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Landscape and Urban Planning xxx (2006) xxx–xxx
LANDSCAPE AND URBAN PLANNING
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The development and testing of an audit for the pedestrian environment

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Received 23 April 2006; received in revised form 20 June 2006; accepted 22 June 2006

Abstract

Recognizing the need for consistent, reliable, and efficient methods to collect information about the walking environment, the authors have developed and tested a complete environmental audit methodology—the Pedestrian Environmental Data Scan (PEDS). In this paper, the development of the audit methodology is presented, including the design of the instrument, the creation of training and supporting materials, administration, and integration with handheld technology. Various tests of inter- and intra-rater reliability of our instrument have been conducted, including individual audit measures and various approaches to administering the audit. The results indicate high reliability for most measures and confirmed administration procedures. The PEDS audit methodology provides a comprehensive method to evaluate pedestrian environments for academics involved with transportation and physical activity research as well as practitioners seeking to an assessment tool for prioritizing investments.

Keywords: Pedestrian; Walking; Physical environment; Audit; Data; Physical activity

1. Introduction

The relationship between transportation choices and the physical environment, including the built and natural elements, has long been the subject of inquiry of transportation researchers (for reviews of this line of research see Crane, 2000; Badoe and Miller, 2000). Various studies have aimed to identify the direction and magnitude of the relationships between land use and urban form characteristics and the amount of travel by various modes. The measures of the built environment commonly used in models of individual or group behavior tend to be limited in scope by the archived data available and aggregated to a large area (such as a census tract or traffic analysis zone). For example, residential population, employment and street network densities are commonly used in these models to reflect the built environment. However, these macroscale measures do not capture the multiple and detailed dimensions of the physical environment, particularly those experienced during non-motorized travel. The contradictory and mixed findings in this line of research have been attributed, in part, to the lack of consistent and appropriate environmental data relevant for non-motorized modes (Frank and Engelke, 2001; Handy et al., 2002).

Recently, considerable interest has been generated around the potential connections between the health outcomes, the built and natural environment, and levels of physical activity, including walking and cycling (Frank and Engelke, 2001; Jackson, 2002; Handy et al., 2002). Inquiries in this line of research have revived the need for comprehensive and detailed environmental measures in order to identify elements of the physical and natural environment that support or detract from walking (Kwon et al., 1998; Painter, 1996). The policy questions for both transportation and public health research converge on the development of generally accepted standards for what constitutes a walkable environment and unearthing the nature of the relationship between this environment and walking behavior—and, in a larger context, health (Frank, 2000; Frank and Engelke, 2001; Funder's Network, 2003; Craig et al., 2002; Jackson, 2002).

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doi:10.1016/j.landurbplan.2006.06.008

audit methodology—the Pedestrian Environmental Data Scan (PEDS). This paper describes this effort. It begins with a brief review of efforts to define the critical elements of the walking environment and assess them using environmental audits. The development of the audit methodology is presented, including the design of the instrument, the creation of training and supporting materials, administration, and integration with handheld technology. Critical to the usefulness of an audit is its reliability in eliciting consistent results. Therefore, we report on various tests of inter- and intra-rater reliability of our instrument: individual audit measures and various approaches to administering the audit. The paper concludes with a discussion of the contributions of this audit methodology, comparisons with other existing pedestrian audits, and directions for future work.

2. Defining and assessing walkability

Planning policy and practice aspires to develop a normative definition of a "walkable" environment and there have been a number of efforts to test these definitions empirically (Ewing, 1999; Partnership for a Walkable America, 2001; Targa and Clifton, 2005). A large number of studies limit their measures of the environment to data that are readily available and comparable across US locations through secondary sources, such as the US Census Bureau (Crane, 1996; Berrigan and Troiano, 2002). These generally consist of measures of population or employment density, land use mix calculated by residential to employment ratios, and street network connectivity from street network files at some aggregate spatial unit such as zip code areas, traffic analysis zones, census tracts or block groups. Geographic information systems (GIS) now permit these land use and urban form variables to be computed at more disaggregate spatial units, such as buffer zones around an individual residence or destination, calculated at some radial distance (either straight line or network) from the location of interest. Despite these advances, it is likely the micro-features in the environment that largely shape how accommodating an area is for pedestrian travel. Because of the slow speed and nature of walking, a pedestrian is typically much more aware of and exposed to the environment than a driver. These features are likely to be important in determining behavioral patterns, but are rarely ascertained because of the difficulty in acquiring and accessing these data (Talen, 2002).

Most studies concerned with walking behavior evaluate the environmental attributes by their degree of accommodation for pedestrians and the correlations with levels of walking (Aultman-Hall et al., 1997; Greenwald and Boarnet, 2001). A variety of measures have been used to represent the built environment in studies of land use and travel behavior. In a study by Berrigan and Troiano (2002), a simple measure of neighborhood age is used as a proxy of walkability. Crane (1996) used three variables to describe the local environment: population density, land use mix and street pattern. And, a more comprehensive array was used by Craig et al. (2002), where 18 environmental measures described characteristics of destinations, aesthetics, and traffic. However, the research has thus far been unable to establish a definitive characterization of the elements that comprise a walkable environment or are influential in affecting rates of pedestrian activity (Crane, 2000; Vernez-Moudon and Lee, 2003). The lack of microscale environmental data has been a limitation but the collection of detailed information about non-motorized activity has been overlooked in many transportation studies, further hampering these efforts.

Others have attempted to capture pedestrian-oriented elements in a composite measure (Cervero and Kockelman, 1997; Holtzclaw, 1994; Parsons et al., 1993; Srinivasan, 2002; Cambridge Systematics, 1994). A Pedestrian Environmental Factor (PEF) was developed by planners in Oregon based on sidewalk continuity, ease of street crossings, street characteristics, and topography (Parsons et al., 1993). A pedestrian level of service (LOS) developed by Sarkar (1993) evaluates a number of criteria deemed important for this mode including: safety, security, comfort and convenience, continuity, system coherence, and attractiveness. The performance measure is expressed by six qualitative descriptors of the pedestrian service level. Pikora et al. (2002) identify four major categories of physical features having an influence on walking: functional, safety, aesthetic and destinations. Ewing (1999) also formulated a list of 10 factors important for "pedestrian friendly environment" (medium to high densities, mix of land uses, short to medium length blocks, transit routes every half-mile, two to four lane streets, continuous sidewalks wide enough for couples, safe crossings, appropriate buffering from traffic, street oriented buildings, and comfortable and safe places to wait). In a similar vein, planners in Montgomery County, Maryland calculated an index of pedestrian friendliness based on building setbacks and the availability of sidewalks, paths, and bus shelters to traffic zones in the region.

As a whole, studies testing the predictive validity of these composite measures of the pedestrian environment at either the origin or the destination of trips have led to ambiguous results, with some showing a positive relationship between the indices and non-motorized travel behavior (Cervero and Kockelman, 1997; Replogle, 1990) and others failing to show a relationship (Holtzclaw, 1994; Parsons et al., 1993). Calculating pedestrian environment factors for Boston, Srinivasan (2002) found that pedestrian attributes of the route between home and work, rather than the attributes of the endpoints themselves, appear to matter most in the decision to walk for work trips. These results suggest that even when we get the measures right, we may fail to evaluate them at the correct locations.

In sum, the important factors contributing to "walkability" are still very much in contention and the relationship and relative importance of each feature has yet to be agreed upon. Among the complications is the nature of the measures: some aspects of the pedestrian environment can be measured objectively and therefore with more ease, but others are more subjective in nature. As Talen (2002) stated, various studies have used one, the other or a combination, but no overall agreement has been reached on what is appropriate.

To assist in the collection of microscale environmental data thought important to pedestrians, several walkability audits have been developed (Pikora et al., 2002; Emery et al., 2003; Day et al., 2006). These audits assess features such as: sidewalk and road infrastructure and condition, safety features, lighting, aesthetics and public transportation facilities. Vernez-Moudon and Lee (2003) present a review of several of these environmental audit instruments from urban design, planning, transportation and public health, which are designed to capture the physical environmental factors related to walking and bicycling. They conclude that measures in the existing audits are varied and still require extensive testing.

Building up on these previous efforts, the authors have developed and tested an instrument and methodology to assess these microscale features reliably and economically. This methodology is described and compared with competing audits in more detail below.

3. Pedestrian environmental data scan

The Pedestrian Environmental Data Scan was designed to capture a range of elements of the built and natural environment efficiently and reliably. PEDS is not alone in this effort; a number of environmental assessment tools have emerged recently (Vernez-Moudon and Lee, 2003; see Table 1 for comparisons between audits). PEDS contribution to this growing field of environmental audits resides in the following areas: (1) consideration of a variety of environmental elements and contexts within in the United States; (2) design for efficient and reliable administration; (3) integration with handheld technology; (4) development of detailed training materials and supporting documentation; and (5) extensive reliability testing of the instrument and its administration. These distinguishing features will be discussed in more detail below and are outlined in Table 1.

