Developing neighbourhood 'walkability' indices for children's active transport

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ABSTRACT: *A surge of investment in Europe, North America and Australasia on children's and school travel planning has highlighted problems of the built, social and policy environment as barriers to children's active transport and independent mobility. Many aspects of the built environment can influence children's active transport, physical activity and health, including excessive trip distances, footpath provision, traffic volumes and speeds and road crossings. Research on the built environment often uses measures of neighbourhood 'walkability' that draw on these barriers/enablers, to allow planners and other actors to understand differences in the potential of built environments to support active transport. However, these measures and indices are usually derived from studies of adult, not child, travel behaviour. This paper summarises recent attempts to develop environmental measures and indices based on children's travel behaviour. It highlights their advances and limitations, and identifies possible ways forward. A new set of measures is outlined, drawn from the literature, which build upon and improve recent practice. Geographic information systems (GIS) are used to transform these measures into a composite walkability index for neighbourhood environments that more accurately reflect children's active travel potential. The method is applied to a school neighbourhood in Brisbane to demonstrate the approach. Refinements and practical applications for the method are advanced. A comparative study currently using the method to help explore built environment influences on children's independent mobility is noted. The method provides the potential for more nuanced and targeted research into children's travel and school travel planning, and for improved transport and land use planning interventions targeting travel behaviour change and children's health.*

Keywords: *walkability index; children's independent mobility, active transport, environmental audits*

Introduction

It is increasingly recognised that recent declines in children's active transport and independent mobility are important in influencing children's health and well-being. Active transport refers to human-powered forms of travel such as walking and cycling (Cole, Owen and Burke 2010:496). Children's independent mobility (CIM) means the freedom of those under 18 years of age to move in public space without adult accompaniment (Hillman, Adams and Whitelegg 1991). The last few decades internationally have seen declining levels of children's independent mobility and active transport, especially due to increased car transportation to/from school, which in turn is contributing to decreasing levels of children's physical activity (Whitzman et al. 2010:105). Many factors have been identified as contributing to the confinement

of children into vehicles and private spaces. These include a series of social factors such as local cultures of parenting (i.e. see Barker 2010) key policy factors such as posted street speeds and policies at school and local government level (see Eyler et al. 2008) and a litany of built environment factors such as street design, path infrastructure and road crossings (Braza, Shoemaker and Seeley 2004; Sharpe and Tranter 2010; Timperio et al. 2006).

Explorations of the effects of the built environment on children's travel have identified the distance between home and school, or the commuting distance, to be negatively associated with children's active travel. Parks, play and sports grounds in proximity to homes are associated with increased walking and cycling trips made by children (Carver et al. 2005; Timperio et al. 2004). The availability of and the condition of path infrastructure (such as footpaths, shared paths and bicycle paths) has been positively associated with children's walking and cycling to school (Davison and Lawson 2006:10). There are also positive associations between the presence of supervised/controlled crossings of major roads and children's walking and cycling (Boarnet et al. 2005). Yet the published research in this area is still limited. While an extensive body of research has informed a growing evidence base on built environment determinants on adult's active travel, this is not the case for children's independent mobility and active travel (Giles-Corti et al. 2009).

Research into the influence of the built environment on active travel for adults has found that determinants vary according to the type of walking, whether for recreational or utilitarian purposes, and the mode of transport, either walking or cycling (Cerin et al. 2006; Owen et al. 2004; Pikora et al. 2006). Giles-Corti et al. (2005) note the importance of focusing on specific types of behaviour (walking for recreation or walking to access a utility) rather than general behaviour (walking or physical activity) and matching built environment elements hypothesized to be associated with these behaviours. If children's behaviour relating to the activities they participate in and their use of space is different to that of adult's, then the range of built environment elements and the way they are measured may need to be considerably different to those relating to the adult population.

This paper highlights the way in which researchers are trying to operationalise measures of the built environment for environment-behaviour studies, focused on children's independent mobility and active transport. The focus is on walkability indices, a common tool used in this field of research. The paper highlights the problems of walkability indices derived from adult travel behaviour being applied to children's travel and outlines how other researchers have developed more child-centered approaches. A new set of methods is then provided, with options that respond more directly to the known influences on children's active travel.

Essentially this paper asks, are more targeted built environment measures for children's AT and IM able to be developed, given what we now know? And how in turn might these help improve our understandings and our policies and practices?

