From TIGER to Audit Instruments

Measuring Neighborhood Walkability with Street Data Based on Geographic Information Systems

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The relationship between urban form and pedestrian mobility is an area of increasing policy interest within the planning, transportation, environmental, and public health fields. Many municipalities are seeking to adopt variations of smart growth principles that seek, in part, to increase pedestrian choice in an urban environment. This paper explores how the path network around key urban destinations can be visually and quantitatively analyzed to provide useful planning and evaluation tools for these pedestrian-oriented environments. Neighborhood environments surrounding transit stops and schools are used as examples of how to visualize and quantify local walkable environments. Three key techniques based on geographic information system (GIS) are presented: street network classification, pedestrian catchment areas, and intersection intensities. Although such measures have been used elsewhere to some extent, this paper includes the idea of impedance, a method to help distinguish between automobile-oriented and pedestrian-oriented areas. A series of GIS-based qualitative visualization and quantitative analyses are presented, as are some basic steps on conducting the analyses within a GIS environment. A discussion of key data sources, including TIGER (topologically integrated geographic encoding and referencing) street data and new pedestrian audit instruments, are also presented as different ways to assess local walkability.

Increasing the amount of walking is a prevalent current topic as planners and public health officials seek ways simultaneously to improve neighborhood quality of life, reduce the growing trend of obesity (especially in children), and limit the need to increase roadway capacity for additional automobiles. The underlying understanding of these approaches is that a variety of land use factors affect travel patterns including density, land use mix, roadway connectivity and design, parking facilities design, and building design (*1–5*).

Often lost in the discussion about local-scaled development [e.g., transit-oriented development (TOD)] is the quality of the walking infrastructure within this local environment that allows individuals to access their desired destination. For example, the capacity for transit users to walk to and from their transit point of entry is a critical component of the overall TOD concept because pedestrian impediments to reaching a transit station become equal impediments to transit usage. That is, "Since all transit trips involve some degree of walking, it follows that transit-friendly environments must also be pedestrian-friendly" (*4*). The same is true about accessing school, another emerging topic among planners and public health officials. The quality of the local walking infrastructure can play a crucial role in the decision-making process for a child (and his or her parents) in choosing an appropriate way to get to school.

Geographic information systems (GIS) provide a useful tool for evaluating the quality of this local transportation infrastructure. This paper uses the street networks around transit stops and schools to analyze local walkability visually and quantitatively to provide useful planning and evaluation tools for transportation planners interested in enhancing the local walkable environment. The approaches demonstrate several methods for evaluation, including the concept of impedance, or the relative influence that nonwalkable streets may have on local walkability. These approaches can be conducted on a range of transportation infrastructure data, from publicly and freely available TIGER (topologically integrated geographic encoding and referencing) street data to data collected with a pedestrian audit instrument. These methods have been developed through an evaluation of a diverse set of TOD and school locations in three cities in Oregon: Portland, Springfield, and Bend. Although this paper focuses on TODs and schools, the techniques can be applied to many destinations in which walking could be a travel mode of choice, including neighborhood parks, the supermarket, government centers, a downtown core, and religious institutions.

CONCEPTUALIZING THE PEDESTRIAN SKELETON

Many potential pedestrian conditions enhance or impede one's ability or desire to reach a destination, including safety issues, existence of appropriate paths, and an interesting viewscape at the pedestrian scale (*5, 6*). Other measures include transportation infrastructure (i.e., number of vehicle lanes, bike lanes, and sidewalks), street design (i.e., cul-de-sacs, grid), neighborhood design (i.e., traditional, suburban, neotraditional), and accessibility (i.e., proximity of destinations and number of destinations within a given distance) (*7*).

For most destinations in most communities, there are three key elements of walkability: the quality, connectivity, and accessibility of the road network. The road network represents the basic skeleton of the urban form, creating the range of opportunities and path choice that can make walking more or less desirable. There are other ways to identify walkable routes, including sidewalks and off-street paths, but for many environments sidewalks and streets are synonymous and off-street paths are rare.

It is believed that good urban form can lead to a reduction of total transportation costs and automobile usage, resulting in more livable communities (*8*). For example, Bernick and Cervero (*4*) found that the residents of more pedestrian-friendly neighborhoods were more

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likely to walk to the market. Handy (*9*) found that residents living in "traditional neighborhoods" made two to four more walk or bicycle trips per week to neighborhood stores than people living in nearby areas who were served mainly by automobile-oriented strip retail establishments. Krizek (*10*) found that people who live in more walkable areas, referred to as areas with good "neighborhood accessibility," are more likely to walk and use transit than people who live in more traditional automobile-oriented environments. A good walkable urban form, therefore, can be a key contributor to local mobility (*9*).

Southworth and Ben-Joseph (*11*) observed that residential streets provide the public framework that shapes urban form and guides neighborhood life. Currently, however, streets are categorized in a hierarchical, automobile-centered manner ranging from arterial to collector to feeder roads, implying that all roads serve the singular purpose of automobile mobility.

