Original Article

Using GIS to analyze the role of barriers and facilitators to walking in children's travel to school

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Abstract Extensive research in response to the decline of walkability in the past 30 years has identified a multitude of factors that affect children's ability to work or bicycle to school. Among others, urban form – the layout and configurations of urban blocks and street networks - can constraint or facilitate pedestrian travel to a destination such as a school. Although contemporary research uses approximate measures of walkability such as straight-line distance between origin and destination, or even measures of distances along roadway networks, the presence of physical barriers and facilitators to walking calls for a more accurate method for assessing walkability as a function of distance dictated by constraints of urban form. Modern technologies like Geographic Information Systems (GIS) offer capabilities to enable calculation of such measures. This article presents a GIS methodology that analyzes children travel to school as a function of distance along the network and the role of barriers and facilitators that impact the path and the accessibility to school. The study is conducted in 32 randomly selected elementary schools in four Florida counties. Three pedestrian sheds of 1/2 mile (10 minutes walk) are generated around each school based respectively on (a) straight-line distance, (b) roadway network distance and (c) pedestrian network distance adjusted for *barriers* such as major roads, and lack of sidewalks and *facilitators* such as pedestrian paths, crossing guards and rear entrances to school. The pedestrian sheds are compared based on two measures: (1) pedestrian route directness (PRD) – an index that measures urban form permeability and connectivity and (2) the student count in each shed – a measure that indicates how effectively the pedestrian shed captures potential students along these networks. Results show that the pedestrian shed decreases in size upon considering network distance over straight-line distance, and readjusts upon consideration of barriers and facilitators. PRD values decrease as the pedestrian shed is adjusted which indicates shorter, more direct paths to schools are available. Findings suggest that inclusion of barriers and facilitators when measuring distance along the network offers a more realistic version of the true distance a child could potentially walk to school. The study found that barriers and facilitators play critical roles in how the urban landscape can be traversed and, in turn, greatly affect walkability and accessibility to school. Barriers can reduce walkability and accessibility to school whereas facilitators can increase the permeability and connectivity of pedestrian networks. In addition to improving walkability measurement methods by enhancing the GIS network analysis to include barriers and facilitators, this research has broader implications for the study of walkability as it relates to urban form. The findings can be used by local governments to develop better policies to promote close coordination of school siting with residential development and transportation. These findings can also inform the urban design of the layout and configuration of street networks, urban blocks and placement of buildings to support safe pedestrian circulation with good permeability connectivity and accessibility throughout the neighborhood. Especially, findings from this study emphasize the importance of designing for connected pedestrian paths that minimize barriers and maximize facilitators.
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Introduction

Cities have historically been recognized as places for people to come together to enjoy the benefits of company, commerce and mutual defense (Frumkin *et al*, 2004). With the advent of the automobile, however, the focus on connecting people with places has progressively diminished.

Places that once provided safe and equitable travel by foot are now dominated by disconnected land uses and hazardous travel conditions. The urban landscape is threatened by ever-encroaching suburbia, an environment well-suited to the automobile. For the pedestrian, the typical suburban environment severely limits accessibility, making it difficult to get from place to place on foot.

One manifestation of such difficulty is an increasingly overweight American population, including children and adolescents. Overweight and obesity are particularly risky for children and adolescents as they may experience immediate health consequences with a greater risk for weight-related health problems later in adulthood (Serdula *et al*, 1993), including cardiovascular disease, diabetes (Fagot-Campagna *et al*, 2000; Hannon *et al*, 2005), psychosocial illnesses (Dietz, 1998; Strauss *et al*, 2001) and a host of other chronic disorders. One solution is to increase the amount of physical activity in which children participate. Walking to school represents an opportunity for children to engage in physical activity, an opportunity fewer and fewer children have participated in over the past half-century. In 2003, the US Environmental Protection Agency reported a decline in the number of students who walked and bicycled to school from 48 per cent in 1969 to 15 per cent in 2001 (Ewing and Greene, 2003). This trend was also projected in a 'Home-to-School Transportation' study conducted by the Florida Department of Transportation in 1992 that estimated that only one out of six children in Florida walk or bicycle to school while the rest are transported by bus or private motor vehicle (Starnes *et al*, 1992).

The decline in walkability generally, and in children's travel to school specifically, has prompted extensive research around the world to understand and address it. Such research has indentified a multitude of factors that affect children's ability to walk to school, including physical characteristics of urban built environment. One of the many factors affecting walkability that is related to the physical built environment is the travel distance. The travel distance is commonly measured by using straight-line distance between origin and destinations. Although this measurement method has its applicability, there is a need to use proper measures of walking distance that reflect physical arrangements of built environment. In reality, travel distance is a function of travel paths which in turn are dictated by urban form. The configuration and layout of urban landscape – consisting mainly of urban blocks, and the street network – does constraint accessibility to a destination such as a school. Permeability of urban form and street layout and connectivity can reduce or increase the opportunities for pedestrian travel to such destinations. Therefore, for a more accurate assessment of walkability, it is important to measure the more accurate distance traveled along the network while accounting for barriers and facilitators of pedestrian travel. Modern technologies like geographic information systems (GIS) offer capabilities to enable calculation of such measures.

