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Transportation Research Part D 11 (2006) 250–263
TRANSPORTATION RESEARCH PART D
www.elsevier.com/locate/trd

Characterizing neighborhood pedestrian environments with secondary data

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Abstract

Commonly used measures of the pedestrian environment rely on field data collection and subjective judgments. This study develops objective measures of the pedestrian environment that use secondary data or plans for proposed neighborhoods and still correlate well with accepted subjective measures. Data to estimate these measures, describing network design, sidewalk availability and building accessibility, were collected for a sample of neighborhoods in the Chicago area using both common secondary sources and subjective field surveys. Linear regression was used to estimate judgmental indices with the laboratory data as independent variables. The measures developed can be substituted for subjective field measures to reduce costs with minimal loss in accuracy and to characterize walkability of proposed neighborhood designs.

Keywords: Pedestrian environment; Walkability; Aerial photography; GIS; Pedestrian friendliness

1. Introduction

Interest in improved pedestrian environments has grown as a result of the desire to encourage non-motorized travel to reduce vehicle-miles and pollution emissions, and more recently to improve public health through increased physical activity in the form of walking. Numerous studies have confirmed that favorable pedestrian environments are a necessary condition for promoting walking.[1] Incorporating pedestrian options into transportation planning has remained difficult because of the lack of data on pedestrian travel and the absence of an accepted, objective measure of the quality of the pedestrian environment that can be used in travel behavior modeling and evaluation. Several different methods of measuring the pedestrian environment have been developed, but most ignore important aspects of design, rely on data that are not available for all areas, or require extensive fieldwork. Some use subjective field ratings of neighborhood pedestrian environments that cannot be used to characterize proposed designs and may lack inter-rater reliability.

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[1] A review of research in this area is given by Saelens et al. (2003).

1361-9209/$ - see front matter
doi:10.1016/j.trd.2006.04.003

Thus, there is a need for a method to characterize neighborhood pedestrian environments that can be applied objectively using commonly available secondary data. Any new measure of the pedestrian environment should meet these criteria:

- Measures should not require field visits to decrease the time and cost associated with application.
- The rating method should be objective to avoid problems of inter-rater reliability.
- There must be a balance between the level of detail and data collection costs. The method should capture the key walking related aspects of the neighborhood but should be simple enough to apply easily to many neighborhoods.
- It must be possible to develop ratings for proposed designs.
- Measures should be based on reliable data sources that are systemically updated, so that measures stay current.

This study develops indices measuring the pedestrian environment that meet the criteria. Indices were specifically designed to correlate well with accepted pedestrian environment (walkability) measures.

1.1. Prior research

Measures of the pedestrian environment (PE) are of particular interest as a mechanism for understanding and utilizing the relationship between the built environment and physical activity (PA) in the form of walking. The connection between PA and health is well-known (Surgeon General of the United States, 1996) but the effect of the PE is less understood (Committee on Physical Activity, 2005). Certainly a mix of factors affect PA, including characteristics of individuals and households, neighborhood density, design, land use mix, the social environment, cultural norms, safety and security, and, logically, the PE. Sorting out the role of PE's a complex task, and a starting point is having a good measure of PE. Such a measure must not only meet the criteria listed, but should also correlate well with walking.

Moudon and Lee (2003) evaluate 31 tools for assessing environmental characteristics. Altogether, nearly 200 variables are used in the reviewed tools. Their review emphasizes that colinearity between many of these variables makes the impact of each difficult, if not impossible, to isolate. This may require using variables in packages rather than individually. At the same time it is important to control the cost of data collection. Aerial photos, which have minimal data collection costs once photos have been taken, were used in only one of the 31 instruments reviewed by Moudon and Lee, suggesting the opportunity to explore this resource for characterizing the PE.

The joint policy study by the Transportation Research Board and the Institute of Medicine (Committee on Physical Activity, 2005) examined the relationship between PA and the built environment. This report found that measures of the built environment are less developed than those used to measure physical activity. A primary reason for this is the lack of theory describing the effects of the built environment on PA; the report identified lack of data for large areas as another obstacle. While parcel-level data on many variables are collected and geocoded by some public agencies, such fine-scaled data are not yet widely available.

Based on the reviews of PE measurement tools by Moudon and Lee (2003) and Committee on Physical Activity (2005), the most relevant methods for this paper fall into four categories: classification schemes; field work methods; either objective or subjective; and laboratory methods using secondary data (Table 1). Classification schemes group neighborhoods into two or three categories characterizing walkability. For example, Cervero and Gorham (1995) classified neighborhoods judgmentally as either transit-oriented or auto-oriented, matched the two types based on similarity of income of residents, and used the results to explain commuting mode choice. Friedman et al. (1994) extended the notion of a binary classification scheme to 550 subzones in the San Francisco Bay Area, excluding the downtown areas of Oakland and San Francisco. Using such simple classification schemes may not capture subtle but important aspects of the pedestrian environment, and judgmental classification may become burdensome and inconsistent.