3.1. Audit instrument

The pencil and paper PEDS audit instrument is shown in Fig. 1. It was designed to balance the need for detailed information about the environment with economy of administration and is thus limited to one page. Each audit item was designed to assess individual elements of the built and natural environment with respect to pedestrian activity. Audit items include sec-

Table 1

	WSAF	WPS	SLU	SPACES	I-M	PBIC	PEPS
Characteristics							
Field protocol	√	×	√	√	√	×	√
Training presentation	×	×	N/A	×	√	×	√
Training test segments	×	×	×	×	×	×	√
PDA/tablet PC compatability	×	×	√	×	√	×	√
Tine required per segment or block	30 mn	N/A	10 mn	N/A	20 mn	5–10 mn	3–5 mn
Items measured							
Land uses							
Land uses (types, intensities, destinations)	×	√	√	√	√	√	√
Walking path/sidewalks							
Sidewalk presence	√	√	√	√	√	√	√
Sidewalk qualities (materials, obstructions, uniformity)	√	√	×	√	√	√	√
Slope	×	×	×	√	×	×	√
Natural barriers (ditch, creek)	√	×	×	×	√	×	×
Vehicle-pedestrian interactions							
Street supports for walking (crosswalks, traffic lights)	√	×	√	√	√	√	√
Traffic volume	√	×	×	×	×	√	√
Parking (on and off-street)	×	√	√	√	√	√	√
Speed limits	√	×	√	√	√	×	√
Segment/road connectivity	×	×	√	√	×	×	√
Road conditions (materials, uniformity)	√	×	×	√	√	√	√
Traffic calming (chokers, chicanes)	×	×	√	√	√	×	√
Safety and appeal							
Lighting	√	√	√	√	√	×	√
View/surveillance	×	√	×	√	√	√	×
Aesthetics (incivilities, gardening, appeal)	×	√	√	√	√	×	√
Unique markers/memorability	×	×	×	×	√	×	×
Architectural variety	×	√	×	√	×	×	√
Enclosure	×	√	×	√	×	×	√
Tree presence	×	√	×	√	√	√	√
Subjective assessmentI							
Perception of attractiveness/appeal	×	√	×	×	√	×	√
Perception of safety	×	×	×	×	√	×	√

WSAF: Walking Suitability Assessment Form—University of North Carolina, Chapel Hill; WPS: Walkable Places Survey—Baltimore Metropolitan Council; SLU: Analytic Audit Tool—Saint Louis University; SPACES: Systematic Pedestrian and Cycling Environmental Scan—The University of Western Australia; I-M Inventory: Irvine-Minnesota Inventory—University of California, Irvine and University of Minnesota; PBIC Checklist: Partnership for a Walkable America; PEDS: Pedestrian Environment Data Scan—University of Maryland, College Park.

Name: ______________ Date: ______________ Study Area: ______________

Segment Number: ______________ Time: ______________ Weather: ______________

Subjective Assessment: Segment…
Enter 1,2,3, or 4 for 1=Strongly Agree 2= Agree, 3=Disagree, 4=Strongly Agree
……is attractive for walking. ____ 1
……is attractive for cycling. ____ 2
……feels safe for walking. ____ 3
……feels safe for cycling. ____ 4

0. Segment type
Low volume road 1
High volume road 2
Bike or Ped path - skip section C 3

A. Environment

1. Uses in Segment *(all that apply)*
Housing - Single Family Detached 1
Housing- Multi-Family 2
Housing- Mobile Homes 3
Office/Institutional 4
Restaurant/Café/Commercial 5
Industrial 6
Vacant/Undeveloped 7
Recreation 8

2. Slope
Flat 1
Slight hill 2
Steep hill 3

3. Cul-de-sac/Dead-end
Segment has dead end 1
Segment continues 2
Road deadends but path continues 3

B. Pedestrian Facility *(skip if none present)*

4. Type(s) of pedestrian facility *(all that apply)*
Footpath (worn dirt path) 1
Paved trail 2
Sidewalk 3
Pedestrian Street (closed to cars) 4

The rest of the questions in section B refer to the best pedestrian facility selected above.

5. Path material *(all that apply)*
Asphalt 1
Concrete 2
Paving Bricks or Flat stone 3
Gravel 4
Dirt or Sand 5

6. Path obstructions *(all that apply)*
Poles or Signs 1
Parked Cars 2
Trees 3
Garbage Cans 4
Other 5

7. Buffers between road and path *(all that apply)*
Hard Buffer
Fence 1
Trees 2
Hedges 3
Soft Buffer
Landscape 4
Grass 5
Path distance from curb (feet): ____ 6
Path width (feet): ____ 7

If no sidewalk,skip now to section C.

8. Sidewalk completeness/continuity
Sidewalk is complete 1
Sidewalk is incomplete 2

9. Sidewalk connectivity to other sidewalks/crosswalks
number of connections ____ 1

10. Sidewalk condition/maintenance
Poor (many bumps/cracks/holes) 1
Fair (some bumps/cracks/holes) 2
Good (very few bumps/cracks/holes) 3
Under Repair 4

C. Road Attributes *(skip if path only)*

11. Condition of road
Poor (many bumps/cracks/holes) 1
Fair (some bumps/cracks/holes) 2
Good (very few bumps/cracks/holes) 3
Under Repair 4

12. Number of lanes
# of lanes to cross ____ 1

13. Posted speed limit
None posted 1
(mph): ____ 2

14. On-Street parking *(if pavement is unmarked, check only if cars parked)*
Parallel or Diagonal 1
Go to Q17 - None 2

15. Off-street parking lot spaces
0-5 | 6-25 | 26+
If none go to Q17 -

16. Must you walk through a parking lot to get to most buildings?
Yes 1
No 2

17. Driveways
There are driveways in segment 1
There are no driveways in segment 2

18. Traffic control devices *(all that apply)*
Traffic Light 1
Stop Sign 2
Traffic Circle 3
Speed bumps 4
Chicanes or chokers 5

19. Curb Cuts in segment
Yes 1
No 2

20. Crossing Aids in segment *(all that apply)*
Cars Must Stop
Pavement Markings 1
Yield to Ped Paddles 2
Pedestrian Signal 3
Crossing Aids
Median/Traffic Island 4
Curb Extension 5
Overpass/Underpass 6
Warnings to Cars
Pedestrian Crossing Street Sign 7
Flashing Warning 8

D. Walking/Cycling Environment

21. Lighting
None 1
Poor 2
Fair 3
Good 4

22. Amenities *(all that apply)*
Garbage cans 1
Benches 2
Water fountain 3
Bicycle parking 4
Street vendors/vending machines 5

23. Are there wayfinding aids?
No 1
Yes 2

24. Number of trees shading walking area
None or Very Few 1
Some 2
Many/Dense 3

25. Degree of enclosure
Little or no enclosure 1
Some enclosure 2
Highly enclosed 3

26. Powerlines along segment?
No 1
Low Voltage/Distribution Line 2
High Voltage/Transmission Line 3

27. Cleanliness (Is there litter, garbage, broken glass, or graffiti?)
None or Almost None 1
Yes Some 2
Yes Lots 3

28. Articulation in building designs
Little or no articulation 1
Some articulation 2
Highly articulated 3

29. Building setbacks from street
At edge of sidewalk 1
Within 20 feet of sidewalk 2
More than 20 feet from sidewalk 3

30. Bicycle lane
None or not marked 1
Striped bicycle lane 2

31. Transit facilities
No 1
Yes 2

Fig. 1.

tions on the macroscale environment, pedestrian facilities, road attributes, and the microscale features of the walking/cycling environment. In recognition that the overall quality of the walking (and cycling) environment may not be adequately reflected by the sum of the individual parts, four subjective evaluation items were added as a separate section to rate the environment as a whole. In total, the number of questions number 40, resulting in 83 measures.

The PEDS audit instrument builds upon existing work in this area with particular emphasis on the audit from Systematic Pedestrian and Cycling Environmental Scan (SPACES) (Pikora et al., 2002), an instrument designed for use in Australia. The SPACES instrument, although the major starting point for the PEDS audit, posses several limitations. One drawback of the SPACES instrument is its specificity to Australia: the features measured were in some cases poorly matched to American environments (e.g.: no differentiation between residential and commercial driveways, no questions about the degree of enclosure or the setback of buildings on the street). The PEDS instrument reflects the changes made to SPACES for use in the United

States. Some questions from SPACES were modified to garner more information about the environment. For instance, a question about number of road lanes was changed to include all driving lanes, including turning lanes, to allow a better assessment of conditions at street crossings.