Visualizing this urban skeleton is also an important component to understand walkability. Lynch (*12*) identified five basic components of urban form—paths, edges, districts, nodes, and landmarks—each of which can be visualized in terms of a walkable urban network. Paths can be thought of as minor roads; edges equate to freeways or other large roads (e.g., arterials) that impede pedestrian movement; districts can represent concentrated zones of walkable urban form; nodes represent street intersections; and landmarks represent key origins or destinations, such as a transit stop. Each of these elements can be measured and viewed spatially to present a qualitative opportunity to assess local environments in terms of walkability.

In terms of pure visualization, Jacobs (*13*) presented a unique method of visualizing the urban form by using a figure-ground technique of displaying the road skeleton that makes up different urban environments. Using the same scale and same visualization techniques, Jacobs visually showed the importance of the street network in framing and supporting walkable urban forms. Southworth et al. (*14*) extended Jacobs' work by incorporating visual examinations of intersection patterns and quantifying several elements of the street network, leading to a spectrum of identifiable development types based solely on the nature of the road network.

The urban form around key places of interest is important for increased pedestrian access and activity, and the street network often acts as the skeleton for this urban form. Yet, the work on visually and quantitatively analyzing the walkable urban skeleton remains relatively undeveloped. For example, in terms of using the street network, Krizek's (*10*) innovative analysis of travel behavior using local measures of neighborhood accessibility looks only to the presence, absence, or concentration of certain street network characteristics, assuming that all streets and intersections are of equal quality and use. Refining how these basic components of the street network are modeled is needed for better planning (or more likely evaluation of past planning) of walkability principles.

Certain automobile-oriented roads (freeways and major arterials) present impedances to pedestrians because the scale and feel of such roads negatively affect one's ability or desire to cross or travel along them. The term "impedance" refers to the notion that some streets restrict, or impede, a pedestrian's ability or desire to move along or across it. By including the concept of impedance into the GIS-based qualitative visualization and quantitative analyses, the road network, route choice, intersection concentrations, and pedestrian-scaled environments can be more accurately identified and measured. Measuring the walkable environment around local destinations such as transit stops and schools can lead to an intraurban level of analysis that allows one to capture the spatial qualities of the elemental city perspective (*15*) and can help to build the quantity of case studies so that the underlying principles, inputs, and outcomes can be understood more fully (*2*). Thus, the following discussion is meant to promote, visualize, and quantify a series of measures that can be used to plan or evaluate urban form on a pedestrian scale.

MEASURES

Evaluating local walkability based on the street network with GIS can yield many different types of analyses. Thirteen individual calculations are presented, which can be generalized into the three broad categories of quality, proximity, and connectivity (see Table 1). The following measures should be thought of as complementary instead of as substitutes for one another. Each measure offers one part of understanding walkability and, by looking at multiple measures simultaneously, a full picture of local walkability can be understood.

Quality: Street Classification Analysis

Street classification analysis is an evaluation and categorization of street type and purpose along the road network within local areas such as TODs and school neighborhood areas. This analysis

TABLE 1 Measurement Domains and Techniques

Measurement Domain	Analysis Technique	Quantitative Measure
Quality	Street classification analysis	Minor roads (mi) Major roads (mi) Minor road density (street miles per area) Minor–major road ratio
Proximity	Pedestrian catchment areas	Pedestrian catchment area (ratio) Impeded pedestrian catchment area (ratio)
Connectivity	Intersection analysis	Intersection density (per mi^2) Dead-end density (per mi^2) Intersection : dead-end ratio Impedance-based intersection density (per mi^2) Impedance-based dead-end density (per mi^2) Impeded intersection : dead-end ratio Change in intersection : dead-end ratio

provides insight into the basic quality of certain paths and reflects the hierarchy of road types within the study zones.

Locales with high automobile speeds or large volumes of traffic are characteristic of locations hostile to pedestrians. Calthorpe and Poticha (5) and Calthorpe (16) recently called for a change in how roads are classified, from an automobile-centric design focus (minor, feeder, and arterial) to focuses that reflect accessibility principles. By identifying and classifying road types with relevant typology—ones that reflect accessibility design principles—researchers and transportation planners can more accurately assess road functionality.

The street classification analysis addresses this request by defining and exploring the relationship of impedance roads (or hostile roads) and accessible roads (or pedestrian-friendly roadways). An impedance road has the ability to divide a community spatially, splitting it into segments via a road that acts as a barrier. Identifying where these roads are reveals the spatial externality of the road placement. By spatially displaying where these roads are in map form, with accompanying metrics on quantity or share of road types, it is possible to create an accessibility profile base for impedance values.

The number of classifications can vary depending on the needs of the evaluation, but, for simplicity sake, the following presents a classification of streets into just two categories: walkable and not-walkable streets. Following are four types of street classification analyses that can be conducted to understand local walkability. After the description are some basic steps one would take to conduct the analysis with GIS and TIGER street data.

