identify the conservation priority (Peterson, Egbert, Sánchez-Cordero, & Price, 2000). This type of studies provides a broad range of methods and tools to identify the ecological priority for conservation based on a portable database, which is made up of a variety of indicators, for this research to select proper evaluation systems for identifying ecological suitability areas for potential nonmotorized routes.

As a summary, existing research for identifying ecological priority is either from the data-based perspective that is too critical or applied the result to multidisciplinary research which did not involve much in transportation issues.

Indicators and tools applied

Defining research priority for ecology was initiated by Ecological Society of America since 1988 (Lubchenco et al., 2016) and developed into two major research directions as the basis (Orsi & Geneletti, 2010). One considered the demand and urgent of the areas where conservation is needed; the other investigated the feasibility to achieve such preservation (Suding, Gross, & Houseman, 2004).

Indicators for the first research direction were more likely to be physical stressors (Messer, Linthurst, & Overton, 1991), which was initially promoted by the U.S. Environmental Protection Agency in Environmental Monitoring and Assessment Program (U.S. EPA, 1988). For instance, soil condition is tested to play a significant role in watershed health (Khan, Gupta, & Moharana, 2001). While the latter that has been done by precinct research as the concept of “restorability” (Orsi, Geneletti, & Newton, 2011), where the feasibility to ecological conservation and the initiated cost were considered to have an alternative action that draws an overall optimal option (Carwardine et al., 2008).

Both research directions could be addressed from two types (Table 1). One type attempted from single issue analysis, such as ecological and socio-ecological concerns, that takes one or two representative indicators as an index, run delicate deep quantitative research to reveal the interrelationship between indicator and suitability, and their potential impacts on either built environment or planned development. These precedent experiences offer overview of various optional indicators that essentially impact on ecological suitability and conservation priority, including biodiversity (Ferrier et al., 2007), soil and water condition (Tripathi, Panda, & Raghuwanshi, 2003), hydrological vulnerability (Chung & Lee, 2009), habitat (Guisan & Zimmermann, 2000), ecosystem service (Naidoo et al., 2008; Snall et al., 2016; Metcalfe et al., 2015), conservation area (Moilanen, Leathwick, & Elith, 2008; Naidoo et al., 2008), species richness and land use (Durán et al., 2014), green infrastructure (Snall et al., 2016), and so on. The other type conducts systematic research to classify multiple indicators as an assessment model and apply the result of evaluation into practical issue either in projects (Jon Oetting, Tom Hoctor, & Michael Volk, 2016) or research (Vimal et al., 2012; H. Xie, Yao, & Wang, 2014). This type of experiences can provide science-based supports for improvement with proper selection and adaptation. Orsi and Geneletti had a good example to solve deforestation issue by supply reforestation options based on suitability maps and design options (Orsi & Geneletti, 2010).

Table 1 Indicators to identify ecological priority in precedent studies

Type	Indicators	Objectives
Single Issue	Biodiversity	Map spatial pattern
	Soil	
	Water	Identify spatial prioritization
	Landscape connectivity	
	Hydrological vulnerability	Spatial ranking
	Habitat distribution	Predictive models and qualification
	Ecosystem service	Quantify ecosystem map Evaluate spatial priority for fisheries
	Conservation area	Assess existing conservation area
	Species richness and land use	New indicators for identification
	Green infrastructure	Integrate with ecosystem service
Systematic Classification	Biodiversity Landscape Surface water Groundwater Marine	Identify Critical Lands and Waters
	Rare or remarkable species Extensive areas of high ecological integrity Landscape diversity	(Vimal et al., 2012)
	Water security Biodiversity Disaster avoidance and protection Recreation security	Maintain ecological security

Transportation Planning

Research development

Thomas firstly promoted the importance of transportation development by stating that "Few forces have been more influential in modifying the earth than transportation" (Thomas, 1956). Road network has been weighted a lion share of transportation research for decades. As part of the required civic infrastructure, it makes physical connections for increasing productivity in a region and efficient transportation network effects (Garrison & Marble, 1962), which also has impacts on social connections and the economic and political decisions that lead to land use change (Coffin, 2007). The field of transportation research gradually broadens with the integration with multidisciplinary studies, from economic improvement to ecological concern (

Table 2).

Table 2 Transportation research development

Time	Research direction	Objectives
1960s	Transportation and economy	Land use layout
1970s	Wildlife biology	Species Habitat
1980s	Environmental Transportation Geography	Sustainable transport Network analysis
1990s	Ecosystem, Landscape	Road ecology

Since the 1990s, environmental concerns are aware of the importance regarding sustainable transportation and life quality. In 1998, the concept of "road ecology" was first proposed by landscape ecologist (Forman & Alexander, 1998), which marks an emerging subject that investigating various ecological impacts. These impacts, such as the disturbance of ecosystem components, process, and structure, are supported by multiple studies, to have a close relation to engineering construction and other human development activities (Coffin, 2007; Forman & Alexander, 1998; Trombulak & Frissell, 2000). Researching on road ecology helps to identify the factors of influence and assess the impact that caused by these road network factors (Coffin, 2007). The effects of roads on abiotic components of ecosystems are various, such as changes to hydrology condition (Grant et al., 2003; Jones, Swanson, Wemple, & Snyder, 2000; Trombulak & Frissell, 2000) and noise effects (Forman, 2003; Slabbekoorn & Peet, 2003). Moreover, roads usually act as barriers to animal movement (Dodd, Barichivich, & Smith, 2004; Forman, 1998; Kerley et al., 2002; Smith & Dodd Jr, 2003) and result in landscape fragmentation (Canaday, 1996; Develey & Stouffer, 2001).

However, due to all these adverse effects, when facing ecological issues, the road network was built to avoid ecologically sensitive areas. These linear constructions separate human with nature not only physically, but also disrupt the ecological equilibrium which deprives places for recreation and education that benefits mental health. Such background made it possible for nonmotorized travel to play an essential role in transportation.

Why nonmotorized transportation

Nonmotorized transportation (NMT) refers to travel approaches that do not use motorized power to move, such as walking, cycling, scooter and handcart use. This type of transportation was considered as sustainable transportation as it has limited ecological impact. Xie set one of the criteria for an eco-city, which has robust transportation infrastructure with minimized car and motorcycle used (H. Xie et al., 2014), Haghshenas reviewed indicators for sustainable transportation and formed up a database for transport modeling (Haghshenas & Vaziri, 2012), while Goldman started from policy perspective, emphasized the importance to consider nonmotorized transport for mobility, Intelligent System Management, and Livability (Goldman & Gorham, 2006).

Besides environmental concern, the efficiency of nonmotorized transportation is also a remarkable indicator for identifying the urban pattern. Based on behavior research, people tend to have a higher ratio of nonmotorized travel when living in places with higher density, greater connectivity, and more mixed-use land use types (Saelens, Sallis, & Frank, 2003). It is also applicable to transportation infrastructures, such as local topography and sidewalk availability, due to the high attractiveness to nonmotorized travel modes (Rodríguez & Joo, 2004).

Moreover, the increasing nonmotorized travel improves the health and safety in mid-sized cities due to the exercise on the way (Milne & Melin, 2014) and the potentially increased social opportunities (Gehl, 2011). Meanwhile, it also brings economic benefits such as reducing car trips (Bellingham, Washington) and saving the cost of tourism spending (Burlington, Vermont).

Nonmotorized transport has been integrated with land use to improve public health (Frank, 2000)and quality of life (McNally & Kulkarni, 1997). Negative health impacts that result from increased motor vehicle travel will potentially mitigate by shifting to nonmotorized modes (Litman, 2003).

Overall, the nonmotorized transportation is a crucial entry point for improving existing transportation network, as its benefits for ecological sustainability, sustainable development pattern and human health improvement.

Transportation Network Assessment

Various studies have tested available tools and models among indicators from different perspectives to get a quantified result to evaluate the efficiency and robustness of a transportation network. These attempts can split into four major types: topological analysis, geometrical analysis, impact assessment and systematic analysis.

Tools and where applicable

Topological analysis

The topological analysis is one of the common approaches for network analysis due to the capability of evaluation that can regardless of the actual scale. It has not only been tested by scale-free model through mathematical ways (Barabási & Albert, 1999), but also be applied to other research fields such as biology (Watts & Strogatz, 1998), economy, and engineering.

Space Syntax is a topological relationship based tool, which is commonly used in social networks and primarily considered as a conceptual theory and analytical method for urban design, architecture, and interior space design that contributes to understanding their morphological logic (Hillier & Hanson, 1989). After this starting point, its practical use was widely applied to urban design proposal considering the building-street relation, open space location, and network analysis (Jiang, 2007; Jiang, Claramunt, & Klarqvist, 2000; Kim & Sohn, 2002). While its practical suitability also expanded along with multidisciplinary research that either combining urban design with monographic studies such as transportation optimization and movement prediction (McCahil & Garrick, 2008; Raford & Ragland, 2004) or further analyzing the relationship between human societies and inhabited space in diverse forms (Bafna, 2003).

For this research, Space Syntax is the major tool that applied to analysis the topological relationship among each of the transportation network components, considering nodes (intersection) and links (routes). Axial map lay the basis for topological relationship analysis by running the 'run graphic analysis' command to identify multiple indicators when importing different value of analysis radius as the variable.

Geometrical analysis

Based on precedent projects and literature review, researchers proposed supplemental measurements such as entropy, connection patterns and continuity of a transportation network (F. Xie & Levinson, 2007). Other studies focus on the Urban form, such as land use types and transportation facilities that have a significant impact on transportation structure (Chen et al., 2011).

The concept of space-time prism was proposed based on the Geographical Information System, which determines the location of travel and activities with the bounded limitation of space and time (Miller, 1991). In addition, network analysis is essential when considering geography (Haggett & Chorley, 1996).

Impact assessment

Traffic impact assessment (TIA) has been widely applied to multiple places and departments (Road and Traffic Devision, 2007) (Land Transport Division, 2015) (City Council, 2017), which assesses the potential traffic impact based on historical traffic data and potential traffic changes according to the proposed plans. These works targeted at improving trip distribution and network service based on the prediction of traffic growth (Table 9). Moreover, multimodal considerations were specified by pedestrian, bicycles and transit vehicles in the updated traffic impact studies

(Transportation Planning Organization, 2014). The traffic impacts usually result from the change of junction, access, or road condition.

Environmental impact is another assessment perspective. For example, Europe and Japan engaged in assessing the impact of Intelligent Transport Systems (ITS) by tracking and calculating CO_2 emission (EC-METI Task Force, 2009). Considering user-optimizing and system-optimizing flow pattern as assessment index for transportation network is another approach (Nagurney, Qiang, & Nagurney, 2010). One of the essential examples is Strategic Environmental Assessment (SEA) through COMMUTE framework by a set of environmental indicators, which applied to the Trans-European Transport Network (TEN-T) since the start of 2014 (Mr Hermann Heich, TÜV Rheinland, 2000).

Systematic analysis

The four-step travel model consists of four basic elements, respectively are trip generation, trip distribution, mode choice, and trip assignment. It is widely used to assess transportation network (McNally, 2007) and predict transportation service efficiency (Boyce, Zhang, & Lupa, 1994; Chen et al., 2011). In addition, Ortuzar provided information, methodology tools, and skills to modeling in a comprehensive way (de Dios Ortuzar & Willumsen, 1994). Based on this framework, transportation-related analysis can either evaluate existing transportation network or improve transportation network in the future to serve traffic demands better.

In order to deal with the uncertainty, decision-making tool for sustainable transportation system was promoted based on multicriteria (Awasthi, Chauhan, & Omrani, 2011). Multiple factors, considering traffic flow, travel pattern and the related cost to identify importance value for assessment (Ryan & WATTS, 2008). Economic concern was also considered by cost-benefit analysis to minimize the necessary cost (Jonsson, 2008; Kunreuther, Grossi, Seeber, & Smyth, 2003).

Network analysis is another set of powerful tools based on Geographic Information System (GIS) platform to assess service efficiency that can support transportation network analysis. Service Area is created to evaluate the accessibility of facilities, which varies from different impendence such as time of travel and travel distance. It also implies the attractiveness of these transportation facilities. While the OD cost matrix is created to find and measure “the least-cost paths along the network from multiple origins to multiple destinations” (ArcMap, 2017). For the result of OD matrix, even though the connection was in straight line graphically, the values of the field “Length” represent the real length of the least-cost routes in the attribute table.

Indicators

Topological indicators

For Space Syntax-based analysis, some frequently-used indicators respectively are integration, depth, choice, connectivity, and node count. Each of which has its concepts explained in

Table 3 (Bill Hillier, 1986), and the four indicators that were applied to this research have more detailed explanation below.

Mean depth

Mean depth is calculated by assigning a depth value to each space according to how many spaces are away from the original space, and then sum these values and divide them by the number of spaces in the system.

Integration

Integration is a normalized measure of distance from any a space of origin to all others in a system. In general, it reflects the closeness from one origin space to all other spaces, and to what extent the origin can be seen as the measure of relative asymmetry (or relative depth).

Connectivity

Connectivity calculates the total number of spaces that are immediately connecting an origin space, which reflects the importance of one transportation segment among the surrounding region and the accessibility to the origin.