The SPACES audit contains subjective evaluations of the attractiveness and the degree of physical difficulty reflected in the pedestrian and cycling environment. PEDS retained the questions about the degree of attractiveness of the walking and cycling environment. Instead of evaluating the degree of physical difficulty, PEDS rates the overall sense of safety/security of a segment, for both walking and cycling. This decision was motivated, in part, by the difficulty in collecting individual measures of safety by objective means. In addition to these changes to SPACES, additional questions were added to the PEDS audit in sections on pedestrian facility (buffer type, sidewalk width, sidewalk connections, sidewalk completeness), road attributes (posted speed limit, walking through parking lot to access buildings, presence of curb cuts) and in the walking/cycling environment (presence of way finding aids, presence of power lines, degree of enclosure and building setback).

The Irvine-Minnesota inventory (I-M) and the St. Louis University Analytic Audit Tool (SLU) evaluate many more features of the environment than PEDS. The I-M inventory results in over 200 measures (Day et al., 2006) and measures from the SLU instrument count nearly 150. For instance, the I-M and SLU both include questions with extensive detail about land uses (presence of churches, marinas, golf courses, check cashing stores, farmer's market, etc.). The PEDS audit is much more concise when asking about land uses, asking only about major categories of uses (single family housing, multi family housing, office/institutional, restaurant/commercial, industrial, vacant, and recreational). On the other hand, the I-M and the SLU both have fewer questions about the walking path and associated elements. The I-M, for instance, does not assess sidewalk width, distance from the curb, or connectivity to other sidewalks. The SLU does not address connectivity or type of buffer.

In the development of PEDS, a shorter, more time-efficient audit was favored. The longer audits result in a more detailed characterization of the environment but do require a greater time commitment to administer (time costs are discussed in more detail below). Of course, this entails a tradeoff in the amount and detail of information collected from the audit, but to date, it is unclear whether such an extensive amount of detail as in the I-M or SLU will be important in understanding behavior.

Other audits, in addition to PEDS, have adopted a more parsimonious approach; however, they are differentiated from PEDS by either: their narrow scope, their lack of rigorous training and protocols and/or their aim to involve the community in action research. The Pedestrian Bicycle Information Center Checklist (PBIC) collects information about the environment for use in evaluating residents' satisfaction with their walking environment but isn't as useful for characterizing the environment for use in behavioral models. The PBIC checklist is meant as a scoring system for laypeople and thus does not designed to collect detailed, comprehensive features about the environment. For example, the PBIC instrument does not evaluate land uses, presence of destinations, aesthetics or any other feature not related to safety.

The Walking Suitability Assessment Form (WSAF) was developed by Emery et al. (2003) to examine features associated with pedestrian safety. As such, WSAF focuses only on aspects of the pedestrian facilities and street crossings such as road attributes (e.g.: number of driving lanes, posted speed limit), traffic control devices (e.g.: presence of crosswalks, pedestrian signals) and pedestrian facilities (e.g.: sidewalk width, surface condition). This instrument, like the PBIC checklist, does not evaluate land uses, aesthetics or other non-safety related walkability measures. However, the WSAF instrument does feature a scoring system which allows a rapid assessment of the level of safety for walkers on any given street segment.

The Walkable Places Survey (WPS) tool was designed to be implemented by laypeople and is meant to foster "community-based neighborhood planning" (Shriver, 2003). Unlike other instruments, this one does not include any efforts to increase agreement among raters through training and clear definition of the features to be measured. Although the instrument itself is not available, the description and results from Shriver's paper (2003) provide information about the questions and format of the instrument. The instrument includes 30 streetscape characteristics all scored on a three-point Likert scale. The measured characteristics include traffic and parking (e.g.: traffic speeds, noise/fumes), buildings (e.g.: setback, convenience), sidewalks (e.g.: width, curb), amenities (e.g.: seating, lighting, public art), intersections (e.g.: crosswalks, road width) and perceptual (e.g.: enclosure, well-being). Although the WPS measures multiple aspects of the pedestrian environment, there are a few notable missing variables, such as land uses, traffic control devices, and maintenance/cleanliness of the street.

3.2. Training

Another prominent feature of PEDS is the extensive use of detailed and intensive training to ensure reliability of the audit. The training materials developed for the PEDS audit include a visual presentation of each of the audit elements, video segments for practice audits and testing to insure homogeneity in rating for all raters. Prior to data collection, audit raters, is required to participate in two days of training, including classroom and field exercises.

The training comprises two parts. A presentation thoroughly explains the segmentation of streets or pedestrian networks used for administration of this audit. Each question and answer option is then reviewed in depth with photographic examples. The first part of the training concludes with videos of segments that the raters rate and then discuss. The second part of the training is tailored for the location of the audit and conducted in the field. Raters survey half a dozen varied segments and then discuss and compare their ratings under supervision. Training sessions continue until all raters have a good understanding of each of the audit items. The training materials and protocols provide detailed background information so that laypeople, once trained, can administer the audit reliably.

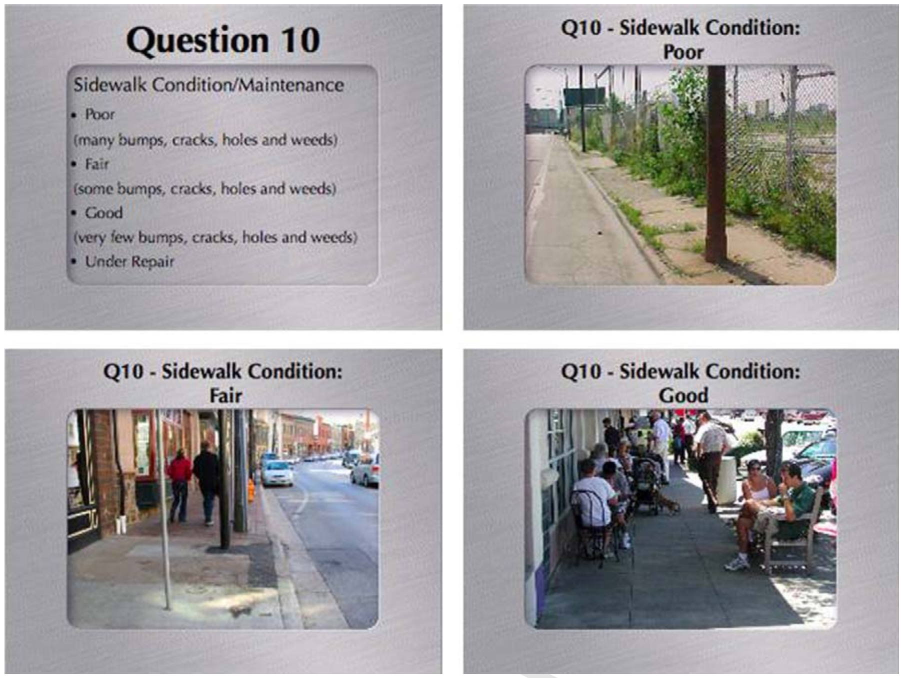


Fig. 2.

To complement the training, we developed an audit protocol to provide instruction and reference for data collection in the field. The protocol addresses particular issues and singularities found in the field. The protocol was updated regularly during administration to provide as much direction as possible to each auditor. After each auditing session, raters met to discuss any problems or new features encountered during the day. Their questions were answered at that time and that information was added to the protocol. Examples of the training materials and protocol are shown in Figs. 2 and 3.

