Journal of Transport & Health xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Health impacts of urban transport policy measures: A guidance note for practice

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ABSTRACT

Background: Urban transport related exposures and practices are associated with a significant burden of morbidity and premature mortality, which could be prevented by changing current practices. Cities now have access to an increasingly wide range of transport policy measures which continue to expand. However, the health impacts of these measures are not always explicitly defined or well understood and therefore may not be sufficiently considered when selecting policy measures.

Aims: The aim of this paper is to qualitatively review 64 different transport policy measures indexed in the Knowledgebase on Sustainable Urban Land use and Transport (KonSULT), and provide an indication of their potential health impacts, based on expert judgment.

Results: We report that key health impacts of transport occur via pathways of motor vehicle crashes, traffic-related air pollution, noise, heat islands, lack of green space, physical inactivity, climate change and social exclusion and community severance. We systematically describe the expected health impacts of transport policy measures sourced from KonSULT and find that many, but not all, can have a positive impact on health. The magnitude of both the positive and negative impacts remains largely unknown and warrants further research and synthesis.

Conclusions: Urban transport is responsible for a large mortality and morbidity burden and policy measures that are beneficial to health need to be implemented to reduce this burden. There are considerable differences between these policy measures in terms of potential health impacts and this should be considered in any transport planning. It is important to monitor the health impacts of all policy measures to provide further evidence on whether they work as expected or not, to ensure that the most cost-effective solutions, with the largest benefits and the smallest health risks, are being adopted.

1. Introduction

Over half the world's population lives in cities and this proportion is expected to increase to over 70% in the next 20 years (Rydin et al., 2012). Transport plays a central role in shaping cities' economic and social development, layout and spatial arrangement (Eddington, 2006). However, there is an ever-growing awareness of the adverse health impacts associated with a range of transport-related exposures and practices. A recent health impact assessment in Barcelona investigated the health impacts of urban transport-

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http://dx.doi.org/10.1016/j.jth.2017.06.003
Received 11 November 2016; Received in revised form 1 June 2017; Accepted 6 June 2017
2214-1405/

related exposures including air pollution, noise, heat, green space and physical activity and suggested that 20% of premature mortality may be preventable by changing current urban transport practices (Mueller et al., 2017a).

The health impacts associated with transport are increasingly being recognized both in academic (Khreis et al., 2016; Dora and Racioppi, 2003; Dora, 1999; Nieuwenhuijsen, 2016; Cohen et al., 2014), and policy circles. For example, the European Commission's Action Plan on Urban Mobility (European Commission, 2009) recommended encouraging and accelerating the take-up of Sustainable Urban Mobility Plans (SUMPs), which, in contrast to traditional transport planning approaches, include "health" as a primary objective and emphasize the coordination of policies between related sectors, including health (ELTIS, 2014; Gerike et al., 2016). The 2011 White Paper on Transport (European Commission, 2011) proposed that there might be a mandatory requirement for SUMPs for cities over a certain population and that the allocation of regional and cohesion funds might be conditional on the submission and auditing of a SUMP (May et al., 2016). However and despite these and other initiatives, there remains a lack of a substantive influence of health considerations in transport policy and practice (Khreis et al., 2016; McAndrews and Marcus, 2014), which may be traced back to the lack of clarity in policy guidance on the importance of considering and incorporating health objectives in transport plans and strategies (Khreis et al., 2016) and/or the lack of transport practitioners' awareness of the wider range of health impacts related to transport plans and strategies (Cohen et al., 2014).

Cities now have access to an increasingly wide range of policy measures which are used to develop local transport plans. Detailed information on individual policy measures and guidance on their effectiveness are available from several sources. The Knowledgebase on Sustainable Urban Land use and Transport (KonSULT) (www.konsult.leeds.ac.uk) is one principal source. Health as an objective is yet not *explicitly* part of KonSULT's objectives. The health impacts of policy measures indexed in KonSULT are not explicitly described and there is no consistent assessment of the performance of these policy measures, in terms of their health impacts. The aim of this paper is to review different transport policy measures focusing on 64 measures described in KonSULT (www.konsult.leeds.ac.uk), and provide an indication of their potential health impacts, in terms of direction(s) (i.e. benefit or risk) and pathway(s) of action, based on expert judgement and opinion. Future work will include Public Health as an objective in the KonSULT knowledgebase and provide case studies on the indicated health impacts and their magnitude, where possible.

This paper is structured as follows. First, we provide an overview of the initial development and content of KonSULT. Second, we outline the methodologies used to (1) synthesize the health effects of transport-related exposures and practices and (2) to assign potential health impacts to KonSULT's specific measures. We overview the literature on the established health effects of urban transport exposures and practices. This is followed by showing the pathway(s) of action and the potential health impacts of each of KonSULT's 64 policy measures. We finally discuss our findings and the strengths and limitations of this work. We conclude the paper by making research and practice recommendations.

2. Methods

2.1. KonSULT

KonSULT was first presented at the World Conference on Transport Research Society (WCTRS) in Leeds in 2002. The aim of KonSULT is to assist policy makers, professionals and interest groups with the challenges of achieving sustainability in urban transport, and find appropriate policy measures and packages for their specific contexts and objectives. KonSULT gives an explanation and information on individual policy measures. The knowledgebase has three elements: a Measure Option Generator, a Policy Guidebook and a Decision-Makers' Guidebook. The Measure Option Generator includes facilities for suggesting individual policy measures, complementary policy measures and packages, and is based on the specified context of the user and scores which are given in the Policy Guidebook. The Policy Guidebook gives information on each policy measures included in the knowledgebase. The Decision-Makers' Guidebook shows the challenges facing those involved in urban transport policy, provides a logical staged structure for tackling those challenges, and gives guidance at each stage (May et al., 2016). Here, we focus our work on the content of The Policy Guidebook. Jopson et al. (2004) provide a fuller description of the development of the Policy Guidebook. In brief, urban transport policy measures are grouped into six higher level categories in the Policy Guidebook: (1) land use, (2) infrastructure, (3) management and service, (4) attitudinal and behavioural, (5) information provision and (6) pricing.