One way to go beyond simplistic neighborhood classification schemes is to do extensive fieldwork. This can yield detailed information about urban design characteristics but it can be expensive and time-consuming. For example, Kockelman and Cervero (1997) collected over twenty detailed objective measurements of street and

Table 1
Summary of prior research

Category	Sub-category	Representative papers	Description of work
Classification scheme		Cervero and Gorham (1995)	Matched pair analysis of transit and auto-oriented neighborhoods
		Handy (1996)	Designated 6 neighborhoods in Austin as Traditional, Early-Modern or Late-Modern
		Friedman et al. (1994)	Characterized 550 subzones in San Francisco region as either "standard suburban" or "traditional"
Field work	Objective	Kockelman and Cervero (1997)	Measured over 20 aspects of pedestrian design through field observations
		Kitamura et al. (1997)	Did site surveys of 5 neighborhoods in the San Francisco Bay Area
	Subjective	Friends of Oregon (1993), LUTRAQ	Rated topography, presence of sidewalks, ease of street crossing and street connectivity on a 1–3 scale
		Replogle (1988), MNCPPC	Used a 0–1 scale accounting for sidewalks, building setbacks, land use mix, transit stop conditions and bicycle infrastructure
		Pikora et al. (2002)	Developed the SPACES audit instrument to measure the quality of the pedestrian environment
Laboratory measures		Krizek (2003)	Measured average block size for a neighborhood
		Boarnet and Sarmiento (1998)	Calculated % of street network characterized by 4-way intersections
		Frank et al. (2000)	Measured census-block density

site design (e.g., distance between streetlights and the proportion of blocks with planting strips) for neighborhoods in the San Francisco bay area. This approach is too time-consuming to be applied to large areas. Similarly, Kitamura et al. (1997) conducted extensive site surveys of 5 San Francisco neighborhoods along with travel behavior data to analyze the effects of land use on travel.

A less time-consuming way to evaluate pedestrian design is to rate neighborhoods based on subjective scales. This requires field visits, but is more efficient because subjective assessments can be made quickly. One of the most widely known of these surveys is the Land-use Transportation and Air Quality (LUTRAQ) Pedestrian Environment Factor (PEF) developed in Portland, OR (1000 Friends of Oregon, 1993). This is a network measure based on four factors: topography, ease of street crossings, presence of sidewalks and connectivity of the street network. Each of these measures is given a subjective score between 1 and 3, which are then added together for a maximum score of 12 for any neighborhood. PEFs were calculated for each Traffic Analysis Zone (TAZ) in the Portland region, and used to examine the effect of the pedestrian environment on travel behavior. The analysis showed that zones with high PEFs experienced significantly more walking trips than did zones with low PEFs, and that there is a significant inverse correlation between the PEF and vehicle miles traveled.

Replogle (1990) developed a subjective Pedestrian Friendliness Index (PFI) for the Maryland National Capital Parks and Planning Commission (MNCPPC) that goes beyond the network measures used in the PEF to include land use characteristics to reflect the fact that, when land use permits, some trips can be accomplished by short-distance, non-motorized travel. This measure rates pedestrian and bicycle suitability based on five characteristics using a scale of 0–1 (Table 2). The PFI was used in estimation of the MNCPPC mode choice model to determine the likelihood of transit trips, and to distinguish between walk and auto access for transit trips. Results showed that the PFI at both trip origin and destination was a "highly explanatory" factor in mode choice.

Pikora et al. (2002) developed the SPACES audit instrument to measure the pedestrian environment. Sixteen observers audited over 12,000 street segments, collecting data on over 25 variables, which were then combined with GIS and roadway data for each segment. Tests showed that inter-rater reliability was high for most of the variables collected. Achieving this, however, required 3 days of training for each auditor, and the costs of the fieldwork were thus high.

Table 2
PFI rating scheme

Factor	Ratings
Sidewalks	
No sidewalks	0
Discontinuous, narrow sidewalks	0.05
Narrow sidewalks along all major streets	0.15
Adequate sidewalks along all major streets	0.25
Adequate sidewalks along most streets with some off-street paths	0.35
Pedestrian district with sidewalks everywhere, pedestrian streets and auto restraints	0.45
Land use mix	
Homogeneous land use within easy walking distance	0
Some walk accessible lunch time service retail in employment centers	0.1
Mixed land use at moderate density	0.2
Mixed land use at high density	0.25
Building setbacks	
Mostly setback sprawled campus style	0
Mixed campus style but clustered with bus stops within walking distance	0.05
Few or no building setbacks from streets with transit	0.1
Transit stop conditions	
No shelters	0
Some bus stop shelters	0.05
Widely available bus stop shelters	0.1
Bicycle infrastructure	
Little or none	0
Some cycle paths or routes	0.05
Many cycle paths, lanes, or routes forming network	0.1

