A GIS-BASED FRAMEWORK FOR MODELING NON-MOTORIZED TRANSPORTATION

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ABSTRACT

The Federal Highway Administration is currently participating in several related efforts to improve access to forecasting tools for non-motorized travel modes. In addition to research, reports and documentation of techniques that support improved non-motorized forecasting, an innovative element among these efforts is the development of a non-motorized forecasting software framework in which planners have simple access to a range of available modeling strategies based on their own local data and planning needs. This paper describes that framework and its capabilities, and presents plans for its future development.

The framework is an open-source software tool that is deployed as a web application. It can run either locally or on a public server. Within the framework, planners can establish a study area, import data in a variety of popular formats, conduct analyses, and retrieve results. The framework is designed to be readily extended as alternate modeling approaches become available, with minimal effort on the part of researchers or developers. It initially supports several GIS-based non-motorized modeling techniques that are under development in existing research projects sponsored by FHWA and others.

In addition to providing a practical tool for planners, the framework is also available as a means by which research results in non-motorized travel forecasting may be shared, applied in new study areas, and put into practical application. At present, the framework exists as a prototype application, with a formal release planned for 2012.

INTRODUCTION

Secretary of Transportation Ray LaHood has offered this succinct definition of livability: "Livability means being able to take your kids to school, go to work, see a doctor, drop by the grocery or Post Office, go out to dinner and a movie, and play with your kids at the park – all without having to get in your car." (*1*) Accordingly, the Federal Highway Administration has recently been pursuing several initiatives to improve support for planning related to bicycle and pedestrian modes (*2*). This paper describes one of these initiatives, which is to create an extensible and easy-to-use framework for delivering sophisticated non-motorized models to planners and other interested persons. The primary goals are:

1. To increase access to modeling and analysis tools that support planning for non-motorized modes;
2. To simplify deployment of new tools; and
3. To foster the emergence of recognized best practices for modeling and quantitative analysis in bicycle and pedestrian planning.

MOTIVATION FOR THE FRAMEWORK

While numerous approaches exist for bicycle and pedestrian modeling, and more are being invented (*3, 4, 5*), there are few general-purpose tools available for that purpose. Agencies that have wished to examine non-motorized modes have generally developed custom models and analysis procedures. The lack of widely accepted techniques, and the corresponding dearth of tools, has led in turn to a relatively high cost of entry. What low-cost approaches do exist are sketch models, and present little spatial and behavioral detail. Furthermore, research on non-motorized travel modeling and analysis has tended to occur in communities where the need for bicycle and pedestrian planning is well-established, leaving policy-makers and planners in other communities with an uphill ride and no "low gears" in their attempts to add non-motorized analysis to their planning process.

Due to the lack of standardization in practice, the diverse and often incompatible state of performance measures, and a proliferation of research from which transferable solutions have yet to be synthesized, there has been no practical path for commercial vendors to produce marketable tools for this relatively small market. Agencies new to the field are often reluctant to commit funds buying, learning and configuring an untested model. Yet without the ability to test models in practice, and to evaluate them against concrete planning needs, there is little hope of establishing good, commonly accepted standards that might make commercial tool sets viable.

Those impediments make it difficult even to begin the exploration of a consistent framework in which alternate approaches and techniques can be developed, deployed, and "tried on for size". In addition, efforts simply to ignore these challenges and to build a capable toolset risk shutting down alternate lines of research, making it harder to nurture a competitive private sector, and worst of all, failing to address the needs of planners as they evolve in the future.

In order to encourage cost-effective development and practical application of new analysis methods, the approach presented here has been to develop a web application that functions as a well-documented "toolbox" or "framework" within which new methods may conveniently be implemented and deployed, rather than as a static product that implements a fixed menu of analytic approaches. This framework is built entirely from freely available open source software, and will itself be released as an open source product. The aim of pursuing an open source approach is to lower the cost of entry for potential users, and also the costs for researchers or other developers who may use the toolbox to implement new approaches on a platform that encourages and simplifies field evaluation and deployment. The licensing of this software is expected to be liberal, in order to encourage entrepreneurial improvement of the framework with respect to performance, ease of use, and technical support, while retaining the virtues of an open platform with respect to extensibility by researchers and planning agencies.

