Review of public health and productivity benefits from different urban transport and related land use options in Australia.

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DISCLAIMER

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Abstract

The relationship between public health, urban forms and transportation options in Australia is examined through a review aimed at determining possible health indicators to be used in assessing future land use and transportation scenarios. The health benefits, and subsequent economic benefits of walkable, transit orientated urban forms are well established and are measurable. Important health indicators include vehicle miles travelled, access to public transport, access to green areas, transportation related air pollution levels, transportation related noise levels, density and mixed land use. A comparison between a high walkability urban environment and a low walkability urban environment identifies various infrastructure, transportation greenhouse gas emissions and health costs. From this it is determined that infrastructure and transport costs dominate, health costs are relatively small and that health-related productivity gains associated with highly walkable urban areas are substantial. This review provides heath and economic rationale for developing urban forms geared towards active travel.

Keywords: *public health, active transport, urban form, pollution, productivity.*

Introduction

The relationship between public health, urban forms and transportation options is now the subject of significant research. Much of this research focuses on the urban attributes, such as transport and urban form that can encourage human health building on a long tradition in the health profession that stressed health outcomes from town planning (Broadbent, 1990; Newman & Hogan, 1981; WHO, Canadian Public Health Association, & Health and Welfare Canada, 1986). Many studies support that car dependent urban forms have led to the creation of obesogenic environments increasing the health burden (Ewing et al. 2003; Frank et al. 2004; Trubka et al. 2010). Furthermore, rising temperatures, increasing extreme weather and poor air quality related to climate change, urban heat island effects and transport-related air pollution are a major public health concern for cities, and are predicted to place an increasing health burden on urban populations (Harlan & Ruddell, 2011). There is much overlap between policies aimed at mitigating climate change and those that would increase active travel (Harlan & Ruddell, 2011; Hoornweg, et al., 2011; Kent et al., 2011; WHO, 2011b). Additionally, there are strong financial justifications to include health costs in appraisals of developments (Trubka et al., 2010) along with a growing cultural shift to more sustainable urban lifestyles, a reduction in car use and increasing competition between cities to attract educated residents and economic development (Brookings Institution Metropolitan Program, 2008; Florida, 2002; Newman & Kenworthy, 2011; Newman & Newman, 2006).

This paper first looks at the relationship between public health, urban forms and transport options as found through the literature, discussing potential health outcomes related to urban form and transport. The paper then identifies studies that discuss the potential economic impacts of urban form and transport choices. Lastly, the result of a comparison between a high walkability urban environment and a low walkability urban environment is presented. This comparison identifies various infrastructure, transportation greenhouse gas emissions and health costs. This review is the first stage of a project looking at developing potential human health impacts of future urban development scenarios able to be modelled to determine the consequences of urban transport and land use policies on human health under various climate change scenarios. This review does not investigate socio-economic factors, access to employment, health care, education or other land uses which can also influence urban transport choices as these are beyond the scope of the paper.

Background

The relationship between public health, urban forms and transportation options is now the subject of significant research. Much of this research focuses on the urban attributes, such as transport and urban form that can encourage human health. It is now commonly accepted that the conventional model for residential developments located in greenfield sites that have been prolific in Australian cities since World War II have resulted in car-dependent locations and inactive travel (Ewing & Cervero, 2010; Jackson, 2003; Newman & Kenworthy, 1999; Saelens & Handy, 2008; Saelens et al., 2003). These neighbourhoods are generally characterised by low population densities, poor accessibility and connectivity and a lack of services within walkable distances, resulting in low levels of active transport. Growing evidence links these areas to obesity and other chronic illnesses (Giles-Corti, 2006; Giles-Corti et al., 2012; Jackson & Sinclair, 2011; Kent et al., 2011; Sturm & Cohen, 2004).

A large current stream of research is looking at the carbon impacts of land use decisions. It has been determined that people living in dense urban centres can emit half the amount of greenhouse gases (GHGs) than those living in suburban areas (Hoornweg et al., 2011). Importantly however, is the link between policies to reduce GHG emissions and policies to increase health. Policies suggested to reduce GHG emissions often also have health benefits including increasing public transport use and access, discouraging car use, reducing trip lengths through mixed use zoning and compact urban forms, supporting non-motorised traffic modes through traffic calming and bike lanes, and reducing the heat island effect (Kent et al. 2011; Hoornweg et al., 2011; WHO, 2011b).

