Walkway Network Analysis

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Abstract

This paper describes the development of new geospatial analysis tools intended to help communities choose where to invest in infrastructure improvements to support walking. The tools use network distance as opposed to geometric (as-the-crow-flies) distance and weighting of network segments according to their attractiveness or impedance.

Key to the analysis is the creation of a walkway network that represents the topology of the network used by pedestrians. This network is different from the street centerline network in having a separate line segment for each side of the street and line segments representing crosswalks.

Many types of analysis may be done, including: individual shortest-effective-distance walking routes, quality scores, network utilization by segment, service areas, surfaces of difference, and slope shaded maps that highlight opportunities for walkway network improvement. Visualizing the surface of difference for a proposed project illustrates the geographic extent and magnitude of benefit of an improvement.

Authors

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Pedestrian Network Analysis

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Introduction

This paper describes the development of new geospatial analysis tools intended to help communities choose where to invest in infrastructure improvements to support walking.

Such tools can increase the transparency of selection processes through the explicit choice and weighting of selection criteria. The use of objective tools favors equity in public investments. By contrast, when we rely on "experts" or even public outreach, project selection may be improperly influenced. Communities will still make choices: do we invest to increase the total number of miles walked, or the total number of people walking? Are we trying to make walkers out of the people who live in an area, or attract new residents who will walk? Do we give greater weight to walking to transit or to walking for other purposes?

A key to the new tools is the creation of a walkway network that more accurately represents the topology of the network used by pedestrians. This network differs from the street centerline network in having separate line segments for each side of the street and line segments representing crosswalks.

Special purpose GIS tools make it possible for planners and advocates to create and analyze the walkway network. These tools make it easier to determine what facility improvements are most likely to lead to more walking in a neighborhood.

Network analysis and mapping

There are already a number of geospatial tools available to analyze and illustrate networks. Network analysis can generate and evaluate tens of thousands of routes; from every residence to every destination. This can help answer questions such as where the greatest demand for walking can be expected, or where improvements can be made that will significantly reduce the difficulty of walking to important destinations.

Route finding (shortest or least-cost path)

Many people are familiar with route finding systems because they have used an online mapping service to get directions. A route finding system consists of a routing engine, a network, and a set of constraints or weights applied to segments of the network. A rail transit route finder will use a different network than an automobile route finder. A route finder for trucks uses the same network as for cars, but with additional constraints for height-restricted underpasses or weight-restricted overpasses. Like rail transit, pedestrians use a different network than motorized vehicles and bicycles. Although many attempts have been made to use the street network for pedestrian routing, we will see that the walkway network cannot be modeled accurately by using the street network with trails added and freeways removed.

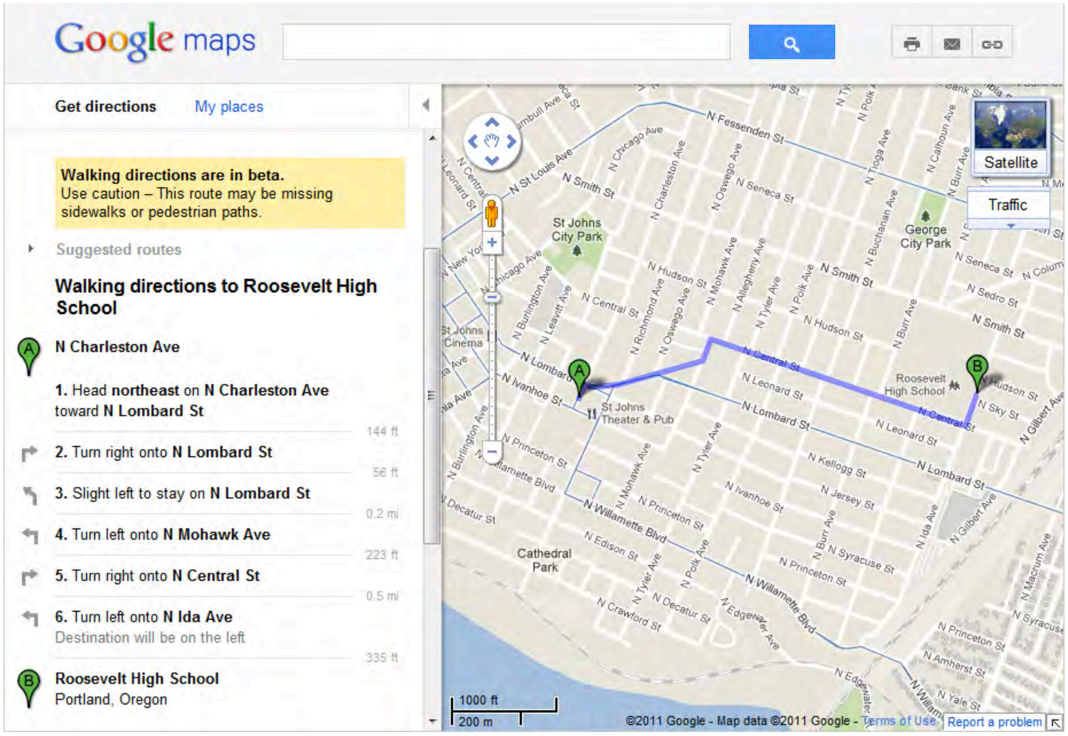

Figure 1. A dynamically generated walking route shown on the street network

Zonal quality index

A zonal quality index creates a composite score for a point or set of points based on the cost of routes to certain destinations, such as transit stops or grocery stores. Scores generated for all similar points within an area, such as intersections or dwellings, can be mapped with a color ramp or other visualizations such as contour lines.

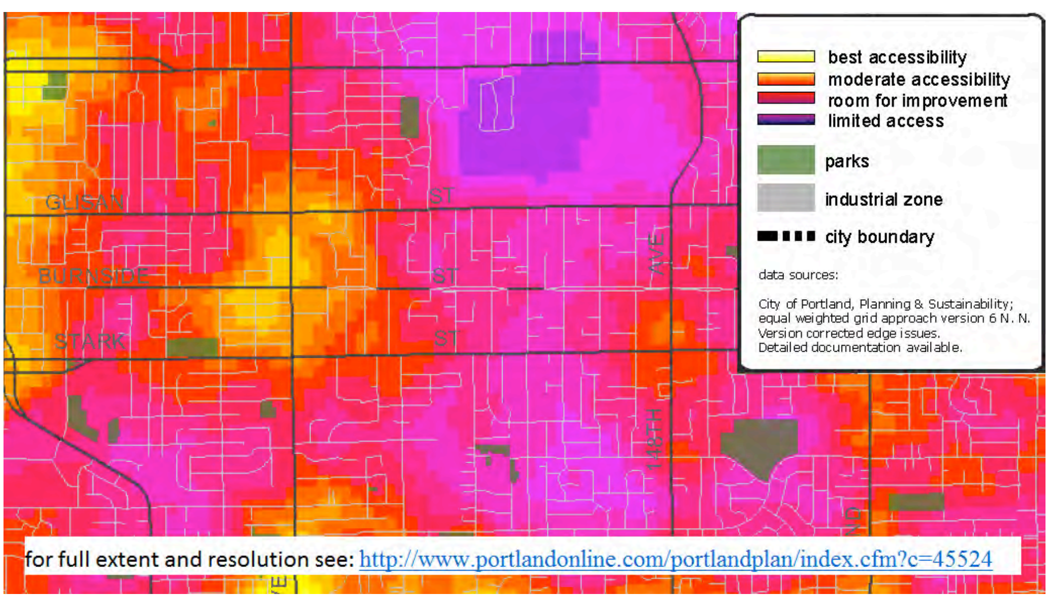

Figure 2. "Twenty-minute neighborhood " score generated from factors including walking distances on the street network

Network utilization by segment

This type of analysis is intended primarily for people and agencies interested in transportation infrastructure. It generates routes from all dwellings in a study area to many destinations, and tallies the number of routes that use each network segment. This reveals segments that can be expected to have high demand. Results can be visualized, as in Figure 3, by using line weights to represent segment utilization.