Total depth

Total depth is defined as “the sum of the topological depth from any a node to all the others”. The higher total depth value of one transportation route is, the more far away it is, and more turns need to take to access it.

Table 3 Definitions of each indicator in Space Syntax (Hillier & Hanson, 1989)

Indicators	Definition
Integration	A normalized measure of distance from any a space of origin to all others in a system.
Total Depth	The sum of the topological depth from any a node to all the others.
Choice	measures how likely an axial line or a street segment it is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a predetermined distance (radius) from each segment.
Connectivity	Refers to the number of spaces immediately connecting an area of origin.
Node Count	The number of lines (or segments) encountered on the route from the selected line (or segment) to all others.

Geometrical indicators

Accessibility

The Accessibility indicator can further divided into length, time, or costs that measure the ease of access to evaluate the efficiency of a network and the mobility the network can provide (Gutierrez, Monzon, & Piñero, 1998). Accessibility Analyst incorporates a lot of measurements, such as cumulative opportunity measures, gravity-type measures, and utility-based measures (Liu & Zhu, 2004).

Accessibility is one of the essential characteristics in transportation research field. For decades, researchers apply accessibility to reveal the relationship between transport and land use that benefits urban planning (Liu & Zhu, 2004). Meanwhile, it also works as a major factor in efficiency analysis for transportation network and infrastructure planning (Gutierrez et al., 1998), as well as to analyze and distribute the travel demands on public transit (O'Sullivan, et al. 2000). Moreover, accessibility is also used to reduce social inequity, provide new road infrastructure (Curl, Nelson, & Anable, 2011), and evaluate regional impact from new transport construction (Linneker & Spence, 1996).

Mobility

An efficient transportation is targeted to make it affordable and fast to move both people and goods (Sohail, Maunder, & Cavill, 2006). To be more specific, the mobility measures the quality of movement and the quantity of objectives that have been moved (Zuidgeest, 2005).

Mobility usually associated with accessibility to defined the ease with which certain destinations can be reached from a particular origin using a specific mode of transport (Means & O’Sullivan, 2000). The mobility of a transportation network can improve the possibility that a destination can be accessed within a certain time or distance depending on the spatial distribution of activities, the origins of demands and transportation system connecting the origins and destinations.

Equity

Equity is used to identify whether the distribution of transportation is appropriate (Litman, 2002), which can split into horizontal and vertical types (Bogale, 2012).

Transportation infrastructure availability

Transportation infrastructure consists of basic engineer elements ranging from road length and width (especially per unit zoning or unit population), public transport hubs to street furniture. All these components can affect the accessibility and mobility of a transportation network, considering the density, service area, distribution. Links and nodes are two basic structural elements (Taaffe, 1996).

Spatial mismatch

The concept of spatial mismatch is originally proposed to assess the employment availability since the 1960s. It targeted at the analysis of the spatial difference between demand and supply. One critical application in transportation research is to analysis the option of transportation mode. Most of the existing sources focused on the relationship between transportation and economical as a basis to identify transportation development demands. Joseph involved income level into consideration for spatial mismatch to improve public transportation (Lau, 2011), Paul identified spatial mismatch by simulating employment and car ownership (Ong & Miller, 2005), while Coulson's team established an equilibrium model to indicate distribution differences between urban and rural areas (Coulson, Laing, & Wang, 2001).

Systematic indicators

Goldman & Gorham provided more flexible and integrated options of travel by identifying other four indicators from a system-oriented approach, respectively are New Mobility, City Logistics, Intelligent System Management, and Livability (Goldman & Gorham, 2006).Some of these strategies, such as vehicle sharing, new service paradigm, and comprehensive bus system management are inspiring and applicable for this research. While Paulley and his colleagues commenced from the socioeconomic aspects considering the quality of public transportation service, income, and car ownership (Paulley et al., 2006).

Systematic analysis is more suitable for research that focuses on or combines with non-spatial factors such as social works and policies, hence the indicators are not appropriate for this studies in the current progress.

Summary

Research gap

Existing transportation usually tends to negatively avoid ecological sensitivity areas to mitigate the ecological impact, while the nonmotorized routes usually built in natural places in urban areas or act as commuter ways for connecting different destinations. This negative transportation development leaves huge blanks to be improved either by providing healthier regional connectivity routes or improve accessibility to traffic attractors.

Ecological conservation priority and suitability analysis have long been discussed for decades, these works either focus on single issues that may affect ecosystem to figure out ‘how’ different parameters are related to ecology, or being considered as a foundation for practical research, such as helping with decision-making and instructing a plan. However, when integrating with transportation, the only research direction that can be researched is road ecology. Admittedly, nonmotorized ways have a much smaller ecological impact than roadways, they are newly developed and still extremely worth exploring.

Tools and indicators for comparative analysis

For county level research, this study used topological analysis to test whether the optimized transportation network can improve regional topological relationship to facilitate nonmotorized travel. Connectivity, integration, Total Depth, and Mean Depth are four indicators for the comparison. Impact assessment is also applied at this scale by overlaying the existing transportation network and ecological suitability map. In addition, OD matrix is applied to check the accessibility by least cost and reflect the concentration extent within the study area.

While at the city scale, the transportation network has denser distribution and easier to assess the service efficiency. This research took Gainesville as an example, evaluating the Service Area tool to see the service coverage and how far the traffic attractions can impact within different scenarios of travel time. Meanwhile, this study zoomed into areas as typical cases to test the generalized context suitability.

CHAPTER 3
METHODOLOGY AND DATA

This study is designed as a multidisciplinary research that integrating ecological network and transportation network towards sustainability. Three sessions are arranged progressively to conduct the study to approach the final goal, optimizing transportation network (OTN) through an ecology sustainable way.

The first part was to identify potential nonmotorized routes for the optimized for the study area from an ecological perspective considering various parameters and multiple screenings that could limit the ecological impact. While the following part consists of a comparative research that assesses the difference between ETN and OTN and a series of evaluation that assesses the service efficiency of OTN to see whether the ecologically based transportation network can serve development demand efficiently.

These two sessions lay a foundation for the comparative analysis of the existing transportation network and optimized transportation network to see whether the ecological approach contributes to improving the existing transportation network while adaptive to the context.

Applicable Tools

Geographic Information Systems (GIS) and Space Syntax (SSX) software are two platforms for conducting this research. GIS is mainly used for Raster analysis and network analysis to get a data-based systematic result, while the SSX is applied to focus on the topological relationship of transportation network analysis based on topo graphics.

Table 4 provides an overview of multiple tools and functions and related objectives based on each of the software respectively, each of the tools was following the research process. Each step and tools applied are listed below.

Table 4 Overview of software and tools for each step of analysis

Software Platform	Tools	Analysis
Geographic Information System	Raster Calculator	Ecological Suitability Map (Local)
	Cell Statistics	Ecological Suitability Map (Overall)
	Map Editor	Potential areas for commuters, visitors, and sportspeople
	Cost Connectivity	Potential New Routes
	Euclidean Distance	Proximity to existing transportation network
	OD Matrix	Least cost routes among multiple origins and destinations
	Service Area	Accessible coverage and service area that can be reached with time or distance impedance
Space Syntax	Axial Map	Linear assessment
	Depth Map	Depth assessment
	Segment Map	Integrity and connectivity assessment

Identify ecological suitability map (ESM)

Raster calculator is an essential step to get the ecological suitability map at the local scale, multiple indicators that represented in shapefile (a GIS data format) was collected from the local level and reclassified into 1-9 scale classification with proper weighting that has been discussed by the committee based on prior experiences for the calculation. The results are represented as ecological suitability map, where the higher the ecological value is, the more essential the priority is. This local scale ecological suitability map (ESM) is then combined with state scale ESM using cell statistics tool by both maximum and average approach to get the overall ecological suitability maps. The cell statistics maximum approach took the maximum value wherever the value is different between the ESM from two scales to ensure high priority will be protected during the following development. While the cell statistic average approach took the mean value of both county scale and city scale that balance the effect from the different measurement.

Identify traffic demand areas

Based on the types of destination and purposes of travel, Table 5 shows parameters for the various potential purposes of travel and characteristics of each kind of the trip option. This research selects three major travel purposes that happen within the study are, respectively are commuting, recreation, and education (usually combines with tourism). Commuting and recreational purposes of travel happen concentrate based on land use due to the function of zoning and property ownership. While tourism activities usually happen at places that are developed for such function (e.g. preserve), and these areas also have high potential to contain educational functions to lead people to be aware of the importance of ecological conservation. Hence land use and conservation area are two indexes for identifying potential traffic demand areas.

These purpose-oriented destinations are collectively called as the traffic attractions due to the attractiveness to various groups of people. Travel characteristics will be considered as one of the parameters to select nonmotorized transportation routes. Such areas are identified based on land use planning with functional area (e.g. get rid of the parking lot) that merge into one layer and then reclassify them into unified calculation scale with proper weighting to identify potential traffic demand areas in GIS raster calculator to get the traffic demand priority map.

Table 5 Identify potential traffic demand areas

Index	Purpose	Parameter	Subdivision	Travel Characteristics
Land use	Commute	Residential land		Point to point
		Institutional land	170 institutional 179 institutional under construction	
		Commercial land	143 professional service 144 cultural and entertainment 145 tourist services 149 commercial and services under construction	
	Recreation	Green space	180 recreational 185 park and zoos 187 stadiums 189 other recreational 190 open land	Accessibility to existing network
	Multiple use	Mixed use	147 mixed commercial and services	
Conservation areas and parks	Education Education Tourism	Conservation area Wetland Parks		Accessibility Free path inside

Get potential nonmotorized routes

Cost connectivity tool is recently updated new feature in GIS 10.4 or later version, which is applied to produces the least-cost connectivity routes among multiple areas. This research makes use of the principle of the tools, based on ESM, the higher the ecological priority is, the higher cost should be. Hence the map of potential nonmotorized routes map was produced by the least ecological priority routes.

Two more steps were applied to select nonmotorized routes. One is to identify the proximity to both traffic attractors and existing transportation infrastructure; the other is to analysis the land suitability based on land use type. Based on these two screenings, the final nonmotorized routes was integrated into existing road network as the optimized transportation network (OTN).

Comparative analysis between OTN and ETN

Both OTN and ETN are export from ArcGIS as DXF files, import to AutoCAD to check connectivity, and then import into Space Syntax for analysis based on the converted Axial Map. The Axial Map was adapted according to the transportation network (right of way and turning radius). For road network, the axial lines were adapted from road centerline. For nonmotorized routes, the axial lines were adapted from the path polyline due to the scale.

The axial roadway lines are the same in ETN and OTN. While the nonmotorized routes are different: the existing nonmotorized axial lines were adapted from existing trials that connecting to major roads, the optimized nonmotorized axial lines were integrated with the ones that generated based on ecological identification while adaptive to existing trails.

Data and Sources

Transportation base map is drawn by the author based on the GIS export and been verified and revises based on the Google aerial map. The GIS and the Google map were tools to eliminate and clean the transportation network data.

Data for GIS analysis were unified into shapefile files, either in Raster or Vector. Most of the shapefile came from Florida Geographic Data Library (FGDL) and applied to the local scale ESM, while ecological priority map at state scale was retrieved from the final report of Critical Lands and Waters Identification Project (Oetting, J., Hoctor, T., & Volk, M., 2016) that based on indicators that have been classified into biodiversity, landscape, and surface water resources, for statewide and regional analysis. These two scales of results are integrated as a final ESM to improve the validity.

For the transportation part, traffic attractions are identified based on land use and land cover (LULC) data (Florida, 1999) and conservation areas (from FGDL), which are then adapted from Google map to make sure the the current information is updated. The shapefile data for existing transportation network, including roads, trails, and bicycle lanes, are collected as secondary data from existing GIS database.

As for SSX analysis, both transportation networks (ETN and OTN) are export into DXF format, edit by AutoCAD to meet the requirement to run the topological calculation, and then import into SSX as an axial map that is ready for analysis. This part focus on comparative analysis based on the preceding steps.

Indicators and Weightings

This research classified single issue indicators into a two-layer hierarchy framework, which gets rid of secondary indicator such as the distribution map for ecosystem service value that based on land use, green infrastructure. The six classes respectively are landscape, habitat, watershed, conservation, green space, and land type, each of them has a subdivision with one or more indicators. These indicators are selected based on precedent research and feasibility of data source.

The weighting is ranked by the accessibility of each type and finally set by multiple times of attempts and discussion. For instance, habitats usually have larger areas that could go through as a shortcut for nonmotorized traveler while road traffic may have a long way detour. In addition, their vulnerability to human impact also makes the habitat index has the highest weighting. There are many reasons to support the vulnerability, take an extreme case as an example, animals are flexible and can migrate to another habitat that is more suitable for their life, once the migration happens, the original habitat either degradation or become an only landscape that is relatively quiet and still. Hence the Landscape index ranks following.

Table 6 provides the proportion of each indicator under index classification and weighting for each index. Still, take habitat as an example, the index of habitat account for 25% of overall weighting for suitability calculation among other indexes, while the proportion column represents sub-weighting under this 25% part, thus the weighting of the potential habitat richness is 25% * 25%= 6.25%.