2.2. Review of health effects of transport policy measures

To determine the potential health impacts of each individual policy measure included in KonSULT, we were guided by some recent publications on the synergies between urban transport and health (Khreis et al., 2016; Nieuwenhuijsen, 2016; Nieuwenhuijsen et al., 2016b). We searched PubMed, Web of Science, Science Direct, and references from relevant articles in English language from January 1, 1980, to September 1, 2016, using the search terms: "traffic", "transport", "car", "public transport", "walking", "cycling" in combination with "motor vehicle crashes", "air pollution", "noise", "temperature", "green space", "heat island", "carbon emissions", "built environment", "walkability", and/or "mortality", "respiratory disease", "cardiovascular disease", "hypertension", "blood pressure", "annoyance", "cognitive function" and "reproductive outcomes". Following an initial review of the literature and the authors´ knowledge, we determined the higher-level pathways by which urban transport can impact on health and gathered evidence on these impacts. We do not systematically report the results but focus on systematic reviews, meta-analyses and articles published in the past five years to provide the latest and most up to date information. We use older articles if they represent seminal research or are necessary to understand recent findings.

2.3. Assigning potential health impacts to KonSULT's policy measures

KonSULT's Policy Guidebook, including the 64 transport policy measures, was accessed from http://www.konsult.leeds.ac.uk/pg/. HK and MJN systematically and independently went through each of the individual policy measures included in the Policy Guidebook including going through their 'summary', 'first principles assessment' and 'evidence on performance' sections. Each of the measures was assigned an expected health impact(s), based on professional judgment and the first principles identified from the former literature review. In addition, where the impacts were unclear or contested (for example in the case of low emission zones, electric vehicles), further literature search was carried out to establish the current evidence, and the following studies on interventions effects were consulted (Holman et al., 2015; Morfeld et al., 2014; Ji et al., 2012; Timmers and Achten, 2016). Subsequently, HK and MJN concurrently went through each of the individual policy measures and their assigned health impacts, and agreed by consensus, on the final assigned health impacts for each measure. In a final stage, ADM went through each of the individual policy measures and their assigned health impact to confirm the direction of the impacts assigned to each measure. Differences were resolved by consensus. The final presented impacts have been approved by all authors. As at this stage it was not possible to provide detailed quantitative measures of the potential health impacts of each of KonSULT's measures, we conducted a qualitative assessment of the measures' health impacts instead and point the reader to seminal papers on the topic.

3. Results

3.1. Overview of transport and health linkages and effects

Besides the widely-acknowledged health impacts associated with road traffic injuries and premature mortality due to motor vehicle crashes, there is a whole range of health impacts, including premature mortality and numerous morbidity outcomes, related to urban transport exposures and practices. Fig. 1 illustrates the linkages between urban transport exposures or practices and adverse health impacts, which current evidence suggests. Adverse health impacts occur through motor vehicles air pollution and noise, local urban heat exposures, lack of green space and biodiversity loss, climate change effects, social exclusion, community severance and physical inactivity from sedentary behaviour and an over reliance on motorised travel.

These exposures, and hence their associated health impacts, are not equally distributed in the population, with lower socio-economic groups being exposed more and bearing the highest burden (Marshall et al., 2015; Crawford et al., 2008; Estabrooks et al., 2003; Havard et al., 2009; O'Neill et al., 2003; Carrier et al., 2016; Nega et al., 2013). As such, transport practices have the potential to increase existing health inequalities (Marmot, 2005), contributing further to the ill health of the most deprived groups, who exhibit a variety of other factors that makes them more vulnerable to environmental exposures (e.g. poor diet, suboptimal health care, stress, violence etc.).

Table 1 is a summary of the evidence gathered from the review of the health effects associated with transport policy measures. Worldwide, over 1.5 million deaths and 79.6 million injuries are due to road motor vehicle crashes, annually (Bhalla et al., 2014). Traffic-related air pollution causes an annual 184,000 deaths globally, including 91,000 deaths from ischemic heart disease, 59,000

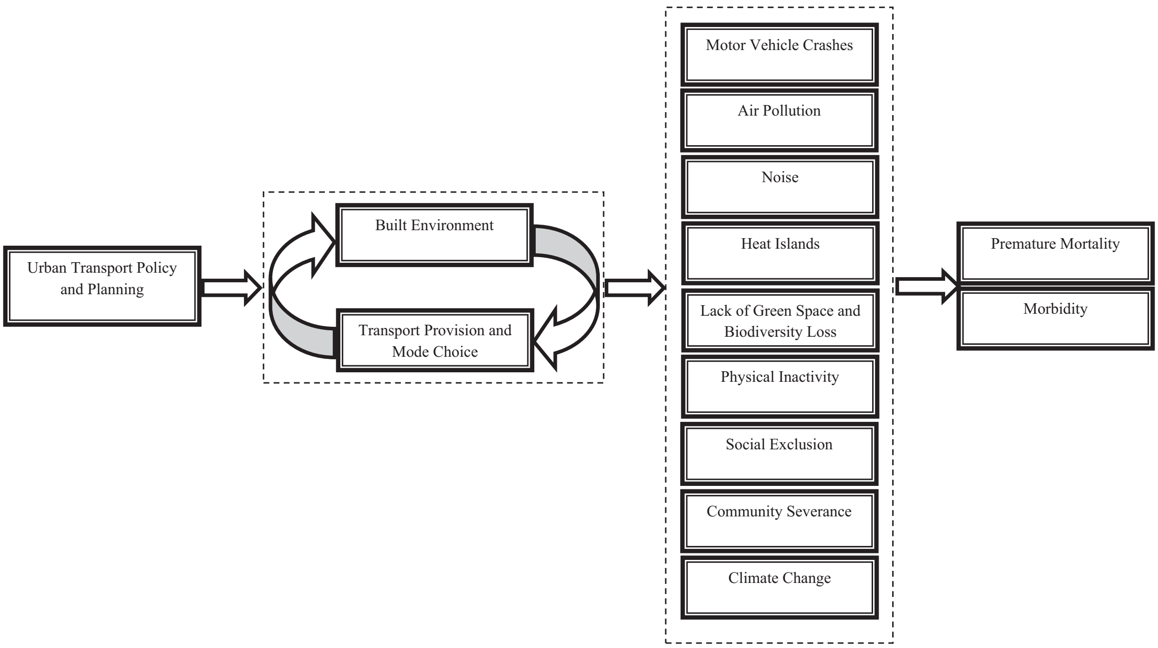

Fig. 1. Linkages between urban transport and adverse health impacts.