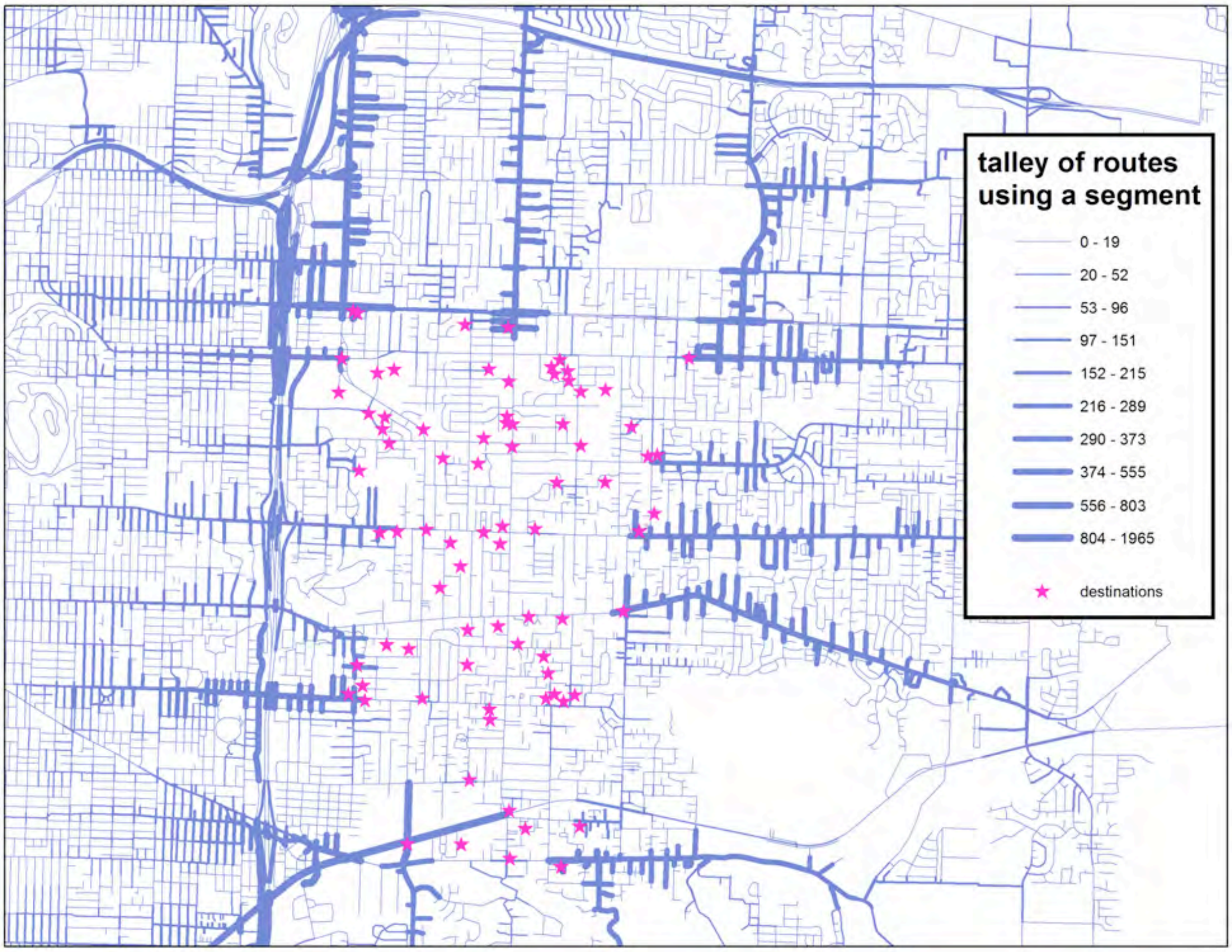

Figure 3. Tally of routes using segments of the street network to reach the nearest destination

Service area

Analysis of service areas or catchment areas is often used for choosing a site, such as for emergency services or warehouses. Figure 4 illustrates the area within a quarter mile, half mile, or mile distance along the street network from full service grocery stores in Portland, Oregon. The use of network distance can be noted from the irregular shapes of the service areas.

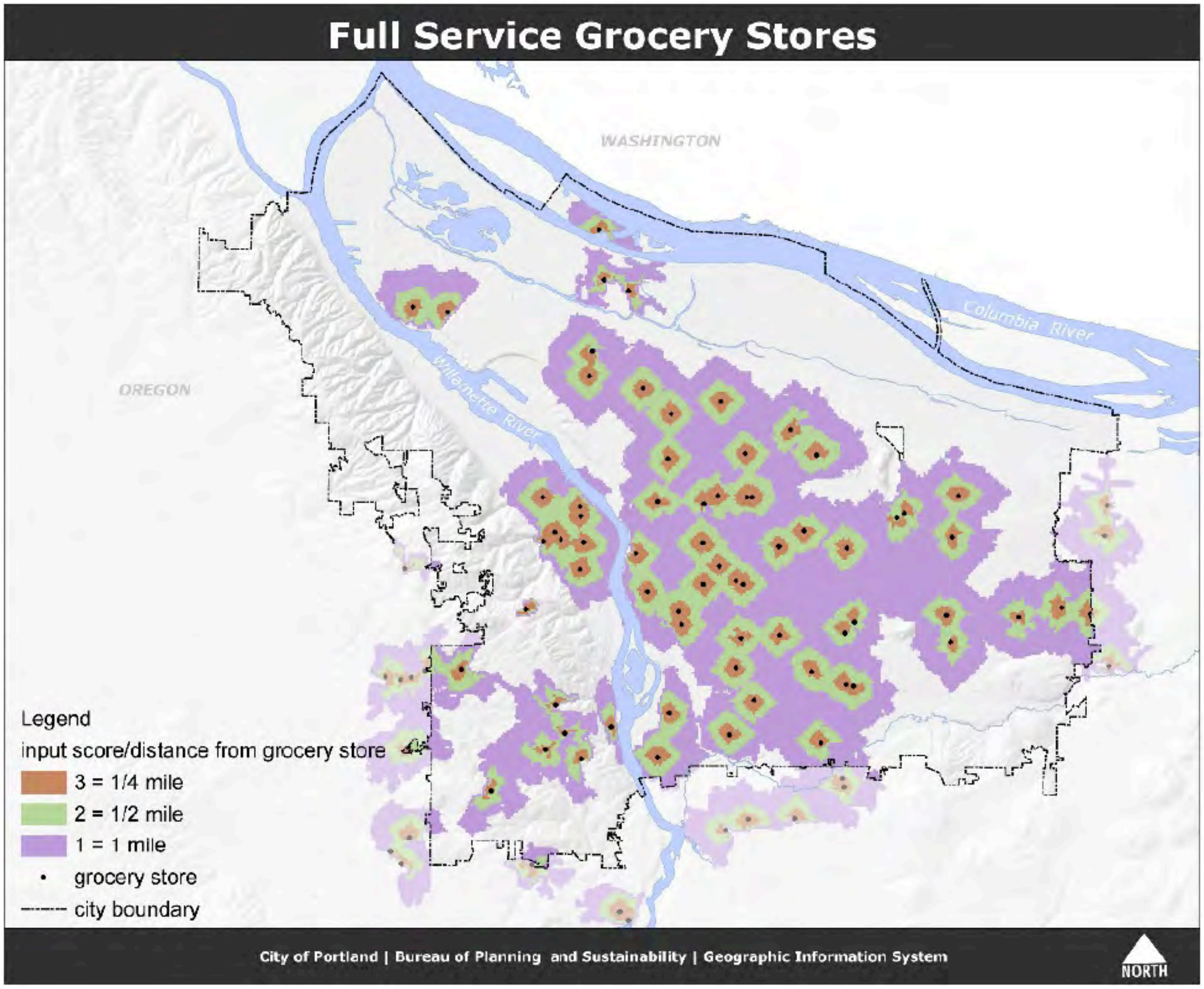

Figure 4. Service areas calculated from distance along the street network

Surfaces of difference

When scores are created before and after a change in the network, the difference between these scores can be taken and used to illustrate the magnitude of the improvement. Differences generated for all similar points within an area can be mapped as a surface of improvement. Visualizing the surface of difference for a proposed project illustrates the geographic extent and magnitude of benefit of any given improvement.