Table 6 Suitability objectives, indicators, and weightings to identify ecological priority areas

Index	Weighting	Indicator	Proportion
landscape	20	landscape integration index	35
		landscape resource priority	35
		natural community	30
habitat	25	potential habitat richness	25
		biodiversity	25
		habitat conservation area	25
		strategic habitat conservation area	25
watershed	15	surface water resource priority	25
		groundwater recharge area	20
		floodplain	25
		wetland	30
conservation	15	FLMA	100

green space	10	greenway	100
land	15	land use	40
		land cover	60

Criteria and Assessment

To select potential traffic demand areas

Due to the limitation, considering the typicality of sample areas, as well as the potential demand and effect for both ecology and transportation, the acreage of mixed-use clusters were seen as an essential factor to select potential areas among the variety traffic attractions. On the one hand, mixed use can attract more people and potentially trigger more activities. For instance, one family plans to eat in the restaurant, if there is a park or supermarket nearby, they would possibly go for a walk or shopping while back home if there is only a restaurant. On the other hand, large area, especially large conservation areas interdict the construction of road traffic, thus have more demands for nonmotorized traffic to improve the transportation network.

Based on the travel purposes listed in Table 5, ten kinds of level 3 land uses are selected, including Commercial and services, commercial and services under construction, institutional, open land, Recreational, other recreational, Parks and zoos, Residential high density (six or more dwelling units per acre), Residential high density under construction (six or more dwelling units per acre) under construction), and Tourist services. Then combine with Basemap and Reference to create a new layer that identifying mixed-use clusters. These clusters are then further screened by areas that larger than 150 acres as the sample, and export to a new layer as potential traffic attractive area based on land use.

The other part of potential traffic attractive areas is identified based on existing conservation areas that work for tourism and educational purpose. Using Calculate geometry to update the values of areas by acres of conservation land, from which potential areas are identified by acreage that larger than 1000. Three places that locate in northwest part of Alachua County that is less than 1000 acres were included because they are crossing the political boundary, where the calculated areas within the study area are smaller than while the total acres of these conservation areas can meet the acreage criteria.

These two kinds of potential traffic demand areas are then merged as the input feature called traffic attraction, and then run Cost Connectivity based on the ecological value to get potential nonmotorized routes.

To select nonmotorized route for an OTN

Two screening criteria are applied to select nonmotorized routes, respectively are land use type (considering ownership that affects public accessibility) and proximity to existing nonmotorized routes.

This research reclassifies land use into five classes in 1-9 scale, based on land use type level1 and level2 when needed (

Table 7). The higher value represents higher suitability for nonmotorized routes. Agriculture, Rangeland, and upland forests were the most suitable types of nonmotorized routes for a healthy environment and less construction. Commercial and services, Institutional, and high-density residential were secondary suitable. However, the demand for more privacy made Residential lands rank in class 5. Open land ranked in the same class because of the necessity to reserve for future development, thus at a medium level suitable for nonmotorized routes. Water and wetlands were exception areas for nonmotorized routes construction because of the highest level of conservation priority, while utility lands were not suitable due to the security and management requirement. The rest of the land use types were put into class 3.

All land use types except Class 1 were potential locations for nonmotorized routes; other classification values are applied only when multiple routes are available connecting same destinations to select a better path.

Table 7 Land suitability classification for nonmotorized routes

Level 1	Level 2	Class
Agricultural	/	9
Barren land	/	9
Rangeland	/	9
Upland forests	/	9
Transportation, communication, and utilities	Transportation	3
	Communication	3
	utilities	1
Urban and built-up	Commercial and services	7
	Industrial	3
	Institutional	7
	Open land	5
	Residential, high density (six or more dwelling units per acre)	5
	Residential, low density (two or less dwelling units per acre)	3
	Residential, high density (two to five dwelling units per acre)	3
Water	-	1
wetlands	-	1

Next screening is identifying the proximity to existing transportation network. To calculate the proximity to existing nonmotorized routes, this research run Euclidean Distance tool, using quantile classification to get the result. The reason for using quantile classification results from the diminishing impact from existing routes, thus the more adjacent to the existing route, the less demand for a new route construction.

Meanwhile, nonmotorized routes can combine with road network under the prerequisite of concerning about safety for nonmotorized travelers.

Commuters use nonmotorized routes more than other purposes of travel because commuting is necessity activity while others might be spontaneous activity. Hence this indicator has the highest weighting. However, the proximity to low traffic area could be either be a lack of or unnecessary for traffic development. Thus this indicator has a lower weighting. Other indicators have the same weighting result from being no big difference in importance for traffic demand.

Table 8 Suitability objectives, indicators, and weightings to identify priority for nonmotorized routes

Suitability Objective	Weighting	Indicators	Proportion
Identify areas proximal to low traffic roadways	15	Annual Average Daily Traffic	15
Identify areas proximal to mixed- use lands	20	Adapted from the Google map, attractor	20
Identify areas proximal to existing nonmotorized trails			
Identify areas suitable for nonmotorized routes based on land use			
Areas with traffic Attraction	65	For commute	25
		For recreation	20
		for education and tourism	20

CHAPTER 4
RESEARCH PROCESS AND RESULTS

Study Area

Overview

The study area, Alachua County, locates North Central Florida, with a total area of 969 square miles (620160 acres), and has a diverse culture, local music, and artisans. The county has about 100,000 acres of conservation lands that supporting the health of the ecosystem, where some of the conservation areas are shared with adjacent counties (e.g. Columbia County that located at northwest) from a regional perspective. Gainesville, the county seat and the largest city in this county, contains multiple institutions, such as University of Florida and Santa Fe College, was awarded by National Geographic Adventure magazine as one of the 2007 "best places to live and play" in the United States[1], containing 71 parks and natural areas.

The county has a multiple layer road system, which is served by northwest-southeast Interstate 75 (I-75), several Florida State Routes (such as US27, US41, US301), other county roads and local streets. While in more urbanized areas, such as Gainesville, grid system forms up the core pattern for the transportation network with northwest, northeast, southeast, southwest four quadrants.

Even so, dealing with urban ecology is one of the critical issues that a complete transportation network was faced with, especially the routes that are connecting traffic attractions. Typically, the transportation routes are distributed to avoid the ecologically sensitive area at the very beginning of planning process to minimize the ecological

1 "The Best Places to Live + Play: Cities". National Geographic. Archived from the original on April 16, 2008. Retrieved 2008-04-16.

impact. However, this results in the insufficient connection of road networks, such as only one street connecting a residential area to a major road due to the wetland at the other sides of the property, which further impact on the trip options and convenience of travelers.

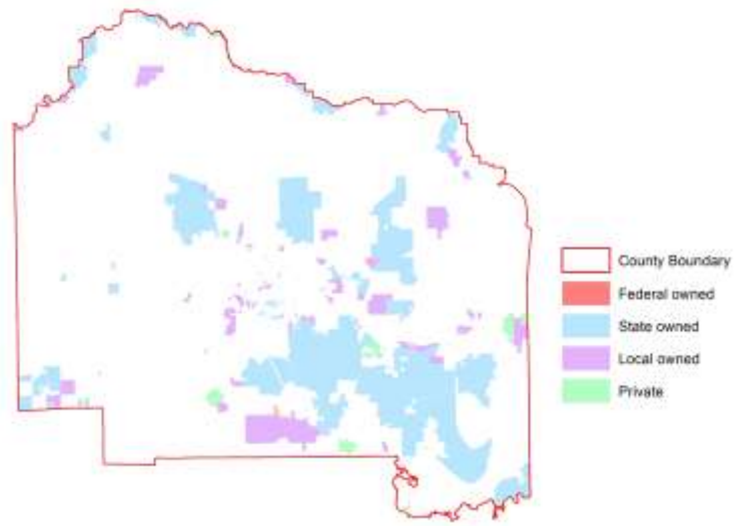


Fig. 4 Ecological conservation area in Alachua County

Fig. 4 shows the distribution of ecological area, including wetland conservation areas, urban parks, and community gardens, and their relation to the urban transportation network. Most of these areas, especially those have larger areas, left holes while only several of them are connected to existing road network by trails. Thus, to integrate transportation planning with urban ecology, the connection between natural area and road network is an essential process that needs to be addressed. Moreover, according to the final report of Alachua County Countywide Recreation Master Plan Phase 2, an interconnected system of greenways and trails is one of the top 10 countywide recreational desires (Robert M., 2005), which indicated the high public desire that in concordance with the objective of this research.

Considering of the vulnerability of urban ecology, this study researches on the nonmotorized routes concerning both minimize environmental impact and improve accessibility and connectivity of transportation network as an optimized transportation network.

Admittedly, this issue has been considered by multiple departments, however, from the previous actions and fiscal year plan, there are still many things to do to improve the transportation network. On the one hand, ongoing regional transportation connection projects mainly focus on road traffic when considering accessibility. Significant Projects is a representative example (Transportation Improvement Program, 2017). On the other hand, multiple nonmotorized projects only concern within Gainesville Urbanized area rather than the connection among the surrounding region, such as Bicycle and Pedestrian Projects (Transportation Improvement Program, 2017), Bicycle/Pedestrian Priority (List of Priority Projects, 2017), and Bicycle/Pedestrian Advisory Board (Public Involvement Plan, 2017), Transit Ridership Monitoring Report (Annual Transit Ridership Monitoring Report, 2017). In addition to taking advantage of bicycle culture near the university, this research focuses on the direction that was forgotten by the authorities, to identify potential nonmotorized routes that are connecting among urban clusters and conservation areas at the regional scale to optimize transportation network.

Population

Alachua County has an uneven distribution of population density (Fig. 5). Urban centers and community clusters attract more population and contain more human activities than rural areas that are unincorporated. In order to balance thr equity of accessibility while saving road construction cost, new nonmotorized routes are an indispensable part of the transportation network to connect traffic attractions among the study areas.

Gainesville has long been the top population place in Alachua County (Fig. 6), and its population keeps increasing according to the historical census statistics (Fig. 7). To optimize the existing transportation infrastructure for better service coverage and higher efficiency is an additional essential part.

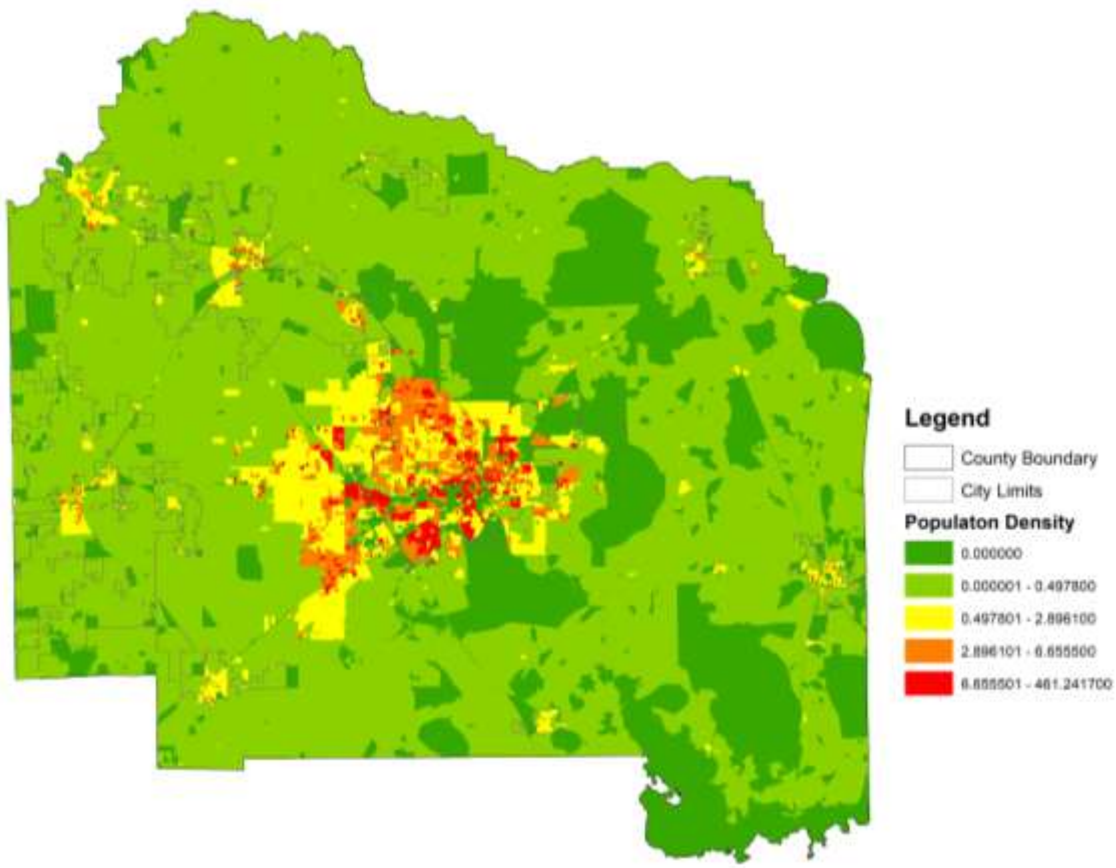
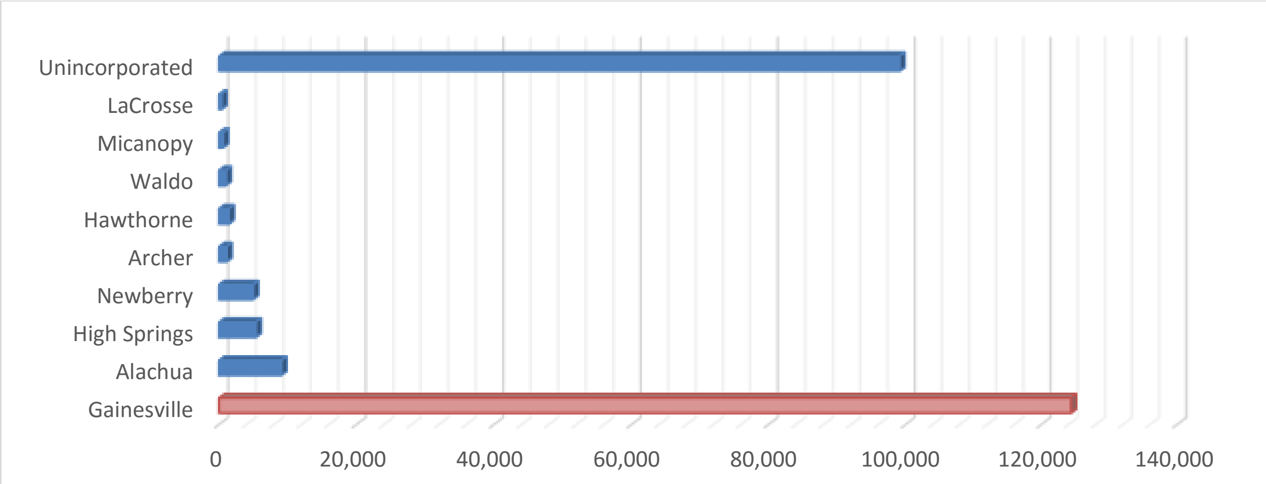