Although simple to apply, subjective rating scales raise several problems. Most importantly, inter-rater reliability is an issue because of the inherent variability of subjective judgments. This can usually be overcome by using multiple, well-trained raters. Because field visits are required, data collection costs can be high. Furthermore, it is not possible to use this method to characterize proposed designs.[2]

A final method that has been used is applying GIS data to analyze neighborhood street network characteristics. Typically, this means measuring either Block Length or characterizing intersection type. Data can be collected automatically using geographic information system (GIS) software, and thus it is possible to use such measures to characterize large areas or proposed designs. Many recent studies have used some variation of this approach. Krizek (2003) measured average block area as defined by the area of fully enclosed polygons within the road network. Boarnet and Sarmiento (1998) used the percentage of 4-way intersections on the network. McNally and Kulkarni (1997) used both intersection type and intersection density to measure pedestrian environment.

There are limitations to relying only on measures of network design, however. Although street network features are influential in determining pedestrian environment, they do not measure many important aspects of the pedestrian environment, such as availability of sidewalks or characteristics of the built environment, such as building setbacks and presence of parking lots, which increase vehicle conflicts and decrease visual interest.

2. Methodology

Here we develop a method to evaluate the pedestrian environment that is objective and does not require field visits, and which is anchored to two widely accepted subjective field rating systems, LUTRAQ's PEF

[2] Raters can be asked to judge designs using pictures and models, but reliability of the results may be threatened because of uncertainties in the veridicality of design representation and the ability of raters to interpret it.

(1000 Friends of Oregon, 1993) and MNCPPC's PFI (Replogle, 1990).[3] Both of these rating systems are positively correlated with walking. Estimation data were collected for 23 neighborhoods in the Chicago region; several objective measures of the pedestrian environment were collected for each neighborhood using GIS and digital aerial photographs. The field ratings were used as dependent variables in regression analyses with the laboratory data as independent variables to identify the best combination of laboratory measures to represent the information in the popular field methods.

2.1. Data sources

Two sources were used to measure the variables: digital aerial photographs and digital maps. The maps used are 2000 US Census TIGER files, which are available online at no charge.[4] These maps show the existing street network in great detail. While TIGER files are subject to some inaccuracy, they are chosen because of their availability for the entire US. The Northeastern Illinois Planning Commission (NIPC) provided the aerial photographs on DVD-ROM. The photographs were taken in April, 2001 making them less than 4 years old at the time of study, and have a pixel resolution of 1 foot.[5] The photographs are divided into tiles by townships that are 69 MB apiece. The tiles for the entire region are 7.03 GB. The files are formatted for use in ArcView GIS software. NIPC land use data for the Chicago region were also considered for incorporation. However, examination of these data found them too coarse to be useful.[6]

2.2. Measures

Six factors thought to be associated with good pedestrian design, and which can be measured remotely, were considered: sidewalks, parking lots, building setbacks, Block Length, intersection type, and census block density. The variables described here represent three main classes of features that contribute to pedestrian design: network design (block length, census-block density and intersection type), pedestrian facilities (sidewalks) and the roadside built environment (setbacks and parking). Network design helps determine the ability of pedestrians to reach their destinations; grid networks with short blocks allow for relatively direct routes, while long blocks and curvilinear streets lengthen pedestrian trips by requiring circuitous routes. Sidewalks also are an essential component of good pedestrian design in areas where automobile traffic is more than minimal. Lack of sidewalks implies pedestrians must either walk in the roadway, which decreases safety, or walk alongside the road in an environment that may be muddy, rocky or have steep terrain. Finally, setbacks and parking also play a role in creating a pedestrian friendly area. Small building setbacks make stores and residences easily accessible to pedestrians, while large setbacks increase the effort required to reach buildings from the street and provide a less interesting streetscape. Streets with a large amount of frontage taken up by parking make pedestrian access to buildings more difficult by requiring pedestrians to cross a parking lot. Additionally, parking frontage is a proxy for curb cuts, which decrease pedestrian safety by increasing the number of places at which vehicles can cross the sidewalk (conflict points).

Nine variables were selected to measure these factors, as 3 factors are measured in 2 different (but similar) ways – Table 3. All of the variables described here are objective and can be measured remotely using digital aerial photographs and maps, thus eliminating the necessity for field visits. Intersection type was measured both as the density of 4-way intersections per square mile and as the ratio of 4-way intersections to all intersections. While the 4-way ratio will describe network type, a grid network with long blocks will have a high ratio but may not provide pedestrians with direct routes. Finally, both Setback, the distance of building fronts from the sidewalk, as well as Setback^{-1} were tested. Setback^{-1} has conceptual advantages in that higher setbacks are assumed to have a decreasing marginal affect on the pedestrian environment.

[3] The LUTRAQ measure is no longer in use in Portland, where it has been replaced by more objective, GIS-based measures.

[4] http://www.esri.com/data/download/census2000_tigerline/index.html

[5] This corresponds to a negative scale of $1'' = 2000'$, which generated an orthophotographic database with a mapping scale of $1''400'$.