Figure 5 shows an example of a surface of difference rendered as a color-ramped surface with contour lines.

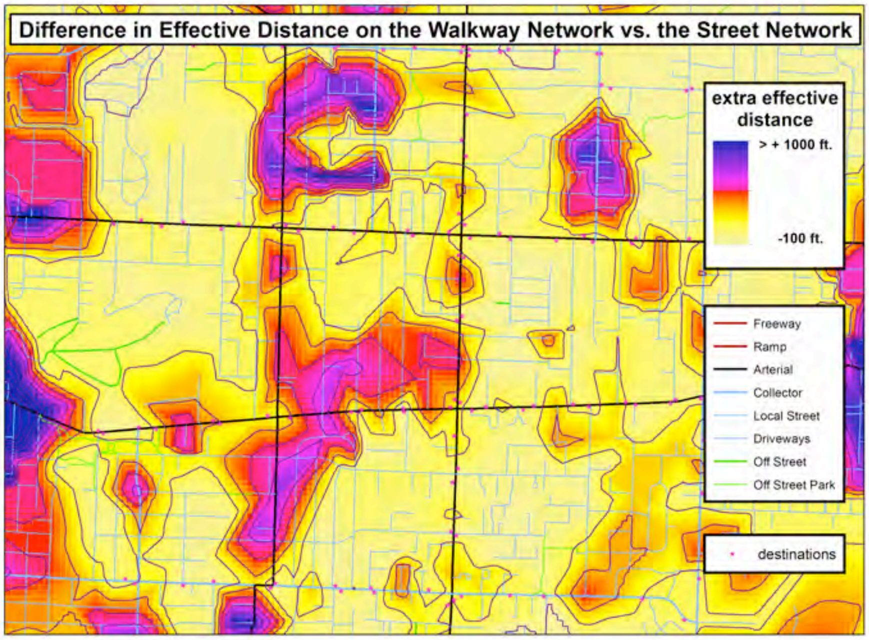

Figure 5. Map showing the difference between access by street network and access by walkway network

Such a surface can also be illustrated using tilted perspective (as used by Google Earth™). This is especially interesting if users can rotate the illustration to get the full three-dimensional effect. Figure 6 shows the same surface of difference as Figure 5, rendered using tilted perspective.

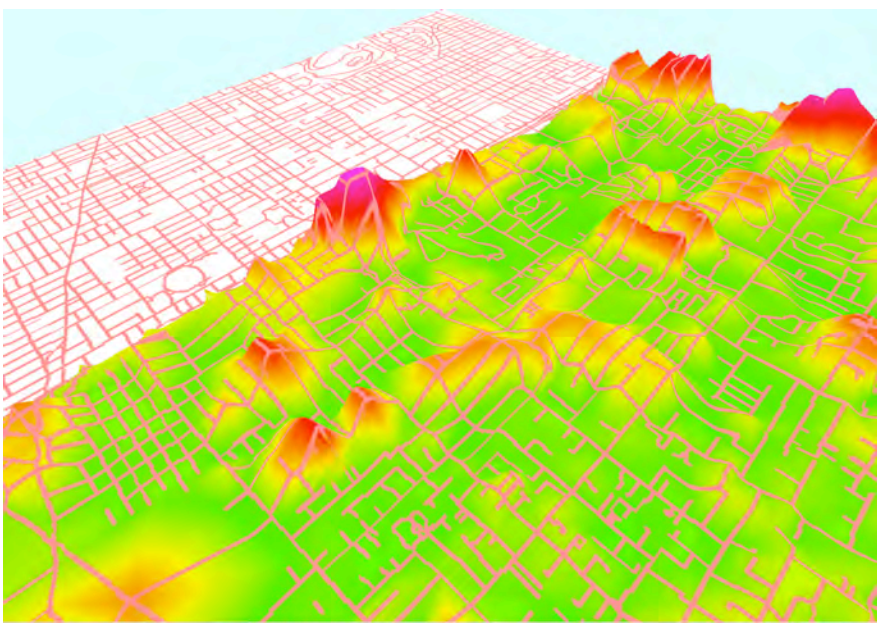

Figure 6. Tilted perspective projection showing a surface of difference

Custom maps

Maps such as road maps, transit maps, bike maps, and trail maps are generated to assist particular users with navigation. In the Safe Routes to School example shown, the street network is used to describe both walking and bicycling routes.

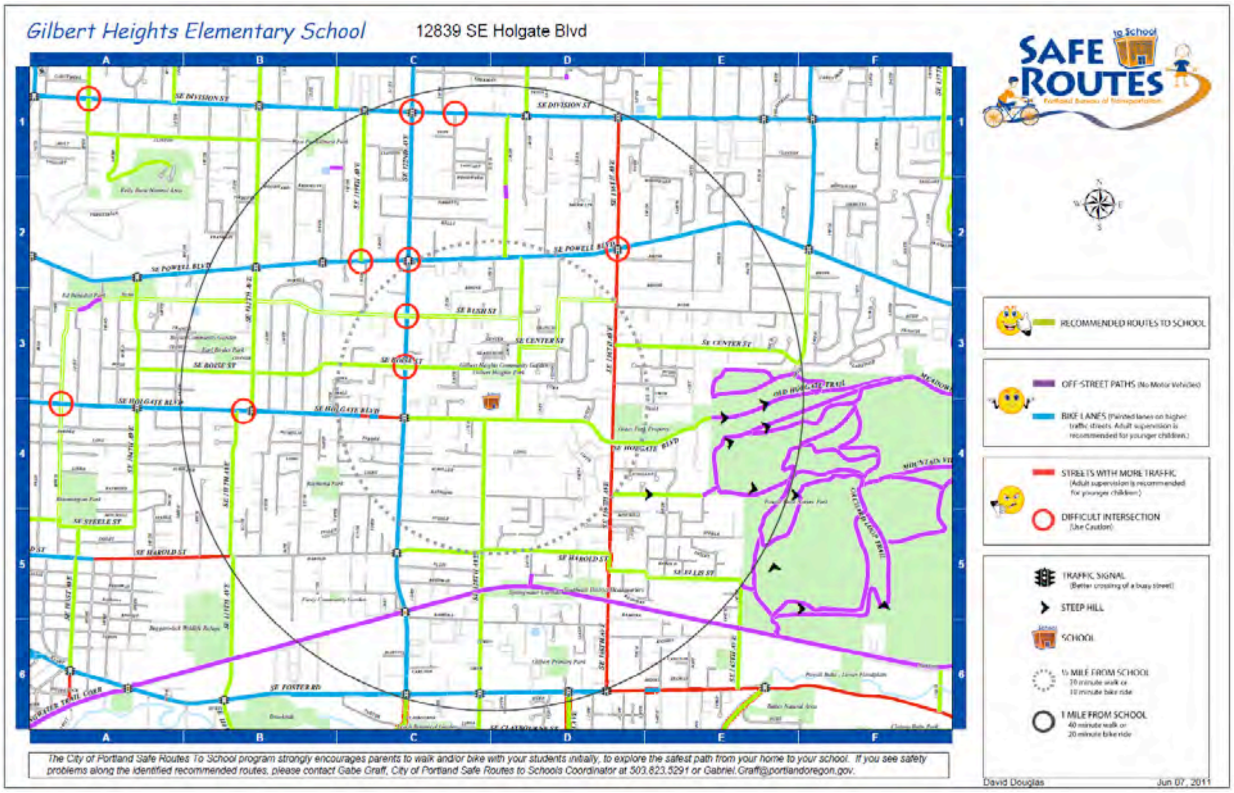

Figure 7. A custom map for walking and biking to an elementary school

The walkway network

The walkway network is different from the street network. It is typically different in construction, with narrower facilities, no lanes, and no traffic control of its own. It is also different in topology, and that is important for analysis of a transportation network.