FRAMEWORK DESIGN

The primary design goals for the framework include openness, low cost of entry, and simple deployment. To attain these goals, the framework was constructed with a simple architecture. The framework architecture manages user authentication and allows those users to create and manage studies, which in turn manage sets of data files uploaded by the user, and sets of analyses that can be built from tools currently installed in the toolbox.

The framework itself supports authenticating users, uploading data in tabular and GIS formats, managing user access to the data, organizing studies and selecting analyses to perform, presenting input screens and help information through which an analysis may be configured, performing the analysis, and displaying and downloading results. The analyses themselves are set up as application extension modules that manage input data, the analysis operations, and that offer either tabular, graphic or geospatial results for display. Interface code specific to each analysis extension is written according to an application program interface (API) and consists of HTML templates and code to support necessary options including:

- Setting up analysis inputs using uploaded data and user-specified parameters;
- Performing the analysis;
- Enumerating available results of a specific type;
- Reporting errors and providing help to the users;
- Offering downloads of various types

An important design consideration has been to keep the programming overhead for framework extensions as low as possible. Thus, even though the framework itself allows users to load their own local data, the API specifies that an analysis will copy the available data into its own environment (and reformat the data if necessary). When presenting results, the framework expects simply to display HTML tables or JPEG images (although the framework includes code for mapping locations in the image to geospatial coordinates in order to allow the user to interact with the image). The API provides the ability for an analysis to present for download whatever additional outputs its designer may choose to make available, including, for example, processed data files, detailed images, GIS layers, or additional statistics.

In order to support a simple, intuitive interface for use by planners and others whose primary goal is to run analyses that have already been installed in the framework, there is no mechanism for end users to add new tools. Instead, new tools written to use the framework API must be installed on the server by a system administrator. The expectation is that the application framework and its installed tools will be hosted on a server that users will connect to across a local network or across the internet. The framework will also run on a standalone machine through a Python-enabled web server. The open licensing of the core framework permits users to operate their own server, and to extend or reuse the framework code however they see fit.

The framework has been constructed with common, widely-used tools including Python (*6)*, the Python-based Django Web Application Framework (*7*) and the R environment for statistical computing and graphics (*8*). The choice of these languages for the prototype was motivated by their wide use, the large body of existing modules and packages available to extend their basic functionality, and the relatively short effort required to become productive in either language. The framework can easily be extended with tools written in either of those languages. Extending the framework with tools written in other languages may require some additional bridge code in Python or R, but is otherwise uncomplicated. (Of course, users who simply wish to apply tools that are installed in the framework need have no knowledge at all of the internal details of the framework.)

DEMONSTRATION ANALYSIS TOOLSET

While developing the framework, a set of GIS raster analysis tools have also been developed to exercise the framework's features. These tools are expected to have some utility in their own right and are described here to illustrate a range of tasks that the framework can facilitate. GIS-based approaches (e.g. (*9*)) have the potential to handle high-resolution data, to analyze interactions between different sets of factors that may either be assembled from a variety of inventory data (including data sets commonly available to planners), and to generate useful visualizations of the results of such analysis.

The prototype application includes a set of sample tools that perform raster-based accessibility analysis using the R packages raster (*10*) and gdistance (*11*). The sample tools permit the user to examine the accessibility and barriers present in a study area, develop accessibility profiles to specific locations in the study area, to develop maps of potential demand, and to explore accessible paths across the study area. The steps in this analysis are illustrated in the accompanying series of figures. The study area presented in each figure corresponds to the eastern half of Alexandria, Virginia. Axes in each figure represent the projected geographic coordinates of the study area. The specific projection in the demonstration analysis is expressed in the language of the widely used proj.4 geographic package (*12*) as:

```
+proj=utm +zone=18 +ellps=GRS80 +datum=NAD83 +units=m +no_defs +towgs84=0,0,0
```

The boundary of the study area and key transportation facilities are shown in Figure 1.

FIGURE 1 Demonstration Study Area

The framework can load and manage geographic layers and tabular data files. Supported geographic layer formats include most popular vector and raster layers (specifically, those supported by the open source GDAL/OGR libraries (*13, 14*)). In the first version of the framework, these layers must be pre-processed to the same projection, in keeping with the design principle that the framework is intended to deliver analysis tools that cooperate nicely with other systems that the user may have in place for generating input data, or for displaying or performing additional external analyses on output data.