Fig. 5 Population density in Alachua County



	Gainesville	Alachua	High Springs	Newberry	Archer	Hawthorne	Waldo	Micanopy	LaCrosse	Unincorporated
Census 2010	124,354	9,059	5,350	4,950	1,118	1,417	1015	600	360	99,113

Fig. 6 Census of City/Towns population in Alachua County (2010)

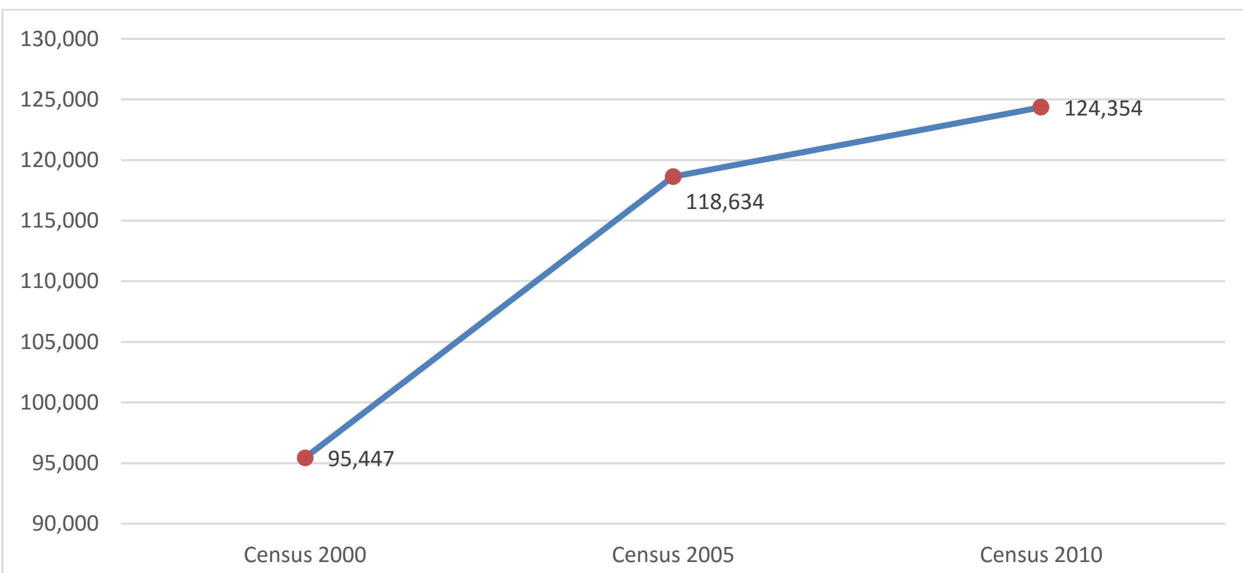


Fig. 7 Population increase in Gainesville

Transportation facts

Alachua County has 80% Single occupant vehicle for travel since 2014, while the Transit mode share to work is only 2.1% (DATAUSA, 2015). However, the mean commute time in Alachua County is only 26.4 minutes, which is compatible to develop nonmotorized transport.

From the old travel mode in the State of Florida, private motor vehicles such as cars, trucks, and vans kept the dominant position, but with a decreasing trend (Fig. 8). Other kinds of travel modes show a clear increase, which implies the potential for developing nonmotorized transportation (Fig. 9). However, when comparing with the average level of the state, the study area has nearly three times of nonmotorized traveler than that of Florida (Fig. 10). Such changing trend of travel mode also verified the demand of developing nonmotorized transportation infrastructures.

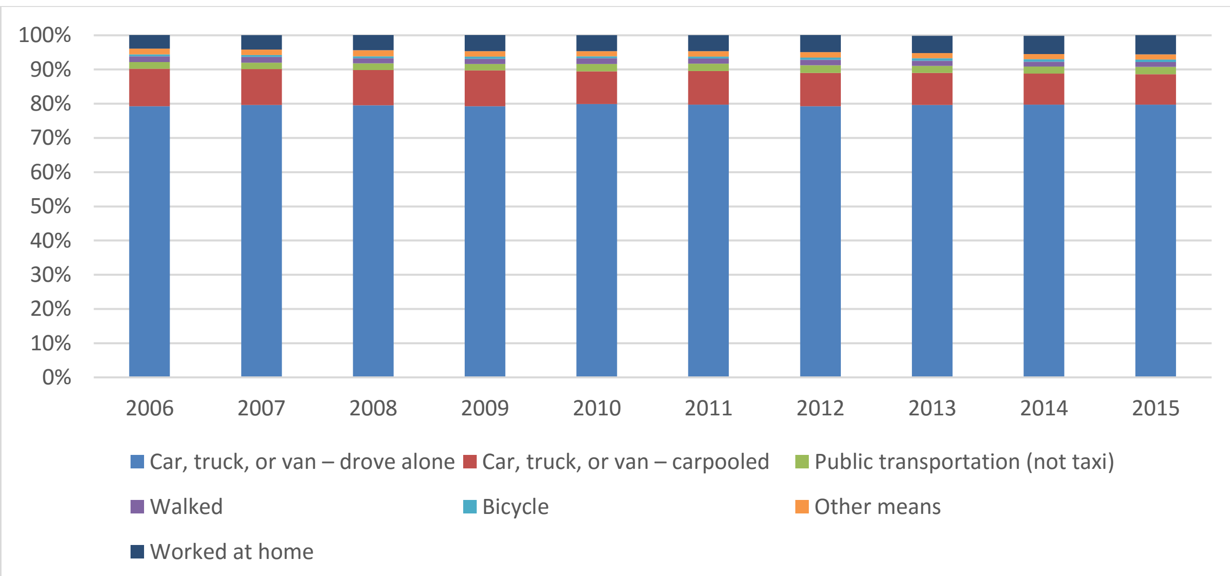


Fig. 8 Travel mode change in Florida (2006-2015)

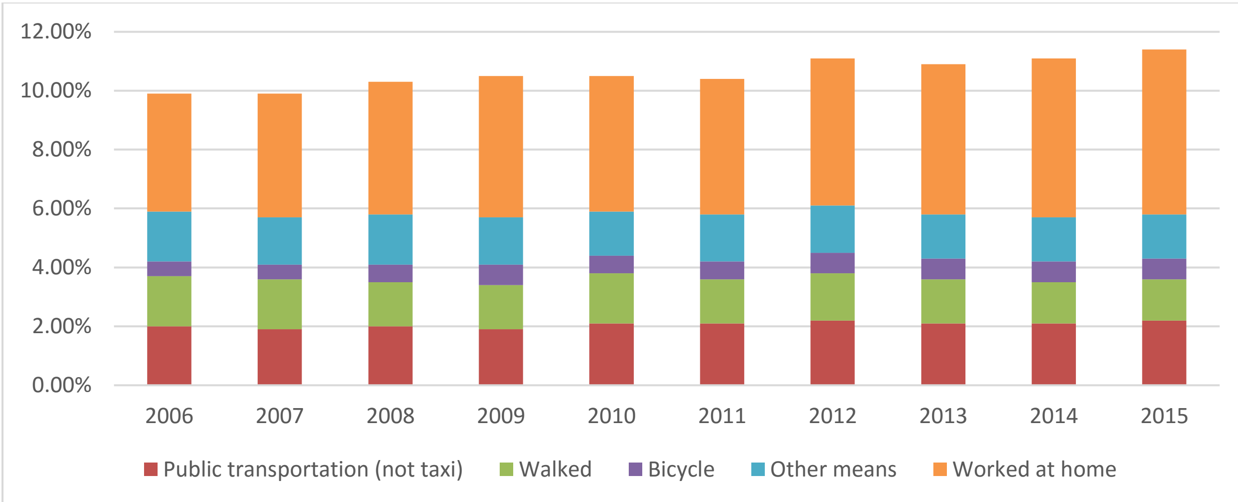
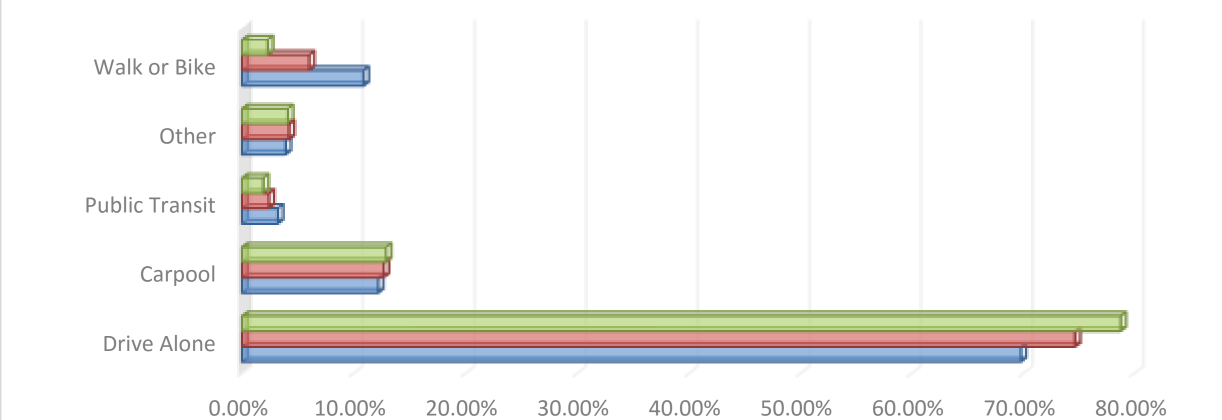


Fig. 9 Nonmotorized travel mode change in Florida (2006-2015)



	Drive Alone	Carpool	Public Transit	Other	Walk or Bike
Florida	78.80%	12.90%	1.90%	4.10%	2.30%
Alachua County	74.70%	12.70%	2.40%	4.20%	6.00%
Gainesville	69.80%	12.20%	3.20%	3.90%	10.90%

Fig. 10 Annual average travel mode proportion in state, county, and city scale

Identify Ecological Suitability Maps

Local scale ecological suitability map was the result by overlaying six classifications with multiple indicators, respectively are landscape, habitat, watershed, conservation, green space, and land use (Table 6). Each of the indicators was classified into 1-9 scale as single maps for the overlay calculation where higher level refers to the higher ecological value (example in Fig. 11).