A vexed problem facing researchers is how to transform general understandings of the influence of the built environment into measures that can be used to compare and/or control for the built environment in studies of travel behaviour. In other words, how can one turn a neighbourhood environment into a measure of how it rates as an enabler or barrier to active transport? This is most often achieved by focusing on a number of observable factors and using these to construct, scale and 'score' defined neighbourhoods, creating metrics which in turn may be useful in regression or other statistical analyses. Our interest in this area relates to two major projects exploring children's travel – the *Independent Mobility, Active Travel and Children's Health* (iMATCH) and *Children's Active Travel, Connectedness, and Health* (CATCH) projects. These are exploring children's travel in Australian school neighbourhoods and seek to understand how the built environment is influencing children's independent mobility and active travel. Whilst iMATCH and CATCH are considering a much broader sweep of the ways in which neighbourhoods provide for children's outdoor play, cycling, socializing and other activities, these studies demand a method to rate or score the built environment as an enabler/barrier to walking per se, that can in turn be used later to control for the built environment in further analysis of social environment and/or policy influences.

Children's walkability indexes

One way that built environment elements are organised and measured in research on active travel is with a 'walkability index'. The function of a walkability index is to group and measure built environment elements linked to walking, producing an aggregate value that can be incorporated into quantitative analysis, such as regression analysis. Neighbourhoods and various elements within their boundaries can be compared to isolate specific urban forms or other built environment aspects that are associated with higher levels of walking.

The most widely known and a popularly used measure is Walk Score$^{®}$ (see www.walkscore.com) which uses Google Maps and distance-based algorithms to measure and score accessibility on foot to a range of amenities (destinations) in a neighbourhood. Much of the data on destinations is provided by other users. Figure 1 shows the Walk Score for the Coopers Plains Primary School, located in the suburbs approximately 11km south of Brisbane's central business district. Walk Score uses destinations more suited to all members of a household, not just children, with such land uses as 'Pubs', 'Banking' and shops such as 'Landscaping Supplies' all contributing to the Coopers Plain's school's relatively high score. Other limitations of Walk Score are that it ignores topography, urban design measures (other than those that affect networks and distances such as 'connectivity') and safety concerns.
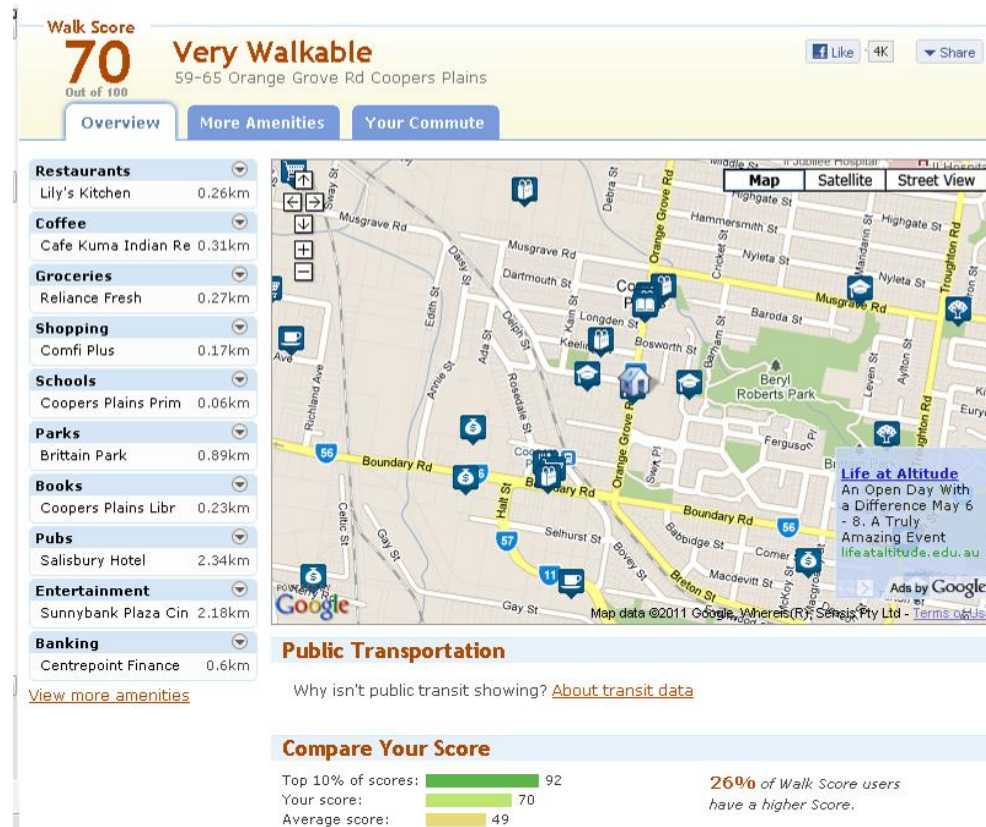
Figure 1 Screen shot of a Walk Score for the Coopers Plains Primary School, Coopers Plains, Brisbane, Australia (date: 27 April 2011; source: www.walkscore.com)

Similar indices or scores have been used for a number of purposes in research on active travel, independent mobility and physical activity. Pabayo et al (2010) used an area social fragmentation score to investigate levels of children's physical activity in the US. Walkability indexes have also been used to develop sampling frames in order to compare samples representing good areas for walkability and bad areas for walkability (Leslie et al 2007). Indices can also be utilised in planning and design interventions, identifying areas or features of an area in terms of their need for measures to improve walkability.