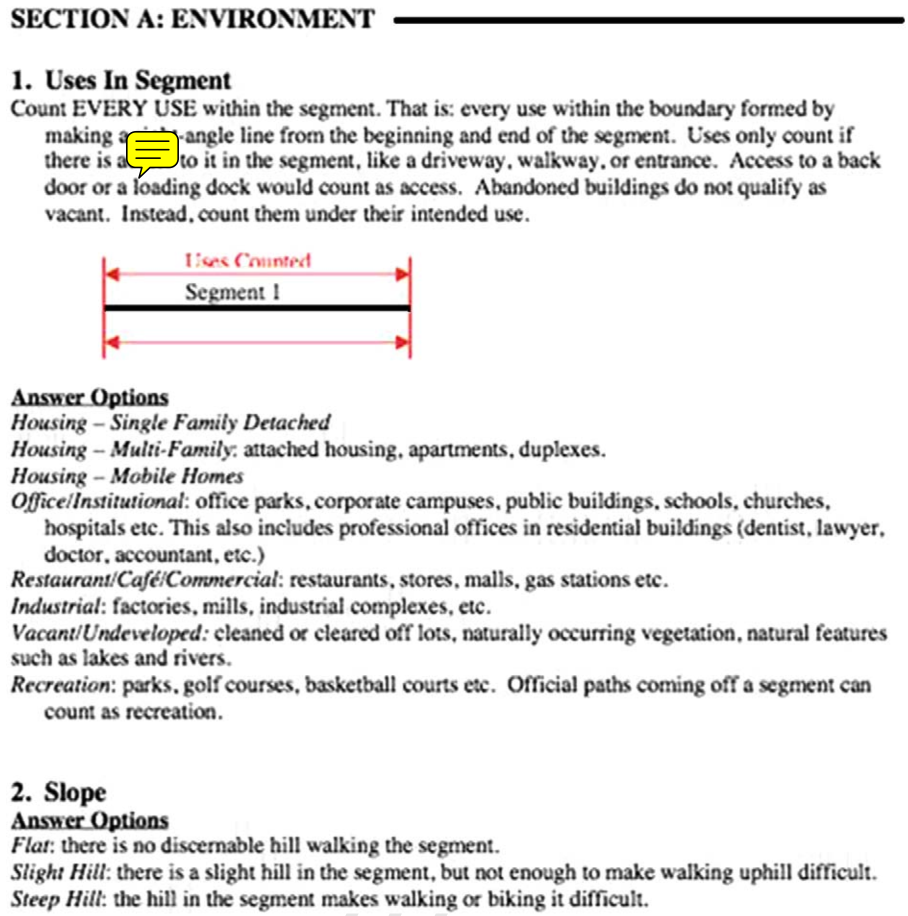
The audit instrument, the training materials, and the audit protocol were piloted-tested in a residential and a strip-mall commercial environment in Chapel Hill, NC during the months of February and March of 2004. The pilot study allowed us to identify preliminary inter-rater reliability measures by urban environment context (residential or commercial), thereby identifying audit attributes that needed further clarification and/or training.

3.3. Administration

For various purposes, pedestrian environmental data have been collected at different spatial scales or units of analysis: blocks (Shriver, 2003), intersections (Zegeer et al., 2006), and segments (Emery et al., 2003; Pikora et al., 2002; Brownson et al., 2004; Day et al., 2006). The PEDS audit, like most of the audits in Table 1, is designed to be administered on segments of a pedestrian network or pathway. This permits flexibility in the designation of the length or bounds of the segment based upon the nature of the area being audited. For example, Pikora et al. (2002) divided each segment by the nearest intersection, while Emery et al. (2003) used variously sized segments. The PBIC audit is designed for residents' subjective evaluation of entire walks and thus, the unit of analysis is variable.

In application of PEDS presented here, segments are generally defined as a road or pedestrian path bounded by cross streets or intersections. These segments are identified using secondary street or pedestrian network layers (such as TIGER street centerline files from the US Census) in a geographic information systems software platform. In cases where segments are longer than 700 ft, the segment is subdivided to ensure consistency in the segment length and for better comparison of variation across segments. As a result of these subdivided segments, segment length and overall block length are not always synonymous (block length is not measured directly from the audit but rather calculated from the network data using GIS). Each segment is given a unique identifier code to differentiate the segments and to assist with integration of other spatial data in the geographic database at a later time. Segments of pedestrian facilities that are not adjacent to roadways, such as trails and pathways, are added to the database. Segments inaccessible to pedestrians, such as limited-access highways and ramps, are removed from the dataset before the administration. Audit raters evaluate the pedestrian environment collecting information for each segment, evaluating both sides of the street at once. If the pedestrian pathway is adjacent to a major arterial or other roadway with high traffic volume, the audit is conducted on both sides of the street separately. This is done with the understanding that arterials often contain obstacles (high volume or speed of traffic, width of the street) that make crossing the street difficult or unattractive to pedestrians, thereby making each side of the street important to measure individually.

The PEDS audit was designed to be administered in pairs. Surveying in pairs improves reliability and to ensures the safety of raters. However, different methods of administering the audit were tested for reliability, including raters auditing segments individually and in "waves", where each administrator is



SECTION A: ENVIRONMENT

1. Uses In Segment

Count EVERY USE within the segment. That is: every use within the boundary formed by making a right-angle line from the beginning and end of the segment. Uses only count if there is access to it in the segment, like a driveway, walkway, or entrance. Access to a back door or a loading dock would count as access. Abandoned buildings do not qualify as vacant. Instead, count them under their intended use.

Answer Options

Housing – Single Family Detached
Housing – Multi-Family: attached housing, apartments, duplexes.
Housing – Mobile Homes
Office/Institutional: office parks, corporate campuses, public buildings, schools, churches, hospitals etc. This also includes professional offices in residential buildings (dentist, lawyer, doctor, accountant, etc.)
Restaurant/Café/Commercial: restaurants, stores, malls, gas stations etc.
Industrial: factories, mills, industrial complexes, etc.
Vacant/Undeveloped: cleaned or cleared off lots, naturally occurring vegetation, natural features such as lakes and rivers.
Recreation: parks, golf courses, basketball courts etc. Official paths coming off a segment can count as recreation.

2. Slope

Answer Options

Flat: there is no discernable hill walking the segment.
Slight Hill: there is a slight hill in the segment, but not enough to make walking uphill difficult.
Steep Hill: the hill in the segment makes walking or biking it difficult.

Fig. 3.

given additional training for a particular set of environmental attributes, and then becomes the sole evaluator for that feature (e.g. land use and street network, pedestrian facilities, design elements, etc.). The testing of the administration methods is described in the reliability section below.

3.4. Integration with handheld technology

The PEDS audit was developed as a pencil and paper instrument but the instrument and supporting materials were adapted for use with handheld technology (see Fig. 4). Personal digital assistants (PDAs) offer an increasing number of features that are attractive for survey administration and are relatively inexpensive. These handheld electronic devices can support a variety of software packages, including database programs that can be used for data entry, word processors or document readers for supporting materials and protocols, and in some cases, geographic information systems and global positioning systems (GPS) to include geospatial referencing. Some PDAs also have the capacity to interface with digital photography, allowing pictures of the audit environment to be incorporated directly into the data set.

Advantages of administering audits using the PDAs include the ease of administration and the improved quality of data. Administering the audits using handheld technology improves data quality over pencil and paper administration by eliminating the need for data entry. The PDA instrument also reduces rater error through a number of response checks. The maps used by the raters, the list of segments to be audited, and the protocol are all available on the PDA, reducing the need to carry additional materials. The PDA platform audit can be com-

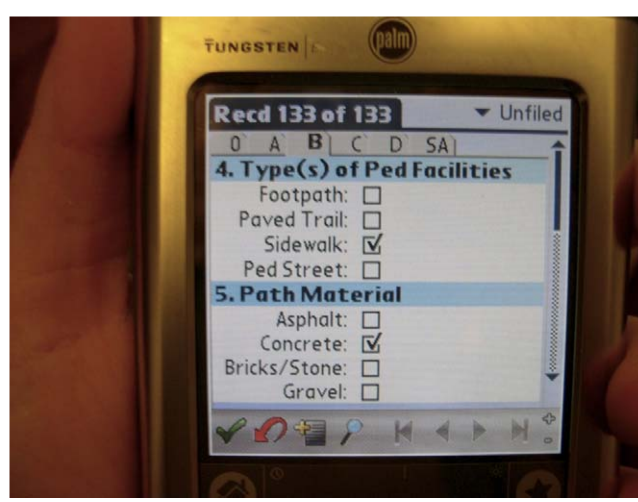


Fig. 4.

bined with global positioning system units for geo-referencing or in conjunction with platforms that support with geographic information systems. This permits the addition of segments or features to the base map in the field. Although the SLU and I-M audit instruments have also been adapted for PDA or tablet PC data gathering, the PEDS audit is the only one that has been tested for reliability using such an interface.

3.5. Reliability testing

The PEDS audit was administered during the months of June and July 2004 on street and pedestrian network segments in the city of College Park, MD. The City of College Park, located in Prince George's County, is the home of the University of Maryland. In a college town with more than 54.4% of its population enrolled in higher education, a large number of residents are pedestrians and bicyclists. A very large percentage of College Park residents walk, bicycle or ride public transportation to work. Similarly, the University is clearly instrumental in contributing to the diverse ethnic distribution. The population consists mostly of young adults, with fewer elderly and children. Residents of College Park have slightly lower rates of car ownership and drivers licensure than the US population. These levels of car ownership most likely reflect the student-oriented nature of the city. Although the University of Maryland campus is in the city, the campus was not surveyed during this study because much of the pedestrian network on the campus is not mapped. However, the development of the audit outlined above included methods to integrate previously unmapped segments in the audit.