Table 1
Health effects and impacts of exposures and lifestyles linked to urban transport.

Pathways of action	Transport-related source	Health effect or impact	Evidence
Motor vehicle crashes	Crashes	Premature mortality, injuries, traumas, post-traumatic stress, other indirect impacts including less active travel and outdoor play/physical activity due to perceived unsafety (see health effects of physical inactivity), e.g. road traffic causes over 1.5 million deaths and 79.6 million injuries	Bhalla et al. (2014); World Health Organization (2015); (Geurs et al., 2009)
Air pollution exposure	Motor vehicle exhaust and non-exhaust emissions, secondary air pollutants formation, underground, metro, rail exposures	Premature mortality, e.g. 184,000 deaths globally, including 91,000 deaths from ischemic heart disease, 59,000 deaths from stroke, and 34,000 deaths from lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer	Bhalla et al. (2014); Beelen et al. (2014); Health Effects Institute (2010)
		Lung cancer incidence	Raaschou-Nielsen et al. (2013); Health Effects Institute (2010); Beelen et al. (2008); Raaschou-Nielsen et al. (2011)
		Cardiovascular disease incidence	Cesaroni et al. (2014); Bhaskaran et al. (2009); Shah et al. (2013)
		Asthma incidence	Khreis et al. (2017); Health Effects Institute (2010); Bowatte et al. (2014); Anderson et al. (2013); Jacquemin et al. (2015)
		Reduced lung function in children	Gehring et al. (2013); Adam et al. (2015); Eeftens et al. (2014); Health Effects Institute (2010); (Barone-Adesi et al., 2015)
		Reduced cognitive function	Sunyer et al. (2015); Freire et al. (2010); Power et al. (2011)
		Respiratory infections during early childhood	MacIntyre et al. (2014); Brauer et al. (2002)
		Low birth weight	Pedersen et al. (2013); Brauer et al. (2015); Stieb et al. (2012)
		Premature birth	Gehring et al. (2011); Stieb et al. (2012)
		Diabetes	Krämer et al. (2010); Coogan et al. (2012); Eze et al. (2015)
		Obesity	Jerrett et al. (2014); McConnell et al. (2015)
Noise exposure	Motor vehicle engine, tyre/ road contact, operational noise	Premature mortality, e.g. one million healthy life years are lost every year from traffic-related noise in the western part of Europe (conservative estimates), including 61 000 years for ischaemic heart disease, 45 000 years for cognitive impairment of children, 903 000 years for sleep disturbance, 22 000 years for tinnitus and 654 000 years for annoyance	Fritschi et al. (2011); Halonen et al. (2015)
		Cardiovascular mortality and morbidity	Ndrepepa and Twardella (2011); Babisch et al. (2014); Münzel et al. (2014); Basner et al. (2014)
		Annoyance and sleep disturbance	Omlin et al. (2011); Laszlo et al. (2012); Basner et al. (2014)
		High blood pressure in children	Paunović et al. (2011)
		Reduced cognitive function in children	Stansfeld et al. (2005); Van Kempen and Babisch (2012); Basner et al. (2014)
		Adverse reproductive outcomes	Ristovska et al. (2014)
		Type 2 diabetes	Dzhambov (2015)
Increased urban temperature exposure	Urban heat island effect, tailpipe and evaporative heat and emissions	Premature mortality	Ma et al. (2014); Guo et al. (2014)
		Cardiorespiratory morbidity	Turner et al. (2012); Ye et al. (2012); Cheng et al. (2014)
		Hospital admissions	Hondula and Barnett (2014)
		Children´s mortality and hospitalization	Xu et al. (2012)
Lack of green space and biodiversity loss	Land acquisition for infrastructure, depletions of green space, partition or destruction of wildlife from	Immune system, allergies and asthma	Hanski et al. (2012); Dadvand et al. (2014)
		Mortality and longevity	Mitchell and Popham (2008); Gascon

(continued on next page)

Table 1 *(continued)*

Pathways of action	Transport-related source	Health effect or impact	Evidence
	infrastructure		et al. (2016)
		Cardiovascular disease	Pereira et al. (2012); Tamosiunas et al. (2014)
		Self-reported general health	Maas et al. (2006); De Vries et al. (2013)
		Mental health	Gascon et al. (2015)
		Behavioral problems in children	Amoly et al. (2014)
		Cognitive function	Dadvand et al. (2015)
		Sleep patterns	Astell-Burt et al. (2013)
		Recovery from illness	Ulrich (1984)
Physical inactivity	Reliance on motor vehicle travel and lack of active travel	2.1 million deaths each year are attributable to insufficient physical activity	Forouzanfar et al. (2015)
		Premature mortality	Woodcock et al. (2011)
		Cardiovascular disease	Hamer and Chida (2009)
		Diabetes	Jeon et al. (2007)
		Dementia	Hamer and Chida (2009)
		Breast cancer	Monninkhof et al. (2007)
		Colon cancer	Harriss et al. (2009)
Climate change	Extreme weather events, effects on the ecosystem and species, sea level rise, salination of coastal land and sea water, environmental degradation	Thermal stress, premature deaths (150,000–250,000 annually), illness and injury from floods, storms, cyclones etc., food poisoning, unsafe drinking water, changes in vector-pathogen host relations and in infectious disease geography/seasonality, impaired crop, livestock and fisheries yield and impaired nutrition, health, survival, changes in air pollution, loss of livelihoods, displacement, leading to poverty and adverse mental and physical health	McMichael et al. (2006); Patz et al. (2005),; Watts et al. (2015); Woodcock et al. (2009); Hales et al. (2014)
Social exclusion and community severance (barrier effects)	Social exclusion and widening socio-economic divides, lack of access to active and public transport means reducing physical activity, lack of access to healthy food, recreation facilities, healthcare, work, social interaction and public transport nodes due to physical or physiological severance caused by transport infrastructure or activity, increased risk of motor vehicle crashes	Mental health and well-being, premature mortality, lack of physical activity (e.g. active transport and children's play; see effects of physical inactivity), stress	Markovich and Lucas (2011); Schwanen et al. (2015); Mackett and Thoreau (2015); Lochner et al. (2003); Holt-Lunstad et al. (2015); Anciaes et al. (2016); Mindell and Karlsen (2012); Cohen et al. (2014)