Several issues arise with the construction and use of indices. First, the ability to build a valid index is determined by the availability of quality data. Data quality is influenced by the methods used to objectively measure the built environment. GIS can provide spatial representation of data relevant to CIM and active transport, including distance between locations, street connectivity and networks, built form diversity and

density, and topographical features. A field audit is often used to supplement what is obtained via desktop GIS, which can incorporate an evaluation of the finer-grained design qualities of the local environment (Cervero and Duncan 2003). Audits are usually conducted in the field through observation on foot or in car by auditors and involve inventories of both objective measurements and subjective assessments of the environment. Although, audits can offer a detailed assessment of the built environment, they can be extremely time consuming and are therefore limited by available resources (Schaefer-McDaniel et al. 2010).

A second issue relates to the assumptions that underpin the choice of measures that inform the index. Pikora et al (2006) caution against attributing complex urban environments with simplified numerical representations and stress the need to remember that indexes are made up of individual factors. Elements of walkability indices are primarily based on hypothesised relationships between built environment elements and walking, or for which associations are known. Common elements that contribute to walkability indexes are density; land use mix; street network design or connectivity; and/or urban design quality (Badland et al. 2009; Frank et al. 2009; Owen et al. 2007). Whereas these measures are important aspects, they can also exclude parts of the population whose needs and capacities may not be relevant to the assumed links between behaviour and environment. This is particularly relevant to research on children. Some research on children's travel bases walkability indices on measures established in research on adult's travel behaviour (Kerr et al. 2006). Holt et al (2008) compared children's perceptions of the built environment in a study of two neighbourhoods in Edmonton, Canada. The neighbourhoods, one hypothesised to be a good walkable area and the other a bad walkable area, were chosen using an index comprised of density, street connectivity and land use mix measures. Younger children within the higher walkable area were found to be less likely to engage in play outside of the home environment. The presence of culs-de-sac in the less walkable area reduced street connectivity yet was suggested to provide an opportunity for play for children. This finding is supported in other research on children's play in the neighbourhood (Handy, Cao and Mokhtarian 2008; Veitch et al. 2006).

Little research has incorporated indices specifically based on children's hypothesised relationships with the built environment. Two of the largest recent studies on

children's active travel have not even attempted this task. The *Children's Activities, Perceptions And Behaviour in the Local Environment* (CAPABLE) project in the UK used desktop GIS to classify all land parcels in their school study neighbourhoods as different types including buildings, natural environment, general surface, path, road or track, roadside, and structure (Mackett et al. 2007:4-5). But this was only to allow comparison with student reported travel information, not to more broadly appraise and score that environment. The *Personal and Environmental Associations with Children's Health* (PEACH) project also used GIS, but just to compare children's travel with summary measures such as 'greenspace' (see Wheeler et al. 2009) rather than to rate the local environment's overall walkability.

There are two main methods for providing an evaluation of a neighbourhoods' walkability. The first is to follow the pioneering approach of Lynch (Lynch 1980) and undertake a thorough 'walkability audit' using trained observers to undertake objective environmental audits of the micro-scale design features of every path and street in a defined school neighbourhood area. Examples include the *Irvine-Minnesota Inventory* which provides an audit tool with a range of environmental features known to be enablers of walking – for adults (Day et al. 2006). However, this approach is expensive to pursue, given the demands of having individual observers walking each link in a large school catchment. There are extensive iterations and development cycles needed to create a tool that has reliability and a scoring system for the set of measures that is reliable. And there are no such tools yet available specifically targeted at children's walkability.

The other main approach to building a walkability index is to use desktop GIS, which has the advantage of being able to use existing data sources, and evaluate large areas of the city quickly, but which cannot deliver the fine-grained detail of a field audit. Wood et al. (2010) have advanced this approach furthest, using a children's walkability index as part of the *TRansport, Environments and Kids* study (TREK) to investigate a range of individual, social and environmental influences on children's active travel to school in Perth, WA. Their index combined two proxy measures that indicated walkability based on access and traffic safety, and applied to 288 schools in the Perth metropolitan area. Their index incorporated a Pedshed (see below) surrounding the schools as well as a ratio of links (segments of roads) of high volume

roads within the broader catchment, versus the links of local access roads. The advantages of Wood et al.'s approach are that it relies solely on desktop analysis, requiring little field auditing, and can therefore be applied over very large metropolitan areas. There are number of limitations with this approach, including that it omits many known enablers/barriers to children's active transport. The measure of road safety is weak in that road hierarchies represent potential capacity not observed traffic data. And they calculate neighbourhood walkability based on street networks only, neglecting the arrangement of land uses on that network, including how residential lots are laid out in the neighbourhood.