College Park contains the flagship campus for the University of Maryland, a great generator of pedestrian activity. Neighborhoods vary in their age (the median year of construction of housing at the block group level ranges from 1945 to 1981), street design (with variations ranging from grid to curvilinear street patterns), population and housing density at the block group level (ranges from about 350–8000 persons per square miles and about 120–3000 housing units per square miles, respectively), and degree of pedestrian accommodation. Most residential areas are relatively low density with non-residential uses located on arterials bounding neighborhoods. The focus of most commercial development in College Park is the US 1 corridor. This state highway serves as the "main street" in College Park and development is largely oriented toward automobile access. A few blocks of commercial development near campus provide the exception, with storefronts oriented toward the sidewalk with parking in the rear or side of the building. Pedestrian connectivity to the University of Maryland campus is rather poor, in part due to Rt. 1, severing residential neighborhoods from campus. Although the environment in College Park is largely suburban, there is significant variation in the urban form and pedestrian environment across the city and thus provides a suitable location to test the reliability of the PEDS audit.

A total of 71.5 miles of street and pedestrian pathways, equal to 995 segments, were surveyed on foot. Fig. 5 shows a map of the completeness of sidewalks by segment and illustrates the geographic extent of the area audited. The raters audited approx-

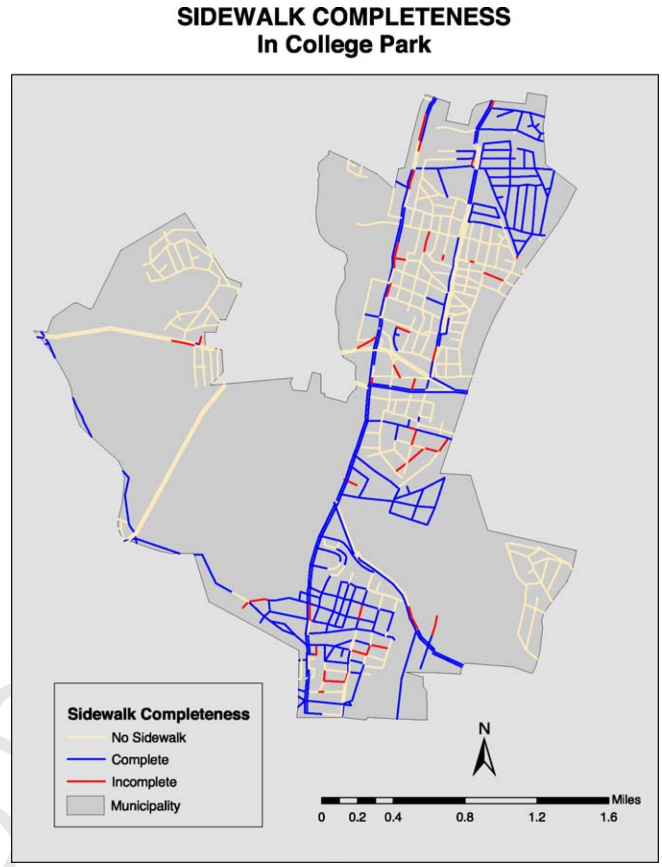


Fig. 5.

imately 100 segments each day. One day a week was dedicated to reliability testing. After each day, the raters discussed any problems they had in the field so as to inform improvements to the protocol, which was updated regularly. Segments that were mapped but not present in the field were removed from the dataset at the end of each day. The data was transferred from the PDAs in Excel format and were then exported to SPSS for analysis.

Our analysis is designed to test three questions about that audit and its administration: (1) the overall rater reliability (intra- and inter-) of the audit; (2) variation in the reliability by urban context; and (3) influence of various modes of implementation of the audit (pairs, individuals, wave) on reliability of the data collected.

Kappa statistics, percent agreement, and the concordance correlation coefficient are used to test reliability and are consistent with other reliability measures reported by others. Pikora et al. (2002) and Brownson et al. (2004) used Kappa statistics in reporting the reliability of SPACES and SLU, respectively; Boarnet et al. (2006) and Brownson et al. (2004) employ percent agreement to test I-M and SLU. We provide both statistics, when appropriate, for comparison. Explanations of these reliability measures follow.

Kappa statistics provide a chance-corrected measure of agreement between raters (see Landis and Koch, 1977). A Kappa coefficient of 1.0 represents perfect agreement; Kappa coefficients equal to 0 represent agreement corresponding to that expected by chance, and Kappa coefficients less than 0 represent agreement less than that expected by chance. In calculating the Kappa statistic, we apply a weighting scheme that weights disagreements between responses that are just one category away (e.g., high versus medium) more favorably than disagreements between responses that are several categories away (e.g., high versus low).

Since the Kappa statistic is applicable only for categorical variables, the concordance correlation coefficient is used for the measures which are measured on a continuous scale. Four questions in the instrument (number of lanes, number of sidewalk connections, width of sidewalk and distance from curb) are continuous variables and therefore received a concordance correlation coefficient. This coefficient was first proposed by Lin (1989) and is the accepted method in assessing agreement in continuous data. The concordance statistic has a range of 1.0–0, with 1.0 representing perfect agreement.

We also include percent agreement as a reliability measure because we feel these are more appropriate for data that exhibit little variation (Boarnet et al., 2006). Percent agreement also more accurately shows the reliability of the features that are not very frequent in the environment tested. For example, if a feature is only present a few times and there is low disagreement (but not perfect agreement), Kappa scores will be low when the agreement will actually be very high. By presenting both the Kappa score and percent agreement, both the agreement among raters and the prevalence of the feature in the environment are shown and allow for comparison with other audits.

Twenty four features (mostly unusual or rare features such as fence or hedge buffers, gravel or dirt sidewalks, chicanes and chokers, curb extensions, overpasses, water fountains bicycle parking, mobile homes, etc.) do not have Kappa scores because they were not present in a sufficient number (three or fewer occurrences) of the tested segments and are denoted by an asterisk in Table 2 through Table 5. For these cases, we report the percent agreement between raters with the understanding that agreement due to chance may be high.

Sample sizes varied for the reliability tests. Inter-rater reliability was tested on a large sample ($N = 192$) and entire neighborhoods were selected for this. Neighborhoods rather than randomly sampled segments were chosen to be tested to ensure that a significant number of segments contained sidewalks (since a whole section of the audit concerns sidewalks, it was important to survey sufficient segments with that feature present). For testing of the urban context, smaller samples of approximately 25 segments each were deemed appropriate from both previous studies (Pikora et al., 2002) and a pilot of the audit conducted in Chapel Hill, NC. Commercial segments were selected randomly, with segments not containing sidewalks removed from the dataset. Because the sample in this case was very small; more features of the audit could be tested by including only segments with sidewalks. The Old Town neighborhood was selected as the location for reliability testing of the residential segments: most streets have sidewalks and there is a variety of single and multi family housing in the area. Entire neighborhoods around College

Table 2
Reliability of audit (number of segments = 192)

Questions	Kappa score	Percent agreement
Subjective assessment: segment . . .		
. . . is attractive for walking	0.131	50.5
. . . is attractive for cycling	0.317	82.3
. . . feels safe for walking	0.366	75.5
. . . feels safe for cycling	0.407	84.9
0. Segment type	1.000	100.0
1. Uses in segment (all that apply)		
Housing—single family detached	0.824	96.4
Housing—multi-family	0.659	98.4
Housing—mobile homes	N/A[a]	100.0
Office/institutional	0.688	88.0
Restaurant/café/commercial	0.766	92.2
Industrial	N/A[a]	100.0
Vacant/undeveloped	0.571	89.6
Recreation	0.402	89.1
2. Slope	0.532	70.3
3. Cul-de-sac/dead-end	1.000	100.0
4. Type(s) of pedestrian facility		
Footpath (worn dirt path)	N/A[a]	100.0
Paved trail	N/A[a]	98.4
Sidewalk	0.778	90.1
Pedestrian street (closed to cars)	N/A[a]	100.0
5. Path material (all that apply)		
Asphalt	0.237	94.3
Concrete	0.815	91.7
Paving bricks or flat stone	N/A[a]	98.4
Gravel	N/A[a]	100.0
Dirt or sand	N/A[a]	100.0
6. Path obstructions (all that apply)		
Poles or signs	N/A[a]	100.0
Parked cars	N/A[a]	100.0
Trees	0.111	93.2
Garbage cans	0.240	92.7
Other	N/A[b]	93.8
7. Buffers between road and path		
Hard buffer		
Fence	N/A[a]	100.0
Trees	N/A[a]	98.4
Hedges	N/A[a]	100.0
Soft buffer		
Landscape	N/A[a]	100.0
Grass	1.000	100.0
Path distance from curb (feet)	0.998[c]	96.9
Path width (feet)	0.998[c]	76.6
8. Sidewalk completeness/continuity	0.798	90.1
9. Sidewalk connectivity to other	0.984[c]	81.3
10. Sidewalk condition/maintenance	0.715	83.9
11. Condition of road	0.123	65.6
12. Number of lanes	0.996[c]	93.2
13. Posted speed limit	0.650	95.8
14. On-street parking	0.623	85.4
15. Off-street parking lot spaces	N/A[b]	88.0
16. Must you walk through a parking lot	0.687	90.1
17. Driveways	N/A[d]	91.1
18. Traffic control devices		
Traffic light	0.901	98.4
Stop sign	0.965	98.4
Traffic circle	N/A[a]	98.4