[6] For example, a commercial node near a train station surrounded by residential uses is coded entirely as residential despite a grocery store, laundromat, and several restaurants, all of which may attract significant numbers of walking trips.

Table 3
Summary of measurements

Factor	Variable	Source
Average block length	(Total roadway length)/(# of blocks)	Calculated using GIS and census maps
	Standard deviation of road segment lengths	Calculated using GIS, SPSS and census maps
Intersection type	(# of 4-way intersections)/ (Total intersections + Dead-ends)	Manually counted for entire neighborhood using census maps
	(# of 4-way intersections)/(square mile)	Manually counted for entire neighborhood using census maps
Census block density	(# of census blocks)/(neighborhood area)	Calculated using GIS and census block maps
Sidewalk provision	(Feet of sidewalk)/(feet of roadway)	Manually measured for sample of block faces from aerial photos
Building setbacks	Mean setback of buildings fronting the street	Manually measured for sample of block faces from aerial photos
	Inverse of mean setback	Manually measured for sample of block faces from aerial photos
Adjacent parking	(Feet of adjacent parking)/(feet of roadway)	Manually measured for sample of block faces from aerial photos

Block Length was measured as both mean Block Length and standard deviation of Block Length. While using the average may seem intuitive, the mean does not account for variance in Block Length, a factor that can be detrimental to the pedestrian environment. Discontinuous suburban street networks, for instance, usually have many very short blocks (often cul-de-sacs) interspersed with several roads with very long blocks. Using standard deviation accounts for this. Many "good" pedestrian environments are not based on grids with uniform block lengths (e.g., Venice or Manhattan). However, the Block Lengths in these cases are so short that the standard deviation is still quite small.

2.3. Selected sites

The 23 neighborhoods were selected judgmentally to include a wide range of pedestrian environments and development patterns. Seven of the areas were within the City of Chicago, seven from the inner suburbs and 9 from the outer suburbs (Table 4 and Fig. 1). In general, the neighborhoods inside the Chicago city limits were characterized by high density, grid street networks and mixed land-use. The inner suburban areas also have grid networks, and some exhibit significant land-use mix, while others are almost entirely single-use. With one exception (downtown Elgin), the nine outer suburban neighborhoods are characterized by relatively low densities, separated land-uses, and absence of a grid street network. Most do not have extensive sidewalk networks. Downtown Elgin, however, was developed prior to WWI and has significant mixed-use and fairly high densities.

2.4. Test procedure

Neighborhoods were defined in this work as areas within a 2000 ft radius around a center point. This represents a 10 min walk from circle center to the periphery, and thus approximates an ideal walking neighborhood. Center points were selected to represent the centroid of activity for that neighborhood – for example, concentrations of commercial land use or some activity center. Of course, this method could be applied to a neighborhood of any size, but the areas under observation should be small enough such that they are relatively homogeneous in their PE. Otherwise, the measure loses validity. All streets catalogued in the Census Tiger files were used in the analysis, except for freeway segments, where no pedestrians are permitted.

Variables for Block Length and Intersection Type, as well as Census Block Density were calculated for the entirety of each selected neighborhood.[7] However, because data collection for Sidewalk Coverage,

[7] Census block density is used here because it is used by the Chicago-area MPO to measure pedestrian environment friendliness. It is defined as census blocks per quartersection, where all census blocks that have their center of population within the specified area are counted.

Table 4
Selected neighborhoods

Neighborhood name	Distance from CBD	Description of land-use
Within city of Chicago		
Loop	0	CBD of large metropolitan area
West Loop	1	Dense Urban Mixed-Use (residential, light industrial and commercial)
North and Clybourn	3	Urban, old industrial area with significant new commercial development
E. Garfield Park	4	Economically depressed area on Chicago's West Side
W. Washington Park	6	Economically depressed area on Chicago's South Side
Rogers Park	9	Dense urban residential with mixed use (retail and residential)
West Ridge	10	Mid-density urban residential with limited mixed-use
Inner suburbs		
Evanston	12	Suburban center with mid-high density and extensive land-use mix (retail, office and residential)
Loyola Medical Center	11	Large campus style medical center in the West suburbs
Niles (Howard Industrial)	14	Suburban Industrial Park
Wilmette	14	Older, upscale suburb on the North Shore
Morton Grove (Dempster St.)	13	Post WWII suburban commercial strip development with residential behind
Park Ridge	12	Downtown of inner commuter rail suburb
Arlington Heights	23	Suburban center characterized by extensive new transit-oriented development surrounding old rail station, with several high-rise residential buildings
Outer suburbs		
Lake-Cook Rd.	27	Location near intersection of 2 interstates, many office buildings, as well as some residential development (separated land-use)
Dundee and Rand	26	New Suburban commercial strip, with some residential behind
Rolling Meadows	25	Suburban middle-class residential development
Palatine	24	Suburban area with townhouses and office park (separated land-use)
Woodfield Mall	22	Large mall, with surrounding shops and office buildings
Schaumburg	33	Suburban middle-class residential development
South Barrington	27	New, upscale suburban development with large lots and setbacks
Sears Headquarters	31	200-acre suburban campus-style office complex
Elgin	35	Downtown of large suburban satellite city