- Minor roads (total length). Minor roads are generally more walkable because of decreased speeds and automobile volume, and therefore areas with longer total mileage of minor roads may indicate a more walkable area than an area with relatively fewer minor roads.
- Major roads (total length). Major roads (e.g., arterials) often act as impediments for pedestrians who have to walk along them or cross them to access a destination. Therefore, the greater the number of these major roads, the worse the walking environment may be.
- Minor road density and minor–major road ratio. These two variables represent ways to normalize the measures and can be used together to understand an element of the local mobility infrastructure. Areas with a high density of minor roads may offer more pedestrian route options than areas with lower densities. Likewise, areas that have a large number of minor roads relative to the number of major roads may provide pedestrians with a number of viable non-major-road options. Looking at both measures, it is possible that the presence of major roads can offset the benefit of a large number of minor roads, especially if the major roads are located central to the walkable area of interest.

GIS Steps with TIGER Data

Embedded within TIGER street data is a street segment classification system labeled Census Feature Class Codes (CFCC). The CFCC uses a hierarchical system to categorize different street types ranging from "Primary road, interstate highway and limited access road" (A10) to "Alley" (A73). The following three steps can be used within GIS to develop a simple segregation of local streets into major and minor roads:

1. Select and delete all Interstate and limited access roads (CFCC: A1x, primary road, where x can be any number between 1 and 9). These roads are not options for pedestrians and can be removed from the data set before conducting the walkability analyses if desired.
2. Select the minor roads (CFCC: A4x, neighborhood roads) and save as a separate data layer; these can be referred to as the more pedestrian-friendly routes.
3. Select the inverse streets from Step 2 and save as a separate layer of impedance streets.

It is important to double check the selected features in Steps 2 and 3 and make small adjustments to the selected features if necessary. For example, it may not be desirable to include service drives (A64) as major streets. Combined with some common sense and a basic knowledge of the local area, using TIGER files in this way can generate a quick and easy classification of the local street network. (For a listing of CFCC codes, refer to TopoDepot at http://www.topodepot.com/Docs/Doc_Tiger.htm.)

Proximity: Pedestrian Catchment Areas

Pedestrian catchment areas (PCAs) [also referred to as ped-sheds (17)] are theoretically walkable zones that can be mapped to show the actual area that can be accessed via the path network from a fixed point (e.g., a quarter-mile walk from a school). PCAs capture how well the street coverage relates to a specific key destination. The basic calculation of a PCA is to divide the area of a quarter mile (or any distance) by the area of the polygon that results by traveling a quarter mile (or similar distance as before) from the key destination in question (see Figure 1). The resulting polygon is a somewhat generalized representation of a walkable area compared with space around actual street right-of-ways and the influence of different tax lot sizes on placement of actual paths. Nonetheless, the PCA provides one measure that, when used in conjunction with others, helps build an overall walkability assessment.

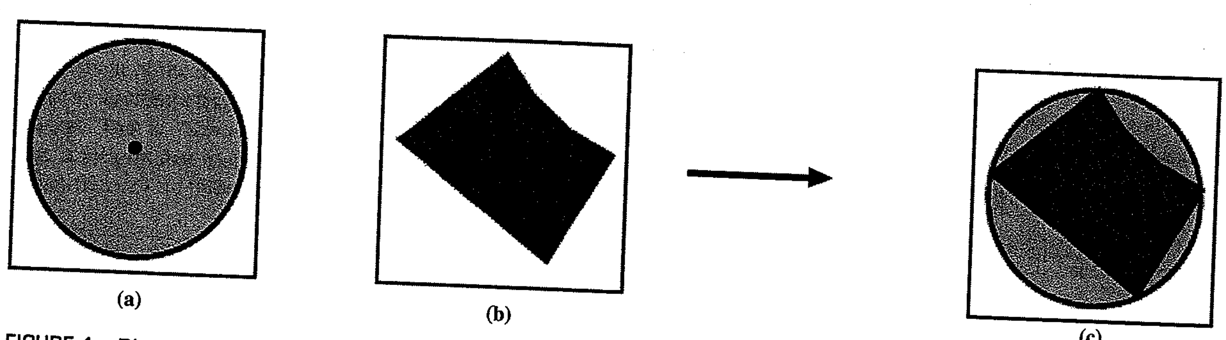

FIGURE 1 Diagram of pedestrian catchment area ratio calculation: (a) theoretical pedestrian service area, (b) network-defined pedestrian service area, and (c) pedestrian catchment area ratio.

There has not been enough research to determine an optimal PCA score, although it is suggested that a minimum score of 0.50–0.60 (50% to 60% coverage) is a useful threshold (*17–19*). A score less than 0.30 would reflect an inaccessible walking environment.

One adjustment can be made to the PCA to reflect the influence of the impedance roads mentioned previously. The impeded PCA (IPCA) is calculated by using the street network without the major roads (or otherwise classified pedestrian-hostile roads). Removing these roads from the street GIS data and recalculating the network distances one can travel from a destination yields a ratio that may better reflect the actual zone of walkability around a school or transit stop. In this way, the walkable zone is one that is accessible exclusively via pedestrian-friendly roads.