Table 2 (*Continued*)

Questions	Kappa score	Percent agreement
Speed bumps	0.901	98.4
Chicanes or chokers	N/A[a]	100.0
19. Curb cuts in segment	0.695	85.9
20. Crossing aids in segment		
Cars must stop		
Pavement markings	0.669	83.9
Yield to ped paddles	N/A[a]	100.0
Pedestrian signal	0.515	96.4
Crossing aids		
Median/traffic island	N/A[a]	100.0
Curb extension	N/A[a]	100.0
Overpass/underpass	N/A[a]	100.0
Warnings to cars		
Pedestrian crossing street sign	0.558	87.0
Flashing warning	N/A[a]	100.0
21. Lighting	0.196	41.7
22. Amenities (all that apply)		
Garbage cans	0.208	94.3
Benches	0.645	95.8
Water fountain	N/A[a]	100.0
Bicycle parking	N/A[a]	100.0
Street vendors/vending machines	0.249	90.1
23. Are there wayfinding aids?	N/A[d]	96.4
24. Number of trees shading	0.688	87.5
25. Degree of enclosure	0.311	87.0
26. Power lines along segment?	1.000	92.2
27. Cleanliness	0.176	55.2
28. Articulation in building designs	0.085	88.0
29. Building setbacks from street	0.198	46.9
30. Bicycle lane	N/A[a]	100.0
31. Transit facilities	1.000	100.0

[a] This feature was not present in any of the tested segments or was too rare for Kappa testing.
[b] These questions did not have fixed answers and therefore a Kappa score cannot be computed.
[c] When a concordance statistic is calculated.
[d] This question was changed in the middle of the audit and was therefore not tested.

Park were also selected for the testing of different implementation modes.

The raters consisted of 12 undergraduate students who had undergone the training process described above. Most of the students had no previous experience with environmental audits and little to no knowledge of urban planning. The students were chosen in part because of their lay status to demonstrate that non-planners, with effective training, can administer the audit. Most of the other audits in Table 1 had very few, specialized raters (for instance, five raters total for the I-M inventory, two raters in WASF) or multiple but untrained laypeople, resulting in significantly poorer reliability (WPS).

Overall, the instrument proved to be reliable. Landis and Koch (1977) suggest that Kappa statistics between 0.61 and 0.80 indicate substantial agreement; Kappa statistics greater than 0.80 indicate almost perfect agreement. The rater reliability testing showed that only a small number of items in the audit consistently garnered Kappa scores below 0.40. These were mainly the questions involving more subjective assessment or more abstract concepts, like amount of street lighting, articulation of building designs and degree of enclosure. On the other hand, many items (such as land uses, traffic control features, and presence of sidewalk) in the audit received very high Kappa scores (0.75 or above).

The four subjective questions in the audit all had low reliability, as might be expected. A strong correlation was found between the variables for "safe for walking" and "attractive for walking". These two variables were added to form a "walking index". All of the other variables in the audit had a high correlation with this index, which indicates that the environmental features chosen for the audit do have a direct relationship with the perceived walkability of the segments despite their low reliability.

All but one of the low reliability questions, found in Table 2, ask for a subjective assessment in the environment. Assessing the quality of lighting was difficult because the audit was administered during the day and thus the low reliability result is not surprising. The presence of asphalt as a sidewalk material received low reliability score in the early weeks of auditing. This was remedied by additional training. Reliability scores improved after the material was discussed and explained to the raters.

The reliability of the audit was tested for different urban contexts: commercial and residential segments. As expected, residential segments garnered higher reliability scores in almost all measures. Commercial environments tend to have more activity and complexity in the environment, resulting in more variation within the segment. Although commercial segments had lower reliability scores, most questions in the audit were still highly or moderately reliable. As shown in Table 3 , variation in reliability scores was higher for commercial segments: some raters compared well, whereas others did not. This points to the need for more training and guidance to rate segments in commercial areas and other complex environments.

The reliability of different modes of administration was examined to guide the development of procedures and protocols. The audit was primarily administered in pairs, for reasons described above. However, some segments were re-surveyed by individuals. This method proved to have a lower reliability overall than surveying in pairs. The reliability scores for the administration by a single rater are shown in Table 4 . Surveying alone also made some raters uncomfortable in certain situations and they felt safer surveying the streets in pairs.

The method of surveying "in waves" was tested for reliability. Here, each rater specializes in a class of features representing a section of the audit. Raters evaluate all segments focusing only on features in their area of specialization. The rationale for this method of administration is that raters who specialize may be better able to evaluate individual features of the environment, resulting in better reliability. However, test results of the "wave" method suggested that this mode of administration is not as reliable as having raters evaluate all features of the environment. Kappa scores for the "wave" method are shown in Table 5 .

Table 3
Reliability for commercial (number of segments = 22) and residential (number of segments = 67) segments

Questions	Commercial		Residential	
	Kappa score	Percent agreement	Kappa score	Percent agreement
Subjective assessment: segment . . .				
. . . is attractive for walking	N/A[a]	30.4	0.275	59.7
. . . is attractive for cycling	0.079	26.1	0.144	77.6
. . . feels safe for walking	0.259	21.7	0.152	71.6
. . . feels safe for cycling	0.352	26.1	0.223	80.6
0. Segment type	1.000	100.0	1.000	100.0
1. Uses in segment (all that apply)				
Housing—single family detached	0.750	87.0	1.000	100.0
Housing—multi-family	0.864	95.7	0.591	85.1
Housing—mobile homes	N/A[b]	100.0	N/A[b]	100.0
Office/institutional	0.545	78.3	0.568	94.0
Restaurant/café/commercial	0.500	91.3	N/A[b]	97.0
Industrial	0.647	95.7	N/A[b]	100.0
Vacant/undeveloped	N/A[b]	91.3	0.552	95.5
Recreation	N/A[b]	95.7	N/A[b]	98.5
2. Slope	0.561	73.9	0.568	89.6
3. Cul-de-sac/dead-end	0.647	95.7	1.000	100.0
4. Type(s) of pedestrian facility				
Footpath (worn dirt path)	N/A[b]	87.0	N/A[b]	95.5
Paved trail	N/A[b]	95.7	0.646	95.5
Sidewalk	0.778	95.7	0.951	98.8
Pedestrian street (closed to cars)	N/A[b]	100.0	N/A[b]	100.0
5. Path material (all that apply)				
Asphalt	0.408	82.6	0.738	92.5
Concrete	1.000	100.0	0.951	98.5
Paving bricks or flat stone	0.500	91.3	0.651	97.0
Gravel	N/A[b]	87.0	N/A[b]	100.0
Dirt or sand	N/A[b]	95.7	N/A[b]	100.0
6. Path obstructions (all that apply)				
Poles or signs	0.299	69.6	0.633	89.6
Parked cars	N/A[b]	95.7	N/A[b]	97.0
Trees	0.400	82.6	0.287	67.2
Garbage cans	N/A[b]	100.0	0.647	98.5
Other	−0.071	87.0	0.306	94.0
7. Buffers between road and path				
Hard buffer				
Fence	N/A[b]	100.0	N/A[b]	100.0
Trees	0.704	91.3	0.350	83.6
Hedges	N/A[b]	95.7	N/A[b]	100.0
Soft buffer				
Landscape	N/A[b]	95.7	N/A[b]	100.0
Grass	0.830	87.0	0.788	89.6
Path distance from curb (feet)	0.989[c]	65.2	0.995[c]	62.7
Path width (feet)	0.972[c]	39.1	0.999[c]	65.7
8. Sidewalk completeness/continuity	N/A[b]	65.2	0.699	92.5
9. Sidewalk connectivity to other	0.969[c]	39.1	0.998[c]	59.7
10. Sidewalk condition/maintenance	0.305	47.8	0.296	65.7
11. Condition of ~~road~~	0.060	52.2	0.416	85.1
12. Number of lanes	0.938[c]	73.9	0.965[c]	82.1
13. Posted speed limit				
Yes/no	0.467	91.3	0.915	98.5
mph	N/A[a]	91.3	N/A[a]	97.0
14. On-street parking	0.895	91.3	0.691	88.1
15. Off-street parking lot spaces	N/A[a]	56.5	N/A[a]	100.0
16. Must you walk through a parking lot	0.132	52.2	0.849	98.5
17. Driveways	0.228	60.9	0.407	89.6