deaths from stroke and 34,000 deaths from lower respiratory infections, chronic obstructive pulmonary disease, and lung cancer, and these figures are likely underestimated (Bhalla et al., 2014). Traffic-related air pollution also causes numerous adverse health outcomes and is associated with increasingly prevalent diseases such as obesity and diabetes which are now responsible for a large financial and health resources burden and lost productivity. Transport-related air pollution is not limited to traffic sources but public transport such as metro and rail can also be a key source of particular exposures such as ambient particulate matter (Cartenì et al., 2015; Martins et al., 2016). Motor vehicle noise has been associated with a range of adverse health outcomes, including cardiovascular morbidity and sleep disturbance and was suggested to be attributing to a disease burden comparable to that of air pollution. For example, a recent health impact assessment in the metropolitan areas of Barcelona found that 599 premature deaths are attributable to traffic-related noise, compared to 659 attributable to air pollution. Roads and traffic-related infrastructure including roads and parking areas take up significant amounts of already limited urban space that could be otherwise used for green or public space in cities. The lack of green space is associated with, amongst others, premature mortality and poor mental health while the provision of green space is associated with many health benefits including reduced all-cause and cardiovascular mortality and improved mental health (Nieuwenhuijsen et al., 2016a; Van Den Bosch and Nieuwenhuijsen, 2017). Increasing the abundance and cover of vegetation can also mitigate the impact of climate change on public health (Knight et al., 2016).

Roads and traffic-related infrastructure may increase local temperatures in urban areas, via the so-called heat island effect, where green, wooded or open areas have been substituted by asphalt and concrete for infrastructure such as parking areas or roadways (Zhang et al., 2013; Gago et al., 2013). Besides traffic-related infrastructure, motor vehicles can also raise temperatures through tailpipe emissions (methane, nitrous oxide, carbon dioxide, and black carbon). Together with long term climate change and re-radiation effects of dense urban structures, motor vehicles increase urban and global temperatures (Petralli et al., 2014; United States Environmental Protection Agency, 2016), potentially halting progress to stop climate change (Estrada et al., 2017). Increases in temperatures causes premature mortality, cardiorespiratory morbidity, and an increase in the number of hospital admissions.

The lack of physical activity, in part, due to lack of opportunities for active travel and sedentary behavior related to driving a car, causes 2.1 million premature deaths, annually. It also increases the risks of various morbidity endpoints including cardiovascular disease, diabetes, dementia and breast and colon cancers (Woodcock et al., 2011).

Community severance arises when transport infrastructure or motorised traffic act as a physical or psychological barrier separating built-up areas from other built-up areas or open spaces (Anciaes et al., 2016). It can increase the risk of motor vehicle crashes, discourage and decrease levels of active transport, restrict access to public transport also reducing physical activity, and restrict access to healthy food, recreation facilities, healthcare, work and social interactions; all of which can lead to increased morbidity and premature mortality.

Warming, precipitation and climate fluctuations trends due to anthropogenic climate change are linked to around 150,000–250,000 annual premature deaths and numerous prevalent diseases. Further, climate change effects can occur through extreme weather events, changes in air pollution, water and food scarcity and displacement. Yet, the health impacts through climate change are considered the most difficult set of impacts to quantify, due to their long term nature, and uncertainties in attributing the expansion or resurgence of diseases to climate change (Patz et al., 2005).

The evidence of the adverse health impacts associated with the above exposures and lifestyles has been strengthening over the past years and there is evidence that the disease burden due to motorised transport has been growing and is alarming. For example, deaths due to road crashes grew by 46% and deaths attributable to air pollution grew by 11% in the last two decades. Both combined, the road transport death toll exceeds that of, for example, HIV/AIDS, tuberculosis, malaria, or diabetes (Bhalla et al., 2014).

3.2. Potential health impacts to KonSULT's policy measures

KonSULT contains 64 policy measures which are divided into 6 categories representing different types of possible interventions under: (1) land use, (2) infrastructure, (3) management and service, (4) attitudinal and behavioral, (5) information provision and (6) pricing. The individual policy measures under each of these categories are listed in Table 2, alongside their potential health impact and pathway of action. The table describes the direction of the expected health impacts (positive or negative), but does not describe the scale of the impacts or attempts to quantify it. Such assessment is difficult to make with the current limited evidence base quantifying impacts and is beyond the scope of the current paper. Fig. 2 is an example of the mental models that governed the impacts assignment, as applied to the first policy measure in KonSULT: “development density and mix”.