Australia now has one of the highest obesity rates in the world ranking 21st in the world and third among all English-speaking countries (Forbes, 2007), with much of Australia's adult population not getting enough physical activity to remain healthy. The cost of inactivity in Australia was estimated by Medibank Private to be $13.8 billion a year with residents living in cities generally more physically active than those living outside of major cities (Australian Government, 2011, p.175). It is estimated that 1.5-3.0% of total direct healthcare costs are related to inactivity in developed countries (Oldridge, 2008). The National Physical Activity Guidelines for Australians recommends that people should engage in 30 minutes of physical activity per day over 5 days of the week in order to be healthy and to be considered physically active. Some of this could be met by increasing the amount of active transport and incidental walking (Trubka et al., 2010).

Walking and cycling are widely recognised as the healthiest ways to get around our cities for both public and environmental health (Hoornwe et al., 2011; Huy et al., 2008; Newman & Kenworthy, 1999; Pucher & Buehler, 2010). Direct and indirect benefits of walking include increasing physical activity and the reduction of air pollution, road-based stormwater and noise pollution through the reduction in the use of automobiles (Newman & Kenworthy, 1999; Pucher & Buehler, 2010). However, it has also been identified that pedestrians and cyclists can also be exposed to high levels of air pollution in certain urban microenvironments such as busy street canyon (Kaur et al., 2007).

Urban form, transportation and human health

This section examines the relationships between human health, built forms and transportation options. From the literature, the urban form structures that can relate to or indicate increased physical activity and health (and which often overlap in their ability to help create walkability) are density of urban form, accessibility, particularly the number of intersections per area, compactness, diversity of land use, amount of time spent in a car or vehicle kilometres travelled (VKT), proximity to public transport, access to public space, particularly green space, and the presence of appropriate active transport infrastructure (Ewing & Cervero, 2010; Forsyth & Krizek, 2010; Guo, 2009; Handy et al., 2005; Jackson, 2003; Larco et al., 2011; Saelens & Handy, 2008; Saelens et al., 2003; Soltani, 2006). Furthermore, transport related air pollution, noise pollution and accident levels are also potential important indicators able to be modelled. All of these elements relate to minimising the need and distances required to travel for everyday services and activities, and residents of these types of areas have been found to be more active (Frank et al., 2005), especially where these features are combined and act in synergy (Saelens et al., 2003). These features overlap and work together in ways that is yet to be completely understood. This section highlights some of the key findings or measures around these urban form and transport indicators.

Urban density and human health

The links between human health and urban density are a particularly important potential indicator. People that live in higher density, mixed use neighbourhoods have been found to have lower rates of obesity than those that live in lower density residential areas, although this result is mixed in the literature. Appropriate levels of density and mixed land use are required to encourage active travel and public transport (Giles-Corti et al., 2012), presumably because distances for travel become less. Cross-sectional research indicates that people that live in higher density, mixed use neighbourhoods have lower rates of obesity than those that live in lower density residential areas, however longitudinal studies show mixed results (Berry et al. 2010). Wilson et al. (2012) in a survey of areas in Brisbane found that residents that lived in the densest neighbourhoods were 80% more likely to walk between 1 and 60 minutes weekly, and more than twice as likely to walk more than 150 minutes. Sturm and Cohen (2004) found that a difference in their sprawl index of 100 points (the difference between a very sprawling area and an inner city) was associated with about 200 fewer chronic medical problems per 1000 persons. In their research Newman and Kenworthy (1999; 2006) found that 35 people and jobs per hectare (referred to as ‘activity density’) was the threshold density for decreased car dependence and beyond that, travel by car lessens and active travel and public transport use begin to increase.

Importantly however, increased urban density is related to increased levels of walking but not necessarily to increases in levels of walking for physical activity or for leisure (Forsyth et al., 2009; 2009). The relationship between density and walking, in particular, relates to issues of self-selection of residential locations based on preference, i.e. people that prefer a highly walkable neighbourhood and live in one walk and people that are not interested in walking don't regardless of the walkability of their neighbourhood (Berry et al., 2010; Frank et al., 2007). These studies imply that it takes more than simply increasing density to increase activity levels, although the reverse is more likely, that low density levels lead to less walking as the distances and time required for travel mean that a motor vehicle is used for most transport (Newman & Kenworthy, 1999). Furthermore, a quasi-longitudinal study from Northern California (Handy et al., 2005) determined that people who move to a more walkable area began over the course of a year to adapt their travel behaviours accordingly. The links between personal preferences, density and levels of walking are clearly difficult to measure. The link between public transport use and density is a little easier to determine with public transport ridership found to increase steadily as residential density increases, along with other measures to restrict car use (Lee et al., 2009).