The iMATCH and CATCH studies are more thoroughly investigating a smaller number of schools and need richer understandings as to how their neighbourhood environments either enable or stymie children's active transport. We believe a more comprehensive picture of children's walkability is needed than what previous research has provided, hence the search for improved methods.

Objective

The objective of this research is to develop workable methods that can score or rank a school neighbourhood for children's walkability. The intent is to generate a measure that can be operationalised for use in regression and other statistical analyses.

Methods

The only methods to be used are desktop GIS analysis of specific datasets and limited field surveys (including ground-truthing) to create a workable solution that is within the scope of most transport/land use research project resourcing. As a conceptual framework, the index developed here can be operationalised in any of the GIS software packages that includes such procedures for network overlay and analysis, and buffering. This is, however, work in progress, and there are many options available to the researcher to suit the needs of specific sites and the availability of key input data.

Step 1. Development of a street & path network layer

To commence analysis, a representation of the main movement system for children is required, including:

- o Roads
- o Footpaths, shared paths and bicycle paths

The key separate paths, streets and public transport routes/stops should be available from state and local authorities as GIS data layers. Where footpath data is available as a separate GIS layer to the road network, this could conceivably be used in conjunction with the roads data layer. However, footpath data layers are rare in Australian cities and this will simply not be possible for many sites. Key path networks are often displayed in street directories and can be digitised within GIS. Eventually these datasets must be merged to create a combined street & path layer. And then they should be checked via either local informants or ground-truthing. Desktop analysis will reveal possible gaps for investigation in the field but to develop a rigorous network at sufficient detail, there will always be some need for ground-truthing or correction by someone familiar with the site.

Step 2. Pedshed analysis

Pedsheds may now be identified for a school neighbourhood, using the combined street & path network layer. A Pedshed is defined as the pedestrian catchment of a land use destination, via the pedestrian network. It is usually limited to a specific walking distance of around 1 mile or 2km (the latter being used in the TREK study). We used GIS to generate a 2km buffer via the street & path network for the same Coopers Plains Primary School, as shown in Figure 2. In a contiguous urban area such as southern Brisbane, a 2km buffer covers the central catchment of a primary school and encroaches into the catchments of neighbouring state primary schools, without too much overlap.

As a measure of ease of access, it is then possible to calculate the *Pedshed ratio* of the street and path network covered by the Pedshed versus the street and path network located in a hypothetical circular 2km Euclidian ('as the crow flies') buffer around the school. A higher ratio or Pedshed network area to the Euclidian area suggests more of

the catchment can easily access the school. A lower ratio suggests there are difficulties accessing the school from the surrounding neighbourhood. A ratio above 0.60 is considered reasonably good in describing 'walkability' in the Australian suburban context. The Coopers Plains school falls just short of this measure achieving a ratio of 0.56.
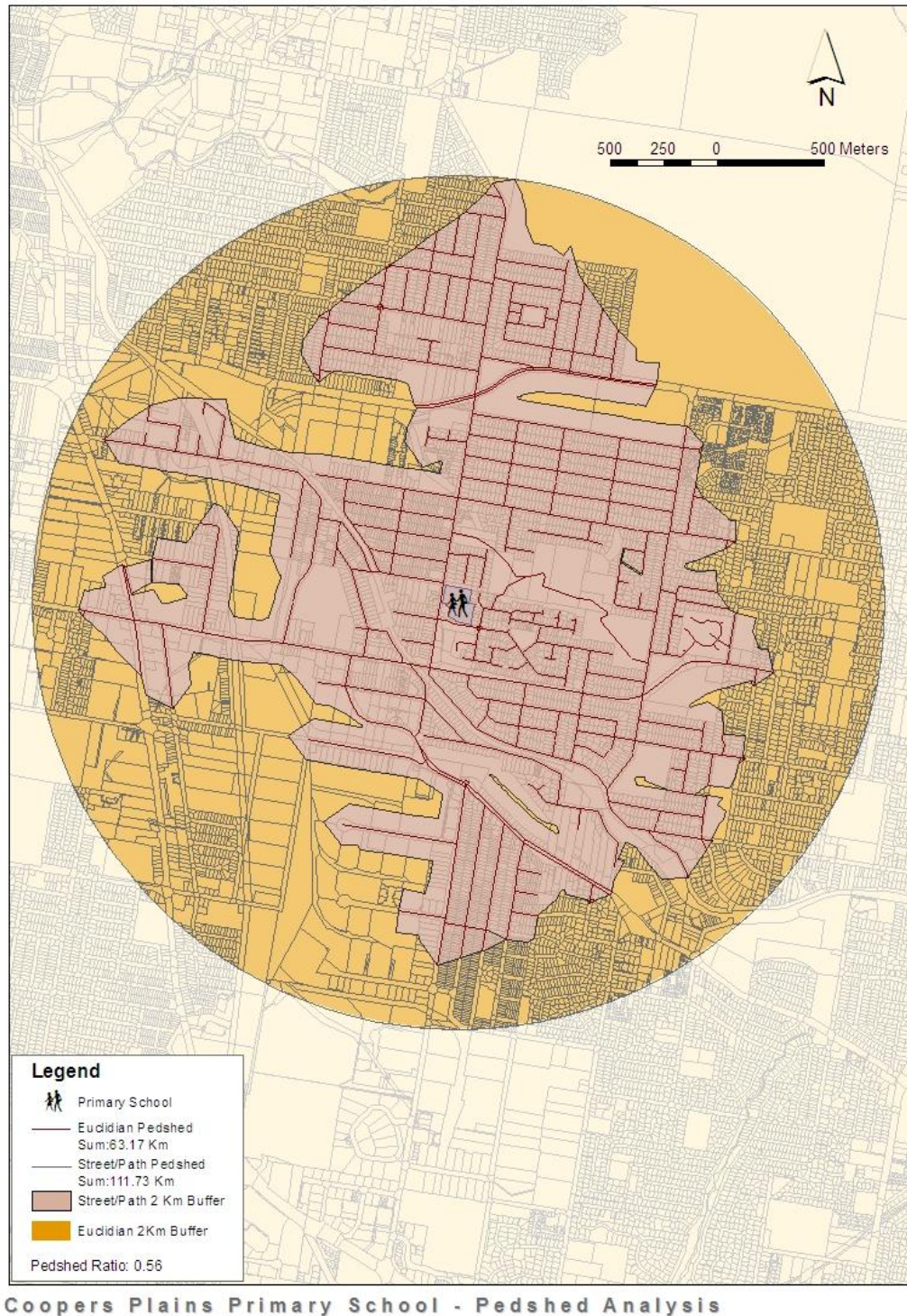
Figure 2   PedShed analysis of Coopers Plains Primary School, Brisbane, Australia