The primary analysis offered in this sample set generates an accessibility surface as a GIS raster data structure. The data presented by the user can be analyzed at arbitrary resolution; the sample data has been analyzed on a 300 x 300 grid, corresponding to cells approximately 15 meters on a side, and a study area which is a little less than three miles on each side. Higher resolutions increase processing time, whereas lower resolutions obscure details in the input data. The example presented focuses on a pedestrian analysis, but the same principles apply to bicycle analysis.

In bicycle and pedestrian studies that attempt to do trip modeling, a common difficulty is construction of a suitable network over which travel is accomplished. Historically, tools for generating such a network entail extensive manual effort, and the resulting data sets are costly to maintain. A motivating goal in the current effort is to emphasize use of commonly available data sources that are maintained for other purposes such as roadway centerlines, motorized travel networks, roadway volumes, sidewalk and bike-lane maps, walkability inventories, crash locations and so on. The tools within the current framework illustrate how one can develop a fairly sophisticated analysis of the potential for non-motorized travel without requiring construction of new link-node networks.

ACCESSIBILITY AND ROUTING METHODS

The framework draws on existing functionality in R (the gdistance package) to treat a layered raster representation of the study area as a network. In this approach each cell forms a node on the network with the possible “transitions” between the cells as links. The transitions are themselves computed from interactions among the raster layers, allowing very precise representation of the potential for, and cost of, movements between cells. Path costs can be calculated by traversing the raster surfaces using link-node nomenclature with well-established routing algorithms.

The approach taken in the demonstration analysis begins with a uniform possibility of movement across the study area. The analysis then identifies features that represent obstacles to movement in certain directions such as barriers or grade separations (Figure 2, showing facilities on which pedestrian movements are prohibited), as well as features that facilitate pedestrian movements such as sidewalk or lightly used roads (Figure 3, showing roadways with sidewalk facilities or that are otherwise especially amenable to walking).