The topology of the street network is contained in a street centerline file. A typical street intersection is represented by line segments that meet at a point, or node. The same area of the walkway network will have eight line segments for sidewalks, four line segments for crosswalks, and four corner points.

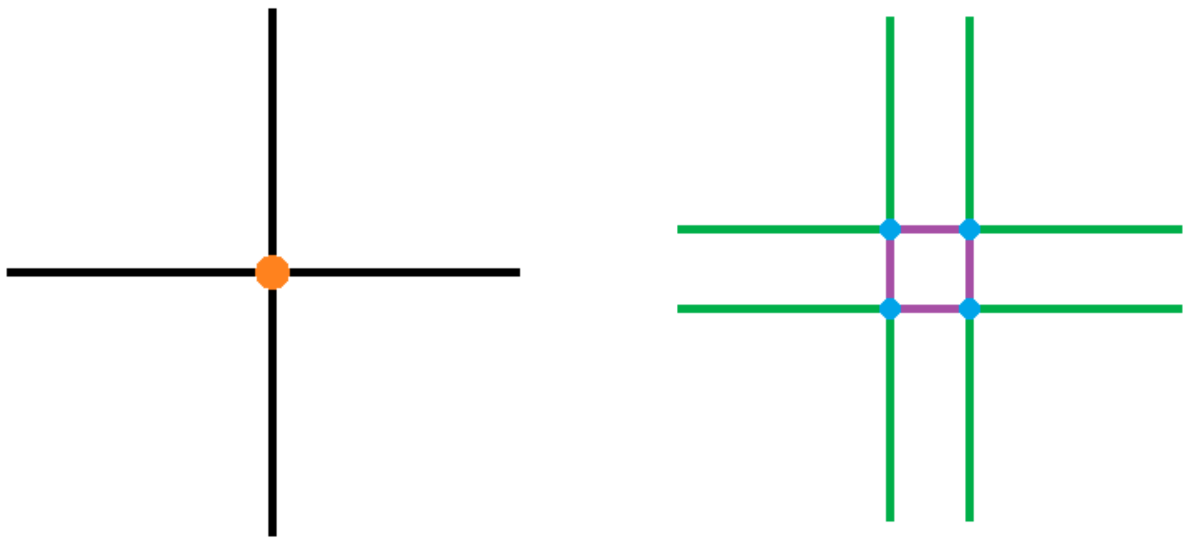

Figure 8. Street network intersection (left) compared to walkway network intersection (right)

Why use the walkway network instead of the street network for analysis?

Use of the street network distorts all types of network analysis of walking trips. The real pedestrian barriers can't be considered if the walkway model doesn't include both sides of the street and the street crossings. Using the street network discounts both street crossings and gaps in pedestrian facilities. If walking trips are analyzed on the street network rather than the walkway network, the results will be dominated by the cost of distance (and possibly the quality of the walkway facility) rather than the cost of traffic at crossings.

A further shortcoming of the street network for analyzing walking trips is that there is no place in the street network model for information about some features of the walkway network. Without information on some of these features, like curb ramps, the routing engine may create a route that is not feasible in the real world, particularly for someone using a wheelchair or mobility device.

Creating a walkway network model

The development by the authors of a tool to automatically generate a walkway network from a street centerline network has revealed a number of important concepts and steps that must be considered.

The nature of the walkway network model

In places where there is no physical walkway present, it is necessary to understand the difference between a walkway corridor that has no facility and a place that has no walkway corridor. Examples of walkway corridors without walkway facilities include an undeveloped street right-of-way or a rural road without sidewalks. Such places can be modeled in the walkway network as line segments with high impedance. A limited access highway is an example of a roadway with no walkway corridor. Even roadways with no walkway corridor, such as the ramps to a limited access highway, may need to be modeled in the walkway network if pedestrians must cross them.

The walkway centerline file, like the street centerline file, holds topological and geometric information about the walkway network. It is not necessary to locate the walkway segments in the precise geographic location of the physical sidewalk: an approximate location is sufficient for the purposes of network analysis.

Preparing the centerlines

Street centerline files come from many sources. The transportation department maintains the street centerline. The parks department maintains the trail centerlines. It is likely that at a city or county boundary two street centerline files will be required. There are minimal requirements for compatibility but it helps to have an automated method of checking and editing node and segment IDs for duplicates and other error types.

Some walkways such as trails or paths in undeveloped rights-of-way many not exist in any centerline files. They will need to be added manually. An automated "node checker" helps here by verifying manually created files.

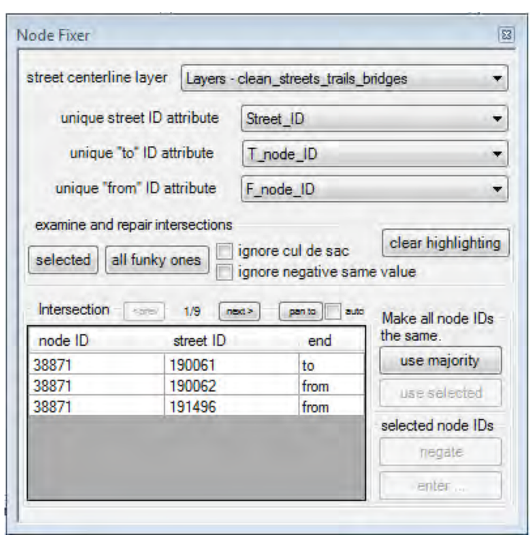

Figure 9. User interface of a software tool to examine and edit nodes in a centerline file

Generating the walkway geometry

The topology of the walkway network can be derived from the topology of a street. Corners can be located on the angle bisector between joining streets. Sidewalks can be located along streets and terminated at corners. Crosswalks are drawn between corners.

Walkway segments vary in their topological relation to the street. For example, a crosswalk crosses the street and a sidewalk doesn't. For the purpose of the walkway generator, five types of walkway segments were identified:

- sidewalks
- crosswalks
- midwalks
- streetwalks/trails
- connectors

Sidewalks go from corner to corner between intersections and have left and right side cases. Crosswalks go from corner to corner at the same street intersection. Midwalks represent mid-block crosswalks. They are a particular case of crosswalks that go from walkway corner to walkway corner, but not at a street intersection. Streetwalks represent local streets where traffic volumes are low, it doesn't matter which side of the street you're on, and crossing the street is easy. Within the network model, streetwalks and off-street trails are modeled in the same way. They connect to street centerline nodes, and they don't have a left and right side. Connectors are necessary where there are sidewalks and streetwalks joining at the same street intersection. They connect a walkway corner to a street centerline node.