Once the IPCA is completed, an insightful calculation is to compare the PCA with the IPCA; the larger the decline from PCA to IPCA, the greater the influence of major streets on local walkability. In other words, the spatial placement of those pedestrian-hostile paths has a negative influence on local walkable conditions if the IPCA is substantially lower than the PCA ratio.

GIS Steps with TIGER Data

Calculating the PCA and IPCA is straightforward within GIS using the following steps:

1. Determine the central point of study (e.g., transit stop, school, or centroid of a park or neighborhood);
2. Determine the size of the walkable study area (e.g., 0.5 mi) and use the GIS to create a buffer circle of that Euclidean distance from the point of interest;
3. Use a tool such as Network Analyst in ArcGIS to calculate a network distance from the point of interest using all streets;
4. Repeat Step 3 using just the walkable streets (the data layer with all major streets removed); and
5. Use GIS to calculate the area of the polygons that result from Steps 3 and 4 and divide this area by the area of the circle created in Step 1; the resulting ratio is the PCA or the IPCA.

Connectivity: Intersection Intensity

The intersection intensity analysis examines the street network within the analysis area based on the spatial location of certain types of intersections to capture the grain (density of intersections) and the interconnectedness (types of intersection) of a neighborhood. Intersections are a core set of data because they represent the number of choices available to a pedestrian and, from a spatial perspective, how these choices are arranged throughout the study zones. Understanding intersection and dead-end densities is fairly straightforward; areas that are more walkable would tend to have higher intersection densities and lower dead-end densities. One would expect that areas with more roads would have more intersections, yet, independently analyzing intersection densities is important because it gives insight into the connectedness of the mobility network that might not be evident from simply looking at the length of the network. The ratio between intersections and dead ends is another useful way to understand the mobility infrastructure, because path continuity is important and the higher the ratio, the fewer potential barriers there are for walkers. The author has found that walkable areas are characterized by minimum intersection densities of 100 intersections per mi^2, with areas exceeding 150 intersections per mi^2 being highly walkable.

The impeded intersection and dead-end calculations measure the impact of major roads on intersections and dead ends. These measures are calculated by removing major roads from an area and reanalyzing where intersections and dead ends occur. For example, a minor road that ends at a major road (a T-intersection) may feel like a dead end to a pedestrian, rendering that path an unacceptable alternative. In the impeded calculation, that intersection would actually be converted to a dead end in the data set. An intersection that exists when two major roads cross each other would be removed from the data set for the impeded calculations. In all cases, the impeded calculations will decrease the number of intersections and increase the number of dead ends. One key, then, is to measure the extent of this shift, and the ratio between the impeded intersection density and the impeded dead-end density gives some indication of the relative influence of major streets on pedestrian path connectivity. Finally, the change in ratios between the regular street data and the impeded street data can provide another indicator of the extent to which unwalkable paths influence the local area for pedestrians.

GIS Steps with TIGER Data

Intersections are not provided with TIGER data, so calculating intersection and dead-end densities is slightly more complicated than the previous analyses because a layer of intersections must first be developed from the TIGER street layer. There are numerous ways to create an intersection data layer, but each essentially is deriving the points where street segments meet and assigning a number to the point that corresponds to the number of segments that radiate out from it. This number correlates to the type of intersection it is (1 = dead-end, 3 = three-way intersection, etc.). The following steps are based on the ArcGIS environment:

1. Convert the TIGER GIS layer to a coverage file;
2. Download a script called addvalence.aml from the ESRI website (arcscripts.esri.com) and place in the same directory as the street coverage file; this script will create intersections from a line file;
3. Run the script [and run addvalence.aml (street coverage file name)];
4. Open the new node layer that was created from Step 3 and select dead ends (valence = 1) and good intersections (valence = 3, 4) within the study area;
5. Divide the dead-end and intersection results by the study area to derive densities; and
6. Repeat Steps 3–5 using the street layer with the impedance streets removed for a more accurate calculation of dead ends and intersections from a pedestrian point of view.

QUANTITATIVE WALKABILITY OUTPUT

Once the data layers are customized and calculations are completed, results can be combined into a synthesis table. From a planning perspective, it may be desired to compare multiple sites to see how each performs on these measures relative to others (*18*). Table 2 details the quantitative results of a walkability comparison of four middle schools in Oregon, two of which are located on the urban fringe (fringe) and two of which are in more centrally located neighborhoods (central). The analysis zone included 1.5 mi around each