Parking Ratio and Building Setbacks is done manually, and thus is quite time-consuming, these variables were only collected for a sample of neighborhood block faces using digital aerial photographs viewed with GIS software. The sample is chosen randomly from the pool of census road segments (excluding freeway segments), with each road segment weighted according to its length.[8] In the event the longer blocks in a neighborhood have appreciably different characteristics than short blocks, the sampling approach will favor the characteristics of the longer blocks. This is reasonable, as longer segments contribute proportionally more to the pedestrian environment than do short segments. To determine the necessary sample size of block faces, all block faces were examined for 5 of the 23 neighborhoods. From this data, the effects of using several different sample sizes were analyzed, ranging from 5 blocks up to 20, to select the preferred sample size, as described below.

From these totals, the following variables were calculated for each neighborhood:

$$\text{Sidewalk ratio}: (\text{Total sidewalk length, feet})/(\text{Centerline feet of roadway})$$

[8] The sampling was automated using Microsoft Excel. The probability of each segment being chosen was: (Segment length)/(Total roadway length of neighborhood). Selection was done without replacement.

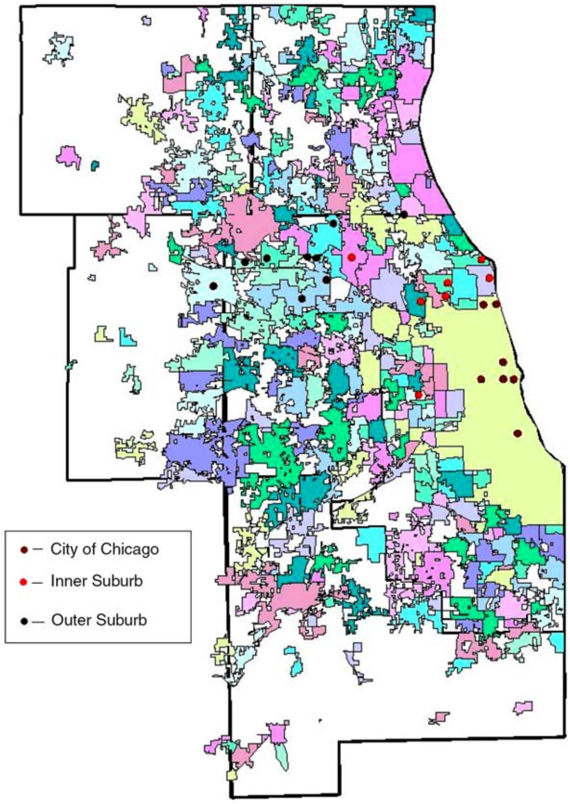

Fig. 1. Location of selected neighborhoods.

Average building setback : (Total setback, feet)/(Total number of buildings)

Adjacent parking ratio : (Total adjacent parking, feet)/(Centerline feet of roadway)

In a larger application, where data processing requirements are much larger, several of these tasks may be further automated using GIS tools.

2.5. Field data collection

Two standard, judgment-based pedestrian environment rating systems were applied to each of the neighborhoods using a team of observers. These ratings were then compared with the remotely collected data. The PFI, developed in the late 1980s, rates pedestrian friendliness on a scale of 0–1 (Table 2). Observers are asked to judge the quality of several factors, primarily presence of sidewalks, land use mix, building setback and transit stop conditions. The rating system also asks about bicycle infrastructure, but this portion was excluded since our research only concerns pedestrian environment. The rating scheme is subjective, although guidelines are provided to suggest how to score different types of environments. The PEF was also applied. This method rates neighborhoods on 1–12 scale. Equal weights are given to sidewalk provision, ease of street crossings, network connectivity and topography. Because of Chicago's predominantly flat terrain, topography was not considered.

The rating systems were applied to each neighborhood by either three or four paid observers. Prior to field visits, observers were provided with evaluation sheets with instructions for rating neighborhoods. The instructions were brief, in the case of the PEF, for instance, stating that ease of street crossing should be rated from 1 to 4, but not indicating what should be considered an easy street crossing. Observers did not all have prior experience evaluating pedestrian environments. This differs from the original applications of these rating systems, where so-called experts with specific training were used. Observers walked each area for 30–45 min

Table 5
Intraclass correlations for field data

	LUTRAQ	MNCPPC
MS between	70.5	0.527
MS within	2.11	0.018
k (harmonic mean for number of raters)	3.52	3.52
ICC	0.87	0.87
Reliability with 3 raters	0.95	0.95