The first category of interventions: *land use*, includes four individual policy measures. Land use policy measures such as development density and mix and land use to support public transport can have health impacts through affecting both the level of travel and the overall travel patterns. Higher densities of activities can improve accessibility, reduce the need for motorised travel and encourage shorter journeys and increased levels of active travel (e.g. walking and cycling) and physical activity. This can result in reductions in air pollution, noise and climate change effects and possibly local heat islands and motor vehicle crashes due to reductions in road traffic levels. Dense and mixed developments can help make public transport provision viable. Encouraging public transport use through land use planning can have positive health impacts through increasing the accessibility of urban areas, the convenience of public transport use and encouraging a mode shift away from private car use that is usually accompanied by increases in active travel and physical activity. Further positive health impacts are possible if there is an increase in green space provision and a decrease in inequalities by supporting the mobility needs of vulnerable groups by transport means other than the private car. The health impacts of parking standards policies vary, depending on the direction of these policies. If the amount of parking required, or permitted, for new developments is reduced, then developers might rethink where to position their developments to provide access for their target customers by transport means other than the private car. This can have positive health impacts through the same pathways above if the development is positioned in dense and mixed urban space and/or near public transport hubs. On the contrary, the generous provision of parking for new developments can reinforce the use of the private car for travel from and to the development, increase the amount of lift-giving and have negative impacts because of local air pollution due to the induced travel demand associated with the new development. Further negative impacts are possible if there is a new land uptake leading to a decrease in exposure to green space or biodiversity loss. The impact of developers' contribution depends on the infrastructure they support.

The second category of interventions: *infrastructure*, includes nine individual policy measures. Many infrastructure policy measures including trams and light rail, new rail stations and lines, bus rapid transit, park and ride, terminals and interchanges, cycle networks and pedestrian areas and routes can have positive health impacts through some increase in active travel and physical activity and possible reductions in traffic levels and traffic-related air pollution, noise, heat island effect and climate change effects. If there is an increase in green space, more health benefits are expected. Furthermore, as green space may improve the pedestrian and cyclists experience, then green space provision may also reinforce a shift from the private car to using these active travel modes. Further positive impacts are expected if there is a reduction in inequalities, for example, by supporting the travel of vulnerable groups by transport means other than the private car. As some of these infrastructure policy measures also tend to increase the geographical accessibility of urban space, then integrating these interventions within a wider land use framework is desirable and can help to better account for and realize potential positive health impacts. On the other hand, measures like new rail stations and lines may have impacts through encouraging urban sprawl, new low-density development, longer distance travel and higher associated emissions. Further negative impacts are possible if there is a decrease in exposure to green space and an increase in community severance and inequalities by for example unaffordable fares or land acquisition and displacement of vulnerable groups. From the infrastructure category, new road construction and off-street parking can have negative health impacts through increased car use and motorised travel convenience and therefore the potential to reduce active travel and physical activity, increase air pollution, heat, noise and climate change effects and possibly motor vehicle crashes. Further negative health impacts will occur if the land uptake for the new

Table 2
Potential health effects and impacts of urban transport policy measures sourced from KonSULT (http://www.konsult.leeds.ac.uk/pg/).

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
Land use – 4 policy measures	Development density and mix http://www.konsult.leeds.ac.uk/pg/10/	Higher development densities may reduce travel distance and the need for and use of private cars. Mixed developments can improve accessibility and reduce the need for travel and increase diversity of (reliable/effective) transport modes e.g. public transport and make active travel more convenient/efficient	Positive impacts through increased active travel and physical activity, reduction in air pollution, noise and climate change effects and possibly heat island effect and motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space
	Land use to support public transport http://www.konsult.leeds.ac.uk/pg/26/	Increasing public transport and active travel for non-commuting trips. Reducing car use and encouraging mode change from the private car	Positive impacts through increased active travel and physical activity, reduction in air pollution, noise and climate change effects and possibly heat island effect and motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space and a reduction in inequalities
	Parking standards http://www.konsult.leeds.ac.uk/pg/16/	Effects depend on whether parking supply for new development is increased or decreased since it may increase or decrease car use. Reduced parking supply may reduce land up take	Impacts depend on direction of parking supply. Increasing parking supply will produce negative impacts because of increased car use and car-related infrastructure; increasing air pollution, noise, heat island effect and climate change effects, alongside increased local air pollution surrounding the parking areas and potentially decreasing active travel and physical activity. Further negative impacts are possible if there is a decrease in exposure to green space
	Developer contributions http://www.konsult.leeds.ac.uk/pg/53/	Developers providing a payment (or levy) to support infrastructure in the area they develop. Improved transport infrastructure but effect depends on use and the type of transport infrastructure put in place with new development	Depends on development size and location/accessibility and type of transport infrastructure put in place. Transport infrastructure catering for car traffic will generate negative impacts by inducing more traffic in the area and hence more air pollution, noise, heat island effect and climate change effects and generating conflicts with other road users leading to more motor vehicle crashes, and potentially increasing parking spaces related to the above. Further negative impacts are possible if there is a decrease in exposure to green space and an increase in inequalities
Infrastructure – 9 policy measures	New road construction http://www.konsult.leeds.ac.uk/pg/54/	Increase in traffic and in traffic related exposures and community severance, and possibly reduced road safety. Induced demand on new roads or older roads with increased capacity	Negative impacts through decreased active travel and physical activity, increase in air pollution, noise, heat island effect, climate change effects and possibly motor vehicle crashes. Further negative impacts are possible if there is a decrease in exposure to green space and an increase in social exclusion, inequalities and community severance
	Off street parking http://www.konsult.leeds.ac.uk/pg/39/	Taking parked cars off the streets and freeing up space, providing off street parking space possibly increasing car use and its convenience	Positive impacts are possible through increasing the quality of public space (e.g. if parked cars are taken off the streets and not replaced). Negative impacts through some increase in car use and a reduction in active travel and in physical activity, increase in air pollution, heat island effect, noise and climate change effects are possible. Further negative impacts are possible if there is a decrease in exposure to green space
	Trams and light rail http://www.konsult.leeds.ac.uk/pg/02/	Improving accessibility in urban areas, increasing the diversity of mode choice and possibly reducing car use and increasing modal shifts from the car. New light rail lines may encourage more decentralised patterns of land use and longer distance travel	Positive impacts through some increase in active travel and physical activity, reduction in air pollution, noise and climate change effects and possibly motor vehicle crashes. Further possible positive impacts are possible if there is an increase in exposure to green space and a reduction in social