TABLE 2 Walkability Results for Four Middle School Areas

	Springfield		Bend	
Measure	Agnes Stewart (fringe)	Springfield (central)	Sky View (fringe)	Pilot Butte (central)
Minor roads (mi)	62.3	108.4	47.7	112.3
Major roads (mi)	3.5	9.6	4.0	5.6
Minor road density (street miles per area)	8.8	15.3	6.8	15.9
Minor-major road ratio	18.0	11.3	11.9	20.2
Intersection density (per mi^2)	50.2	96.6	31.8	110.3
Dead-end density (per mi^2)	19.4	25.2	18.5	41.4
Intersection : dead-end ratio	2.6	3.8	1.7	2.7
Impedance-based intersection density (per mi^2)	42.8	84.3	28.6	101.1
Impedance-based dead-end density (per mi^2)	25.6	31.0	20.8	45.1
Impeded intersection : dead-end ratio	1.7	2.7	1.4	2.2
Change in intersection : dead-end ratio	−35.4%	−29.1%	−20.0%	−15.8%
Pedestrian catchment area (ratio)	0.48	0.60	0.39	0.54
Impeded pedestrian catchment area (ratio)	0.39	0.59	0.38	0.54

NOTE: All schools are no more than 1.5 mi from the transit stop.

school, because school buses are not available to students within that distance (unless a hazardous road condition exists, when an exception may be possible).

Including the impedance-based measures enhances the analysis by understanding the impact of automobile-dominant roads on the pedestrian infrastructure. This impact can be seen in the changes in intersection and dead-end densities, the change in the intersection to dead-end density ratio, and the change between the PCA and the IPCA. If minimum desirable thresholds were established for intersections, for example, the impeded intersection density may be a more accurate measure of the local condition. For example, if a local planning code called for a minimum intersection density of 90 intersections per mi^2 within 1.5 mi of schools, then Springfield Middle School would go from meeting that standard (96.6) to not meeting the standard (84.3) once the impeded-based calculations were used. Because the impeded analysis also reduces the number of intersections and creates more dead ends, the change in ratios between the regular and the impeded calculations can give another indication of the impact of major roads on the overall pedestrian environment. Finally, the IPCA analysis indicates how far one can reach from a fixed location if pedestrian-hostile paths are eliminated from consideration. This approach may better model the areas where people are more willing to walk than an approach that considers all paths to be equally attractive. In the preceding school example, major roads affect the walkable zone only in the case of Agnes Stewart Middle School, reducing the PCA score by 20%.

Overall, in the preceding example, the walkable zone around each school, based on the street network infrastructure, varies considerably across the four schools. In general, the two centrally located schools, Springfield and Pilot Butte, had street infrastructures that were much more conducive to walking than the two fringe schools (Agnes Stewart and Sky View). Table 3 presents a simplified summary of the spatial variables discussed previously, ranking the key indicators as positive (+), neither positive nor negative (O), or negative (−). This simplified overview makes clear that the two more centrally located schools (Springfield and Pilot Butte) perform well in relation to the other two schools, receiving positive assessments on all but one variable. Agnes Stewart, residing on the fringe of the more developed city of Springfield, received a mostly neutral assessment, whereas Sky View was mostly negative. This would lead one to expect Springfield and Pilot Butte to have a larger number of

TABLE 3 Mobility Infrastructure Summary

	Springfield		Bend	
Measure	Agnes Stewart (fringe)	Springfield (central)	Sky View (fringe)	Pilot Butte (central)
Minor roads (mi)	−	+	−	+
Minor-major road ratio	+	O	O	+
Intersection : dead-end ratio	O	+	−	O
Impeded intersection : dead-end ratio	O	+	O	+
Pedestrian catchment area (ratio)	O	+	−	+
Impeded pedestrian catchment area (ratio)	−	+	−	+

walkers and bikers, followed by Agnes Stewart and Sky View. Travel behavior surveys could then be used to compare the relationship between the local walkability infrastructure and actual transportation modes used by students.

GIS WALKABILITY VISUALIZATION

Results of each of these analyses can also be presented and analyzed visually. Visualizing neighborhood walkability spatially is an important component in planning and evaluation because the visualization allows for a spatially explicit investigation and comparison of various phenomena that can get lost in the pure quantification of important concepts. Visualizing TODs through the preceding measures, for example, can provide valuable insight into the spatial location of a transit stop relative to the existence of both pedestrian-oriented street infrastructure and automobile-centric routes.

Figure 2 illustrates the preceding walkability analyses together as small multiple maps. Each map shows a quarter-mile and a half-mile area around the Lloyd transit stop in Portland, Oregon. Intersection densities are illustrated here as a continuous surface map with darker regions indicating areas of high densities of three- and four-way intersections. That is, darker areas are regions with greater connectivity and thus contain a desirable infrastructure for walkability. The intersection map is purposefully at a different scale than the other three maps so that more of the region beyond the transit stop can be viewed on walkability principles. In this way, one can view whether the transit stop is appropriately located within a walkable area, or if a slightly altered transit location could have been more desirable in terms of pedestrian access. A map showing the actual locations of intersections (or dead ends) could be substituted if desired.