Table 3 (*Continued*)

Questions	Commercial		Residential	
	Kappa score	Percent agreement	Kappa score	Percent agreement
18. Traffic control devices				
Traffic light	0.829	91.3	0.793	98.5
Stop sign	0.600	100.0	0.861	94.0
Traffic circle	N/A[b]	100.0	N/A[b]	97.0
Speed bumps	N/A[b]	100.0	0.817	97.0
Chicanes or chokers	N/A[b]	100.0	1.000	100.0
19. Curb cuts in segment	0.421	69.6	0.732	85.9
20. Crossing aids in segment				
Cars must stop				
Pavement markings	0.832	87.0	0.809	91.0
Yield to ped paddles	N/A[b]	100.0	N/A[b]	100.0
Pedestrian signal	0.909	91.3	0.378	95.5
Crossing aids				
Median/traffic island	−0.059	87.0	N/A[b]	98.5
Curb extension	N/A[b]	100.0	N/A[b]	100.0
Overpass/underpass	N/A[b]	100.0	N/A[b]	100.0
Warnings to cars				
Pedestrian crossing street sign	0.333	87.0	1.000	100.0
Flashing warning	N/A[b]	100.0	N/A[b]	100.0
21. Lighting	0.100	43.5	0.055	38.8
22. Amenities (all that apply)				
Garbage cans	−0.059	91.3	N/A[b]	91.0
Benches	0.467	95.7	0.784	97.0
Water fountain	N/A[b]	100.0	N/A[b]	100.0
Bicycle parking	N/A[b]	95.7	N/A[b]	100.0
Street vendors/vending machines	0.647	91.3	N/A[b]	95.5
23. Are there wayfinding aids?	0.111	73.9	N/A[a]	67.2
24. Number of trees shading	0.377	56.5	0.210	62.7
25. Degree of enclosure	0.351	60.9	0.144	100.0
26. Powerlines along segment?	1.000	100.0	1.000	100.0
27. Cleanliness	−0.068	39.1	0.102	55.2
28. Articulation in building designs	N/A[a]	21.7	N/A[a]	100.0
29. Building setbacks from street	0.143	78.3	0.283	38.8
30. Bicycle lane	N/A[b]	100.0	0.552	95.5
31. Transit facilities	0.362	82.6	0.881	98.5

[d]This question was changed in the middle of the audit and was therefore not tested.
[a] These questions did not have fixed answers and therefore a Kappa score cannot be computed.
[b] This feature was not present in any of the tested segment or was too rare for Kappa testing.
[c] When a concordance statistic is calculated.

3.6. Costs and time

Efficiency of administration was one central goal guiding the development of the PEDS audit and one key advantage over other audit methodologies. The testing and administration of the audit on 995 segments in College Park, MD, as describe above, and subsequent administration in Montgomery County, MD totaling 3635 segments, allow detailed time and cost estimates for audit administration. Administering PEDS on a segment with an average length of 400 ft takes approximately 3–5 min on foot.

These time estimates are very different when used to estimate project labor costs in person hours, however. PEDS is designed to be administered with two raters and the labor commitment (or person hours) per segment is approximately double the administration time or 6–10 min per segment. Also the time for adequate training, reliability testing and other related project administration issues should be accounted for in estimating the total costs of conducting an audit for a new project. When training and reliability testing are included, the labor investment for PEDS increases to 10–12 min per segment per rater. This added time will vary depending on the number of segments surveyed, the amount of reliability testing done and the average length of segments. Even with the training and other administrative costs included, PEDS is an efficient methodology for collecting microscale pedestrian data. Estimates from PEDS and other audits, which range from 5 to 30 min are shown in Table 1.

Conducting the PEDS audit with the PDA interface saves labor costs approximately 2 min per segment: where data had to be entered by hand in paper-and-pencil audits, the process is now automated. Data cleaning, equipment maintenance and reliability testing, on the other hand, will vary with the number of segments audited. The cost of materials to administer the PEDS

Table 4
Reliability of segments audited by single administrator (number of segments = 70)

Questions	Kappa score	Percent agreement
Subjective assessment: segment . . .		
. . . is attractive for walking	N/A[a]	67.1
. . . is attractive for cycling	N/A[a]	74.3
. . . feels safe for walking	N/A[a]	80.0
. . . feels safe for cycling	N/A[a]	71.4
0. Segment type	1.000	100.0
1. Uses in segment (all that apply)		
Housing—single family detached	0.785	97.1
Housing—multi-family	N/A[b]	100.0
Housing—mobile homes	N/A[b]	100.0
Office/institutional	N/A[b]	100.0
Restaurant/café/commercial	0.736	97.1
Industrial	N/A[b]	100.0
Vacant/undeveloped	0.259	87.1
Recreation	0.653	97.1
2. Slope	0.523	75.7
3. Cul-de-sac/dead-end	0.660	91.4
4. Type(s) of pedestrian facility		
Footpath (worn dirt path)	N/A[b]	100.0
Paved trail	0.022	94.3
Sidewalk	0.249	92.9
Pedestrian street (closed to cars)	N/A[b]	100.0
5. Path material (all that apply)		
Asphalt	0.386	95.7
Concrete	1.000	100.0
Paving bricks or flat stone	N/A[b]	100.0
Gravel	N/A[b]	100.0
Dirt or sand	N/A[b]	100.0
6. Path obstructions (all that apply)		
Poles or signs	N/A[b]	97.1
Parked cars	1.000	100.0
Trees	0.246	80.0
Garbage cans	N/A[b]	100.0
Other	0.489	97.1
7. Buffers between road and path		
Hard buffer		
Fence	N/A[b]	100.0
Trees	0.765	88.6
Hedges	N/A[b]	100.0
Soft buffer		
Landscape	N/A[b]	98.6
Grass	0.379	95.7
Path distance from curb (feet)	0.744[c]	52.9
Path width (feet)	0.966[c]	77.1
8. Sidewalk completeness/continuity	0.384	95.7
9. Sidewalk connectivity to other	0.994[c]	62.9
10. Sidewalk condition/maintenance	0.783	88.6
11. Condition of road	N/A[a]	71.4
12. Number of lanes	0.825[c]	95.7
13. Posted speed limit	0.639	94.3
14. On-street parking	0.933	98.6
15. Off-street parking lot spaces	0.735	94.3
16. Must you walk through a parking lot	0.687	97.1
17. Driveways	N/A[a]	91.4
18. Traffic control devices		
Traffic light	N/A[b]	100.0
Stop sign	0.713	85.7
Traffic circle	N/A[b]	100.0
Speed bumps	0.805	98.6
Chicanes or chokers	0.793	98.6
19. Curb cuts in segment	0.510	92.9
20. Crossing aids in segment		
Cars must stop		
Pavement markings	0.757	92.9
Yield to ped paddles	N/A[b]	100.0
Pedestrian signal	N/A[b]	100.0
Crossing aids		
Median/traffic island	0.850	98.6
Curb extension	N/A[b]	100.0
Overpass/underpass	N/A[b]	100.0
Warnings to cars		
Pedestrian crossing street sign	0.288	88.6
Flashing warning	N/A[b]	100.0
21. Lighting	0.178	55.7
22. Amenities (all that apply)		
Garbage cans	N/A[b]	100.0
Benches	N/A[b]	100.0
Water fountain	N/A[b]	100.0
Bicycle parking	N/A[b]	100.0
Street vendors/vending machines	0.653	97.1
23. Are there wayfinding aids?	0.177	81.4
24. Number of trees shading	0.226	72.9
25. Degree of enclosure	0.460	91.4
26. Powerlines along segment?	0.022	94.3
27. Cleanliness	0.330	70.0
28. Articulation in building designs	0.022	94.3
29. Building setbacks from street	0.915	97.1
30. Bicycle lane	N/A[b]	98.6
31. Transit facilities	N/A[b]	98.6

[a] Answer options were not symmetric in these variables and Kappa scores were therefore unavailable.
[b] This feature was not present in any of the tested segments or was too rare for Kappa testing.
[c] When a concordance statistic is calculated.

audit with the PDA interface is small. A PDA costs approximately $100–$200 per unit and the software needed to enter the data is $50. This means that a relatively small area needs to be audited for investment in PDA units to be financially worthwhile.