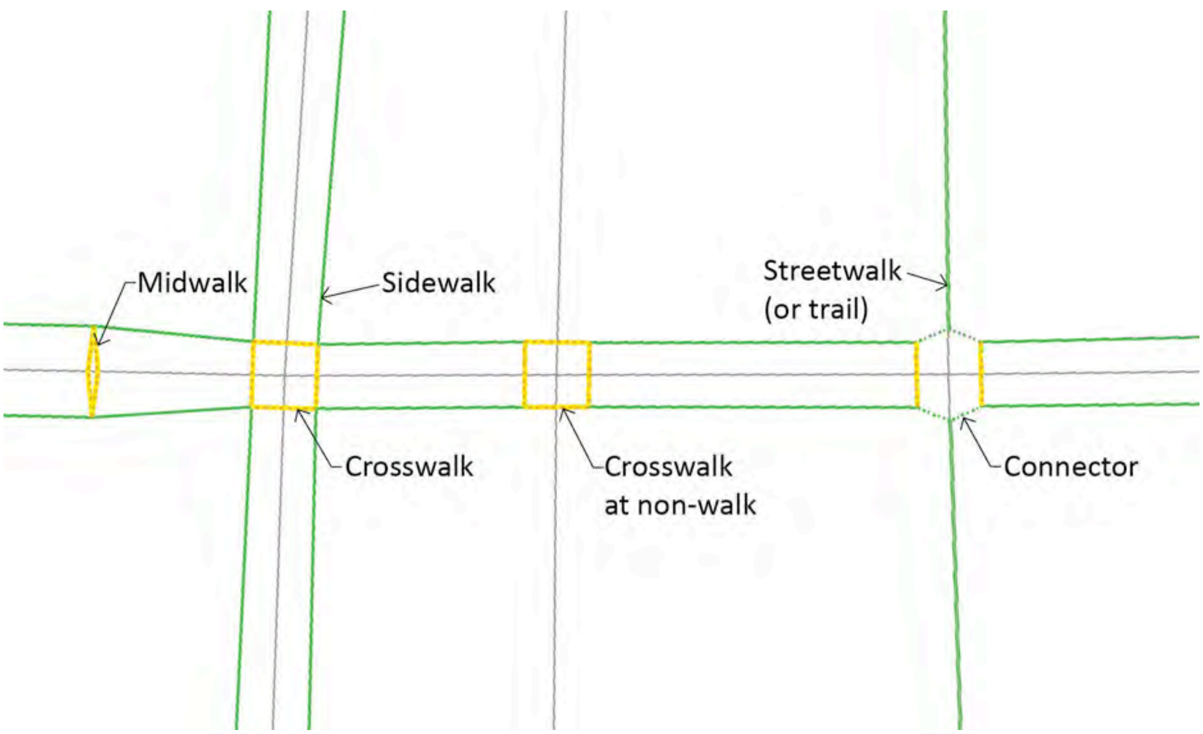

Figure 10. Walkway network segment types

Streetwalks serve some useful functions in the walkway network. They allow a seamless interface between a part of town that has a walkway network and a part of town where the walkway network hasn't been modeled yet. This makes a network where the interface is transparent to a routing engine, and allows incremental modeling of the walkway network. Streetwalks also make a modeler's job easier since it is not necessary to collect detailed information about conditions on both sides of the street.

The walkway generator offers three ways to process street segments into walkway segments. One way is to generate sidewalks and crosswalks. Another way is to generate streetwalks and trails. Another way is to generate crosswalks only. A street segment that has only crosswalks and no sidewalks is called a non-walk. This is the way to process a freeway ramp, which has no walkway corridor but still needs to be crossed.

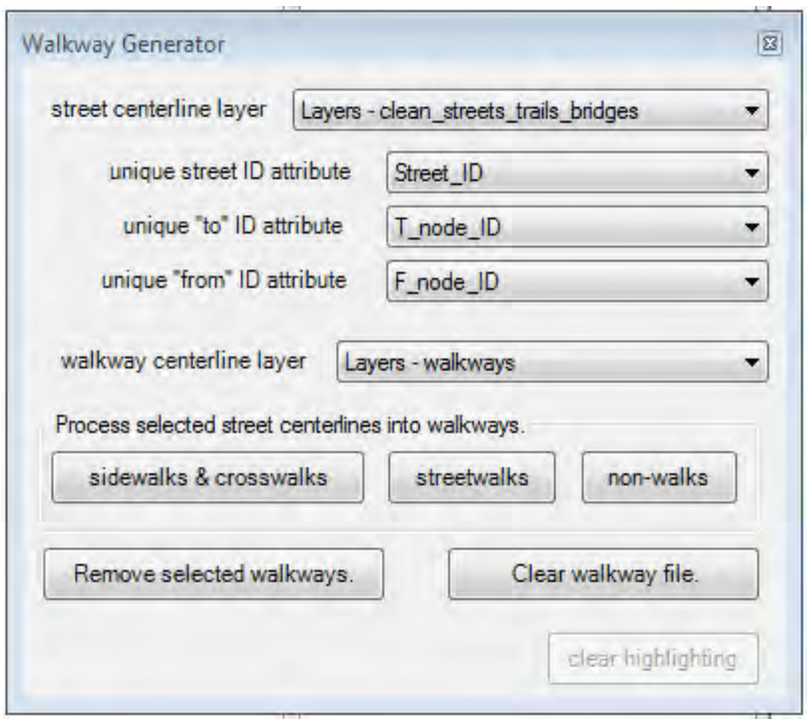

Figure 11. User interface of the walkway generator software tool

In processing street segments it is possible to use standard selection tools to select sets of streets to be processed a certain way. For example, streets classified as local service streets that have traffic volumes below 1500 vehicles per day may be selected to be processed as streetwalks.

It would be easy to locate the walkway line segments automatically if they could be placed very close to the street centerlines, but this makes visualization on a map difficult. We used a typical offset of five meters from the street centerline in generating walkway segments. However, this created problems in cases where the street centerline has very short street segments at street jogs, or very tight turns, or where streets merge at an acute angle. These geometry problems sometimes reflect real world problems in locating sidewalks in these circumstances. The walkway generator program solves the problem by allowing the sidewalk to come closer to the street centerline where necessary.

Weighting the walkways

Segments of the walkway network are cost-weighted according to their length and other attributes, such as whether there is a sidewalk, the volume of traffic on the street, and the presence of an improved crossing such as a traffic signal. These weights are expressed in equivalent distance.

Equivalent distance weighting facilitates differencing. It is intuitive and allows different people at different times to attach weights that will be mathematically reasonable (that is, two numbers with the same units that can be meaningfully subtracted).

One way to describe equivalent distance weighting is that it answers the question (for crosswalks), "How far would I walk down the street to get to a magical place where the walk sign is always on and there's no right turn on red?" This is expressed as an absolute distance. For sidewalks, the question is, "How long a detour would I make to walk through a park or a car-free zone to avoid the sidewalk (or lack of sidewalk facility) on this block?" This is expressed as a multiplier on the length of sidewalk.

There is no limit to the detail and complexity of weighting schemes. One project at Portland State University used SPSS® to generate walkway weights that were merged into the walkway centerline file. Excel® also can be used.