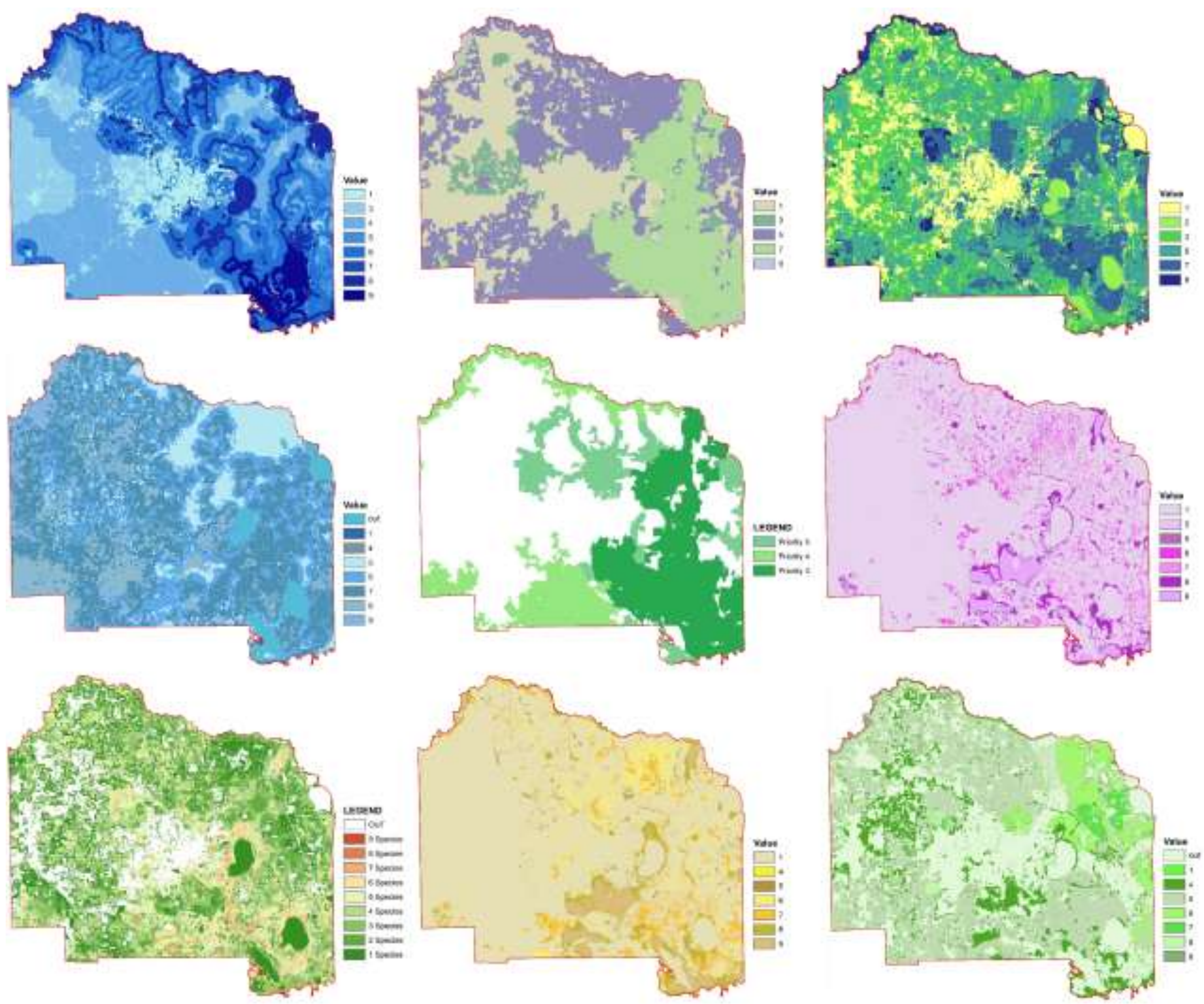


Fig. 11 Examples of single indicator map for ecological suitability identification

Data-based ESM

In order to get more precise analysis, the original ecological suitability maps were generated based on two scales: the local scale data that is localized and specific to the context-based situation (**Error! Reference source not found.**), and the regional scale map that more suitable for research at regional scale (**Error! Reference source not found.**). Local ESM is calculated based on using raster calculator, while the CLIP project provided the regional ESM. The symbology of suitability maps was reclassified into five levels color range for the following analysis. The ecological value (conservation priority) increases from blue to red.

The calculation of local scale ESM was comprehensive, but the weighting of each index was adapted based on the summary of literature review and the discussion with committee members. While the state level ESM was tested and verified after four updated project versions. Overall, the regional ESM considered riparian factors more important. Hence the linear water flows are more clearly shown in **Error! Reference source not found.** with higher priority.

Tool-based ESM

These two maps result from Cell statistics tool based on the unified classification and symbology by two approaches. One is the Cell Statistics Maximum approach, which referred to get the higher value of whichever layer the data came from to make sure high ecological priority areas were protected no matter what process was done to get the result. The other one is the Average approach, which calculated the mean value of both layers to treat with local priority and regional priority evenly. These two maps were prepared as the basemaps for the following selection when portable nonmotorized routes were identified.

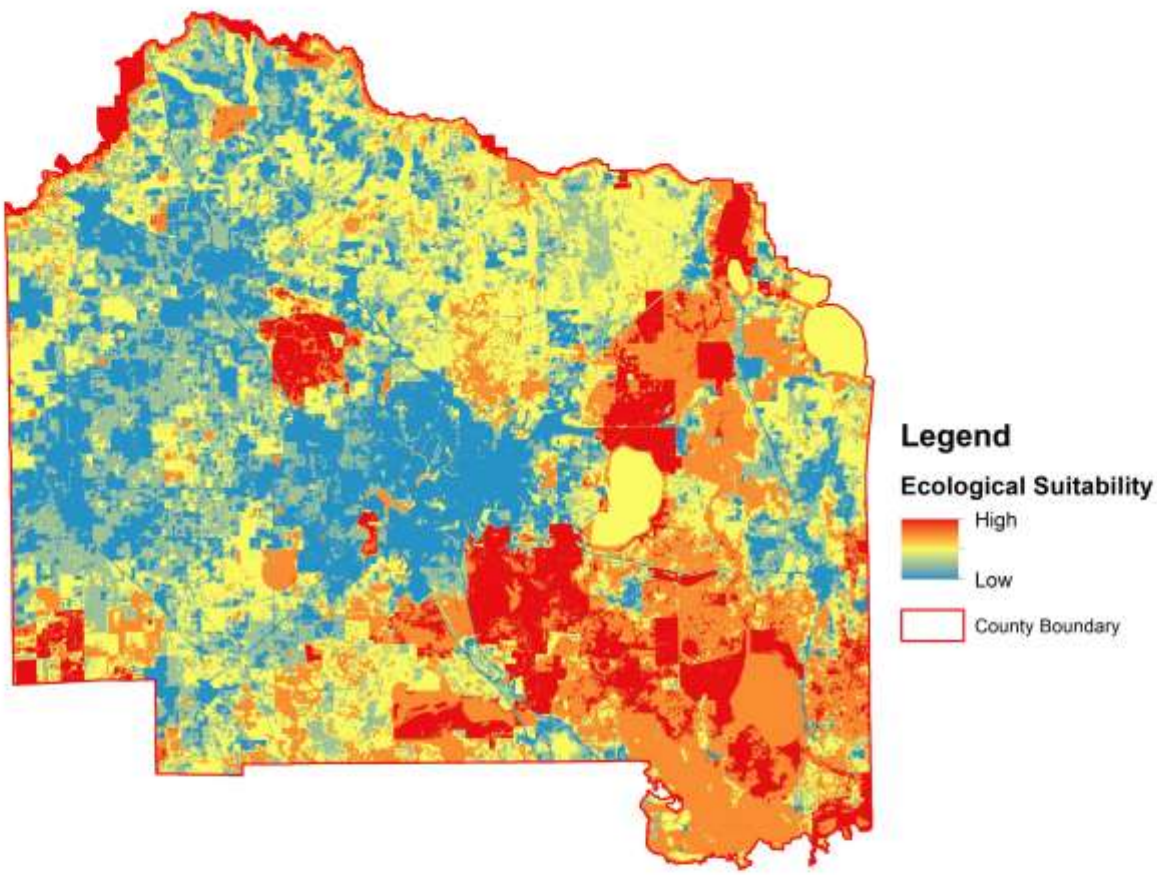


Fig. 12 ESM based on cell statistics maximum approach

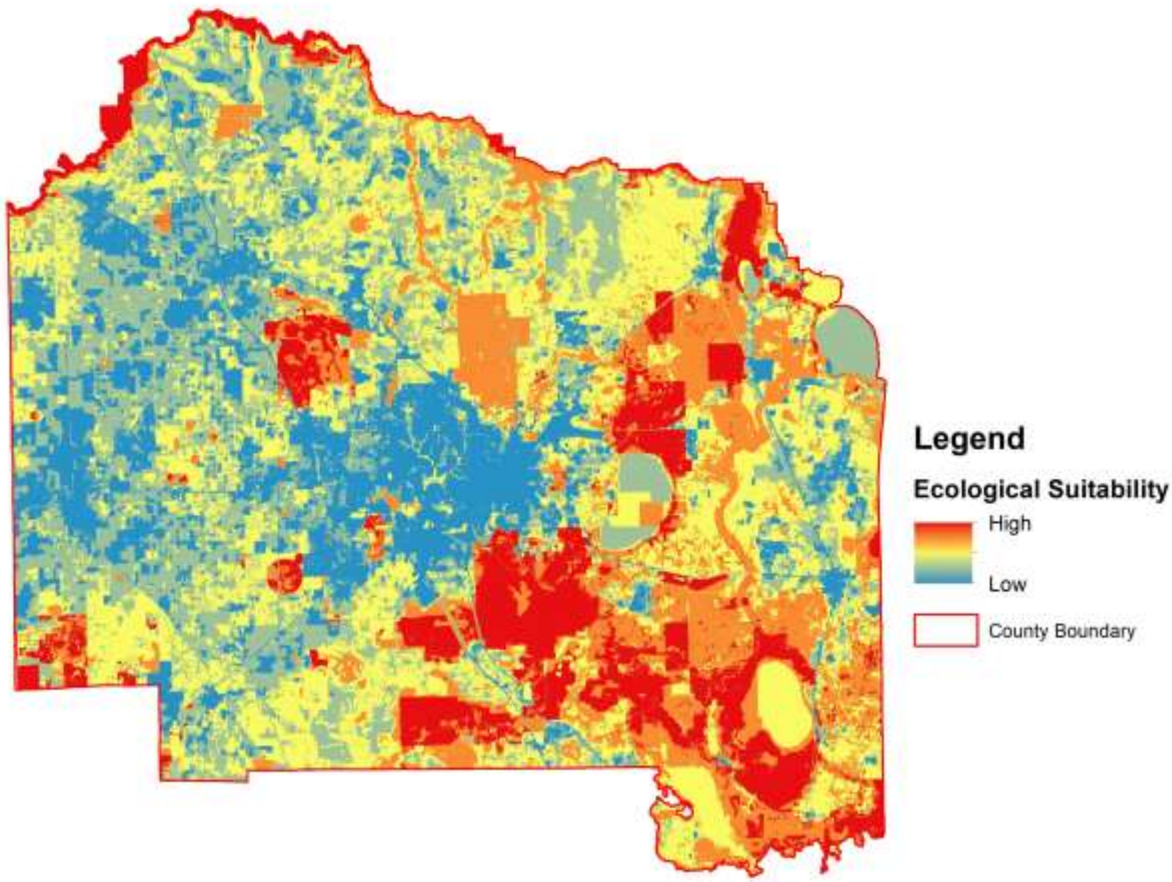


Fig. 13 ESM based on cell statistics average approach

Identify Traffic Demand Areas

Traffic attractions are the most obvious indicators of traffic demand and could be identified easily for the purposes of travel and the density of traffic attractions. This research identified three major types of travel purpose, respectively are commuting, recreation, and education, based on land use type. Commuter attractive areas concentrate on convenience that is directly connecting origins to destinations, and the two endpoints of each route are either the high-density dwelling districts or working places such as institutional lands. While recreational attractions consist of multiple land use types, including commercial and services, parks, open spaces, and so on. Educational is a concept of tourism development that can potentially appeal people to get aware of the importance to protect ecology and living environment. Hence this purpose of travel focuses on conservation areas. Based on the fact that all these types do not have impacts on potential routes producing, all these areas are eventually selected and merged into one layer to identify mixed-use cluster within the study area when overlapping among three kinds of travel purposes.

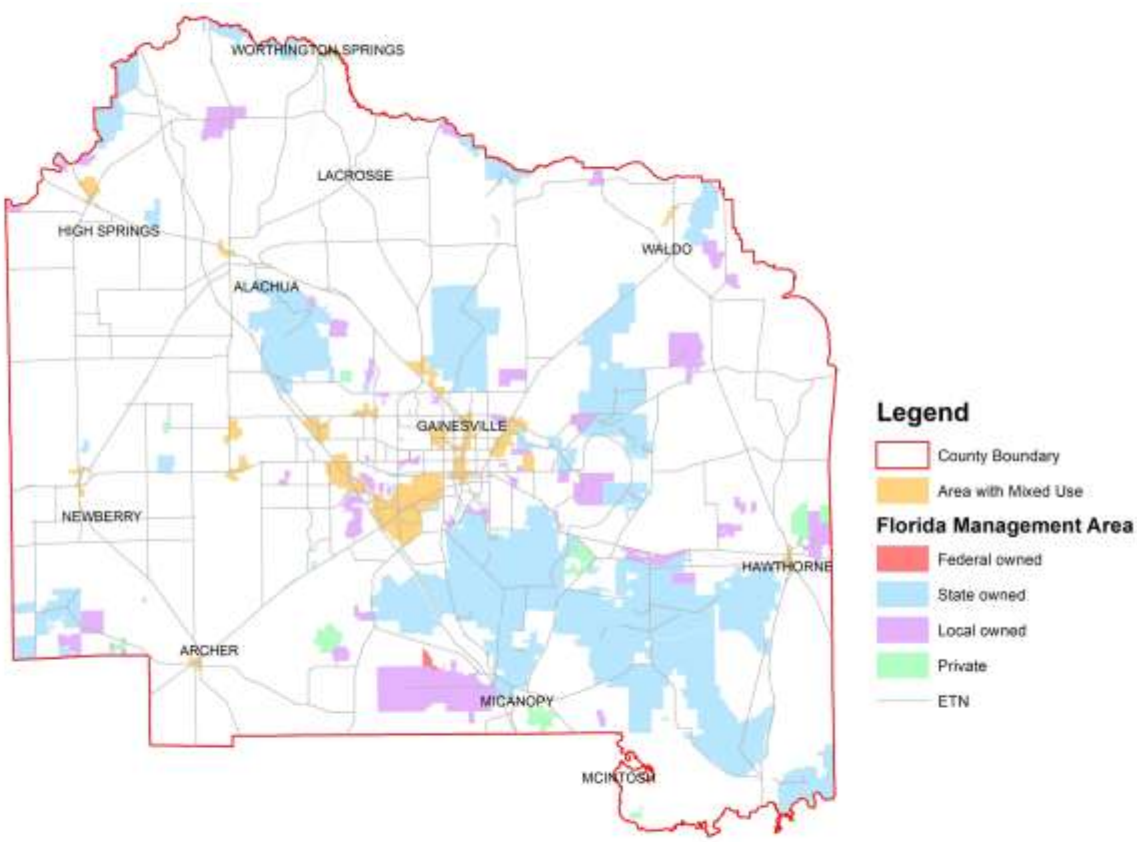


Fig. 14 Potential traffic attractions in Alachua County

This research applied both generalized land use type with mixed use and ecological areas and then merged them into one layer. Urban mixed-use areas that more than 150 acres and ecological areas that are larger than 1000 acres were selected as potential nonmotorized traffic attractions (Fig. 14).