At least three key types of analyses can result from this visual approach:

1. Theoretical walkability analysis. In this analysis, one can look at the general street network (classified by quarter-mile, half-mile, and impedance characteristics) and compare the theoretical walkable zone (as the crow flies) with the zone one can actually reach by walking along the street network starting from the transit stop. This analysis can give one the initial sense of how the street skeleton affects pedestrian mobility. In this case, it appears that the theoretical quarter-mile and half-mile walking distances are relatively achievable by walking along the existing street network.
2. Refined walkability analysis. By comparing the PCA with the IPCA, one can begin to see how large, automobile-centric streets affect the area a pedestrian is likely to access. This analysis gives insight into the effect of transit stop placement and the spatial location of automobile-oriented roads on the potential zone of walkability. In this case, the walkable area shrinks by half and becomes truncated by major automobile-centric roadways.
3. Station–form connectivity analysis. In this analysis, the IPCA and the intersection intensity analyses are compared to understand the relationship between optimal pedestrian environments (in terms of path connectivity) and the likely walkability zones surrounding a transit stop. That is, is the location of good, pedestrian-oriented mobility infrastructure congruent with the area of potential walkability from a transit stop? This analysis provides a fundamental examination of some of the core underpinnings of how people think about TODs (and smart growth more broadly). In this case, where there are good examples of pedestrian-oriented street grids, some are within the likely walkable zone, and some are completely cut off. Moreover, much of the good pedestrian areas north of the transit stop are just beyond the

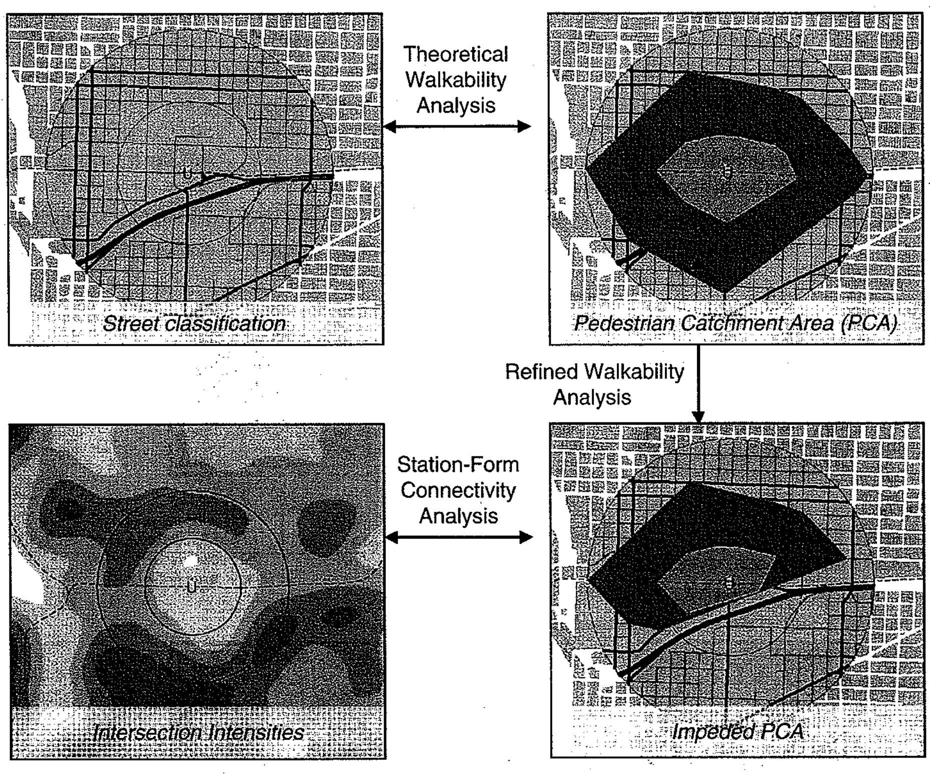

FIGURE 2 Example of visual analysis schema.

walkable zone, suggesting perhaps that the transit line may have been more appropriately routed about a quarter mile further north. With such a rerouting, the commercial zone of the Lloyd District (shown by a "hole" in the intersection surface map) would still have been accessible by foot, and the pedestrian-oriented street network to the north would have enjoyed better transit accessibility.

Figure 3 replicates the preceding figure but replaces the actual map images with conceptual placeholders, creating a schema for walkability analysis. Included in this schema are the key questions that can guide analysis across images. Again, this analysis can be applied to locations other than transit stops such as schools, food outlets, religious institutions, and parks.

OTHER SOURCES OF DATA

TIGER data are the easiest street data to use because they are available for every location in the United States and because they are free and easy to access on the Internet. The downside of TIGER data is that they may not always be consistent with changing local conditions, and, for locations outside the United States, the data (from similar government institutions) may not exist in the same format. A different source of useful street data may include those created by a local municipality. The main data source for the preceding maps, for example, was a street network file developed by METRO, Portland's regional government, classified into different road types. Such data, however, are not universally available and still may lack the level of detail one would want in assessing the walkability of local paths. Responding to this limitation, a series of pedestrian audit instruments are being developed by different researchers. These audit instruments are designed to be used by local planners or researchers to collect original, field-based data on local walkability characteristics. The following section describes one such instrument: the pedestrian environment data scan (PEDS). The PEDS instrument was developed by Kelly Clifton and Andrea Livi at the University of Maryland and Daniel Rodriguez at the University of North Carolina for ArcPad (ArcPad is a licensed GIS product of ESRI), and its use as a source of data in the various walkability analyses was outlined previously. Information on other audit tools is available elsewhere (*20, 21*).