This article presents a GIS methodology that analyzes children travel to school as a function of the distance along the network and the role of barriers and facilitators that impact the distance and the accessibility to school. Although the study is focused on travel to school, the methodology and the findings have broader implications for walkability research as it relates to urban form. It is recognized that the distance is not the only factor that affect walkability. A review of additional factors is presented below; however, they are not implemented in the scope of this particular study.

Background

Physical inactivity has been found to have deleterious effects on the health of children and adolescents (Slater *et al*, 2008). Many children do not engage in enough physical activity to meet the recommendations required to maintain a healthy weight that supports healthy lifestyles (Dellinger and Staunton, 2002). Understanding physical activity behaviors among children and adolescents is complex. Sallis *et al* (2000) reveal that there are a multitude of factors that can influence physical activity behaviors among children and adolescents such as sex differences (male or female), parental overweight status, previous physical activity and perceived activity competence to name a few. Additionally, some children lack physical activity because of parental perceptions concerning safety of the outdoor environment (Valentine and McKendrick, 1997). Children are spending more time indoors, participating in less-physically active alternatives, such as watching television and playing videogames (Robinson, 1999). Furthermore, studies show that more and more children are being driven to school than ever before, negating the opportunities for them to be physically active (Freeman and Quigg, 2009). One of many recommended solutions to help reduce the prevalence of childhood obesity is to increase opportunities for children to walk or bicycle to school. Walking and bicycling to school are utilitarian travel opportunities that provide underlying physical activity for children (Ziviani *et al*, 2004).

Because streets accommodate most forms of travel, their importance serves as a central focus in understanding patterns of walkability. Traditionally, in the United States, streets were laid in gridiron patterns. However, over time the grid pattern became more chaotic consisting of 'loops and lollipops', subsequently converting straight-line distances into journeys of considerable length (Southworth and Owens, 1993; Southworth and Ben-Joseph, 2003). The circuitous nature of looping roadways was strategically aimed at reducing the number of automobile thorough-fares, focused on making residential streets safer for the pedestrian. Conventional street designs have had adverse affects resulting in reduced connectivity, an increase in vehicle miles traveled, increased traffic conditions, and a host of other public nuisances and health-related issues (Frumkin *et al*, 2004). For many of these reasons, walking and bicycling to school are not always feasible or attractive options for many families.

Decisions concerning children's travel to school are contingent upon many factors. Physical-environmental factors influencing decisions include proximity (or distance between home and school) and presence and condition of sidewalks and pathways. Additional factors that also play critical roles include neighborhood and traffic safety, socio-demographics, household transportation options, social/cultural norms, policies, and parental attitudes and personal choice (McMillan, 2006; Kerr *et al*, 2006; Ridgewell *et al*, 2009). Safety concerns or the lack of sense of security play substantial roles in the decision process. These include social-environmental influences, such as real and perceived crime and other undesirable activities like the presence of drug dealers, bullies, and of recent the perception of pedophiles (Tewksbury and Mustaine, 2006). Gender differences may also play a role. One study shows that boys are more likely to be allowed to walk or bicycle to school than are girls (McMillan *et al*, 2006). Ultimately parents make the decision on whether or not a child is allowed to walk or bicycle to school. Interestingly, children sometimes garner a different perception of the environment between home and school and if given the opportunity would rather walk or bicycle to school (Mitchell *et al*, 2007).

Although the literature conveys the psychological influences to walking (Ziviani *et al*, 2006), it also identifies methods of encouraging children to actively travel to school, through programs like Federal Safe Routes to Schools (FHWA, 2010), CDC's KidsWalk-to-School,[1] and walking school buses[2] (Collins and Kearns, 2005). These programs are designed to encourage children to engage in active travel to school and can help develop environments that are safer for children while building a stronger sense of community (Tranter and Pawson, 2001). However, many programs and initiatives focus only on safety rather than distance as a primary barrier to walking to school (McDonald, 2007). Distance between the school and residence is one of the important factors for a child who either walks him/herself to school or is escorted by a parent.

Measures of urban form impacting walkability

One determinant of travel through urban space is physical proximity. The literature shows that on average, an acceptable distance for pedestrian and transit-friendly travel can be distinguished by a 5- to (maximum) 10-min walk, which is approximately one-quarter to one-half of a mile (Ewing, 1999). Understanding distance as one of the determinants in travel behaviors is vitally important, especially in addressing opportunities for children to actively travel to school. Schlossberg *et al* (2006) conducted a study to understand urban form and children's travel to school and found that the farther a child lived from a school, the less likely he or she was to walk or bicycle there. However, the findings also revealed there are circumstances that students are willing to walk at distances greater than the expected (Schlossberg *et al*, 2006). Another study found similar results of increased numbers of students walking or bicycling from school to home, with positive associations linked to several environmental factors including higher land use mix, the presence of street trees and shorter trip length (Larsen *et al*, 2009). Although distance – as a surrogate in understanding the impacts of urban form on walkability – is a primary focus in this article, it is recognized that it is not the sole factor influencing children's mode choice in travelling to school.