Accessibility, compactness, mixed land use and human health

Active commuting is clearly related to proximity and availability of public transport and to the distances between residences, services, commercial activities (particularly local stores) and employment locations (Ewing & Cervero, 2010). Compactness is now a widely accepted planning policy in Europe, Australia and the United States (U.S.). A tighter urban grain enables cities to maintain continuity within a small area and to be easily accessible on foot and by bicycle. A sustainable city needs to be compact and compactness has been shown to influence travel choices and to result in lower GHG emissions than sprawling cities (Cervero & Kockelman, 1997; Dulal et al., 2011; Kenworthy, 2006).

Permeability, particularly as measured by intersection density, is positively correlated to levels of walking (Baran et al., 2008; Ewing & Cervero, 2010; Kerr et al., 2007; Montgomery, 1998; Saelens & Handy, 2008; Saelens et al., 2003; Papas et al., 2007; Parks & Schofer, 2006). Residents that live in neighbourhoods with greater connectivity have been found to be 80% more likely to walk between 1 and 60 minutes per week or more than 150 minutes per week, than residents that lived in less connected areas (Wilson et al., 2012). Furthermore, the presence of footpaths have been strongly linked to improved human health, particularly due to the increase in active transport and to a reduction in vehicle miles travelled (Reed et al., 2006; Sallis et al., 2009) and, therefore, to a reduction in GHG and air pollutant emissions (Frank et al., 2011; Sciara et al., 2011). In New York, the creation of a pedestrian-only plaza at Times Square was found to have resulted in substantially reduced levels of Nitrogen dioxide (NO_2), thereby reducing pedestrian exposure to vehicle pollution (New York City Department of Health and Mental Hygiene, 2011). A study in Brisbane found that residents living in areas with off-road cycleways, used as walkways, were found to be 69% more likely to walk for more than 150 minutes for transport per week (Wilson et al., 2012). However, a Perth based study found that if greater connectivity is not associated with density and public transport access then walking does not increase much due to the lack of destinations reachable by foot (Falconer et al., 2010).

The link between mixed land use and physical activity has also been established (Sallis et al., 2011). Increasing the land use mix has a strong association with a reduction in obesity (Frank et al., 2004). This is because the distances required to travel become less. Frank et al. (2004) conclude that each quartile increase in mixed land use results in a 12.2% reduction in the likelihood of obesity across different genders and ethnicities.

Car use and human health

There is a strong link between car use, usually measured in VKT, and obesity levels (Frank et al., 2004; Grabow, et al., 2011; Lindsay, Macmillan and Woodward, 2011). Frank et al. (2004) determined through their analysis in Atlanta that each additional hour spent in a car per day was associated with an increase of 6% in the likelihood of obesity and that each additional kilometre (km) walked per day was associated with a 4.8% reduction in the likelihood of obesity. Furthermore, the relationship between obesity and active travel is an inverse one. Countries that have high levels of active transport, such as The Netherlands and Denmark, have lower levels of obesity, while countries with low levels of active transport, such as the U.S. and Australia, have higher rates of obesity (Pucher & Buehler, 2010).

Public transport use and human health

People who use public transport have been found to be more physically active than those that drive (Frank et al., 2010; Litman, 2010; MacDonald et al., 2010; Wilson et al., 2012) and less likely to be obese (MacDonald et al., 2010). The link between active transport and public transport is particularly important with the modes being integrated and complementary (Agrawal et al., 2008; Gehl, 2010; Newman & Kenworthy, 1999, 2006; Pucher & Buehler, 2010). The U.S. Active Living Research Program (2009) found that 29% of people who use public transport were physically active for 30 or more minutes per day, due primarily to walking to and from public transport stops. In addition, they found that public transport users compared to car users walked 30% more steps per day and spent 8.3 more minutes walking per day. The New York City Department of Health and Mental Hygiene (2011) determined that New York residents who commuted via public transport got almost half an hour more physical activity per day than those who commuted via automobile or taxi. Litman in his meta-analysis determined that on average public transport users spent a median of 19 minutes walking per day (Besser & Dannenberg 2005; Weinstein & Schimek 2005 as cited in Litman, 2010). Wilson et al. (2012) determine that residents living close to public transport are 72% more likely to walk between 1 and 60 minutes per week.