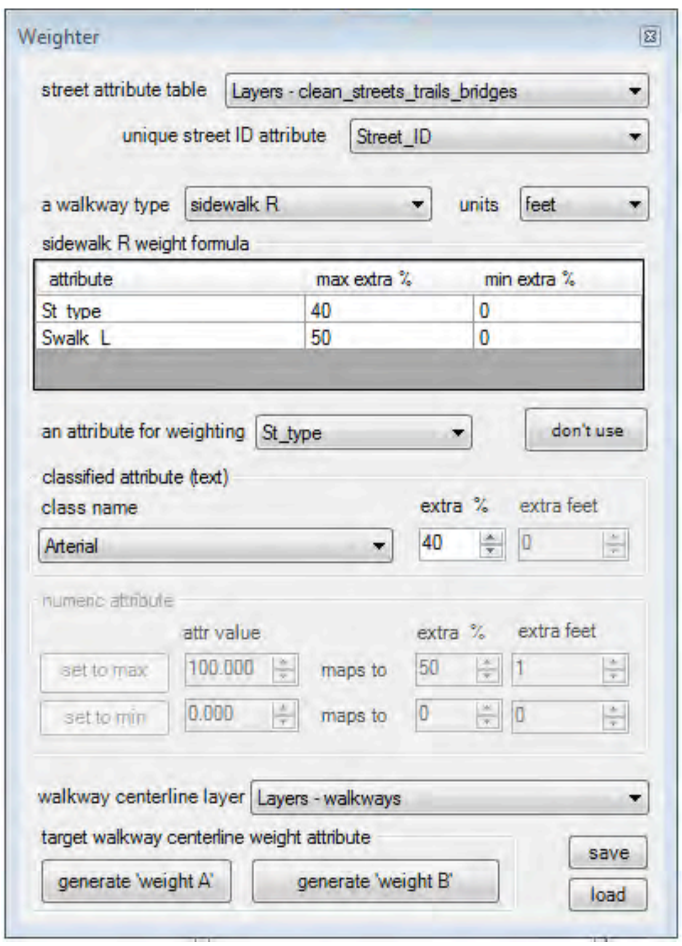

Figure 12. A software tool for creating simple weighting schemes

Analysis and visualization using the walkway network

Once a cost-weighted walkway network has been created, it's possible to perform many types of analysis as described in the earlier section on network analysis and mapping.

One type of visualization, as shown in Figure 13, is the slope-shaded map. Here each point on the surface represents the equivalent walking distance from that point to a given destination, derived from the cost-weighted network. At each point, the slope of the surface is the ratio of the equivalent walking distance to the geometric (crow-fly) distance to the same destination. A steep slope represents a situation in which the shortest walking route either takes someone a long way out of direction or exposes them to discomfort or danger.

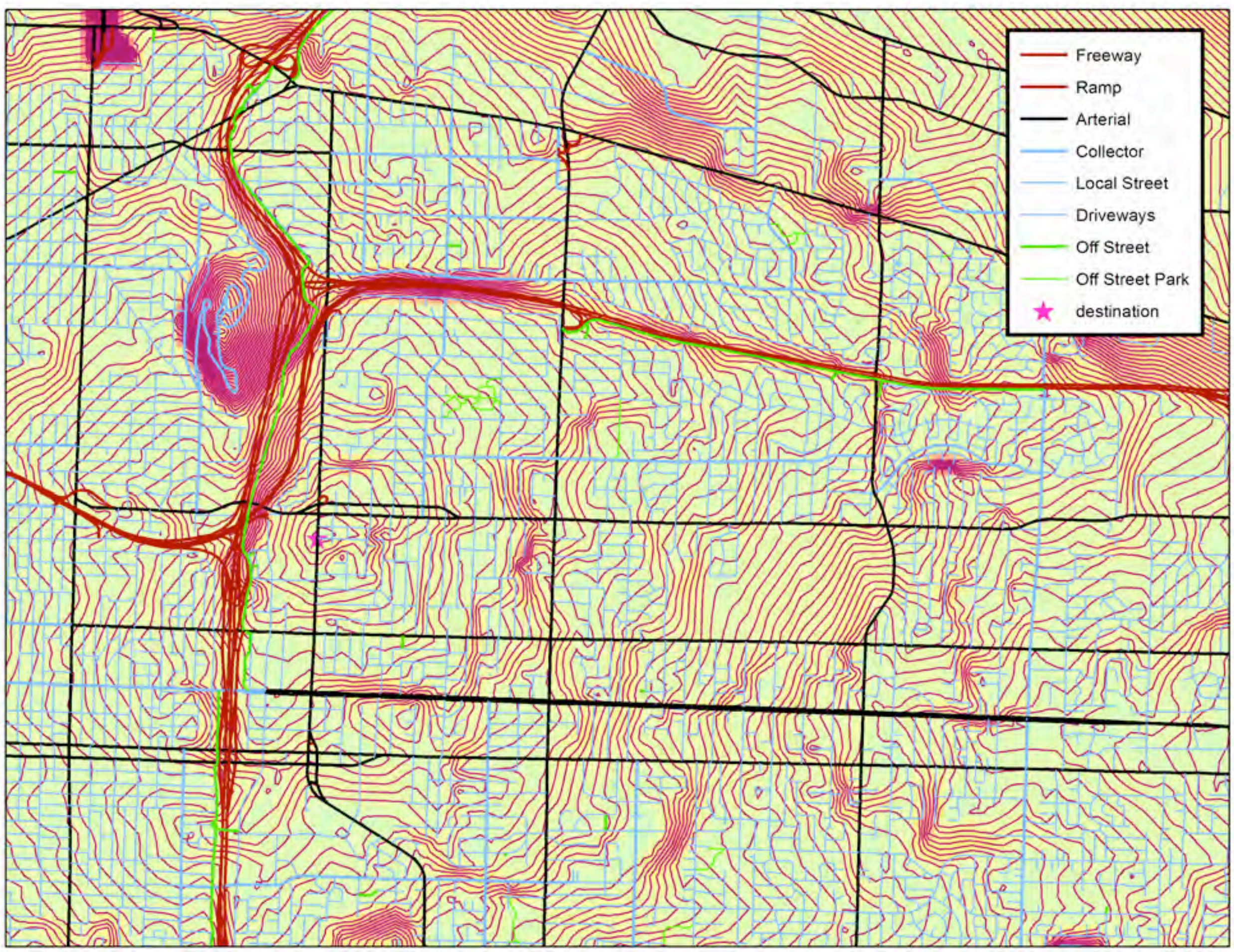

Figure 13. Slope-shaded map with contours shows where impedance to walking is highest

The expected impact of a specific walkway improvement project can be visualized by computing the difference between before and after surfaces of equivalent walking distance. This analysis takes into account destinations, dwellings, and the walkway network between them. Figures 14, 15, and 16 show three visualization techniques.