There are two groups of measures of pedestrian travel in the context of the physical environment: general walkability and origin-destination walkability. General walkability measures are used to characterize urban form of neighborhoods by a set of indices computed based on physical characteristics such as for instance urban block length and size. Smaller block sizes or shorter block lengths indicate better connectivity or greater potential for movement through space (Dill, 2004). Another measure is street and intersection density. A greater number of streets or intersections within an area would mean greater connectivity yielding a higher rate of walkability (Frank *et al*, 2005). One of the limitations of calculating walkability using these types of measures is that they are not destination driven. They provide generalized approximations of walkability and are used to rank geographic areas (neighborhoods or communities) on the walkability potential.

The second group of measures concentrates on origin-destination walkability. They focus on measuring the walkable distance in a straight line between the origin and destination or along the walkable network. Measuring the distance between two points along a network provides a more accurate assessment of walkability. A common measure in this category is pedestrian route directness (PRD) (Dill, 2004). PRD is the ratio of the network distance to the straight line. A ratio approaching a value of one signifies that the distance travelled along the roadway network approximates the straight-line distance, indicating a more direct route. A ratio of 1.2 indicates that the distance travelled along the roadway network is 20 per cent longer than the straight-line distance from origin to destination.

Another measure related to the origin-destination walkability is residential density. Concentrations of residential dwellings in proximity to desired locations provide an indication of the potential for individuals to travel between home and a destination. This is particularly useful in evaluating home-to-school connections (City of Raleigh, North Carolina, 2008). See Table 1 for a summary of the common measures of walkability presented here. For more detail description of these and additional measures of walkability, see Dill (2004).

In origin-destination measures of walkability, such as children's travel between home and school, careful consideration should be given to the components of the urban form that can further reduce or enhance opportunities for safe pedestrian travel. Common barriers that may reduce walkability between home and school could include hazardous walking conditions like inadequate sidewalks, high speed and volume of traffic, fences or walls, and the absence of crossing

Table 1: Common measures of walkability

Measure	*Description*	*Ideal values*
Block length	Blocks are the land area carved out by the street network. It is presumed that shorter the block, the greater amount of connectivity	300 to 600 feet (Dill, 2004)
Block size	Measured by the length and the width, blocks that are smaller in total size presumably infer better connectivity	Fort Collins, Colorado requires block sizes to be between 7 and 12 acres (Steiner *et al*, 2006)
Street density	The total linear miles (or kilometers) of streets per unit of area (usually in square miles or kilometers)	Not identified
Intersection density	The number of intersections per unit of area (usually in square miles or kilometers). It is presumed that higher density equates to higher connectivity	Over 78 intersections per square mile (Frank *et al*, 2005)
Pedestrian route directness (PRD)	The ratio of network distance to straight-line distance for two selected points. Numbers closer to one may represent better connectivity	Values between 1.2 and 1.5 have been recommended as acceptable standards (Dill, 2004)
Residential density	The total number of dwelling units (or parcels) per unit of area (usually in square miles or kilometers)	Schools located in neighborhoods containing 5 dwelling units per acre (City of Raleigh, NC, 2008)

guards[3] to facilitate the safe crossing of the street (Dellinger and Staunton, 2002). In contrast, facilitators that can enhance opportunities for walking could include trails and other informal pathways, rear entrances to school grounds and the employment of crossing guards at hazardous street intersections.

In summary, there are many measures that can be used to analyze walking environments. To this end, it is important to note that there is no single, all-purpose measure that can tell the entire story.

Using GIS to measure walkability

GIS is essential in better understanding the complexities of the pedestrian travel environment. Although a straight-line distance between two points can be measured easily, the measurement of distances along a network is much more complex. GIS has the capability to assist in development of such measures using a tool called network analysis. Given an origin (for example, location of a student residence) and a destination (for example, location of a school), GIS can determine the shortest path between these two points along the street network and it can compute the distance of that path. In addition, using network analysis tools, GIS can determine a catchment area that includes all the residential parcels that are within a certain network distance from the school. Both the shortest path and the catchment areas are spatial complex calculations that can be easily computed in GIS.

A critical factor in measuring walkability when considering distances along a network is the role of barriers and facilitators. Network distance can be calculated along the street network; however, children may take a shorter distance to school if they can take an informal path or they can cross a major roadway with the assistance of a crossing guard. The school can reduce the distance that some children travel to school by allowing access to the school in locations closer to residences. By taking into account these factors, GIS can modify the shortest paths and the catchment areas, provided that the GIS street network is adjusted to reflect the presence or absence of these barriers and facilitators.

This research makes extensive use of GIS network analysis to develop measures of children's travel to school in the presence of barriers and facilitators.

Method

The intent of this study is to examine the role that barriers and facilitators play in children's travel to school. The study takes a cross-sectional research approach and uses case studies of elementary schools in four central Florida school districts[4] in the Tampa Bay and Orlando areas. These school districts – Orange, Seminole, Pasco and Hillsborough – were chosen because they have large populations ($>$400 000 in 2006), high rates of enrollment ($>$30 000 in 2005–2006 with $>$20 per cent student enrollment growth from 2000 to 2005), and contain at least 30 elementary schools representing a range of time periods in which schools were constructed.