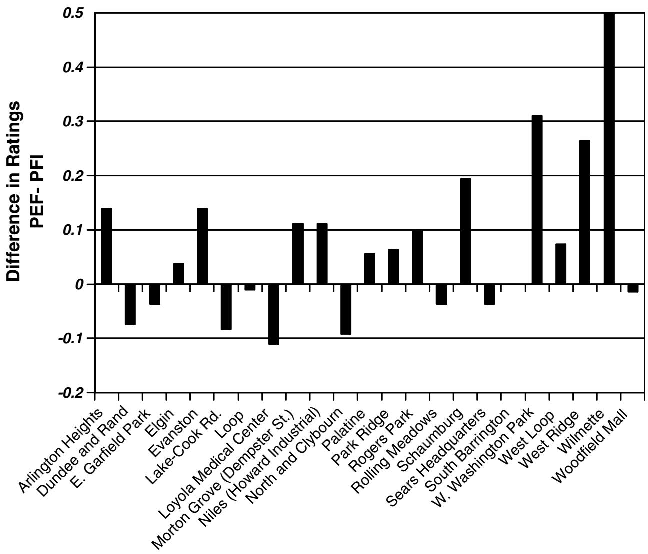

Fig. 2. Comparison of PEF and PFI scores.

together before assigning neighborhood scores. While walking, the pedestrian friendliness of the neighborhood under evaluation was not discussed. The final neighborhood score was the average of individual raters' scores.

The inter-rater reliability of the observers was tested for both the PEF and PFI, and found to be high for both scales. The intraclass correlations for both measures were calculated using the intraclass correlation coefficient developed by Ebel (1951)[9]

$$\mathrm{ICC} = \frac{\mathrm{MS_{btwn}} - \mathrm{MS_{with}}}{\mathrm{MS_{btwn}} + k(\mathrm{MS_{with}})} \tag{1}$$

To determine the reliability x resulting from m raters, the following is used:

$$x = \frac{m(\mathrm{ICC})}{1 - \mathrm{ICC} + m(\mathrm{ICC})} \tag{2}$$

The reliability for both the PEF and PFI was very similar and high (Table 5), measuring 0.95 when 3 raters are used (at least 3 raters were used for each neighborhood). This is considerably higher than values typically used to validate a rating scale.[10] This result supports the use of this field rating procedure as long as multiple raters

[9] MS = mean square = SS/df, where SS is sum of squared error and df is degrees of freedom.
[10] A value over .7 is generally considered acceptable for most applications. See Nunnally (1978).

Table 6
Coefficients of variation for 20-block face sample size

Neighborhood	CoV	Measure	CoV
Evanston (140)	18.6	Sidewalk coverage	8.7
Lake-Cook Road (65)	14.1	Adjacent parking ratio	17.8
Loyola Medical Center (86)	20.5	Average setback	14
Schaumburg (119)	4.9		
Woodfield Mall (39)	9.4		

CoV – Coefficient of variation, ( ) indicate total number of block faces.

are used. More importantly, it suggests that the results of the field data collection are sufficiently reliable to use as dependent variables describing the pedestrian environment.

Although the two field indices have a correlation of 0.91, they differ in important ways – Fig. 2.[11] The PEF has relatively few categories and does not measure aspects of the built environment other than the street network. Due to the nature of the rating system, a neighborhood with a grid network and sidewalks on every street would almost necessarily score at least a 10. The PFI, however, considers neighborhoods in more dimensions, including land-use and building type, thus making it more difficult for a neighborhood to obtain a near-perfect score. The PEF can thus be thought of as a pedestrian impedance measure, while the PFI also reflects the likelihood of satisfying a trip purpose through walking. Thus, the preferred field rating may change depending on what is to be measured.

2.6. Data analysis

The analysis of the laboratory data focused on developing indices that correlate well with the field data. Correlations between laboratory and field data were analyzed to identify relationships that were then used to develop linear regression models describing the pedestrian environment. Two different combined indices were developed, one using the PEF as the dependent variable and the other using the PFI. Numerous models were tested for each index and compared to identify the strongest relationships.

3. Determining block face sample size

At the measured, laboratory data collection rate of approximately 1 block face every 90 s, collecting full data for a single neighborhood could take upwards of 3 h. Therefore, it would be preferable to gather data from only a sample of block faces from each neighborhood. To determine a sample size that balanced collection time with the need for accurate data, measurements were taken for all block faces in 5 of the neighborhoods. These neighborhoods show significant variability both in their overall characteristics and in their internal homogeneity.

Ten different random block face samples were taken for each of several different sample sizes in each of the 5 neighborhoods. Samples were drawn from the pool of census road segments (excluding freeway segments), with each road segment weighted according to its length. The number of total block faces in each neighborhood varied from 39 surrounding Woodfield Mall to 140 in Evanston. Because the expected value of a sample is equal to the population mean regardless of the sample size, the analysis focused on the variability of individual samples.

Based on this analysis, the decision was made to collect data for a sample of 20 block faces for the other neighborhoods. Table 6 shows the coefficients of variation for each neighborhood and measure using a sample size of 20 block faces.[12] Using a sample size of 20 keeps the coefficient of variation under 20 for all measurements and all but one neighborhood (Loyola Medical) and meant that a neighborhood could be characterized in approximately 30 min.