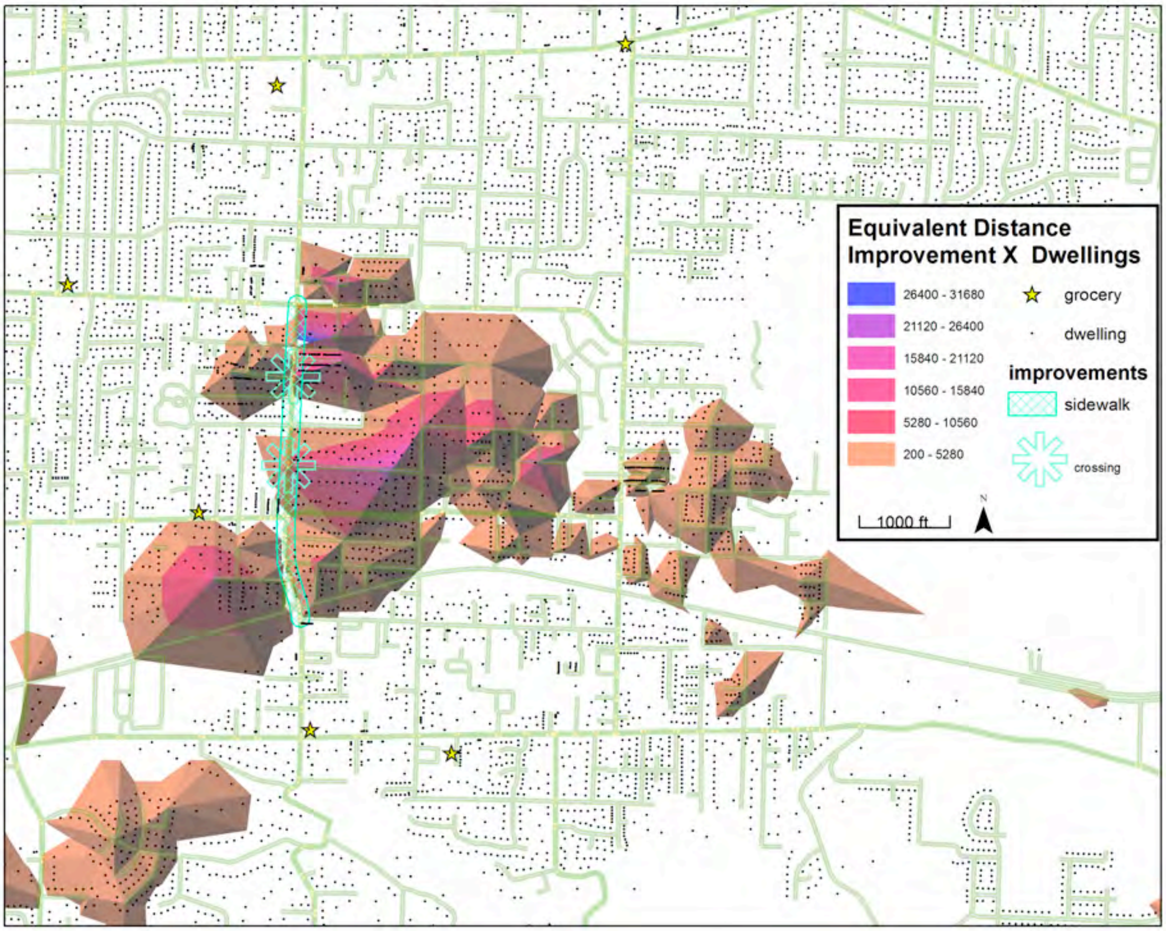

Figure 14. Visualization of project impact using hill shading and coloring

Notice that there are areas some distance to the east of the project that have considerable benefit. This is because there are few grocery stores in this area and the population is high. One area to the southwest of the project is close to a grocery store "as the crow flies" but benefits from the project even though it is out of direction. This is due to poor walkway connectivity in this area. This analysis may alert the project designer to an opportunity to serve people by opening public right-of-way for a more direct route.

A complete walkway model that includes crosswalks is necessary to evaluate the impact of this project. If only streets and/or sidewalks are available in the model the project designer may not include crosswalk improvements that have a significant benefit to a large population to the east. This may cause the project to be ranked too low relative to other projects.

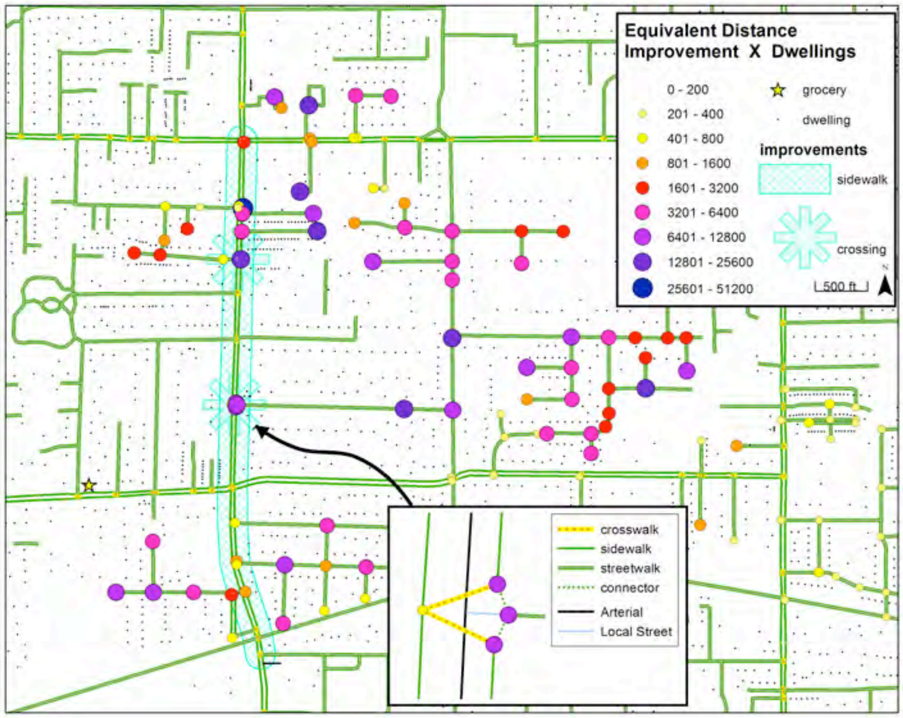

Figure 15. Visualization of project impact using dot size and coloring

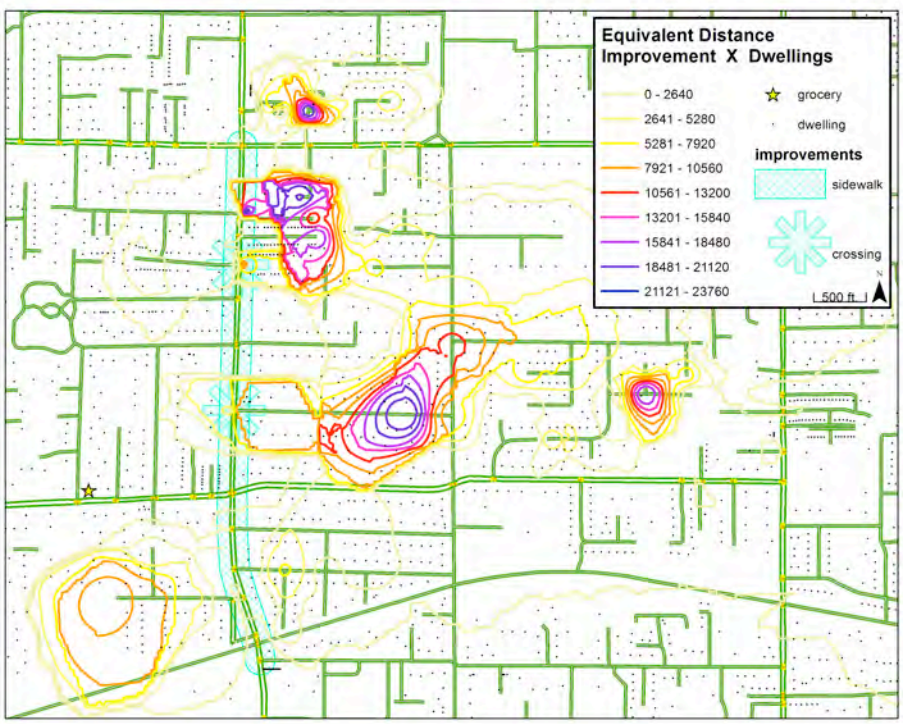

Figure 16. Visualization of project impact using colored contour lines

The underlying analysis technique for all types of walkway network analysis is computation of the lowest impedance route from origin to destination. The maps for this project evaluation are made by calculating tens of thousands of these routes. Each walkway segment will be used by some number of these routes and this can be illustrated with line weight. We refer to this as a "traversal analysis". Figure 17 shows how people at some locations may be expected to walk to a different grocery because it has been made effectively closer by a walkway improvement project.