Thirty-two randomly selected elementary schools were chosen. The general study boundary around each of these schools used for data collection was determined by a combination of a two-miles buffer area around each school and the School Attendance Zones (SAZs). The areas outside the two-mile buffer are excluded from the study because the State of Florida provides funding for school districts to bus children who live more than two miles from the school. The two-mile general area is further constraints by SAZs which are legislative boundaries established to determine which children are assigned to a specific school. The SAZs vary in size and shape across the school district depending upon the density of children in the residential neighborhood surrounding each school. For schools that are located outside of the center of their SAZ, this boundary may present a barrier to children walking because children may go to a school that is a greater distance from their home to which they may not be willing to walk or bicycle.

Data compilation

Data were collected, compiled and analyzed using GIS, interviews with school principals or their designees and field work.

GIS data layers assembled for this study include high resolution aerial photographs, school attendance boundaries, school point locations, roadway network, property parcels and de-identified[5] student residential locations. These data were obtained from various sources including the Florida Geographic Data Library, Florida county property appraiser's offices, the Florida Department of Revenue and four school districts.

The location of hazardous walking conditions was mapped in GIS using a list provided by the Florida Department of Education. The student residential location was originally mapped using GIS geocoding that converts home addresses to GIS point locations.

Interviews were conducted at all of the selected schools. Each principal, or their designee were asked about how students traveled to and from school, safety risks for students who choose to walk or bicycle to school, locations of crossing guards, and access control points around the school site. School officials also identified both formal and informal access points onto school grounds.

Field audit was performed on the school site and in the neighborhood. Using the aerial photography and the information gathered in the interviews, the locations of access points to the school site were mapped. Formal and informal off-road paths to school connected to the access points were also mapped. These paths were followed until they entered a neighborhood or were at least one-mile walking distance from the school's access points. Additional data collected through field audits included locations of crossing guards and sidewalks. A pedestrian network including location of barriers and facilitators was created and the GIS base layer was updated based on the field observations. All field data were mapped digitally and were added to the GIS database for further analyses.

Focus analysis areas and measures

The analysis was focused within areas located one-half mile around each school site. This distance corresponds to a maximum 10-min walk based on the literature referenced previously in this article. This distance represents a reasonable trip-length for most students to walk to elementary schools.

Using this distance, the neighborhoods around each school were analyzed based on three potential walkability areas generated using GIS. These areas hereafter are referred to as 'pedestrian sheds' and are labeled by numerals 1, 2 and 3 (Figure 1). The first shed, referred as 'potential walkability', was generated by creating one-half mile buffers around each elementary school using a straight-line distance. This area of walkability provides only a generalized approximation for potential walkability, while ignoring all other factors. The buffers were created using GIS standard buffering tools. The second shed, 'potential walkability adjusted to network distance', depicts the one-half mile pedestrian shed as measured along the roadway network. The third shed, 'potential walkability adjusted for barriers and facilitators', depicts the one-half mile pedestrian shed distance as measured along the network and adjusted based on the presence of barriers and facilitators to walking in the 32 randomly selected elementary schools. Both sheds 2 and 3 were generated using GIS network analysis tools that have capabilities to create catchment or 'service' areas for a given destination (the school) based on the desired distance from the destination along a linear network. Finally, all three sheds were further adjusted by the SAZ boundaries that would reduce the size of each shed for those schools located close to the edges of the zone.

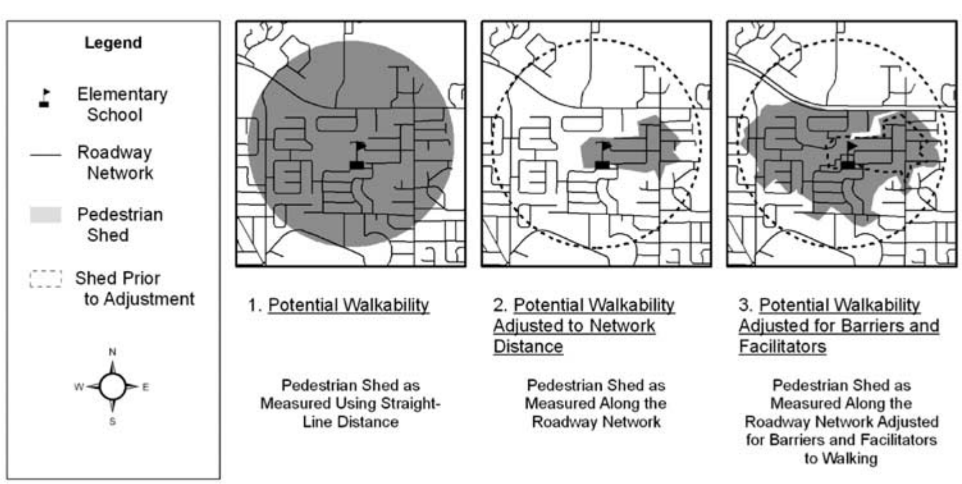

Figure 1: Generation of pedestrian sheds.