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
			exclusion and inequalities. Negative impacts through possible sprawl, longer distance travel and associated emissions
	New rail stations and lines http://www.konsult.leeds.ac.uk/pg/04/	Increasing the geographical accessibility of the rail network, increasing public transport journeys and possible reduction in car use. New stations may encourage more decentralised patterns of land use and longer distance travel and new rail lines may increase community severance	Positive impacts through some increase in active travel and physical activity, reduction in air pollution and climate change effects if trains are not high emitter vehicles (e.g. clean electric trains rather than diesel trains) and possibly motor vehicle crashes. Negative impacts through possible sprawl, longer distance travel and associated emissions. Further negative impacts are possible if there is decrease in exposure to green space and an increase in inequalities (e.g. due to fare structure or land acquisition) and community severance
	Bus rapid transit http://www.konsult.leeds.ac.uk/pg/11/	Faster more reliable and comfortable journeys than conventional bus services, possibly leading to an increase in users and modal shifts from cars	Positive impacts through some increase in active travel and physical activity, reduction in air pollution, noise and climate change effects if the buses are low emitter vehicles and possibly a reduction in motor vehicle crashes. Further possible positive impacts are possible if there is an increase in exposure to green space and a reduction in inequalities
	Park and ride http://www.konsult.leeds.ac.uk/pg/35/	Cut in congestion and increase public transport use towards and in city centre. Possible reductions in traffic levels within urban areas. Will require additional land	Some positive impacts through reduction in air pollution, heat island effect, noise and climate change effects, and possibly increases in active travel and physical activity
	Terminals and interchanges http://www.konsult.leeds.ac.uk/pg/60/	Improve door-door journey times of public transport modes and improving access to urban centres. Possible reductions in car use	Positive impacts through increased active travel and physical activity and reductions in air pollution, noise and climate change effects if there is a reduction in car use. Negative impacts are possible if there is a decrease in exposure to green space
	Cycle networks http://www.konsult.leeds.ac.uk/pg/10/	Cut in congestion and increase cycling by providing safe, efficient, attractive, and convenient cycling infrastructure, and integration of cycling with public transport	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space and a reduction in inequalities
	Pedestrian areas and routes http://www.konsult.leeds.ac.uk/pg/49/	Providing safe and attractive pedestrian areas. Reduction in car presence and increase in walking. Has impacts on mode choice in general	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space
Management and service – 23 policy measures	Road maintenance http://www.konsult.leeds.ac.uk/pg/52/	May improve safety and increase speed. May reduce air pollution and noise through new developments in road building materials	Possible positive impact through reduction of motor vehicle crashes or negative impacts through increase in speeds and possibly motor vehicle crashes and their severity. Possible reductions in air pollution, noise and climate change effects depending on road building or rehabilitation materials
	Conventional traffic management http://www.konsult.leeds.ac.uk/pg/51/	Smoother driving conditions and less congestion, idling, and stop start driving. Possible road space reallocations and re-routing increasing traffic volumes and community severance and reducing local access	Possible positive impacts though reduction of motor vehicle crashes, air pollution from idling and stop start driving. Possible negative impacts through increases in traffic volumes, air pollution, noise, heat island effect, and climate change effects and possibly motor vehicle crashes. Further negative impacts are possible if there is decrease in exposure to green space and an increase in inequalities and community severance

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
	Urban traffic control http://www.konsult.leeds.ac.uk/pg/14/	Reduction of idling, stop start driving and better pedestrian conditions. Increases road capacity which may cause a shift towards car use unless it is used for public transport control	Possible positive impacts though reduction of motor vehicle crashes, air pollution from idling and stop start driving. Potential for more active travel and physical activity if better pedestrian conditions are achieved. Possible negative impacts through increases in road capacity and car use, air pollution, noise, heat island effect and climate change effects and possibly motor vehicle crashes
	Intelligent transport systems http://www.konsult.leeds.ac.uk/pg/24/	Cover a wide range of applications of information and communications technologies to transport. Can lead to increases in effective capacity	Impacts unclear and depend on changes in road capacity and traffic flow parameters. Impacts will vary considerably based on the application
	Accident remedial measures http://www.konsult.leeds.ac.uk/pg/18/	Speed limitation and enforcement. Road marking and signage	Positive impact through reduction of motor vehicle crashes, and noise. Effects of air pollution and climate change effects dependent on speed and potential increases in stop start driving and idling
	Traffic calming measures http://www.konsult.leeds.ac.uk/pg/13/	Reduction in vehicle speed and acceleration. Possible improvements in conditions for non-motorized street users	Positive impact through reduction of motor vehicle crashes, and noise. Effects of air pollution and climate change effects dependent on speed and acceleration potential increases in stop start driving and idling. Potential improvements for non-motorized street users can increase active travel and physical activity
	High occupancy vehicle lanes http://www.konsult.leeds.ac.uk/pg/29/	Discourage single or low occupancy car use resulting in fewer cars or encouraging public transport use. Encourage car sharing or public transport use, or both	Positive impacts through reduction of air pollution, heat island effect, noise and climate change effects and potential increases in active travel and physical activity. Further positive impacts are possible if there is a reduction in inequalities
	Physical restrictions http://www.konsult.leeds.ac.uk/pg/12/	Limit car use in urban areas resulting in fewer vehicles and possible increases in cycling, walking and public transport use and decreases in community severance	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space and a reduction in inequalities and community severance
	Regulatory restrictions http://www.konsult.leeds.ac.uk/pg/09/	Limit car use resulting in fewer vehicles and possible increases in cycling, walking and public transport use and decreases in community severance	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in green space and a reduction in community severance. May have a negative effect through inequalities caused by traffic diversions and emissions shift to lower socio-economic neighbourhoods
	Low emission zones http://www.konsult.leeds.ac.uk/pg/63/	Reinforcing areas where access by vehicles is limited to those with low emissions	Little evidence for a reduction of air pollution, depending on the air pollution metric investigated. Possible negative impacts through inequalities caused by traffic diversions and emissions shift to lower socio-economic neighbourhoods
	Parking controls http://www.konsult.leeds.ac.uk/pg/15/	Fewer cars and more road space for e.g. pedestrians and cyclists	Positive impacts through reduction in air pollution, heat island effect, noise and climate change effects and increase in active travel and physical activity. May reduce severance caused by traffic searching for parking places Further positive impacts are possible if there is an increase in exposure to green space
	New rail services http://www.konsult.leeds.ac.uk/pg/33/	Attracting car users potentially resulting in fewer cars. Increased connectivity but potential increases in community severance	Positive impacts through some increase in active travel and physical activity, reduction in air pollution and climate change effects if