GIS-BASED PEDESTRIAN AUDIT INSTRUMENTS

The PEDS instrument, and others like it, is essentially a comprehensive set of walkability attributes that can be measured on a street-segment-by-street-segment basis. Originally conceived as a paper and clipboard form of data gathering or as a database entry used on a laptop or personal digital assistant (PDA), some researchers at the University of Oregon converted the instrument into a GIS-based data entry form that could work with mobile GIS software on a PDA. This allows local planners to walk the streets, rate each street segment on scores of different pedestrian attributes (i.e., presence and width of sidewalk, buffer and type between sidewalk and street, building setbacks, extent of tree canopy), and enter the data directly into a GIS format while in the field (see Figure 4 for an example of a PDA and customized GIS-based data entry screens).

Such instruments allow planners to begin to collect the more nuanced characteristics of an area that makes it more or less attractive for pedestrians. Instead of classifying streets based on automobile-oriented categories like minor, arterial, or collector road, with an instrument like PEDS, streets can be classified with a pedestrian orientation. GIS analysis can then distinguish between paths based on more relevant variables. For example, streets could be rated on a variety of pedestrian safety attributes such as the quality of the lighting, the number of driveways to cross per street segment, the presence of fixed path obstructions (e.g., utility pole), and whether a particular street subjectively just feels attractive to walk along. These measures could be looked at individually or combined into a safety index, mapped, and analyzed to determine the relative safety of the local walking environment. Figure 5 illustrates how such a safety rating index could be applied to the four schools mentioned earlier to understand the relative safety of the walking environment for students potentially accessing these middle schools by foot. (The Springfield buffer is cut off because of the school catchment area boundary. Children who live in the missing part of the buffer would go to a different middle school.) In this case, the safety index includes 26 different measures synthesized into a single index. Some measures include the presence of crosswalks or other crossing aids, traffic-calming devices, the presence and quality of sidewalks, path obstructions, and lighting, among other variables.

Although the pedestrian audit instruments can be somewhat time-consuming to apply (based on the number of attributes one wants to

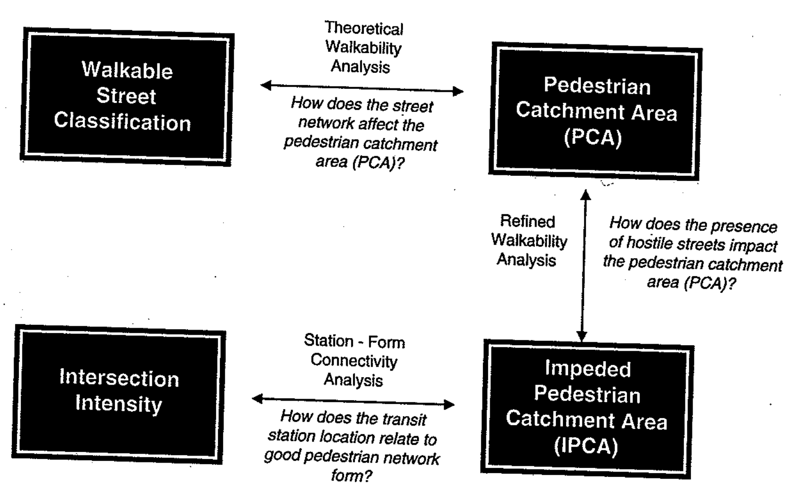

FIGURE 3 Theoretical schema of visual analysis.