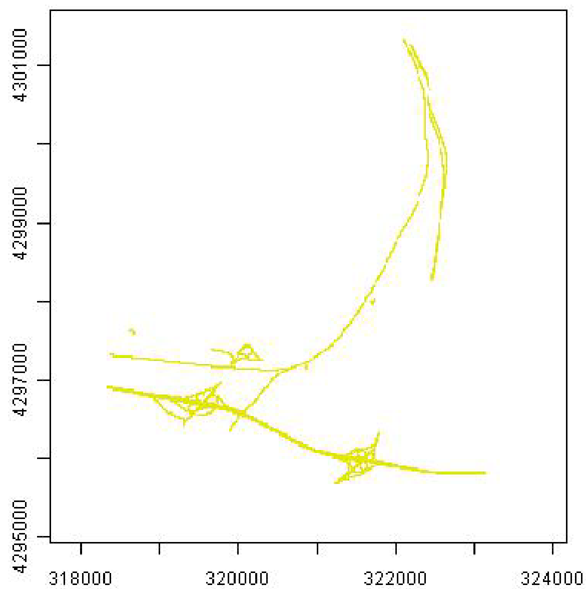

FIGURE 2 Barriers to Pedestrian Access

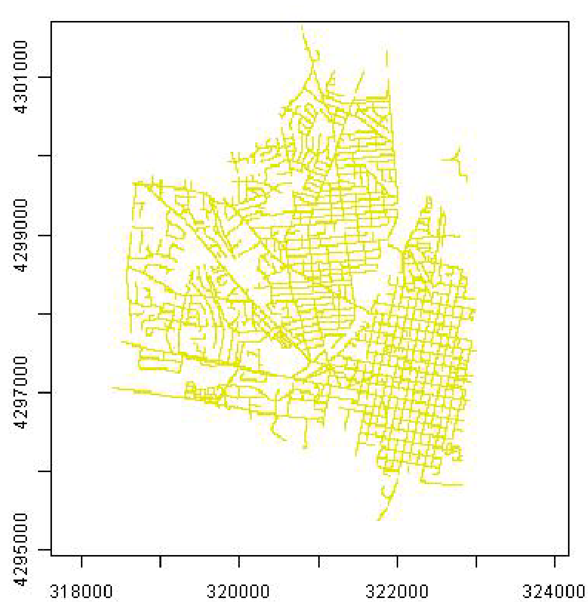

FIGURE 3 Facilities Amenable to Walking

When a set of layers is assembled and analyzed, two layers result: an accessibility map (Figure 4, showing the ease of movement through each cell as illustrated in the inset in that figure), and a "transition layer" (which is more difficult to visualize in two dimensions) that describes how easy it is (or if it is possible at all) to move from one cell to an adjacent cell. In the demonstration analysis, the transition layer values represent a walking distance which is scaled higher or lower based on the difficulty of movement across the accessibility map, yielding what we refer to in the description of subsequent analyses below as "penalized walking times".

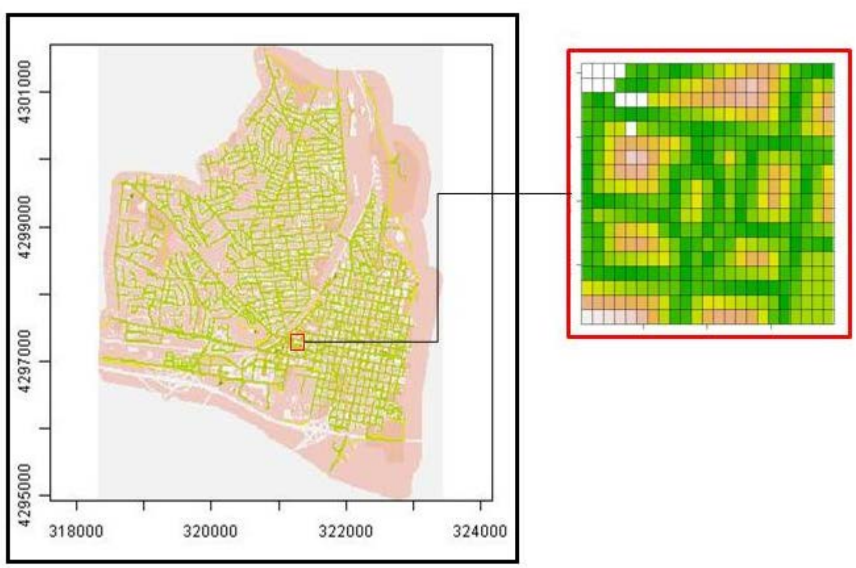

FIGURE 4 Accessibility Map (Ease of Movement)

DEMONSTRATION AND RESULTS

Using the results of the accessibility analysis, a number of useful follow-on analyses can be conveniently prepared. Figure 5 shows an estimate of shortest paths across the accessibility map (computed using the standard Dijkstra shortest path algorithm with link weights from the transition layer) to several points in the study area.

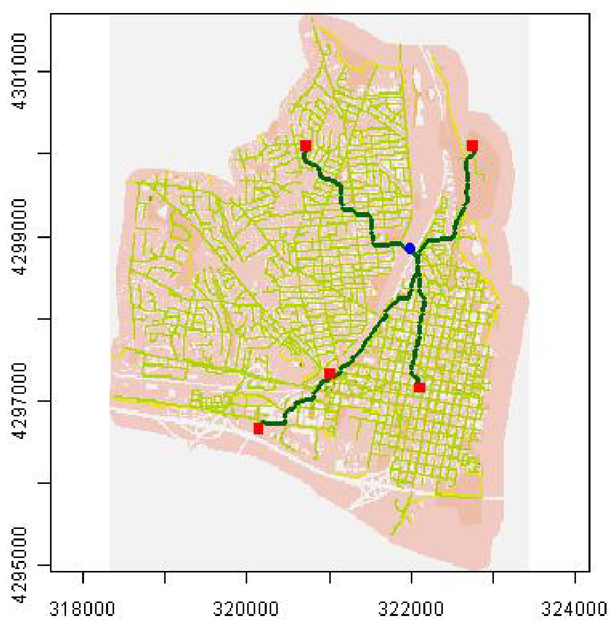

FIGURE 5 Shortest Paths

Figure 6 shows an estimate of penalized walking times to each of three subway stations in the study area presented as an isochrone map. Such an analysis provides an alternative to the standard quarter-mile or half-mile radius buffers commonly used to assess transit accessibility, by providing nuanced estimation of pedestrian facilities and barriers.