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
			trains are not high emitter vehicles and possibly motor vehicle crashes. Negative impacts are possible if new rail lines are build leading to a decrease in exposure to green space and an increase in inequalities or community severance
	Bus services http://www.konsult.leeds.ac.uk/pg/42/	Providing quality, inclusive cost effective public transport services. Can lead to fewer cars and increased connectivity	Positive impacts through some increase in active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects if buses are not high emitter and noisy vehicles and possibly motor vehicle crashes. Possible positive impacts though reduced social exclusion
	Bus priorities http://www.konsult.leeds.ac.uk/pg/41/	Priority interventions applied to buses by for e.g. making bus travel times competitive with individual vehicle travel times. Can lead to fewer cars and smoother driving conditions including less idling and stop start	Positive impacts through some increase in active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects if buses are not high emitters and noisy vehicles and possibly motor vehicle crashes. Possible positive impacts through reduced inequalities
	Demand responsive transport http://www.konsult.leeds.ac.uk/pg/48/	Provide a service for those who otherwise have limited or no public transport service. May cause modal shifts from car	Possible positive impacts through some increases in active travel and physical activity, reductions in traffic, air pollution, heat island effect, noise and climate change effects. Possible positive impacts through reduced inequalities
	Bus fleet management systems http://www.konsult.leeds.ac.uk/pg/34/	Ensure buses run to schedule resulting in efficient and reliable bus services. May cause modal shifts from the car	Positive impacts through increased active travel and physical activity and reductions in traffic, air pollution, heat island effect, noise and climate change effects if buses are not high emitters and noisy vehicles. Further positive impacts are possible through reduced inequalities
	Bus regulation http://www.konsult.leeds.ac.uk/pg/64/	Restricts private operators' freedom to determine routes, frequency and fare. Can increase connectivity and bus usage	Depends on connectivity and quality of services. Positive impacts through increased active travel and physical activity and reductions in traffic, air pollution, heat island effect, noise and climate change effects if buses are not high emitters and noisy vehicles. Further positive impacts are possible through reduced inequalities
	Segregated cycle facilities http://www.konsult.leeds.ac.uk/pg/46/	Increase in cycling by providing safe, efficient, attractive, and convenient cycling infrastructure, and integration of cycling with public transport	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and motor vehicle crashes
	Cycle parking and storage http://www.konsult.leeds.ac.uk/pg/20/	Increase in cycling by providing attractive, and convenient cycling facilities	Positive impacts through some increase in active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and motor vehicle crashes. Further positive impacts are possible through reduced inequalities
	Cycle and pedestrian safety http://www.konsult.leeds.ac.uk/pg/65/	Improved safety for cyclists and pedestrians	Positive impacts through increases in active travel and physical activity, reductions in air pollution, heat island effect, noise and climate change effects and motor vehicle crashes. Further positive impacts are possible through reduced inequalities
	Pedestrian crossing facilities http://www.konsult.leeds.ac.uk/pg/17/	Improved safety and convenience for pedestrians	Positive impacts through reduction in motor vehicle crashes and negative impacts increased exposure to air pollution hotspots. Further positive impacts are possible through reduced inequalities
	Lorry routes and bans http://www.konsult.leeds.ac.uk/pg/38/	Reduction in lorries in some parts but possible increases in others, unless there are suitable alternative routes	Positive impacts through reduction in air pollution and noise in some parts but the reverse in others and possible negative impact through inequalities
	Road freight fleet management systems http://www.konsult.leeds.	More efficient freight through the reduction in excess lorry miles, idling, safer driving	Possible positive impact through reduction in air pollution, heat island effect, noise and