Access to green space and human health

Access to nature plays an important part in the health and productivity of people (Beatley, 2011). People with access to green space within close proximity of their residences perceive their health to be greater than those who do not have easy access to green space and to feel less lonely (Maas et al., 2009). Access to open space is also associated with recreational walking. Adults were found to be more likely to walk 150 minutes or more per week if they lived within 1.6 km of a large and attractive open space (Sugiyama et al., 2010). Guo researching commuter's path choice from public transport stations to work places in downtown Boston determined that commuters were more likely to choose routes that passed through a central public park even if the route was longer (Guo, 2009). Evidence also indicates that living close to places for physical recreation makes people much more likely to use them (Kent et al., 2011), indicating that it is not the size of the green space so much as the location.

There is a growing body of research, summarised in Loftness and Snyder (2008), that determines that views of nature and proximity to windows are linked to "reduced length[s] of stay after surgery, reduced sick building syndrome (SBS), increased performance at task, and overall improved emotional health" (p.120). However, they stress that it is unclear whether the improvement in health and performance is due to the effect of the views, the daylight, the increased air flow or to the increased control of temperature and lighting (which often accompanies being close to a window). Access to natural daylight (particularly time of day lighting) and access to outside air in particular has been found to have a positive impact on health (Loftness & Snyder, 2008; Seppanen & Fisk, 2002; Ulrich, 2008). Carnegie Mellon University reveals that "natural ventilation and mixed-mode conditioning systems can provide 47-79% HVAC [heating, ventilation and air conditioning] energy savings, 0.3-3.6% health cost savings, and 0.2-18% productivity gains, for an average return on investment of 120%" (Loftness & Snyder, 2008, p.125).

Traffic intensity, air pollution, noise pollution and human health

Traffic intensity is associated positively with noise, stress (tension) and air pollution, and negatively with levels of social interaction, territorial extent, awareness of the street environment, and both perceived and actual safety (Hart et al., 2011; Kelly et al., 2012; Mindell et al, 2011; Sugiyama et al., 2010). Environmental noise can seriously harm human health, and interfere with sleep and daily activities reducing performance at school and work. Road traffic noise has been associated with hypertension, increased stress and disturbed sleep (Jarup et al., 2007; Bodin et al., 2009). WHO (2011a) reported that at least one million healthy life years are lost every year from traffic-related noise in the western part of Europe, mainly due to sleep disturbance and annoyance related to road transport noise. However, it is difficult to separate the health effects of road transport-related noise and air pollution because of the strong spatio-temporal co-variation of certain air pollutants with noise in urban areas (Weber & Litschke 2008; Weber 2009). Both road transport noise and air pollution are often higher at busy street junctions where vehicles brake and accelerate due to traffic lights and congestion (Barnett et al., 2011; Vardoulakis et al., 2011). However, in a study looking at the combined effects of road transport (de Kluizenaar et al., 2007), noise was found to be still associated with hypertension (in the 45-55 years old group) after adjustment for air pollution. Although the additional health cost of road transport-related noise has not been fully quantified in Australia, it is likely to be substantial.

Road transport accounts for a large proportion of total air pollutant emissions in Australian cities. Motor vehicle engine design, end-of-pipe emission control technologies (e.g. three-way catalytic converters) and improved fuels (e.g. unleaded and low benzene content petrol) have all contributed to reduced atmospheric emissions from cars. As a result, exposure to certain road transport-related toxic pollutants, such as lead, benzene and carbon monoxide (CO), has substantially decreased in developed countries in the last twenty years (Cowie et al., 1997). However, the ever increasing volume of private cars, the trend towards larger and heavier cars, and the expanding VKT in urban areas have eroded the environment gains from technological improvements in this sector.

The adverse health effects of airborne particulate matter have been well-characterised in several epidemiological studies focusing on short- and long-term exposure effects of different particle size fractions. For example, the large American Cancer Society (Pope et al., 1995; Pope et al., 2002) and the Harvard Six Cities (Dockery et al., 1993) cohort studies have reported a strong association between annual concentrations of particles of less than 2.5 micrometre ($PM_{2.5}$) and mortality in U.S. cities, with more recent European studies broadly confirming this association (COMEAP 2009). In addition, a large number of time-series studies have shown an association between particles of less than 10 micrometre (PM_{10}) (and other pollutants) and daily mortality in North America, Europe and Asia (Katsouyanni et al., 1996; Wong et al., 2008; Bell et al., 2005). The transferability of these studies carried out in other continents can be assessed by reviewing the findings of local epidemiological studies. To this end, we carried out a systematic review of studies focusing on transport-related air pollution in Australian cities.