In Figure 1, which conceptually illustrates the generation of the pedestrian sheds, it may be noted that the shed in image 2 is smaller than the shed in image 3. This is because of poor connectivity of the roadway network that has not been adjusted by any facilitators. In image 3, the dashed line inside the dark area shows the pedestrian pathways (facilitators) which expand the connected pedestrian network. The case of shed adjustment (potential reduction) from barriers to walkability is not illustrated in this figure; however, one of the cases in the article illustrates this situation.

Two measures – PRD and student count – are the focus of the analysis within these pedestrian sheds. An examination of PRD for a pedestrian shed can shed light on the configuration and characteristics of the roadway network and other formal and informal pathways. Student count, a measure of the number of students residing within the pedestrian shed, indicates how effectively the pedestrian shed captures potential pedestrians, or students along these networks.

Results

Table 2 summarizes the results. For all school districts, PRD values decrease as the pedestrian shed is adjusted. Decreasing values indicate that as the pedestrian shed is adjusted to the roadway network and to barriers and facilitators, PRD increases, that is, shorter, more direct paths to schools are available. Orange and Seminole Counties, which have had policies to coordinate school siting with residential development, have the highest number of children in close proximity to schools overall. In contrast, the Tampa Bay area counties – Hillsborough and Pasco Counties have lower student counts. In all but Hillsborough County, the student count increases upon adjusting the network pedestrian shed to account for barriers and facilitators to walking. The increased student count suggests that for schools in these counties, facilitators are in place to enhance the pedestrian environment. This is particularly true of Seminole County, which shows the highest rate of increase and has back entrances to schools that connect to the surrounding cul-de-sac neighborhoods. In contrast, in Hillsborough County, the drop of student counts in the pedestrian shed, which includes barriers and facilitators (shed #3), compared to the network distance shed (shed #2) indicates that the pedestrian network shed has more barriers and hazardous walking conditions than the other three counties.

Overall, the data summarized in Table 2 indicate that using GIS to account for distance along the roadway network and barriers and facilitators to walking results in a more refined representation of walkability than does simply measuring walking distance along a straight-line or even along the roadway network. To further understand this difference and illustrate the findings, it is helpful to examine three selected schools – Bear Lake Elementary in Seminole County, Pineloch Elementary in Orange County and Seven Springs Elementary in Pasco County. Table 3 lists the pedestrian shed size, the PRD value and the student count for the three pedestrian sheds corresponding to each school. Figure 2 illustrates these pedestrian sheds for each school.

Bear Lake Elementary is situated in a neighborhood with an eroding grid street pattern. Upon

Table 2: Average pedestrian route directness and student count for schools in sample of four counties in Tampa Bay and Orlando areas

Corresponding pedestrian shed[a,b]	*Pedestrian route directness (avg.)*			*Student count (avg.)*		
	1	*2*	*3*	*1*	*2*	*3*
Orange County schools	2.08	1.82	1.63	216.27	44.09	66.73
Seminole County schools	2.30	1.79	1.44	232.50	57.25	98.5
Pasco County schools	2.06	1.96	1.45	147.34	30.67	62.5
Hillsborough County schools	2.24	1.68	1.37	156	68.07	59.07

[a]Pedestrian shed numbering corresponds to methodological steps: (1) Calculated using straight-line distance; (2) Adjusted based on distance along the roadway network and school attendance zone boundaries; (3) Adjusted based on barriers and facilitators to walking.
[b]This table takes into account a sample of 32 schools randomly selected across the four counties, as determining the location of barriers and facilitators to walking required field-work and interviews.

Table 3: Examination of three selected schools

Corresponding pedestrian shed[a]	*Pedestrian shed size (sq. miles)*			*Pedestrian route directness*			*Student count*		
	1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Bear Lake Elementary	0.50	0.08	0.36	3.32	1.94	1.39	203	21	122
Pineloch Elementary	0.50	0.24	0.18	1.51	1.35	1.36	221	34	27
Seven Springs Elementary	0.50	0.10	0.18	2.03	1.79	1.66	190	15	39

[a]Pedestrian shed numbering corresponds to methodological steps: (1) Calculated using straight-line distance; (2) Adjusted based on distance along the roadway network and school attendance zone boundaries; (3) Adjusted based on barriers and facilitators to walking.