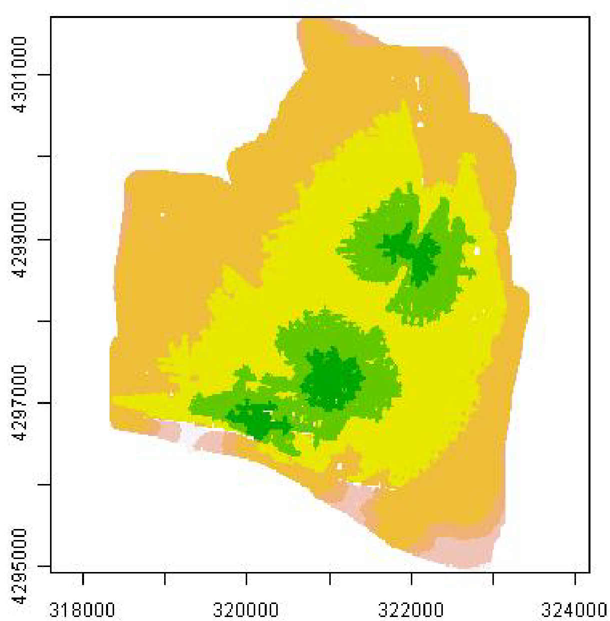

FIGURE 6 Penalized Walking Times to Transit Stations

A natural subsequent step in analysis is to explore demand for walking (in this example) or bicycling. Figure 7 shows the result of a simple trip generation model representing demand for walk-to-transit trips for the home-to-work trip purpose, and Figure 8 illustrates the resulting net demand for walking travel to transit stations in the study area based on an intervening opportunities model (with a logit model to distribute trips originating in places where accessibilities to each of several transit station falls within a certain overlap threshold). This type of analysis permits the user to visualize service areas based not only on theoretical accessibility, but also on the level of potential demand across the accessible areas.