Pedsheds are useful in visualising accessibility by foot along the network, and in producing a ratio that is useful for comparative purposes. But they are naïve to actual populations or numbers of households or dwellings, or their distribution along the network and within the neighbourhood. Pedshed ratios therefore produce a somewhat misleading picture. Additional data is needed.

Problems emerge at this point. Australian Bureau of Statistics (ABS) census data provides the best indication of population density for a school neighbourhood area, however that dataset's smallest unit of analysis, the census collector district (CCD), which generally contain around 200 households, is often too large for this form of analysis and are unable to be fitted neatly within a 2km buffer. There are techniques available to split CCDs at areal boundaries, but this dissolution is problematic. We instead use Digital Cadastre Database (DCDB) data, which is available for all Australian metropolitan areas for analysis within GIS, and which features lots with residential land descriptors. Whilst DCDB data indicates lots and not actual houses, let alone households and their demographics, it does provide information at lot level, such that one can appraise and visualise with greater precision the number of households that lie within the Pedshed, versus those in the broader Euclidian 2km buffer area.

Step 3. Vehicle Exposure / Crossing Main Roads

The TREK study used a vehicular traffic exposure module to further define walkability to school. This employed road hierarchy definitions as a proxy for traffic volume (and presumably traffic danger) based on state government classifications (Wood et al. 2010:14-15). They calculated the proportion of roads within the 2km Pedshed that were different road types, creating a ratio of high-volume vs. low-volume (<3,000 vehicle per day) roads as a metric for the whole Euclidean buffer area. This approach is simple to employ and provides some information, however, there may be differences in the coding of state roads across jurisdictions, leading to problems for national comparisons. Further, main roads may be located on the edge of a buffer, creating nil problems for walking to school for households within the neighbourhood.

We instead have used an approach we believe offers greater insight in determining known barriers to children's active travel provided by crossing main roads. That is to calculate the proportion of households (or more accurately, lots) in the neighbourhood for which residents would have to cross a 'main road' (which is reasonably consistently defined in road hierarchy datasets) where no crossing supervisor is provided, in order to reach the school. This is achieved by locating the main roads in the neighbourhood (as classified by road hierarchy data in the road network layer) and the locations of crossing supervisors, which is readily provided by informants at the school. Then for each lot in the DCDB dataset identifying how many main roads must be crossed on the shortest path or logical route to the school. This is easier than it seems, and can be achieved quickly by visual inspection. An example for the Coopers Plains Primary School is provided in Figure 3.