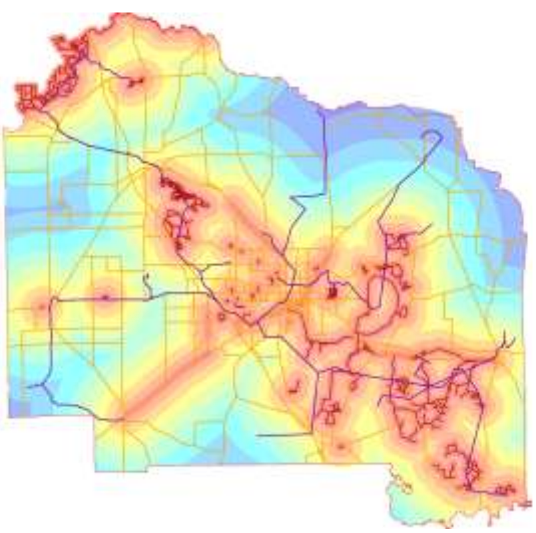
Identify Applicable Nonmotorized Routes

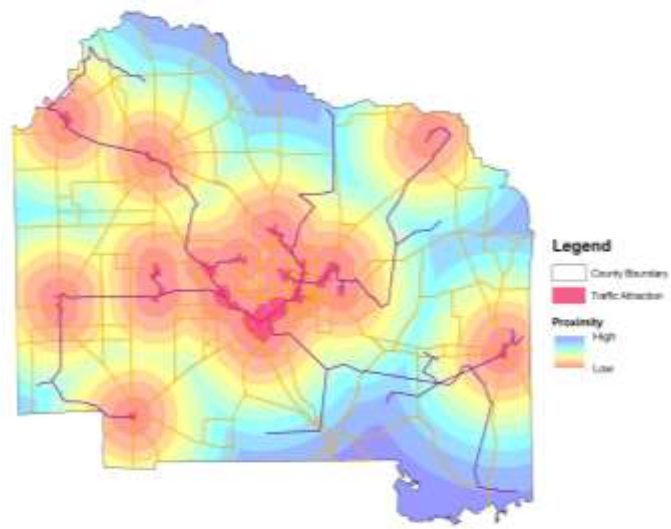
Based on the evaluation of ecological suitability and the identification and selection of potential traffic demand areas, cost connectivity tool was applied to get the least ecological impact routes with road network as a location reference. Fig. 16 and Fig. 15 respectively represents the nonmotorized routes that calculated based on the two too-based ESMs.

Fig. 15 Potential nonmotorized routes from ESM based on cell statistics maximum approach

Fig. 16 Potential nonmotorized routes from ESM based on cell statistics average approach

Two more screening steps were conducted to select from the two routes options to get the final nonmotorized route. The first step is objected to identifying the proximity to existing transportation network (Fig. 18) and potential traffic demand areas (Fig. 17) to ensure the service efficiency and avoid duplication as the prerequisite to prevent duplicate construction. The next step follows up is to analyze land suitability based on land use type, considering the public accessibility and frequency of utilization. Based on this part, the final nonmotorized routes were selected and then integrating with existing trails that have a limited ecological impact to form up the optimized transportation network.





- Fig. 18 Distance to existing trails
- Fig. 17 Distance to traffic attractions

When applying optimized nonmotorized routes, this research identifies shortcut for commuters to travel efficiently from origin to destination comparing to the road traffic. This type of routes is more suitable for cycling, which is faster and less sensitive to surrounding landscape. While for recreational and educational routes, multiple choices and adaptiveness to the context are more important, especially in a conservation area, since several micro-modifications have less ecological impacts than a single huge construction. These two types of routes are more suitable for pedestrian and trials.

For instance, the San Felasco State Hammock Preserve is planned to function both for nature and recreation, one-thirds of the area is used to provide outdoor adventure, such as hike trails, off-road bicycles, horseback rides. Moreover, the reserved fire corridor also leaves space for nonmotorized routes that have limited ecological impacts (Fig. 19). While Paynes Prairie Preserve, as Florida´s first state preserve and National Natural Landmark, contains more than 20 distinct biological communities with extremely high conservation value. Only a few trails and several annual events open in this area (Fig. 20). Such highly ecologically sensitive areas are more suitable for hiking trails and rather than com

Fig. 19 Fire corridor in San Felasco State Hammock Preserve

Fig. 20 Recreational activities with limited impact in Paynes Prairie Preserve

Comparative Analysis

Ecological impact

Identify the confliction between existing trails and the ecologically sensitive areas is essential to compare the ecological impact from ETN and OTN. Optimized routes were generated based on the principle to avoid high ecological conservation priority areas with limited impact while existing trails have confliction with ecological priority.

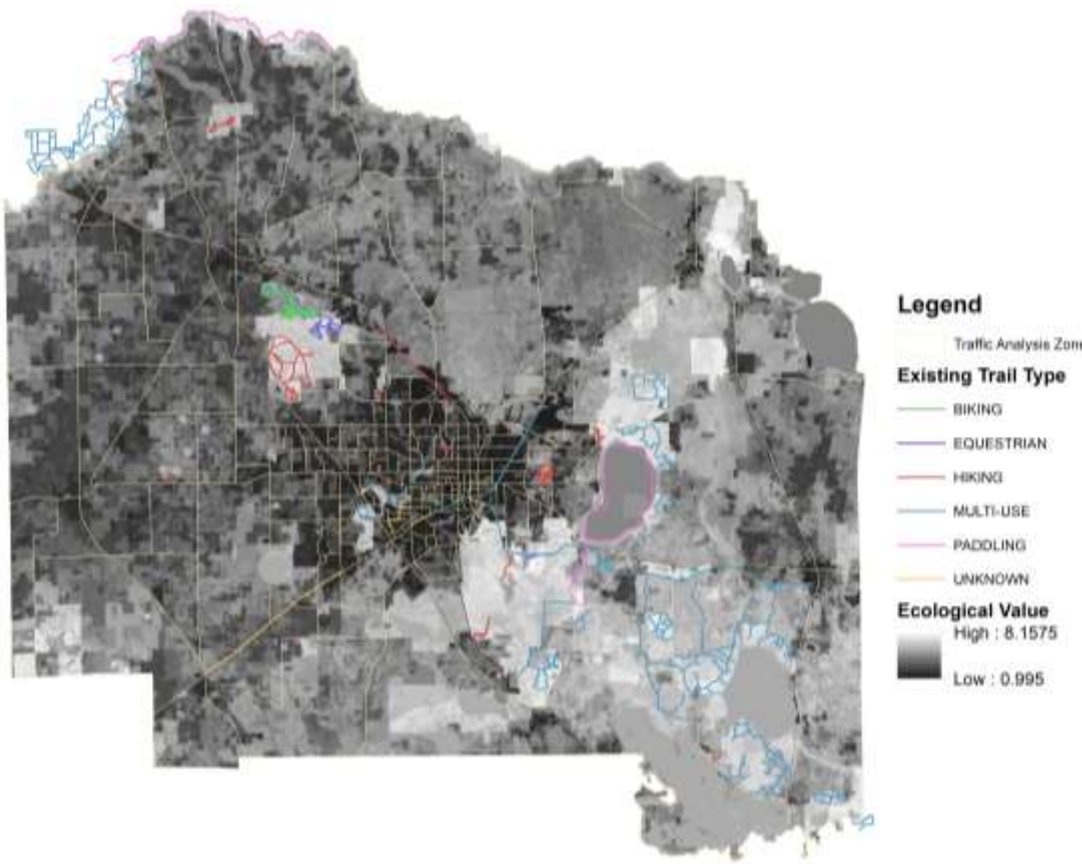


Fig. 21 Distribution of existing trails and ecological priority areas

In order to have these confliction areas identified, this research set ecological suitability map with black to white stretch symbology where white color represents the highest priority, and then overlay the existing trails to see where conflictions fall (Fig. 21). 41 out of 123 existing trail records were built or partially constructed in the highest ecological priority area, which is nearly 35% percent of trails. Let alone the trail length since trails in the preserves are much longer length than in urban area.

This lead to the spatial mismatch that some of the existing trails located in the ecologically sensitive areas, which may have different extent of the ecological impact. For instance, paddling trail in Newmans Lake is less impacted than multi-use trails that are going through the Paynes Prairie Preserve. The optimized nonmotorized routes that identified based on ecological priority has avoided such areas to minimized ecological impact.

Topological relationship

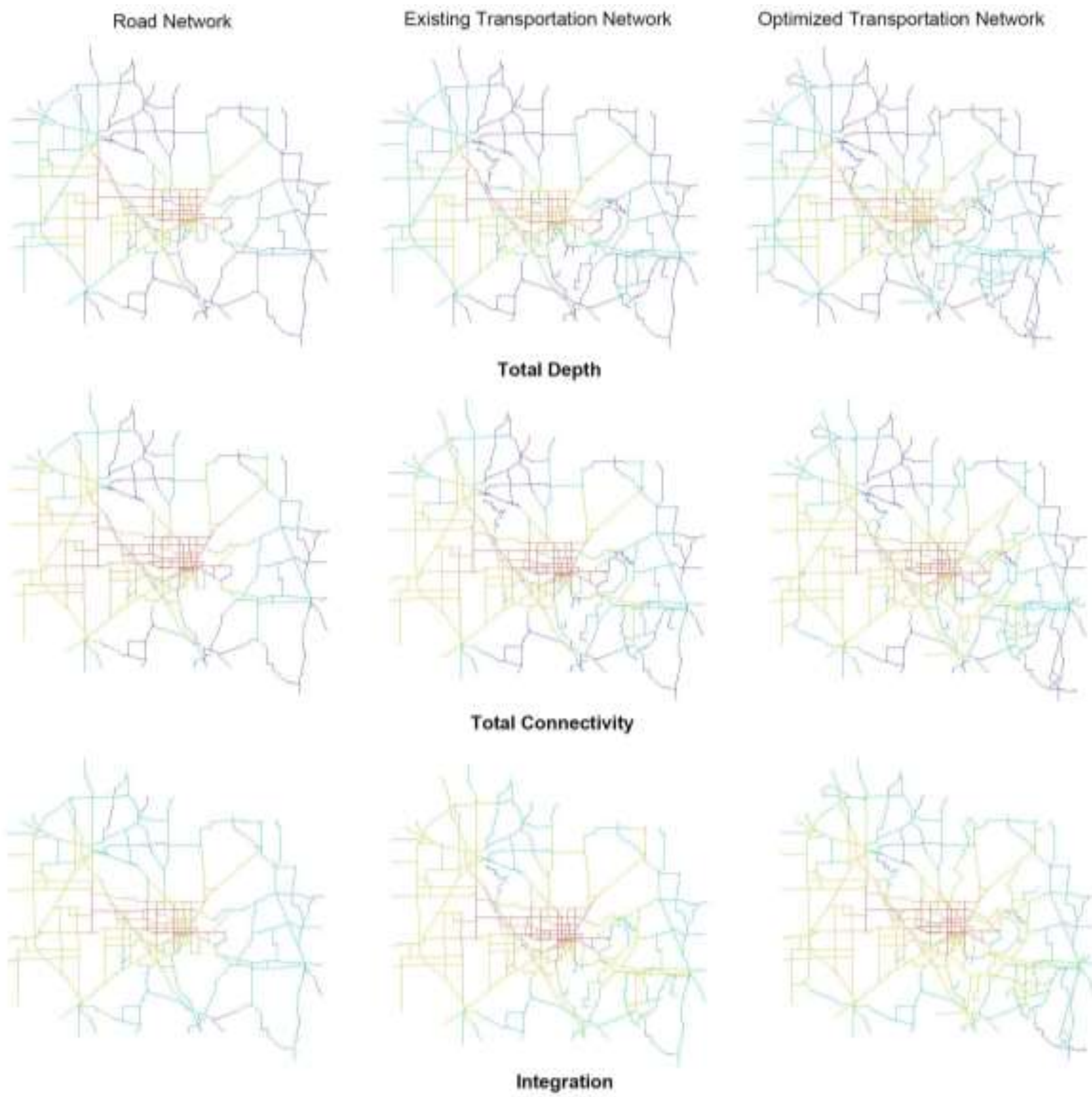
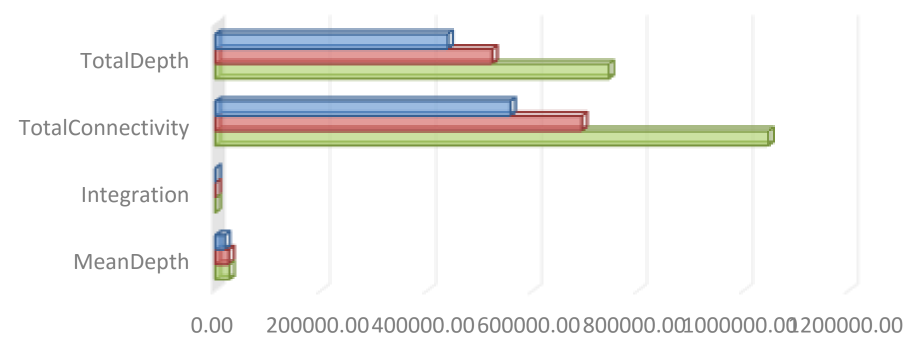


Fig. 22 Axial map for existing road network, ETN, and OTN considering total depth, total connectivity, and integration

This research selected three major indicators, respectively are connectivity, integration, and depth, for topological analysis that produced results for both graphical comparisons that ranked the level of hierarchy relation and statistical comparisons that visualized the statistic data with tables. The results show no big difference in network hierarchy and implicit service efficiency level, but the actual quantity of interrelationship improved a lot from ETN to OTN.