The systematic review identified sixteen air pollution epidemiology studies carried out in Australia. Their findings, broadly consistent with those from large epidemiological studies conducted in North America and Europe, show: (a) positive association between particulate matter (PM) and daily mortality and respiratory hospital admissions (Simpson et al., 2000; Simpson et al., 2005; Simpson et al., 1997; Morgan et al., 1998a; Chen et al., 2007), (b) positive association between ozone (O_3) and daily mortality and respiratory hospital admissions (Simpson et al., 1997; Petroeschevsky et al., 2001), (c) positive associations between NO_2 and daily hospital admissions (although this may reflect the impact of PM) (Morgan et al., 1998b; Barnett et al., 2006), (d) positive association between exposure to road transport-related air pollution and daily emergency department attendances for childhood asthma (Cook et al., 2011; Pereira et al., 2010; Rennick and Jarman 1992;

Jalaludin et al., 2000), (d) suggestive evidence of positive association between exposure to road transport-related air pollution and negative birth outcomes (Barnett et al., 2011; Mannes et al., 2005; Jalaludin et al., 2007; Pereira et al., 2011). These studies highlight the negative impact of transport air pollution on human health indicating that this is an important indicator to model.

Many studies use the distance from major roads as an indicator of potential exposure to road transport-related air pollution when modelling the impact. A recent report of the U.S. Health Effects Institute (HEI 2010) summarising evidence from a wide range of field studies, identified an exposure zone (up to 300-500m from a major road) as the area mostly affected by road transport-related emissions. This is consistent with studies carried out in Australian cities (Barnett et al., 2011; Hitchins et al., 2000; Cheng et al., 2010). Traffic management interventions (e.g. parking and stopping restrictions, redistribution of road space, park and ride schemes) are likely to have a positive impact on reducing potential exposure to road transport-related emissions and on population exposure levels within this zone (Vardoulakis et al., 2008). Broader scale interventions, such as improved fuel and vehicle engine technologies, are expected to reduce potential exposure to road transport-related emissions at a much wider area.

Traffic accidents and human health

Results of studies that determine the rates of pedestrian and cyclist accidents that result from urban form changes are mixed. Woodcock et al. (2009) modelled the changes in transport use towards increasing physical activity using a linear relationship between distance travelled by pedestrians and motor vehicles and risk of injury. They assumed that a doubling in the distance walked resulted in a doubling in the risk of injury. They also assumed that if the distance driven was halved the risk of injury to pedestrians was halved. Other research, however, reveals that the relationship between the numbers of people walking or bicycling and the amount of accidents with motorists is not linear (Litman, 2010). Pucher and Buehler (2010) maintain that injury and fatality rates per trip and per km decrease dramatically as cycling and walking rates increase. Furthermore, they determine that countries with low levels of walking and cycling have higher fatality and accident rates than countries with high levels of bicycling and walking. From this finding, they conclude that increasing levels of walking and cycling in Australian cities could result in less cycling accidents, especially if the increase coincided with a coordination of infrastructure and policies aimed at enabling safe and convenient active travel.

Perception of an area and human health

The ability of the urban form to be conducive to active transport is not purely related to an area’s physical attributes but is also related to the perception of the area as being walkable. Areas that are perceived as walkable have been found to result in increased levels of health (Eisenstein et al., 2011). Gebel et al. (2011) determined that residents of areas that are objectively measured as walkable that perceive their area as having low walkability have significantly lower levels of walking for transport than residents whose perceptions matched that of the objective measures, perhaps due to safety issues. A before-and-after study of improvements to an area, including the implementation of a light rail line (LRT), showed that more-positive perceptions of an area resulted in an average of a -0.36 lower Body Mass Index (BMI), 15% lower odds of obesity, 9% higher odds of meeting weekly recommended physical activity (RPA) levels through walking and 11% higher odds of meeting RPA levels through vigorous exercise (regardless of whether the person used the LRT line) (MacDonald et al., 2010).

Economic value improved through healthy environments and active transport

The research that looks at the health costs of different urban forms is very limited. Much of this lack of literature is due to the complexity of the calculations needed and the large number of assumptions that have to be built into such calculations. There are a few studies that quantify the health from reduced air pollution and increased physical activity and monetary benefits of replacing short car trips with a bicycle trips. This section presents the results of these studies.