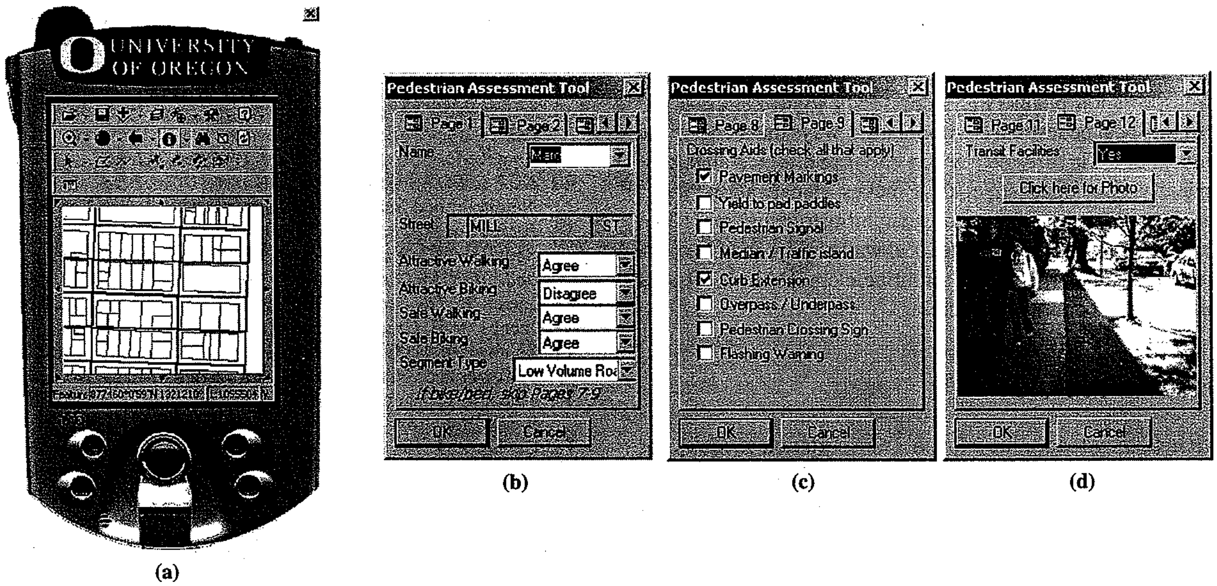

FIGURE 4 GIS-based pedestrian audit tool.

collect and the total area of data collection), the level of detail and direct orientation to walkability makes them an attractive option for better pedestrian planning. Moreover, with new mobile GIS technology, the time incurred on the data-collection side can be reduced on the analysis side because the data are immediately spatially referenced and instantaneously available for analysis once the collection is finished.

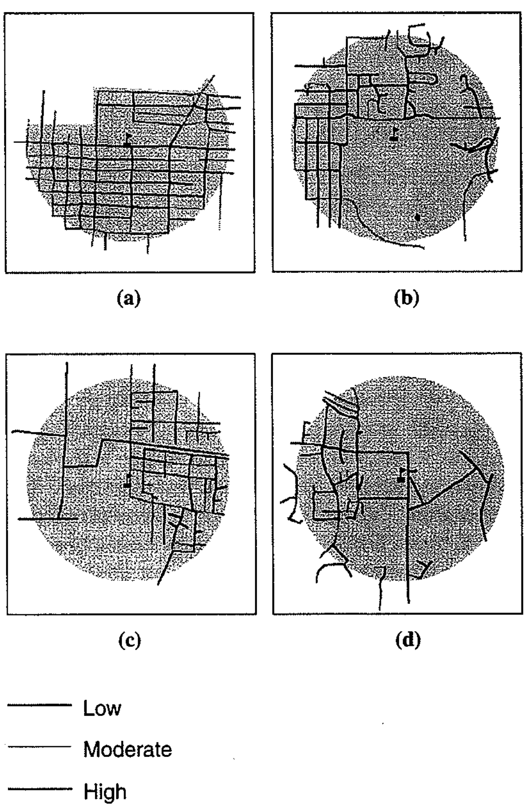

FIGURE 5 Total walkability safety rating *(22)*: *(a)* Springfield, *(b)* Pilot Butte, *(c)* Agnes Stewart, and *(d)* Sky View.

LIMITATIONS

The primary limitation of each of the preceding techniques and ideas is that they represent models of the walkable environment independent of actual walking behavior. It is intended that the multiple approaches to measuring local walkability presented here help move one closer to a more nuanced modeling environment of the pedestrian infrastructure, but these measures also need to be linked to observations of pedestrian activity. One potential approach to link these measures to behavior is to interview people who walk to transit (or school, park, church, etc.), document the route they take and why, and then compare the walkability characteristics of the route they took versus other routes they could have taken. In this way, the objective walkability measurements of the audit instrument, for example, could be compared with actual pedestrian movement within the transit zone that was assessed. There is no doubt this feedback will lead to additional alterations of the approaches presented here to link theorized models to actual behavior.

SUMMARY

Planning for local walkability is an increasingly studied area, especially as the public health benefits of physical activity are being more widely promoted. Whereas the broad principle of walkability is attractive, detailed analysis, visualization, and quantification can help in the understanding of whether the ideals of these development goals result in markedly different situations on the ground. One such area of critical concern is the infrastructure or skeleton of pathways that allow for pedestrian access to local amenities such as schools or to the region through easy access to local transit stops. Planners have been referencing the quarter-mile walking distance as a key tenet of these development schemes, but not all quarter-mile (or half-mile) journeys are the same *(23)*. The techniques presented in this paper offer new ways to analyze and understand the local path component of pedestrian accessibility. By visually and quantitatively documenting and analyzing the patterns around places in the community that are supposed to be walkable, one can create the foundation upon which a spatial–temporal evaluation can take place, documenting the evolutionary alterations in the urban landscape as specific area planning interventions take place. Finally, the development of new pedestrian audit instruments that work with mobile GIS technology offers transportation planners an opportunity to develop classifications of the local pedestrian environment in ways that pedestrians experience them. The use of GIS and either publicly available or independently developed street data makes visualization, interpretation, and evaluation of the pedestrian infrastructure easier than ever. Techniques for understanding local walkability, such as those presented in this paper, should be routine elements in local area transportation and community planning.

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