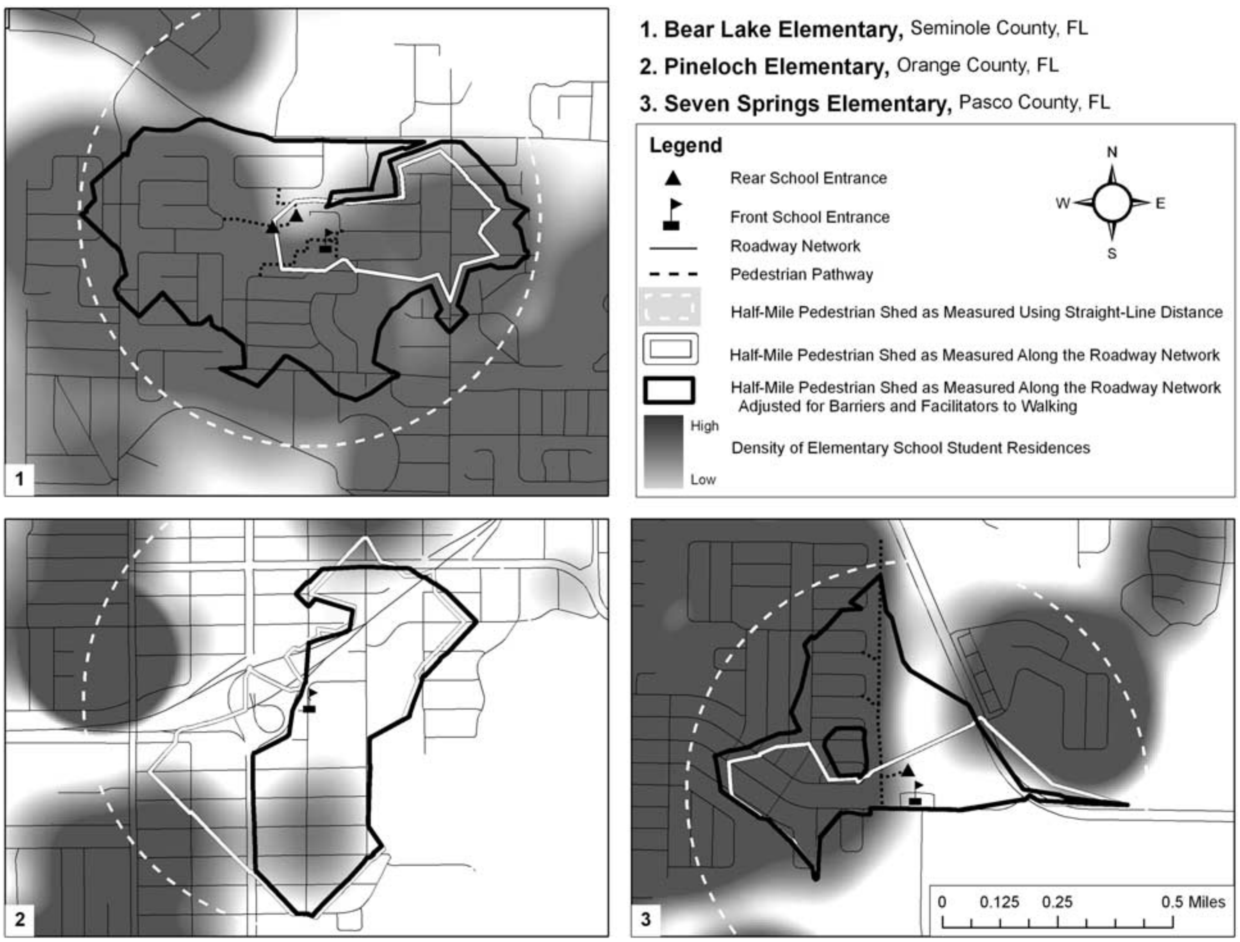

Figure 2: Pedestrian sheds for three selected schools.

adjusting the straight-line pedestrian shed (shed #1 shown in circular white dashed line) to account for network distance, several disconnected cul-de-sacs cause a drop in the shed's size from 0.5 square miles for shed #1 to less than one-tenth of a square mile for shed #2 shown in solid white line. Two formalized pedestrian paths connect these cul-de-sacs to rear school entrances. After adjusting for these facilitators the shed size rebounds to 0.36 square miles (shed #3 shown in solid thick black line). The pedestrian paths contribute to decreased PRD values (reflecting more direct routes) and the capture of an additional 100 students within the shed.

Pineloch Elementary represents an opposing scenario. A major high speed limited access freeway (Interstate 4) running diagonally in the north-east to south west side of the school bisects the SAZ. However an underpass to the northeast of the school allows access for some students living on the north side past the interstate road which explains the expansion of sheds #2 and #3 past the interstate on the north side. The interstate generates substantial traffic on a major north-south roadway intersecting the neighborhood south of the school. Although the underpass facilitates walking accessibility, the north-south arterial acts as a barrier to walking. Unlike the case of Bear Lake in which the pedestrian shed size increases upon accounting for barriers and facilitators to walking, the proximity of the major arterial in the case of Pineloch causes a decrease in pedestrian shed size from 0.24 square miles to 0.18 square miles, capturing seven fewer students.

Seven Springs Elementary is located adjacent to a neighborhood with a curvilinear street pattern and several cul-de-sacs. Only 15 students are captured within the pedestrian shed as measured along the roadway network (shed #2 shown in solid white line) without accounting for barriers and facilitators. As in the case of Bear Lake, however, pedestrian paths exist, linking cul-de-sacs to a rear school entrance. Unlike Bear Lake's formal pathways, the pathways near Seven Springs are informal, yet they produce similar results. Upon accounting for the pathways, the pedestrian shed size increases from 0.10 square miles (shed #2) to 0.18 (shed #3), and an additional 24 students fall within the pedestrian shed. The importance of direct routes is illustrated by the small island of students living directly to the northwest of Seven Springs (small donut hole shown in black solid line). These students live in close proximity to the school, but no direct route exists between their cul-de-sacs and the school, resulting in a lack of accessibility.