Coopers Plains Primary School _ Vehicle Exposure/Crossing
Main Roads
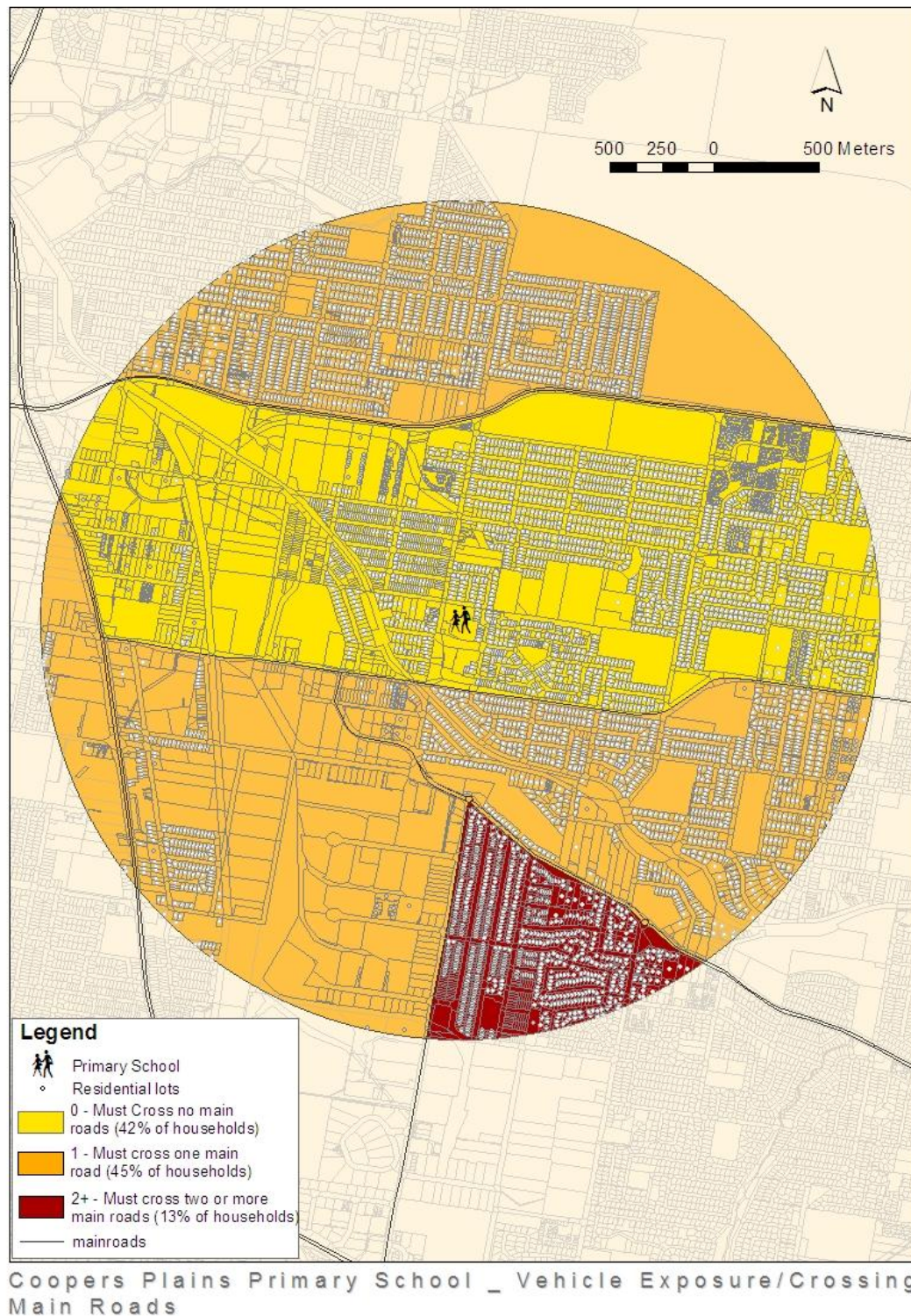
Figure 3 Map of the 2km neighbourhood area showing where children must cross one or more major roads

This shows that the Coopers Plains Primary School is well sited in that as many as 42% of residential lots are on a route that does not require the crossing of a main road, without a crossing supervisor, and only 13% require the crossing of two main roads.

A composite map that combines the Pedshed and Vehicular Exposure modules is provided in Figure 4.