The health (from reduced air pollution and increased physical activity) and monetary benefits of replacing 50% of short car trips (those <4 kms one-way) with a bicycle trip, equating to a 10% reduction in VKT, was quantified by Grabow, et al. (2011) for 11 Midwestern urban areas in the U.S. with a combined population of 31.3 million people. The estimated results of this change in travel behaviour was a mortality decline of 1,100 deaths per year and a combined benefit of improved air quality and increased physical activity resulting in a net health benefit of over $US7 billion per year, equating to approximately 2.5% of the health care costs of the region. A study in New Zealand by Lindsay, Macmillan and Woodward (2011) determined that a shift of 5% of VKT to cycling would reduce vehicle travel by approximately 223 million kms each year, saving about 22 million litres of fuel and reducing transport-related GHG emissions by 0.4%. Furthermore, they determined that the 5% reduction in VKT would result in 116 fewer deaths per year due to increased physical activity, six fewer deaths due to local air pollution from vehicle emissions and 5 more cyclist deaths due to road accidents. They concluded that the combined savings from air pollution and avoided deaths would be NZ$200 million per year. Stokes, MacDonald and Ridgeway (2008) developed a model to quantify public health benefits of a new light rail transit system in Charlotte, North Carolina. Using estimates of future riders, the effects of public transport on physical activity and obesity rates, they estimate future public health cost savings determining a cumulative public health cost savings of $12.6 million over nine years. Rabl and de Nazelle (2012) calculate the health benefits from switching to cycling from driving as 1300 Euro (€) per year for a cycling commute of 5km (one way) 5 days per week, 46 weeks per year. Furthermore in a city of plus 500,000 people the value of the associated reduction in air pollution is 30€ per year. These studies show that the health savings are substantial and when combined with the health outcomes have implications that are not yet fully understood or accounted for.

Several studies have attempted to estimate the cost of air pollution in high income countries. The health cost of ambient air pollution in the Greater Metropolitan Region (GMR) of Sydney was reported in a study published by the NSW Department of Environment and Conservation (DEC 2005). Using PM_{10} as an indicator, this study estimated the cost of air pollution to be between $1.66 billion and $15.21 billion per annum (if the health impacts of PM_{10} are estimated without a threshold), including the cost of life lost, the cost of illness and the cost of productivity losses. Given the contribution of motor vehicles to the total anthropogenic PM_{10} emissions in the Sydney region, the annual health cost of road transport-related PM_{10} in the GMR of Sydney was estimated to be between $105 million and $990 million. It should be noted that this is a conservative estimate since air pollution from motor vehicles is emitted close to the ground in densely populated areas (where many people are exposed) and is therefore likely to have a disproportionally large impact on population health compared to other emission sources. Amoako et al. (2003) estimated a substantially higher health cost of motor vehicles emissions in Sydney (between $496 million and $4.7 billion per year).

Comparison between a high walkability urban environment and a low walkability urban environment

Some urban form types fit the requirements for an active transport lifestyle as set out above. A comparison between a ‘high walkability urban environment’ and a ‘low walkability urban environment’ is made (see Chart 1) building on prior work by Trubka et al. (2010) to demonstrate the kind of monetary value associated with both kinds of urban form and associated lifestyles.

Trubka et al. (2010) examined the health and productivity costs of different urban development forms using a cost-of-illness approach. To do these calculations, Trubka et al. (2010) estimated that Australia’s indirect health cost of physical inactivity due to car dependence would be $AU1.78 billion. This would make the total cost of inactivity $3.82 billion, and the total value of all Australian adults meeting recommended activity levels $6.1 billion. Furthermore, they found that productivity increased by 6% when walking increased due to urban form improvements. This increase in productivity was from the enhanced physical and mental wellbeing due to increased walking.

From these calculations, a comparison between a ‘high walkability urban environment’ modelled on a Transit Oriented Development (TOD) to a ‘low walkability urban environment’ modelled on a conventional low-density suburban development, both of 1000 dwellings, was made. Using the Australian weekly earnings average of $AU1165.40 as the baseline level of productivity, Trubka et al. (2010) calculate that an average development of 1000 dwellings with an average of

1.83 adults of over 18, a reduction in absenteeism would accrue "an annual average of $489.47 per person" per year and an increase in productivity would result in an additional $3,468.23 per person per year in benefit (p.8). For an urban development of 1000 dwellings structured towards active-travel "where 19% more of the population meets their minimum physical activity requirements, these values surge to $170,420 and $1,207,550 per annum respectively, with a total annual health benefit of $1,377,970" (Trubka et al, 2010, p.8). They pursue this further for a 50-year development time span using rates of increase of 3%, to discover that the total value would be "$4,384,900 and $31,070,000 for absenteeism and presenteeism respectively" for a total of $35,454,900 for the productivity-related health benefits (p.8). These are substantial economic benefits from having an urban form geared towards active travel. They considerably outweigh the savings due to increased physical activity and reduced health cost reductions from active travel.