Summary of Findings

Findings emerging from this detailed analysis include:

- *Major roadways can be common barriers to walking; however, the barrier may be mitigated by careful placement of SAZ boundaries and/or the presence of a school crossing guard*. A major roadway bisects the pedestrian sheds of all three schools. In the case of Bear Lake, the SAZ boundary runs along the major road, negating the barrier as students living across the road are zoned to another school. A crossing guard may also negate a major road's impact on accessibility, as in the case of Seven Springs where a crossing guard is positioned at the intersection of a major road just east of the school.
- *Formal and informal pedestrian pathways may increase the size of the pedestrian shed, capturing more students. The travel can be shortened by creating a more direct path from a disconnected street grid or by creating additional entrances to the school*. Pedestrian pathways present at both Bear Lake and Seven Springs allow walking access to school for increased numbers of students. This finding is also illustrated in the pocket of students living on cul-de-sacs disconnected from Seven Springs' rear entrance who do not fall within the pedestrian shed.
- *SAZ boundary placement may affect the presence and role of barriers and facilitators within the pedestrian shed. The boundary placement may also affect how effectively the pedestrian shed captures student residential density*. Pineloch's SAZ boundary in combination with the major north-south arterial limit the amount of residential density captured within the pedestrian shed. In the case of Bear Lake and Seven Springs, accounting for facilitators to walking results in increased capture of student residential density.

Discussion and Conclusions

Understanding the complexities of the built environment and the experience a child entails between home and school is important. Much of the analysis on urban form of neighborhoods in the current literature use simplified surrogates of the distance that pedestrians need to travel, such as straight-line distance, block length or size, street or intersection density to name a few. Although these measures provide a good indication of the overall characteristics of a street network in a neighborhood, they do not always accurately account for the conditions that face pedestrians in their daily travels. When people walk toward a specific destination they will seek the shortest path – whether formal or informal – that will get them safely there. For children walking to school, the distance can be measured more accurately along the paths that include barriers that lengthen or facilitators that shorten the distance. Barriers can include school attendance boundaries, major highways, hazardous walking conditions and fences. Facilitators include school crossing guards, informal paths and back entrances to school sites that connect to cul-de-sac neighborhoods.

This study examines the potential for children to walk to school by using GIS to analyze the role of barriers and facilitators along a pathway network. Accounting for changes to the roadway network caused by barriers and facilitators offers a more realistic version of the true distance a child could potentially walk and more closely aligns with the actual way that pedestrians walk in and around a neighborhood. The method used here indicates that, different from common measure of walkability that uses straight-line distance or network distance, GIS can assist in providing a more accurate assessment of the walkability by factoring in barriers and facilitators in the calculation of the pedestrian network distance. The study found that barriers and facilitators play critical roles in how the urban landscape can be traversed and, in turn, greatly affect walkability and accessibility to school.

This research has implications beyond children's travel to school. The GIS methodology presented here can be generalized for broader applicability to the analysis of pedestrian travel as a function of physical urban form. For instance, network analysis that includes barriers and facilitators could be used to assess walkability to a variety of neighborhood locations, such as shopping centers, restaurants, churches or transit stops. Barriers to such destinations include freeways and wide streets with long distances between crossing walks. Conversely, pedestrians may use facilitators that shorten their walking distance, such as informal and formal pathways connecting cul-de-sacs and pedestrian overpasses.

The GIS automation of network distance calculations enables flexibility in replicating the same methodology for a variety of pedestrian sheds, either smaller or larger than the half mile distance used in this study. Once the pedestrian network is adjusted to include barriers and facilitators, GIS can easily recalculate the pedestrian shed boundaries, network paths, residential dwelling count or other variables used in the study for different shed sizes.

It is recognized that in addition to the distance, social concerns and personal decisions contribute to or inhibit the ability to walk between places. Additional research is needed to investigate these interactions in coupling such findings with what we know and continue to discover about the impacts of our built environments on walkability. For instance, the GIS methodology of this study could be expanded to include assessment of some of the other important variables affecting walkability such as safety from crime and safety from traffic. GIS layers of crime incidences, pedestrian crashes, graffiti and other signs of social disorder can be spatially overlaid on the pedestrian network and each segment of the network could be ranked and weighted based on these factors. This analysis could be useful to inform and target education, law enforcement and policies to enhance the walkability for children. Equipped with this information and the tools to conduct studies like this one is encouraging for future research on this and related topics.

It is important to emphasize that the accuracy of the results developed by the GIS computations depends on the quality of the input data. Typical GIS roadway networks do not include a complete inventory of formal pedestrian walking paths, greenways, sidewalks and informal paths. Field observations will generally be needed to adjust the GIS roadway network to account for pedestrian travel paths and to understand the broader physical conditions impacting the walking paths.

In addition to the contribution on the GIS methodology, this study provides findings that have broader importance to the walkability as it relates to the physical environment. The elements of urban form, such as the layout and configurations of urban blocks and street networks, permeability and connectivity do affect our opportunities to walk. Planning and design of physical urban environments that are conducive to walking are affected by policy and implementation of the policy through urban design.