Coopers Plains Primary School - Composite (Pedshed/Crossing Main Roads)
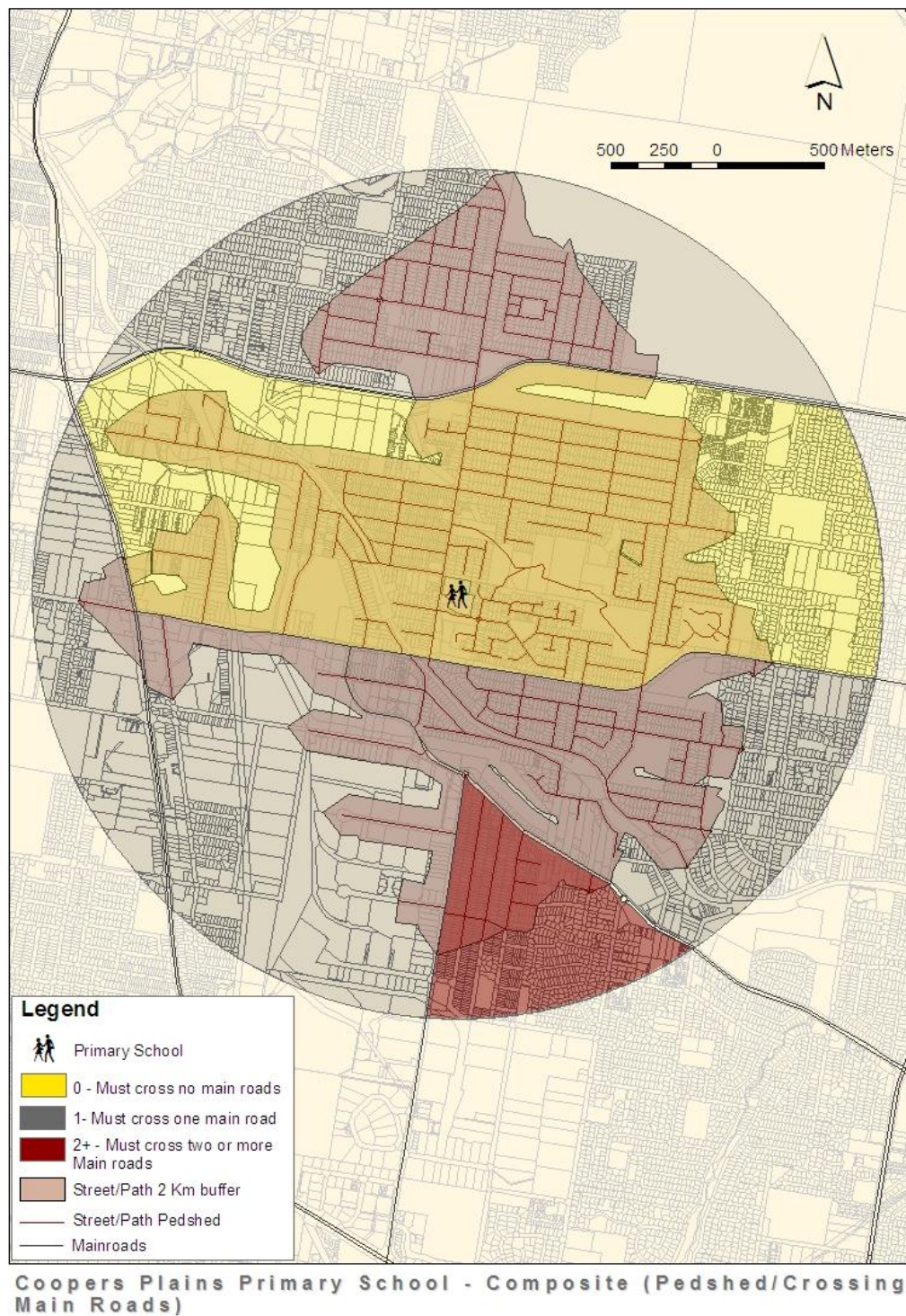
Figure 4 Composite map showing PedShed and vehicular exposure/crossing of main roads

Step 4. Footpaths (optional)

Given footpaths are a known enabler of children's active transport, we have been exploring means to include a measure of footpath availability within a children's walkability index. The key problem, as noted already, is the lack of footpath data availability in Australian cities. If one were to consider footpaths in greater detail, and to try to include this within the walkability score, one could follow the approach used by Kelly et al. (2007) of using fieldworkers to capture data on whether there are footpaths (none; one side of the street; both sides of the street) for each link in the buffer area. This can be accomplished within a few hours for a 2km buffer area using a motor vehicle, especially if there is a driver and a separate researcher making the observations. Once identified and mapped within GIS there are two means to calculate a measure of path availability. The simplest is to calculate the percentage of links with footpaths vs. the total number of links. More sophisticated is to synthesise the path data with DCDB data to identify those housing lots for whom a complete journey to school via a short path is possible solely on footpaths, to again calculate a ratio of lots with a footpath-only route to school vs. the total number of lots in the catchment. The latter approach raises the question of *continuity* of path networks, which is a known influence on active travel for adults. But significant breaks in footpath networks cannot be identified objectively without a trained fieldworker covering every link in the network inside the Euclidean buffer. Then the research team must determine what matters in terms of a break in the network, as to how 'important' that break in connectivity is as a barrier to AT. These questions are being resolved by the research team at present.

Step 5. Non-School Destinations (optional)

In addition to schools, there are a range of other key destinations known to be important for children's active travel including parks, playgrounds, libraries and certain types of shops. Children's travel is regularly comprised of trip-chains to multiple destinations rather than single-stop journeys. Alas, there is no 'Walk Score' available solely for children's destinations, at least as yet.