Chart 1 first provides a summary of transport and land use characteristics and then provides infrastructure costs, transportation costs, greenhouse gas emissions costs, and health costs related to activity levels. The calculations, from Trubka et al. (2010), for health are done by placing a value on an hour of moderate intensity activity per person, looking at adult Australians (approximately 15.4 million people in 2006), 1.83 people per dwelling, 30 minutes of moderate activity per day and 19% more walking in walkable neighbourhoods and cycling trips as 21% of walking trips. The estimated savings benefit due to increased physical activity levels in an active travel neighbourhood was calculated for a development of 1000 dwellings as:

Walking at 45,263 hours x $3.02/hr = $136,694
Cycling at 9,505 hours x $3.02/hr = $28,706.
Total $164,399

Chart 1 shows that when comparing the difference between high walkability urban environments and low walkability urban environments:

1. Infrastructure (regional power, water, sewer, and social infrastructure) and transport costs (mainly time and congestion costs) dominate and should be seen as a rational basis for changing our priorities towards more walkable urban environments. It should not need any other rationale.
2. Greenhouse gas emission costs are small unless social costs are considered, and then they become substantial but still lower than the infrastructure and transport costs. They are cumulative however and will become more important in future.
3. Health costs are very small if considered to be those related to sickness but health-related productivity gains are substantial and should be the focus of the extra rationale for changing our urban form and transport priorities. They are also additive to the other costs and together provide a powerful rationale for making more walkable urban environments.

Chart 2 provides a list of the functions and sources used to compile the table.

Conclusion

This review has attempted to investigate some of the urban form characteristics that can be measured when looking at health impacts of different urban transport and related land use form types, determining that the health benefits, and subsequent economic benefits, of walkable, transit orientated urban form have been well established and are measurable. This review has provided the first stage of a project looking at modelling the health impacts of urban form and transportation options (with an emphasis on Australia) identifying that density and mixed land use, vehicle miles travelled, access to public transport, access to green areas, transportation related air pollution levels, transportation related noise levels, are all measureable and important. Developing indicators to predict the safety for pedestrian and cycling from different urban forms is obviously very dependent on other measures than just simply looking at possible increases in distance travelled by those modes.

The economic impacts of transport and land use decisions can be determined. The comparison between a high walkability urban environment and a low walkability urban environment identified that infrastructure and transport costs dominate. Greenhouse gas emission costs are small unless the social costs are considered, and then they become substantial but still lower than the infrastructure and transport costs, though they are cumulative and will become more important in future. The health costs are relatively small if considered to be those related to sickness however health-related productivity gains that are associated with highly walkable urban areas are substantial. Increased productivity considerably outweighs the savings of increased physical activity and reduced health cost reductions from active travel alone. Furthermore these productivity gains are additive to the other costs and together all of these costs provide a powerful economic rationale for developing urban forms geared towards active travel.

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Per person per year	High Walkability Urban Environment (HWUE)	Low Walkability Urban Environment (LWUE)	Difference
Transport and Land use Characteristics NOTE: Typical characteristics for an Australian City.			
VKT per person per day	3-13 km	20-35 km	
Car trips per person per day	2.32	3.39	
Transit trips per person per day	0.56	0.165	
Transit accessibility	more than 80% w >15min service	less than 15% w >15min service	
Walk/Cycle trips per person per day	2.115	0.945	
Distance to CBD	less than 10 km	more than 40 km	
GhG per capita daily (CO2 -e)	0 to 4 Kg	8 up to 10 Kg	
Activity density	> 35	< 20	
Infrastructure Costs			
Roads	$5,086.56	$30,378.88	$25,292.32
Water and Sewerage	$14,747.62	$22,377.46	$7,629.84
Telecommunications	$2,576.11	$3,711.85	$1,135.74
Electricity	$4,082.12	$9,696.51	$5,614.39
Gas		$3,690.84	$3,690.84
Fire and Ambulance		$302.51	$302.51
Police		$388.42	$388.42
Education	$3,895.46	$33,147.27	$29,251.81
Health (Hospitals, etc.)	$20,114.87	$32,347.33	$12,232.46
Total Infrastructure	$50,502.74	$136,041.07	$85,538.33
Transport Costs			
Transport and Travel Time	$206,542.06	$342,598.10	$136,056.04
Roads and Parking	$46,937.54	$154,826.10	$107,888.56
Externalities	$2,219.88	$9,705.38	$7,485.50
Total Transport	$255,699.48	$507,129.58	$251,430.10
Greenhouse Gas Emissions Cost			
Offset Cost ($25/t)	$2,500.00	$5,400.00	$2,900.00
Social Cost ($215/t)	$21,500.00	$46,440.00	$24,940.00
(NB. not included in total)			
Total Greenhouse	$2,500.00	$5,400.00	$2,900.00
Physical Activity Costs			
Inactivity costs*		$4,229.95	$4,229.95
Productivity Loss		$34,454.90	$34,454.90
Total Activity Costs		$38,684.85	$38,684.85
Total (excluding social cost)	**$308,702.22**	**$687,255.50**	**$378,553.28**