From the policy viewpoint, these findings can be used to develop better policies and regulations to enhance walkability for children. School Boards (decision makers for school locations) and Planning Departments (decision makers on urban development) should coordinate their efforts to promote policies that support location of schools in close proximity to high density developments served by a well-connected and safe pedestrian circulation network. Delineation of SAZs should include criteria that increase walkability to school by maximizing the number of students that go to the nearest school considering the pedestrian network adjusted for barriers and facilitators. Related to this, these decision makers must strategically locate entrances to school to maximize access without jeopardizing safety. Additionally the use of bicycles should be encouraged to potentially increase active travel.

At the urban design level, considerations should be given to the layout of street network blocks and buildings to support safe pedestrian circulation with good permeability connectivity and accessibility throughout the neighborhood. In particular, findings from this study emphasize the importance of designing for connected pedestrian paths that minimize barriers and maximize facilitators. Suitable sidewalks that shelter pedestrian well from vehicle traffic, well-designed intersection crossing that are pedestrian friendly, inclusion of pedestrian-only designated paths that connect residencies to other paths to school and well-designed and strategically placed pedestrian overpasses or underpasses. The design of the well-connected safe paths should be extended to the use of bicycles which students can use to travel longer distances.

Notes

1 Community-based program to increase opportunities for children to walk to and from school (www.cdc.gov/nccdphp/dnpa/kidswalk/).
2 A walking school bus is a group of children who walk to school with one or more adults. It can be as informal as two families taking turns walking their children to school to as structured as a route with meeting points (www.walkingschoolbus.org).
3 An auxiliary police officer, community-volunteer, or other official who directs traffic for the purpose of assisting children in crossing streets near a school. Crossing guards are typically employed by local governments.
4 School districts in the state of Florida are coterminous with Florida's county boundaries.
5 De-identified data refer to a data set in which sensitive information has been removed to protect the identity of students.

References

City of Raleigh, North Carolina. (2008) Design guidelines for pedestrian-friendly neighborhood schools, http://www.raleighnc.gov/publications/Planning/Guides,_Handbooks_and_Manuals/School_Design_Guidelines.pdf, accessed 16 June 2008.

Collins, D. and Kearns, R. (2005) Geographies of inequality: Child pedestrian injury and walking school buses in Auckland, New Zealand. *Social Science and Medicine* 60(1): 61–69.

Dellinger, A. and Staunton, C. (2002) Barriers to children walking and biking to school in the United States. 1999. *Morbidity and Mortality Weekly Report* 51(32): 701–704.

Dietz, W.H. (1998) Health consequences of obesity in youth: Childhood predictors of adult disease. *Pediatrics* 101(3 Pt 2): 518–525.

Dill, J. (2004) Measuring network connectivity for bicycling and walking. Presented at the Annual Transportation Research Board meeting, Washington DC.

Ewing, R. (1999) Pedestrian- and transit-friendly design: A primer for smart growth. *EPA Smart Growth Network*, http://www.lcd.state.or.us/LCD/TGM/docs/ReidEwing Primer_primer.pdf, accessed 16 March 2010.

Ewing, R. and Greene, W. (2003) Travel and Environmental Implications of School Siting. U.S. Environmental Protection Agency (EPA). EPA231-R-03-004.

Fagot-Campagna, A. *et al* (2000) Type 2 diabetes among North American children and adolescents: An epidemiologic health perspective. *Journal of Pediatrics* 136(5): 664–672.

Federal Highway Administration (FHWA). (2010) Safe routes to school program, http://safety.fhwa.dot.gov/saferoutes/, accessed 15 March 2010.

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J. and Saelens, B.E. (2005) Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *American Journal of Preventive Medicine* 28(2S2): 117–125.

Freeman, C. and Quigg, R. (2009) Commuting lives: Children's mobility and energy use. *Journal of Environmental Planning and Management* 52(3): 393–412.

Frumkin, H., Frank, L. and Jackson, R. (2004) *Urban Sprawl and Public Health: Designing, Planning, and Building for Healthy Communities*. Washington DC: Island Press.

Hannon, T.S., Rao, G. and Arslanian, S.A. (2005) Childhood obesity and type 2 diabetes mellitus. *Pediatrics* 116(2): 473–480.

Kerr, J., Rosenberg, D., Sallis, J.F., Saelens, B.E., Frank, L.D. and Conway, T.L. (2006) Active commuting to school: Associations with environment and parental concerns. *Medicine & Science in Sports & Exercise* 38(4): 787–793.

Larsen, K., Gilliand, J., Hess, P., Tucker, P., Irwin, J. and He, M. (2009) The influence of the physical environment and sociodemographic characteristics on children's mode of travel to and from school. *American Journal of Public Health* 99(3): 520–526.

McDonald, N.C. (2007) Children's mode choice for the school trip: The role of distance and school location in walking to school. *Transportation* 35: 23–35.

McMillan, T. (2006) The relative influence of urban form on a child's travel mode to school. *Transportation Research, Part A* 41(1): 69–79.

McMillan, T., Day, K., Boarnet, M., Alfonzo, M. and Anderson, C. (2006) Johnny walks to school – Does Jane? Sex differences in children's travel to school. *Children's Youth and Environments* 16(1): 71–89.

Mitchell, H., Kearns, R. and Collins, D. (2007) Nuances of neighborhood: Children's perceptions of the space between home and school in Auckland, New Zealand. *Geoforum* 38: 614–627.