Within the Pedshed area, many key destinations such as libraries and shops can be identified from Street Directories, local and state government datasets, the Google Maps and Walk Score websites and from *Australia On-Disk*. The latter is especially useful, and it is possible to capture and geo-code land use destinations such as shops from third party sources such as this, as demonstrated in recent research on public transport accessibility on Australia's Gold Coast (Dodson et al. Forthcoming). More difficult is locating playgrounds and play equipment, most of which are omitted in available data sources. One can use 'greenspace' from the coding in DCDB data, in a similar manner to that used in the PEACH project (Wheeler et al. 2009) but playgrounds per se are more difficult. Their location can often only be provided by local informants, being difficult to spot from satellite imagery, especially when located in and under tree canopies. Other destinations of importance that may not be identified readily include vacant lots and rail or bridge overpasses. There are problems in identifying the destinations of most importance as robust studies of children's travel nationally or internationally are scarce, and mainstream household travel surveys such as the *South East Queensland Travel Survey* (Queensland Transport et al. 2005) under-report children's trip-chaining behaviour, and especially their non-motorised trips.

We are currently testing a combination of parks, playgrounds, libraries and convenience shopping as a set of destinations children more commonly travel to, for inclusion within a children's walkability index, using similar algorithms to those underpinning Walk Score. And we are confident these can be included in an assessment of the 'walkability' of any given neighbourhood.

Step 6. Topography (optional)

In most Australian urban school neighbourhoods, topography is unlikely to play a major role in determining walkability. However, there are some school neighbourhoods, including in cities such as Brisbane, where very steep topography is a feature of street networks surrounding particular schools, such that it is a known barrier to active transport at the local scale.

Topographical information is not captured in most two-dimensional road and path network data. But it is possible to use GIS to synthesise topographical data with street network data to produce measures of topography for neighbourhoods. One approach used by Burke, Sipe and Evans (2006) is to use digital elevation model (DEM) data to produce a contour surface, then to compute topographical change across a whole neighbourhood area. However, this approach will be misleading where a major topographical feature such as an uninhabited mountain is included in a school neighbourhood, but for which the surrounding area is effectively flat and where routes to school are unaffected.

Another approach is to incorporate topography into the same field audits conducted to appraise footpath provision, where links on strongly sloping streets (i.e. those with >30m height difference at grades of 10% or higher) may readily be identified. One can then input these into GIS to calculate the percentage of the catchment network with routes affected by major topographical barriers, or the percentage of residential lots with routes affected. We are testing these approaches at present.

Step 7. Synthesis

The above information can be transformed into an index of 'walkability' for children. This will require the use of weightings, and research must determine what we deem appropriate. Questions must be answered such as: is network layout (represented by a Pedshed ratio) and its influence on trip distances more important than crossings of main road, in determining overall walkability? At present we are weighting these two factors equally. But what about footpath provision? Or topography? How important are these extras? A set of activities equivalent to those used to develop the *Irvine-Minnesota Inventory* (Day et al. 2006) are likely necessary to calibrate such a score for wider use in multiple studies.

There are other problems that emerge at this point. Many variables are likely to be inter-related or co-variant. For instance, path networks and greenspace are often co-variant, given that paths are a common feature of parks and reserves in modern cities. This has implications for the means by which a score is calculated, with the conventional linear equation to assess independent variables being unable to account

for co-variance. We are currently trialling alternative approaches to develop a scoring system that accommodates limited covariance.

Discussion

The methods described in this paper open the way for a more robust and child-centred assessment of the built environment for children's walkability. By no means are they perfect or finished, but they show a reasonably cost-effective approach, using readily available data, to generate a set of outputs that can be used to score and compare neighbourhood environments. A key innovation is in the use of DCBD data to appraise how lots are distributed in a neighbourhood, to make for a more robust, but still readily simple desktop GIS assessment of such factors as vehicle exposure/crossings of main roads.

How might this method improve our understandings and our policies and practices regarding children's travel? The methods advanced build on the approach used in the TREK project (Wood et al. 2010) to create an assessment more suited to the needs of the iMATCH and CATCH projects, which are focusing more intensely on a smaller number of schools and their surrounds. This richer picture of the walkability of a school neighbourhood should provide a means to more accurately depict the way in which a built environment enables children's active transport. This should in turn allow for improved understandings of the effects of the built environment on children's travel. And it should also allow for these effects to be controlled for in studies exploring the role of social environment factors, or policy interventions, on children's active transport. As such, the method provides the potential for more nuanced and targeted research into children's travel and school travel planning, and for improved transport and land use planning interventions targeting travel behaviour change and children's health.

There are a number of key limitations to the approach. Restricting our methods to desktop assessment and limited field surveys means the omission of much of the micro-scale design features of the landscape. Shade, shelter, traffic noise, visual amenity and aspects related to crime-prevention are all omitted, in seeking to focus solely on a set of well-understood enablers/barriers to children's active transport.

There are also limitations relating to each of the steps above, though this is work in progress and many of these may be resolved in future enquiry.

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