[11] LUTRAQ ratings are standardized to a 0–1 scale for comparison in Fig. 2.

[12] The coefficient of variations is defined as the ratio of the Standard Deviation to the Mean multiplied by 100.

Table 7
Descriptive statistics for laboratory collected data

	Minimum	Maximum	Mean	Std. deviation
Block length (ft)	278	1045	505.3	203.6
Standard deviation (ft)	106	731	333.0	182.7
4-way Density	2	207	72.0	60.9
4-way Ratio	0.05	0.85	0.5	0.3
Sidewalk coverage	0.02	2	1.5	0.6
Parking ratio	0	0.89	0.2	0.2
Average setback (ft)	8	201	45.9	44.9
Census block density	4	61	27.1	16.7

Table 8
Correlations between variables

	LUTRAQ	Census bl. dens.	Block length	St. dev. length	4-way Density	4-way Ratio	Sidewalk ratio	Parking ratio	Setback
MNCPPC	0.913	0.916	−0.727	−0.886	0.873	0.815	0.858	−0.323	−0.742
LUTRAQ	1	0.864	−0.65	−0.828	0.875	0.879	0.909	−0.404	−0.739
Census block dens		1	−0.666	−0.787	0.941	0.817	0.767	0.308	−0.684
Block length			1	0.902	−0.559	−0.465	−0.72	0.411	0.806
St. dev. length				1	−0.746	−0.681	−0.862	0.507	0.777
4-way density					1	0.893	0.764	−0.349	−0.622
4-Way Ratio						1	0.748	−0.258	−0.583
Sidewalk ratio							1	−0.405	−0.646
Parking Ratio								1	0.353
Setback									1

4. Remote data collection results and analysis

4.1. Correlations

Table 7 shows summary statistics for the laboratory-collected variables.[13] The data vary widely and show good coverage of the possible values. Table 8 shows the correlations between each of the 8 variables and the 2 field-rating measurements. The correlations between most of the variables are significant, showing a high degree of covariance between many of the variables, and all of the signs are as expected. Among the correlations between the remotely collected variables, the correlations between Block Length and St. Dev. Block Length, between 4-way Density and Census Block Density and between 4-way Density and 4-way Ratio, stand out as being particularly high. Additionally, the correlations between both the PEF and PFI and St. Dev. Block Length are higher than for Block Length. This corroborates the theoretical reasons for using St. Dev. Block Length.

With the exception of Parking Ratio, the correlations between the field ratings and the laboratory data are high and very similar, with significance levels of 0.01 or greater. The correlations between the field ratings and Parking Ratio are not significant, however. This is because, while neighborhoods with high Parking Ratios (Woodfield Mall, Niles and Lake-Cook Rd.) generally scored poorly in the field ratings, several auto-oriented residential neighborhoods with very low Parking Ratio also scored poorly in the field ratings (South Barrington and Schaumburg especially).

Thus, while high parking ratios imply a poor pedestrian environment, the lack of parking lots may also be a feature of poor pedestrian environments in predominantly residential areas. Effective use of Parking Ratio in the combined index may be possible as a dichotomous variable taking a unitary value if parking ratio is

[13] In the case of the 5 neighborhoods where data was collected for all block faces, data from the first sample of 20 block faces were used for analysis rather than the full data.

Table 9
Regression models with PFI as dependent variable

Variable		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6[a]
Constant	Coefficient	0.311	0.170	0.312	0.342	0.253	0.270
	t-value	1.9	1.2	1.8	1.9	1.6	1.7
St. dev. block length		−0.000521		−0.000546	−0.00052	−0.00043	−0.00046
		−2.2		−1.3	−2.1	−1.9	−2.0
Block length			−0.000260	0.000020			
			−1.7	0.1			
Census-block density						0.00692	0.00501
						2.7	1.7
4-way Density					0.001148		
					1.6		
4-way Ratio		0.268	0.313	0.265			0.153
		2.3	2.5	2.1			1.2
Sidewalk Ratio		0.0862	0.128	0.086	0.108	0.101	0.0772
		1.3	2.1	1.2	1.5	1.7	1.2
$(\text{Setback})^{-1}$		3.26	3.68	3.25	2.6	1.733	1.96
		3.4	3.8	3.3	2.0	1.4	1.6
SSR		1.790	1.775	1.790	1.769	1.801	1.811
SSE		0.150	0.165	0.150	0.171	0.139	0.129
R^2		0.923	0.915	0.923	0.912	0.928	0.934
Adjusted R^2		0.906	0.896	0.900	0.892	0.912	0.914

[a] Indicates preferred model.