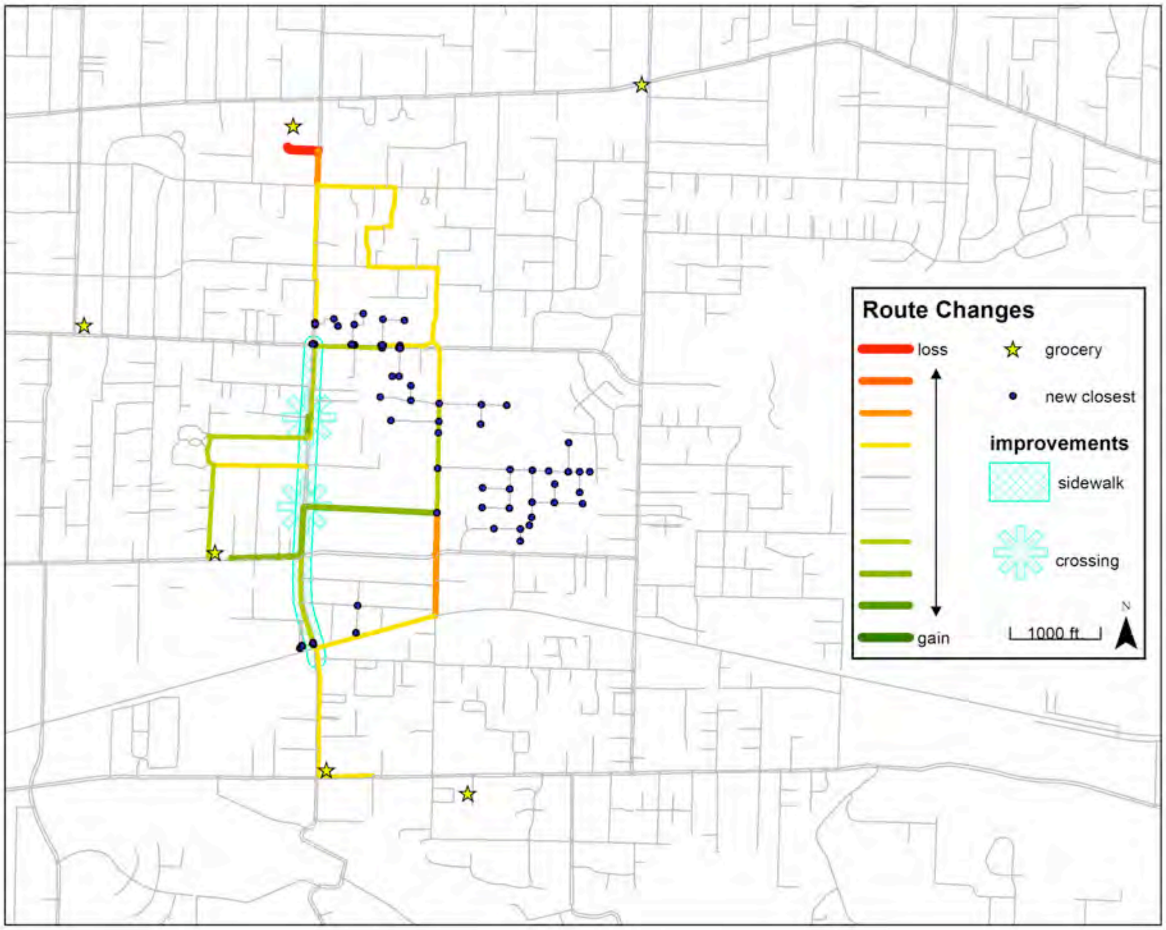

Figure 17. Walkway improvements may make a different grocery store effectively closer

The analysis for Figure 17 is an example of a purely geographic analysis. It considers each origin (in this case each intersection) as having equal weight. This emphasizes place. The analysis for Figures 14, 15, and 16 multiplies the effective distance at each origin by the number of dwellings. This emphasizes population.

Specialized tools move analysis from the "GIS project" domain to the "what-if" domain

While these maps developed for evaluating the impact of walkway projects may be very valuable they would not likely be used if generating them required a GIS project. Using common GIS software such a project can take days to specify and weeks to implement. If a project designer has simple questions such as, "Which intersection should we choose for crossing improvement?" or, "What if we include schools as a destination?" or, "What is the impact of developing this unused public right-of-way?" then turn around time for the analysis must be in minutes not weeks.

If analysis takes only minutes to set up and execute then the designer can use it dynamically and creatively to produce a design that makes the best public investment. To support this "what-if" type of design a software tool must make it easy to specify the analysis and it must execute the analysis quickly.

The calculations necessary for network analysis are significant but software design techniques that take advantage of modern computer technology can reduce execution time to less than a second even for tens of thousands of origins. User interfaces can be designed so that a minimum of information need be specified to the program. Intermediate steps that require naming and locating files that must be recalled for later steps can be eliminated. With conventional GIS programs the complex sequence of these intermediate steps and the dozens of intermediate files that are generated require a GIS professional to perform the analysis.

If an analysis tool is simple to use and executes fast it can be used by neighborhood activists as well as by city governments. We anticipate that walkway network analysis can be offered to citizens and advocacy organizations so that they can make an effective case for specific walkway improvements.

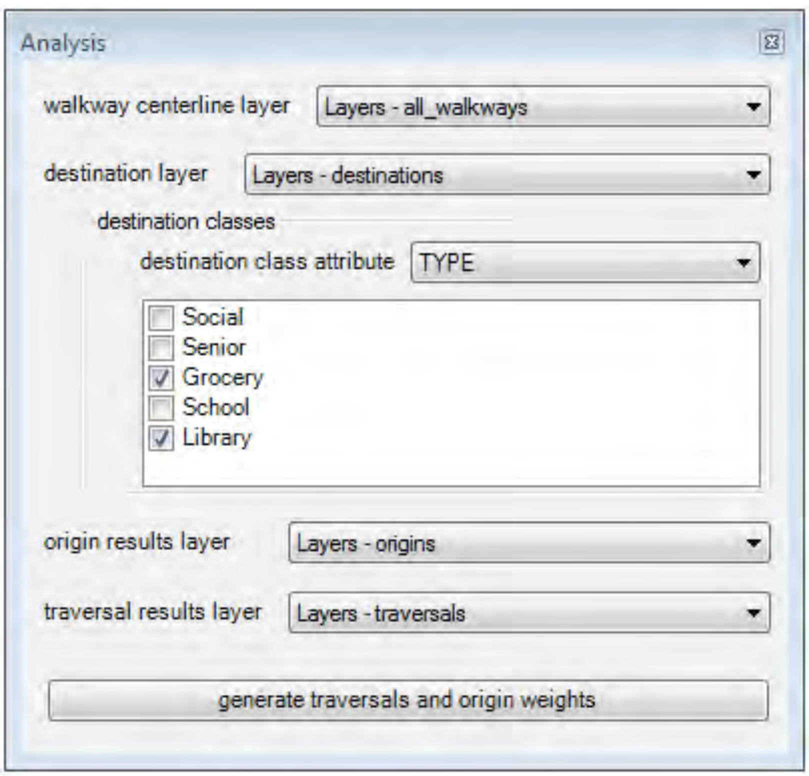

Figure 18. A software tool for specifying walkway network analysis

Additional benefits from the walkway network process

The tools described here were used to generate a walkway network model for East Portland as part of the City of Portland, Oregon's "East Portland in Motion" 5-year active transportation strategy. The very process of creating the model illuminated different ways of thinking about transportation. Looking at aerial photographs with an eye toward making a transportation network, and determining what segments should be added, raised issues of how public land and undeveloped public rights-of-way should be used. In the case of public land, we usually think of parks and schools as destinations themselves, rather than as part of a route to another destination. In the case of public right-of-way, creating a path through an undeveloped bit of right-of-way may put dozens of people a kilometer closer to their grocery store, or it may provide no important connection. GIS analysis can help pedestrian activists know which undeveloped rights-of-way to advocate for retaining and developing as paths.

Another subtle but significant change in thinking that results from developing a walkway network model is an appreciation for walkway facilities as components of a transportation network. Such facilities are often viewed by transportation departments only as assets. For example, the City of Portland has records of its crosswalks in GIS for maintenance purposes, but they are not readily moved into a network model because they are not associated with street centerline segments.