4. Discussion

The PEDS audit methodology showed encouraging results. Much of the training materials and protocol were altered during the project in response to the questions, comments and issues encountered by the raters. These alterations in the supporting materials of the audit improved the already positive reliability results.

In light of the high variation of uses, conditions and aesthetics of the segments in College Park, the reliability scores of the audit questions were very encouraging. Almost all questions in the audit had moderate to high reliability. High reliability questions were mostly objective, as expected. Only a small num-

Table 5
Reliability of "Wave" auditing (number of segments = 33)

Questions	Kappa score	Percent agreement
Subjective assessment: segment . . .		
. . . is attractive for walking	N/A[a]	84.8
. . . is attractive for cycling	N/A[a]	93.9
. . . feels safe for walking	N/A[a]	90.9
. . . feels safe for cycling	N/A[a]	90.9
0. Segment type	1	1.0
1. Uses in segment (all that apply)		
Housing—single family detached	1	100.0
Housing—multi-family	N/A[b]	100.0
Housing—mobile homes	N/A[b]	100.0
Office/institutional	N/A[b]	100.0
Restaurant/café/commercial	N/A[b]	100.0
Industrial	N/A[b]	100.0
Vacant/undeveloped	0.336	81.8
Recreation	1	100.0
2. Slope	0.561	75.8
3. Cul-de-sac/dead-end	1	100.0
4. Type(s) of pedestrian facility		
Footpath (worn dirt path)	N/A[b]	100.0
Paved trail	N/A[b]	100.0
Sidewalk	1	100.0
Pedestrian street (closed to cars)	N/A[b]	100.0
5. Path material (all that apply)		
Asphalt	1	100.0
Concrete	1	100.0
Paving bricks or flat stone	N/A[b]	100.0
Gravel	N/A[b]	100.0
Dirt or sand	N/A[b]	100.0
6. Path obstructions (all that apply)		
Poles or signs	N/A[b]	100.0
Parked cars	1	100.0
Trees	0.310	69.7
Garbage cans	N/A[b]	100.0
Other	N/A[b]	97.0
7. Buffers between road and path		
Hard buffer		
Fence	N/A[b]	100.0
Trees	N/A[a]	27.3
Hedges	N/A[a]	97.0
Soft buffer		
Landscape	N/A[b]	100.0
Grass	1	100.0
Path distance from curb (~~feet~~)	0.935[c]	48.5
Path width (feet)	N/A[d]	81.8
8. Sidewalk completeness/continuity	1	100.0
9. Sidewalk connectivity to other	0.862[c]	54.5
10. Sidewalk condition/maintenance	0.049	60.6
11. Condition of road	0.092	72.7
12. Number of lanes	N/A[d]	100.0
13. Posted speed limit	0.653	97.0
14. On-street parking	N/A[a]	97.0
IS. Off-street parking lot spaces	N/A[b]	100.0
16. Must you walk through a parking lot	1	100.0
17. Driveways	0.653	97.0
I8. Traffic control devices		
Traffic light	N/A[b]	100.0
Stop sign	1	100.0
Traffic circle	N/A[b]	100.0
Speed bumps	1	100.0
Chicanes or chokers	N/A[b]	100.0
19. Curb cuts in segment	0.653	97.0
20. Crossing aids in segment		
Cars must stop		
Pavement markings	N/A[b]	100.0
Yield to ped paddles	N/A[b]	100.0
Pedestrian signal	N/A[b]	100.0
Crossing aids		
Median/traffic island	N/A[b]	90.9
Curb extension	N/A[b]	100.0
Overpass/underpass	N/A[b]	100.0
Warnings to cars		
Pedestrian crossing street sign	0.784	100.0
Flashing warning	1	100.0
21. Lighting	N/A[a]	72.7
22. Amenities (all that apply)		
Garbage cans	N/A[b]	100.0
Benches	N/A[b]	100.0
Water fountain	N/A[b]	100.0
Bicycle parking	N/A[b]	100.0
Street vendors/vending machines	N/A[b]	100.0
23. Are there wayfinding aids?	1	100.0
24. Number of trees shading	N/A[a]	66.7
25. Degree of enclosure	1	100.0
26. Powerlines along segment?	−0.031	93.9
27. Cleanliness	0.140	60.6
28. Articulation in building designs	1	100.0
29. Building setbacks from street	N/A[a]	97.0
30. Bicycle lane	N/A[b]	100.0
31. Transit facilities	N/A[b]	100.0

[a] Answer options were not symmetric in these variables and Kappa scores were therefore unavailable.
[b] This feature was not present in any of the tested segments or was too rare for Kappa testing.
[c] When a concordance statistic is calculated.
[d] There was insufficient variation to compute Lin's concordance statistic.

ber of questions relying on subjective assessments of pedestrian features had consistently low agreement scores. Although the subjective questions did not have high reliability – which is due to their intrinsically subjective nature – they did have a high level of correlation with the objective questions, which indicates that the objective questions capture important aspects of the pedestrian environment. It should be noted that some items (such as the presence of chokers in the roadway, industrial land uses, etc.), because of their paucity in the subject area, should be further tested in areas where they are more common.

Overall, the reliability results were comparable to Pikora et al. (2002): a similar proportion of questions garnered good, fair and poor Kappa or concordance scores (concordance scores were considered good ~~are~~ above 0.9). It is harder to compare with the I-M inventory, as they did not report Kappa statistics but only percent agreement. The I-M inventory reported that 99.2% of the variables had 80% agreement among the raters in Minnesota (Boarnet et al., 2006). In comparison, PEDS had 89%

of the variables with 80% agreement among the raters. This relatively positive comparison is particularly encouraging considering the complexity of the environment in which PEDS was administered and the relatively large number of raters used in the evaluation.

Although a number of measures in PEDS had relatively low reliability, this will not result in their excision from the audit. These measures of the micro-level environment are related to walkability and deserve further attention. In response to these results, we have made some modifications to the audit. In some measures, the number of responses for measures with low reliability was reduced, such as distance to the curb and the width of the pedestrian path. For questions about curb cuts and the road width, we added to the number responses.

The technology incorporated in this audit make it flexible for use in different conditions. While the audit can make use of GPS, GIS and PDAs, it can also be administered with pencil and paper. As mentioned earlier, this is the only audit that has been tested in its electronic rather than paper and pencil format, and the supporting materials for this instrument have been developed to take full advantage of new technologies while staying affordable to implement. Also, although the audit was used objectively in this study, the audit could also be used subjectively (without the training) to find variations in community members' perceptions of the environment.

In this paper, the results of testing PEDS in a predominantly suburban environment are reported; but, in general, PEDS was designed to be versatile with respect to the administration settings (urban, suburban and rural), capturing the features that are most commonly thought to be associated with walking behavior. However, some aspects of administration are likely to be different across these varied environments. For example, the process of designating of street segments is generally more straightforward in urban settings that follow a grid street pattern than in suburban and rural environments that have curvilinear streets and large block lengths, which require subdivision of segments. The presence and type of pedestrian network may vary considerably across these different area types. Rural and suburban areas may have different land uses, such as agricultural land and open space, which may be difficult to identify and are not currently included among the audit measures. There may be other features or issues with pedestrian accommodation in urban areas, such as sophisticated pedestrian crossings, skywalks or crowding problems, that are not captured with this instrument. These variations in the features of the built environment across area types were carefully considered in the development of PEDS. The instrument and methodology can be employed in all of these built environments and can capture differences in the features of the pedestrian environment in each type. PEDS is not appropriate tool for assessing recreational or hiking trails in rural or wilderness settings.

Future research will include administering the audit in urban and rural as well as suburban locations, tests of external validity, using remote sensing and archived GIS data and pedestrian counts. Other more sophisticated tests of internal and external validity (such as weighted Kappa scores) will be conducted. Because PEDS has been administered as a complete census in College Park and in various locations in Montgomery County, including urban and rural areas, various sampling methods can be developed and tested for use in the design of future data collection schemes. Finally, the information from PEDS audit will be used in a behavioral model to test associations between pedestrian activity and the built environment. Here the audit measures will be instrumented and several weighting schemes will be tested. Ultimately, this research should inform future audit design and narrow the number of measures collected to those supported with empirical evidence.

The development of PEDS and the other audit methodologies points to an increasing interest in the pedestrian environment from a wide array of disciplines. This and other data collection efforts fill a longstanding gap that has impeded the progress of pedestrian research and practice and represent a positive step toward elevating walking as a mode of transportation and source of physical activity.

~~Uncited reference~~

~~Cressie (1993).~~

Acknowledgements

The authors would like to acknowledge the Robert Wood Johnson Foundation Active Living Research Program, the National Science Foundation Research Internships in the Sciences and Engineering (RISE), and the National Center for Smart Growth Research and Education at the University of Maryland for their support in this research.

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