*Includes social costs and direct and indirect costs and obesity costs.

Chart 1 – Comparison between a high walkability urban environment and a low walkability urban environment in Australia (costs in $AUS). Source: Authors building on Trubka et al., 2010.

Functions and sources used in establishing the costs.	
Transport and Land use Characteristics	
VKT per person	Extrapolated from Chandra (2005) using 'Total Car Energy Use', 'Total GHG', 'Per Capita GHG', and 'Population' to determine a Daily Total VKT and then a 'Daily Per Capita VKT'.
Car trips per person per day	Based on Melbourne. Source: Kenworthy and Newman (2000).
Transit trips per person per day	Based on Melbourne. Source: Kenworthy and Newman (2000). US Active Living Research Program (2009) 29% of people who use public transport were physically active for 30 + minutes per day, due primarily to walking to and from transit stops and transit users compared to car users walked 30 % more steps per day and spent 8.3 more minutes walking per day.
Transit accessibility	Transit accessibility relates to the proportion of land within an urbanised area that is within 400m of a full-service bus or tram, or within 800m of a train station. 'Full-service' is defined as a route operating seven days a week with at least four services per hour on weekdays and Saturdays during the day and two services per hour on Sundays and holidays.
Walk/Cycle trips per person per day	Based on Melbourne. Source: Kenworthy and Newman (2000).
Density	Walkable areas had + 30 mins exercise per week.
Distance to CBD	
GHG per capita daily (CO2 -e)	Y = [0.073 (Distance to CBD) - 0.25 (Transit accessibility) + 4.35]
Activity density	Jobs plus residences. Frank et al. (2004) conclude that each quartile increase in mixed land use results in a 12.2% reduction in the likelihood of obesity across different genders and ethnicities.
Intersection density	Permeable=250 intersections within one square mile
Infrastructure Costs	
Roads Water and Sewerage Telecommunications Electricity Gas Fire and Ambulance Police Education Health (Hospitals, etc.)	ABS (2008) and WAPC (2001)- weighted inflation rate from the Consumer, Producer and Labour Price Indices. WAPC (2001) comparative costs.
Transport Costs	
Transport and Travel Time Roads and Parking Externalities	Newman and Kenworthy, 1999- weighted inflation rate from the Consumer, Producer and Labour Price Indices, where possible.
Greenhouse Gas Emissions Cost	
Offset Cost ($25/t)	2007. GHG= (365 days/yr)(price/kg CO2-e) (No. of dwellings)(Inhabitants/dwelling) (0.073x - 0.25z + 4.35)
Social Cost ($215/t)	UK Government Economic Service $175 in 2000, = $217 in 2007
Physical Activity Costs	

Healthcare Costs Obesity (inactivity)	Direct: $1.5 billion (Econtech, 2007) = cost of inactivity. 54.2 % of Australia's over 18 population is inactive. Therefore $2.8 billion is the cost associated with an inactive population. Indirect: Health Canada's Economic Burden of Illness (1993) appropriates 54.3 % of the total cost of illness to indirect health = Estimate Australia's indirect cost of inactivity at $1.78 billion, the total cost of inactivity at $3.28 billion.
Productivity Loss	2.1 day reduction in workdays lost due to illness, stress, or waning workplace satisfaction (absenteeism) and 6.2% increased ability for employees to focus on tasks and maintain focus for longer periods of time (presenteeism or on-the-job productivity) based on averages from Shephard (1992) and Lechner and de Vries (1997). Using Australian weekly earnings average of $AU1165.40 as the baseline level of productivity, and an average development of 1000 dwelling with an average of 1.83 adults of over 18.

Chart 2 – Functions and sources used in establishing the costs in the comparison between a high walkability urban environment and a low walkability urban environment in Australia. Source: Compiled by the Authors.