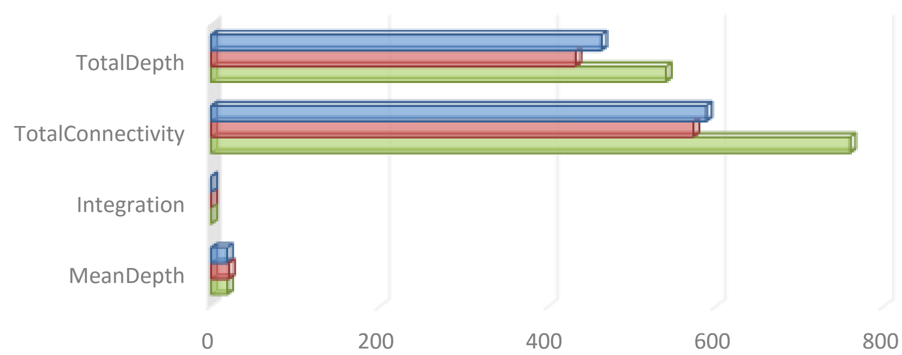
Fig. 22 show the importance of service hierarchy among three networks considering depth, connectivity, and integration. The color refers to a higher level when closer to red, while the blue color means the lowest value. The result of the graphical comparison shows that existing nonmotorized routes did not change the ranking level of each segment of major road, while the optimized nonmotorized routes increased 1-2 level of road network importance when with certain density (e.g. the Paynes Prairie area). Overall, among all three indicators, the most efficient part of network concentrated in Gainesville area, and the High Spring and Alachua area took the second place.



	MeanDepth	Integration	TotalConnectivity	TotalDepth
Road Network	17964.76	401.94	557577	438798
Existing transportation Network	25655.28	479.96	692817	523165
Optimized Transportation Network	26523.89	610.69	1046976	743710

Fig. 23 The comparison of total value among four indicators

However, the extent of improvement is evident when visualizing statistical data. Because the exact value of information is clearer to show the difference, this part further divided the depth indicator into total depth and mean depth for the comparison. The values are calculated by Sum and Ave function to get the result of both total value and the average value of each indicator. Fig. 23 shows the total value of network topological relationship, each of the value has significant growth from single road network to existing transportation network and then to optimized transportation network.



	MeanDepth	Integration	TotalConnectivity	TotalDepth
Road Network	18.97	0.42	588.78	463.36
Existing transportation Network	21.22	0.40	573.50	432.73
Optimized Transportation Network	19.26	0.44	760.33	540.09

- Fig. 24 The comparison of average value among four indicators

Nevertheless, the average value is quite different, which result from the context background and interrelationship with other factors (Fig. 24). The average mean depth value of both ETN and OTN are higher than that of road network because the nonmotorized routes expanded accessible areas that were not able to reach by road network. The lower value of OTN Total Depth with optimized nonmotorized routes result from the better connection to the road network, while the existing nonmotorized routes have poor linkage to the road network. The total value has concordance result as the average value of connectivity. The average values of integration have the same trend as the total value of integration. OTN has the highest average value of depth because it broadens the coverage of network service area so that more places that used to be far away are now accessible.

Service efficiency

Network analysis

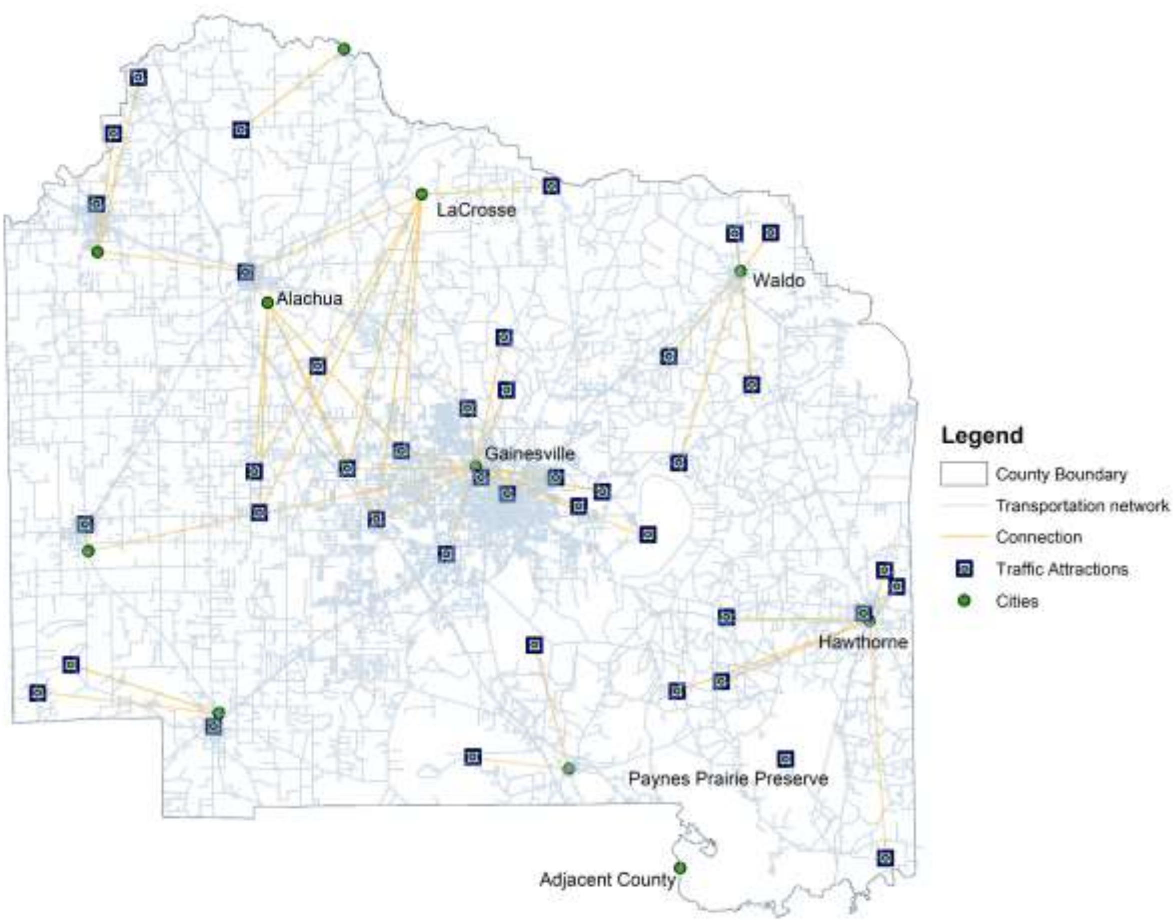


Fig. 25 OD Matrix in Alachua County based on the optimized transportation network

OD Matrix was applied to assess the least cost route among multiple origins and destinations. This research firstly calculated the centroid of each city limit polygon as origin points, and then used the polygon centroid of each traffic attractions as destinations to ran the OD Matrix.

The result in Fig. 6 shows that the only origin that was not connected to the traffic attractions was the centroid of the town that managed by the adjacent county. Thus all the cities and towns in Alachua County is well connected to traffic attractions with reasonable cost. While the only destination that is not connected to any origin urban area located in the Paynes Prairie Preserve, which has good accessibility when considering the real boundary rather than a centroid point.

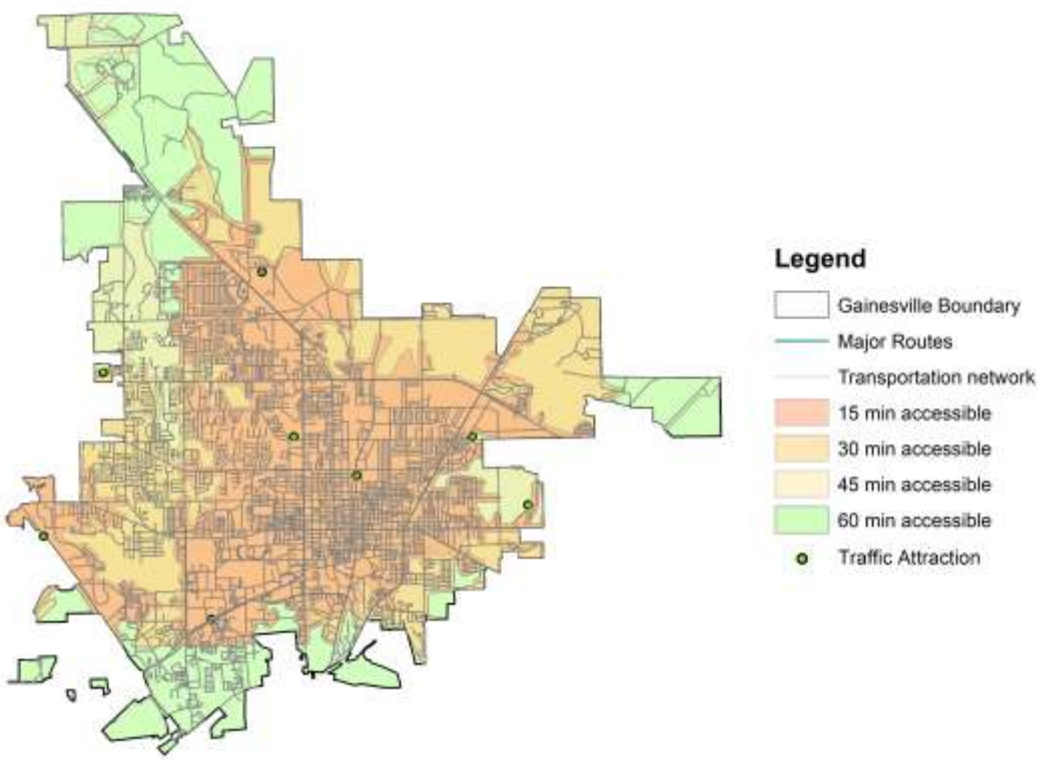


Fig. 26 Service coverage with time impedance in Gainesville

For connection density aspect, it is evident that Gainesville, Alachua, Lacrosse, Waldo, and Hawthorne has centralized attractiveness among surrounding areas. Traffic attractions between the Gainesville and Alachua are more attractive and have higher potential to develop nonmotorized routes because they connected to three of the major cities in the study area, respectively are Gainesville, Alachua, and Lacrosse. Such highly functional areas result in accord with the location of the optimized nonmotorized routes that were generated based on ecological suitability.

When zooming into the city scale, this research set impedance of cycling travel time under four spans, every 25 minutes in an hour (15, 30, 45, 60 minutes) with 16km/h to see the service areas that the traffic attractions can impact and be accessed. 46.03% of the Gainesville area can access traffic attractions within 15minutes by bike, 23.12% of the areas can access traffic attraction in 15-30minutes (Fig. 26). Thus, the half an hour service coverage, as the most urbanized areas in Gainesville with a high density of transportation routes, is holding nearly 70% of the Gainesville city limit area. Such 30 minutes cycling time is acceptable for most travelers. The rest areas that are far away or with un-urbanized land use are accessible within one hour.

Context suitability

One typical example that has confliction between transportation and urban ecology in Gainesville is Hogtown Creek watershed. Multiple actions and strategies have been taken to reach the environmental, educational, and transportation goals (Gainesville (Fla.), 1994), however, even though trails were considered factors, the concern of the previous plan was focused on the confliction between the roadway and ecological conservation.