Table 10
Linear regression models with PEF as dependent variable

Variable		Model 1[a]	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	Coefficient	1.816	3.256	1.863	1.733	1.691	1.822
	t-value	3.9	4.3	1.5	1.1	3.0	3.8
Block length				−0.00006			
				−0.04			
St. dev. block length					−0.0001		
					−0.1		
4-way Ratio		4.500	4.808	4.515	4.502	5.053	4.364
		4.2	4.6	3.9	4.0	2.9	3.3
4-way Density						−0.00928	
Census block density							0.0061
							0.2
Sidewalk ratio		2.448	2.353	2.435	2.472	2.473	2.422
		5.4	5.1	4.2	3.8	5.3	5.0
Setback			−0.0135				
			−2.5				
$(\text{Setback})^{-1}$		19.935		19.83	20.14	23.390	18.228
		2.4		2.2	2.2	1.9	1.5
SSR		205.091	205.292	205.092	205.093	205.220	205.123
SSE		14.139	13.938	14.138	14.137	14.010	14.107
R^2		0.936	0.936	0.936	0.936	0.936	0.936
Adjusted R^2		0.925	0.926	0.921	0.921	0.922	0.921

[a] Indicates preferred model.

greater than a predefined limit, or by segregating commercial from non-commercial neighborhoods. However, the sample size here is not sufficient to test this hypothesis adequately. Consequently, Parking Ratio was not used in the development of a combined index. A better indicator seems to be setbacks, which are high in areas with high Parking Ratios and are also generally high in auto-oriented residential developments such as South Barrington.

Table 11
Single-variable linear regression models

Variable		PFI model	PEF model
Constant	Coefficient	0.079	1.679
	t-value	1.6	2.3
Census block density		0.016	
		10.5	
Sidewalk ratio			4.465
			10.0
SSR		1.630	180.96
SSE		0.311	38.27
R^2		0.840	0.825
Adjusted R^2		0.832	0.817

4.2. Developing a combined index

Separate indices were developed to fit the PEF and the PFI (Tables 9 and 10). Because of the multicollinearity between the field indices and the laboratory variables, several good regression models emerge. The tables show *t*-values for each coefficient as well as the R^2 and adjusted R^2 values for each model as a whole.

Table 9 shows several PFI models with very high goodness-of-fit measures. Models 1–3 show the effect of using St. Dev. Block Length, Block Length, or both. Model 1, with St. Dev. Block Length has better goodness-of-fit statistics than Model 2. This, along with the conceptual advantages to using the standard deviation of Block Length rather than the mean, leads to the selection of Model 1 over Model 2. Model 3, where Block Length and St. Dev. Block Length are both used, gives a negative coefficient for Block Length, contrary to theory, and does not improve significantly on the fit of Model 1, and is therefore rejected.

Models 4, 5, and 6 examine the use of different measures for network density. Model 5, with Census Block Density rather than 4-way ratio outperforms Model 1. However, the highest goodness-of-fit is provided by Model 6, which uses both 4-way Ratio and Census Block Density. While an *F*-test comparing the restricted Model 5 to Model 6 fails to reject the former, the adjusted R^2 for Model 6 is higher and the signs of all coefficients correspond to expectations. Therefore, Model 6 is the preferred model for the PFI.

Table 10 shows several PEF models with high goodness of fit measures. Models 1 and 2 test the effect of using Setback versus $(\text{Setback})^{-1}$. Both have similar goodness-of-fit measures, with Model 2 performing slightly better. However, Model 1 is chosen over 2 because $(\text{Setback})^{-1}$ has conceptual advantages over Setback outweighing the small statistical differences between the models. Models 3–6 each add an additional measure of network characteristics to the base specification. However, none of these models improves significantly on the fit of Model 1; the adjusted R^2 is lower in each case. Thus, Model 1 is preferred to represent the PEF data.

In practical terms, where resources for data collection are limited, using an index with only one variable may provide a viable alternative to the multi-variable indexes. The best-fitting single-variable indexes are shown in Table 11 for both the PEF and PFI. The PFI index uses Census Block Density, while the PEF index uses Sidewalk Ratio.

Table 11 shows that both single-variable models have high an adjusted R^2 values indicating high explanatory power using only one variable. The ability of these simplified models to characterize proposed designs is substantially restricted, as it would be easy to trick the index into giving a good rating by focusing on one design element at the expense of all others. Another drawback to a single-variable index is the inability to distinguish adequately between different neighborhoods. For instance, 11 of the 23 neighborhoods have a measured Sidewalk Ratio greater than 1.9 out of 2.0. An index using only Sidewalk Ratio would give these neighborhoods similar scores despite significant differences in the surveyed pedestrian friendliness (the average PEF for these 11 sites ranged from 7.75 to 12).

5. Conclusions

This study demonstrates that laboratory collected variables can be used to create pedestrian environment indices that accurately reflect the field ratings on which they are based at a fraction of the cost of collecting data in the field. Several variables describing specific elements of the urban pedestrian environment are identified, for which data are relatively easy to collect, that can provide a good substitute for several generally accepted and judgment-based indices that require expensive, field data collection. Of particular value is the fact that the laboratory measures developed here can be used to assess proposed designs, unlike the field indices.

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