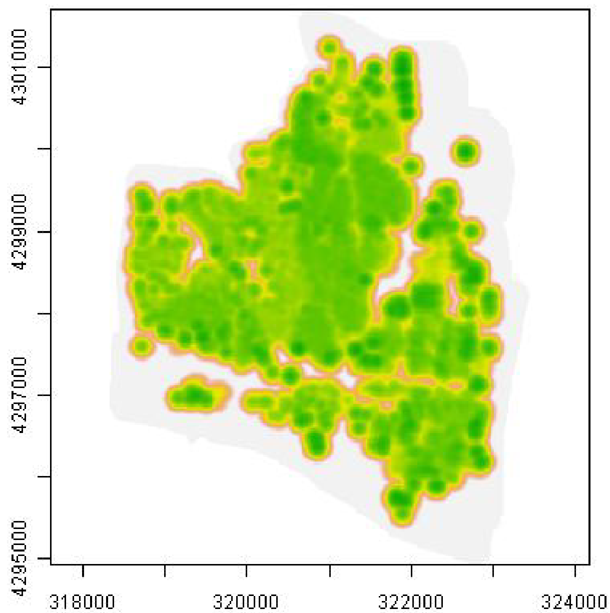

FIGURE 7 Trips to Work via Walk to Transit

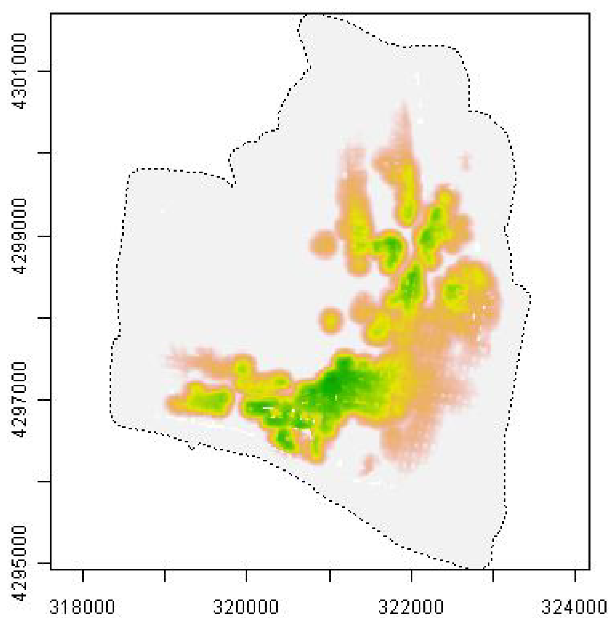

FIGURE 8 Net Demand for Walking Travel after Accessibility Penalty

Finally, an assignment of demand can show where one would expect to find walking trips, based on summing the demand on each shortest path from every cell to each of the transit stations (Figure 9). The resulting walking trip estimates can be copied back into a GIS line layer for use in building a standard travel demand network, or summarized into the zone structure for a regional model to provide a correction to trip tables based on non-motorized accessibility.

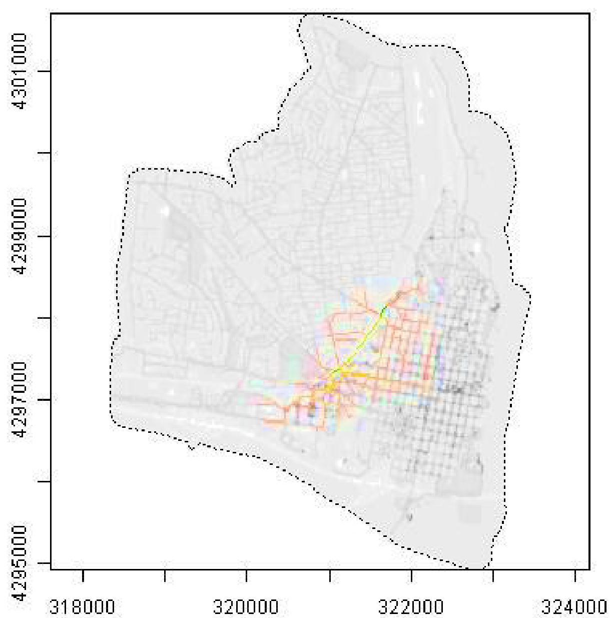

FIGURE 9 Assigned Demand

Finally, the framework allows the user to display the resulting map images (including separate maps of access to and demand for individual transit stations, as well as the combined image shown in the figures). It also allows the user to download these images, the resulting GIS layers, and the R data files that contain the accessibility map, the transition layer, the shortest paths generated, the raster demand and other computed data. In the demonstration analyses, the system builds a series of R scripts that conduct the actual analysis. The framework also presents these scripts for download, so the user has complete access not only to the results of the analysis, but has the ability to inspect the methods applied, to run them interactively outside the framework, and to explore what might happen were the modeling assumptions adjusted in ways not explicitly allowed for in the demonstrations.

The sample analyses do not present a complete modeling facility as they have not yet been calibrated using complete behavioral studies and observed pedestrian activity. Yet in their current form they may be useful for qualitative analysis of pedestrian demand, and more importantly, they illustrate the goal of the framework, which is to present sophisticated analysis tools in a convenient form for further research and practical application. None of the analyses presented here are difficult to set up, nor time-consuming for the 300x300 study area resolution. The R packages used to construct the demonstration analysis allow processing of raster areas much larger than what will fit in memory (and R itself will operate in 64 bit environments, so the potential memory space can be quite large). Most significantly, however, the overall framework environment also makes it quite simple for a modestly sophisticated technical user to alter or extend the framework with new analytic tools.

FUTURE DEVELOPMENT

Though the non-motorized framework and toolkit is still in its infancy, the work so far has been promising, and interest from the community of non-motorized planners and researchers has been high. The framework is currently being tested and prepared for a formal release. In keeping with other on-line toolsets already available through FHWA websites, it is expected that the framework will be deployed for in a public hosted environment. In addition, the application code and documentation for constructing extensions will be made available to researchers and practitioners, as well as commercial developers, who may use it locally or offer tools for installation by others.

By leveraging available GIS and other modeling tools, the framework makes it easy for developers of modeling techniques and analysis tools to present their work in a consistent, familiar environment. The hope is that this effort will facilitate the deployment of novel modeling and analysis techniques into practice, and that it will also facilitate comprehensive efforts to develop effective, useful, usable approaches to incorporating non-motorized analyses into the transportation planning process.

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