Three trails at midstream of Hogtown Creek were selected (Fig. 27). By comparing with previous plan and existing condition, trail 1 remains the same in the optimized nonmotorized route, which declares that this trail is eco-friendly. Trail 2 (Ring Park Trail), is slightly changed from going all the way along the creek to a detour at the north end where located between a lodge and residential complex. This makes the trail

2 have larger service coverage while connecting to NW 16th Ave at which is 60 meters away from a bus stop. This case shows the improvement of the continuous efforts. However, the reason that two existing trails are ecological friendly may result from the existing condition, thus the trail path with low ecological sensitive might because construction was already there.

Trail 3 was newly added to the east of the midstream of Hogtown Creek, connecting from the southeast, an institutional land, to the northwest mixed-use community center. Most of the route segment is suitable to the context, while several parts were going through low-density residential that may need community participation for the decision-making process.

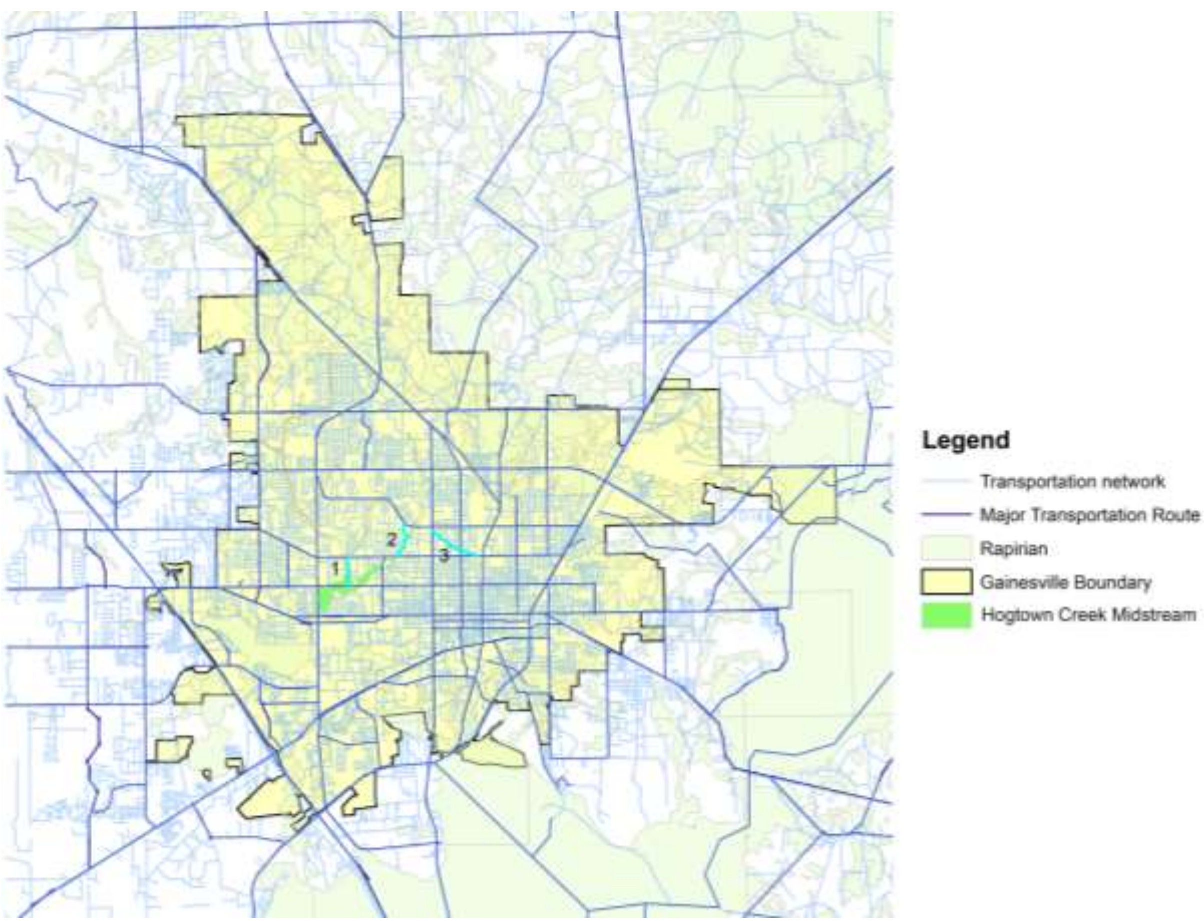


Fig. 27 Typical examples for context suitability analysis

CHAPTER 5
CONCLUSION AND DISCUSSION

Conclusion

Optimized routes can improve transportation network topologically

The research process verified the research hypothesis by the topological relation that the optimized nonmotorized routes that produced based on ecological suitability can enhance transportation network. The Depth, Integration, and connectivity indicator provider support that transportation network has better logic than the existing transportation network. This part of conclusion was drawn based on analysis from the ecological perspective that supporting ecological benefits.

Optimized transportation network can serve traffic demands with efficiency

Based on the first part, the effectiveness of the optimized transportation network has been tested by network analysis that all the traffic attractions can be reached with least cost route, and 70% of the urbanized study areas are accessible within half an hour by bike.

Limitations

The boundary of the study area limited potential regional corridor to connect with ecological conservation areas. A buffer with certain width outside the study area would contribute to the regional connection and cooperation. Moreover, the data for both analysis and assessment came from secondary resources, while the lack of field work may cause inaccuracy and less credibility. The first-hand resources are potentially helpful to verify analysis logic in turn.

The other limitation happened in service efficiency part, where OD Cost Matrix was generated based on point features with the centroid of each oriented polygon, rather the actual shape and location of each polygon objects. This lead to the necessary process to check with existing condition and context information. For instance, the Paynes Prairie Preserve has good transportation connection while its centroid point was disconnected to the origin (Fig. 25).

Confliction Between Ecological Priority and Built Environment

Existing transportation network are generally designed and constructed according to the demand of human with maximum benefits: topographic and soil conditions were considered to save economic expense, convenience to access and right of mental health were considered as prerequisites to select a location for transportation routes. Even though the designers and engineers have been increasingly aware of the importance of ecological conservation, ecological benefits need to make a compromise when facing confliction with over-rapid development and human desires.

The study area, Gainesville, as major cultural and educational center of the region, was the one that did better jobs for ecological conservation than many other places. However, the conflictions between transportation and ecological areas are still quite common based on the tool-based ecological suitability map. To deal with these conflictions, strategies and regulations are indispensable to minimize the existing effects and avoid more future impacts. On the contrary, since the optimized routes were generated, the transfer of function from old to new should be done gradually while recovering the ecosystem and ecological capacity of the affected areas where existing un-eco-friendly routes are.

Another notable dilemma is that the ecological suitability map was generated based on the existing condition, which means the high ecological conservation priority areas are located in ecological areas with limited human impact but might have more threatened if no actions were taken. However, the ecological areas that should be protected but already been destroyed by development are not likely to be recovered anymore. This research is a reminder of such irreversible process.

Feasibility of Practical Projects

In order to make results acceptable and understandable for professions, public, and government, this research was conducted based on widespread concerns of the context condition, including the ecological zoning, land use types, socioeconomic and census statistics, and existing constructions. However, other factors such as topographic information and construction cost were considered but not listed in the calculation process. This result from the principle to focus on ecological conservation orientation to figure out whether and to what extent the transportation network will be improved if temporarily get rid of the human benefits, thus produce nonmotorized routes from ecological assessment and evaluate the service efficiency by developing demands.

In addition to the precautionary concerns, predictive modeling that evaluates the potential impact is essential to help with decision-making and contribute to the follow-up maintenance and management. Some examples of such modeling are listed but limited to how the increased route density will affect the activity area, how the improvement of transportation infrastructure will affect the travel mode option, and what are the preferred nonmotorized connection types to integrate with existing transportation network.

Further Work

For better nonmotorized routes

In addition to the ecological parameters, topographic information is essential to identify OTN suitability for nonmotorized routes more accurately suitable to the different types of nonmotorized travel. Other factors such as the construction cost and parcel ownership are necessary to assess the feasibility. Overlapping cost map and ecological suitability map with proper weighting will be more comprehensive to consider non-human factors for identifying nonmotorized routes.

Another dispensable part is the design context. This research examined the existing condition such as land use type and the proximity of existing transportation infrastructure, while the socioeconomic factors, such as the community wiliness and economic benefits, were not included. Moreover, most analyses are conducted at the regional scale and city scale, while the suitability of the optimized nonmotorized routes to the real world needs to be verified delicately by zoom into the particular scale and the routes for implementation should be more accurate by integrating with contextual information.

Meanwhile, the potential impact should be predictively analyzed by data-based research. For instance, gravity model could be applied to assess the localized effect of the optimized nonmotorized routes due to the uneven distribution from graphic perspective, LUCIS can be applied to see the relationship between transportation and land use, traffic impact assessment and scenario planning could be adapted to predict the volume of nonmotorized travel in the optimized transportation network.

For facilitating implementation

In addition to identifying the potential routes for nonmotorized transportation from the spatial aspect, connection to other types of transportation infrastructure is also important. For instance, good connection to public transportation to make it convenient for nonmotorized travelers to travel across the county could significantly reduce the use of single rider vehicles.

In addition, innovative designs and creations are essential to minimize the confliction. Applying intersections where conflictions happen between road traffic and ecological migration corridor is another common strategy that has been widely applied. Such innovation can also be addressed by separating activity areas, make use of the utilized time and occupancy period.

Moreover, policies and regulations should come along with the whole life cycle of the optimized transportation network, from design to construct, and then to maintenance and management to improve sustainability and facilitate the reconciliation between development and nature.

APPENDIX 1
IMPACT ASSESSMENT

Traffic impact indicators and methodologies are high diversity among different cities, while the software applied are basically the same:

Table 9 Indicators and Methodologies for TIA Guidance

Location	Indicators for Capacity Analysis	Methodology for Trip distribution
Tasmania	Road safety; Internal layout; Street furniture; Parking; Access for disabilities;	Makes assumptions about the development
Tai Po, Hongkong	Annual traffic account; Peak hour traffic; Hourly trip; Junction; Internal paths;	Transport model based on travel characteristics
City of Harrisburg, PA	Safety; Circulation patterns; Traffic control needs; Transit needs or impacts; Transportation system management; Neighborhood impacts; Parking facilities; Pedestrian and bicycle movements; Service and delivery vehicle access;	Analogy; Trip distribution model; Surrogate data.
St. Lucie County City of Fort Pierce City of Port St. Lucie	Geometry, including lane widths and turn-lane lengths Heavy vehicle factor Directional factor Peak-hour factor (PHF, no exceed 0.95) analysis to reflect unconstrained demand conditions Existing signal timing Segment length Class of roadway Maintenance jurisdiction Area type Posted speed LOS standard	Scenario planning Level of service standard Multimodal considerations Mitigation options

Table 10 Preferred software for different types of analysis

Type of analysis	Preferred software
Unsignalized intersections	Highway Capacity Software (HCS)
Signalized intersections	Synchro software (latest version) Highway Capacity Software
interrupted flow road segment	Synchro software (latest version)
Uninterrupted flow road segment	HighPlan (latest version from FDOT)
Other analysis	Local government provision

APPENDIX 2
CENSUS DATA

Historical population census from 2000 to 2010 was collected every five years to show the demographic trends.

Table 11 Population change among city/town level in Alachua County

	Community 2000	Census 2005	Census 2010
Gainesville	95,447	118,634	124,354
Alachua	6,098	7,402	9,059
High Springs	3,863	4,432	5,350
Newberry	3,316	4,261	4,950
Archer	1,289	1,230	1,118
Hawthorne	1,415	1,396	1,417
Waldo	821	832	1015
Micanopy	653	629	600
LaCrosse	143	186	360
Unincorporated	104,910	100,012	99,113
TOTAL	217,955	239,014	247,336

Table 12 Socio-Economic data summary 2010

Permanent Population	247,336
Total Population	251,951
Permanently Occupied Dwelling Units	99,089
Transient and Permanently Occupied Dwelling Units	101,996
Total Service Employment	91,399
Total Commercial Employment	32,669
Total Manufacturing Employment	4,048
Total Other Industrial Employment	9,478
Total Employment	137,594
Permanent Population per Permanently Occupied Dwelling Unit	2.50
Total Population per Total Occupied Dwelling Unit	2.47
Total Employment per Permanent Population	0.556

Service to Total Employment	0.664
Commercial to Total Employment	0.237
Manufacturing to Total Employment	0.029
Other Industrial to Total Employment	0.069
Internal Person Trips per Permanently Occupied Dwelling Unit	11.63
Internal Person Trips per Total Occupied Dwelling Units	11.29
Internal Person Trips per Employee	8.372

APPENDIX 3
TRANSPORTATION STATISTICS

Table 13 Journey-to-Work Mode Split (2000)

Geographic Area	Travel mode				
	Drive Alone	Carpool	Public Transit	Other	Walk or Bike
Gainesville	69.8%	12.2%	3.2%	3.9%	10.9%
Alachua County	74.7%	12.7%	2.4%	4.2%	6.0%
Florida	78.8%	12.9%	1.9%	4.1%	2.3%

Table 14 Travel Time in Minutes (percent of workers)

Geographic Area	0-9	10-19	20-29	30-44	45+
Gainesville	18.6%	49.6%	18.2%	7.7%	5.9%
Alachua County	14.6%	40.1%	23.4%	14.2%	7.8%
Florida	11.2%	30.0%	21.6%	22.3%	14.9%

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