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
	ac.uk/pg/43/	styles and better maintained vehicles	climate change effects and motor vehicle crashes
Attitudinal and behavioural – 10 policy measures	Promotional activities http://www.konsult.leeds.ac.uk/pg/55/	Varied by type of promotional activity. More effective if they are combined with "hard measures" like improvements in the infrastructure	Depends on message conveyed with possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes
	Personalised journey planning http://www.konsult.leeds.ac.uk/pg/06/	Reductions in car use through providing targeted information on alternatives to the car for particular trips and encourage use of alternatives	Possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes
	Company travel plans http://www.konsult.leeds.ac.uk/pg/07/	Reduce car use particularly solo driving e.g. ride sharing scheme	Possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes
	School travel plans http://www.konsult.leeds.ac.uk/pg/56/	Change mobility behaviour of pupils and parents for trips to and from schools – mainly by reducing car travel	Positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in exposure to green space (e.g. walking through parks)
	Promoting low carbon vehicles http://www.konsult.leeds.ac.uk/pg/58/	Lower exhaust emissions of carbon dioxide	Positive impact through reduction in local air pollution if technology is appropriate e.g. clean electric rather than diesel vehicles and climate change effects. Potential negative impacts on regional air pollution and inequalities through increase in emission from power plants particularly in lower socio-economic areas
	Ride sharing http://www.konsult.leeds.ac.uk/pg/03/	Reduction of number of cars on the road	Positive impacts through some reduction in air pollution, heat island effect noise and climate change effects. Further positive impacts are possible through reduced inequalities
	Bike sharing http://www.konsult.leeds.ac.uk/pg/59/	Reduction in car use and increase in cycling and transit usage	Positive impacts through increase in active travel and physical activity, reduction in noise. Small negative impacts through some increase in personal air pollution exposure in cyclist and increased risk for motor vehicle crashes in those switching to cycling. Positive impacts on general population through reduction of air pollution, noise, climate change effects and motor vehicle crashes
	Car clubs http://www.konsult.leeds.ac.uk/pg/05/	Reduction in car travel and use usage and the need for car ownership	Positive impacts through some reduction in air pollution, heat island effect, noise and climate change effects and increase in active travel and physical activity. Reduced parking needs allow more public space. Further positive impacts are possible if there is an increase in exposure to green space and a reduction in inequalities
	Flexible working hours http://www.konsult.leeds.ac.uk/pg/08/	Reduction in congestion through spreading the travel demand beyond the conventional working hours. Can facilitate ride sharing, cycling and public transport use	Positive impacts through reduction of air pollution and climate change effects from idling and stop start driving. Positive impacts through increased active travel and physical activity
	Telecommunications http://www.konsult.leeds.ac.uk/pg/21/	Reduced travel and vehicle kilometres particularly during peak hours	Positive impacts through some reduction in air pollution, noise and climate change effects and possibly motor vehicle crashes
Information provision – 9 policy measures	Conventional signs and markings http://www.konsult.leeds.ac.uk/pg/32/	Reduction in car travel time and congestion and possible reductions in speed	Possible positive impact through reduced motor vehicle crashes
	Variable message signs http://www.	Reducing car driver's stress and providing	Possible positive impact through reduced

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
	konsult.leeds.ac.uk/pg/37/	information to change travel speed, change lanes, divert to a different route	motor vehicle crashes
	In vehicle system guidance system http://www.konsult.leeds.ac.uk/pg/66/	Reduced car travel length and duration. Might lead to an increase in overall capacity of the network and to reduced travel time for most motorists, which could increase car use	Possible minor positive impact through reduction in air pollution, noise and climate change effects. Possible negative impacts on safety, because of the higher traffic volumes on secondary roads and the possible distraction. Negative impacts if the increase in capacity attracts more demand
	Parking guidance systems http://www.konsult.leeds.ac.uk/pg/40/	Reduction in car travel time by influencing drivers' choice of car park and reducing the time spent looking for a parking space and traffic involved in searching	Possible positive impacts through reduction in air pollution, noise and climate change effects
	Conventional timetable and service information http://www.konsult.leeds.ac.uk/pg/67/	Adequate provision of timetable and other service information may prompt behaviour change towards increasing use of public transport and modal shift from cars	Possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects if public transport vehicle are not high emitter noisy vehicle. Possible reductions in motor vehicle crashes and reduced anxiety
	Real time passenger information http://www.konsult.leeds.ac.uk/pg/47/	Can reduce the psychological anxiety associated with waiting for public transport as well as uncertainty and frustration. May prompt behaviour change towards increasing use of public transport and modal shift from car	Possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects if public transport vehicle are not high emitter noisy vehicle. Possible reductions in motor vehicle crashes and reduced anxiety
	Trip planning systems http://www.konsult.leeds.ac.uk/pg/68/	May alter choice of travel mode and prompt a modal shift from car	Possible positive impacts through increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and motor vehicle crashes depending on the selected mode of transport
	Crowd sourcing http://www.konsult.leeds.ac.uk/pg/69/	More efficient travel and less congestion. Can prompt a modal shift from the car	Impact unclear depending on the content but positive if shift towards active travel and public transport means. Possible negative impacts through increased inequalities and social exclusion e.g. low incomes groups and those who are not technology-aware (e.g. the elderly)
	Barrier-free mobility http://www.konsult.leeds.ac.uk/pg/72/	Smoother mobility and increasing social inclusion of people with reduced mobility	Positive impact through reduction in motor vehicle crashes. Possible positive impacts through reduced inequalities
Pricing – 9 policy measures	Vehicle ownership taxes http://www.konsult.leeds.ac.uk/pg/27/	Depending on the direction of taxation. Increased taxation can reduce car ownership and a possible shift to public and active transport and car sharing. It can potentially regulate the age of the vehicle stock to minimize environmental impacts	Positive impacts through slightly increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Negative impacts possible if high emitting vehicles are taxed less (e.g. diesel vehicles)
	Fuel taxes http://www.konsult.leeds.ac.uk/pg/22/	Reduction in car travel use and a possible shift to public and active transport and car sharing. Taxing most polluting fuels at higher level can contribute to minimizing environmental impacts	Positive impacts through slightly increased active travel and physical activity reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Negative impacts possible if polluting fuels are taxed less for (e.g. diesel vehicles)
	Parking charges http://www.konsult.leeds.ac.uk/pg/25/	Increase in parking charges can lead to a reduction in car use and a possible shift to public and active transport and car sharing	Positive impacts through slightly increased active travel and physical activity reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further positive impacts are possible if there is an increase in provision and exposure to green space
	Private parking charges http://www.konsult.leeds.ac.uk/pg/36/	Reduction in car use and a possible shift to public and active transport and car sharing. Possible reductions in land uptake for car parking	Positive impacts through slightly increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor

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Table 2 *(continued)*

Category	Transport policy measure	Pathway of action	Health impact (positive or negative)
			vehicle crashes. Further positive impacts are possible if there is an increase in provision and exposure to green space
	Road user charging http://www.konsult.leeds.ac.uk/pg/01/	Reduction in congestion and car use and possible shift to public and active transport and car sharing. Possible reductions in community severance	Positive impacts through slightly increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and motor vehicle crashes and possibly community severance
	Fare levels http://www.konsult.leeds.ac.uk/pg/28/	Changes in the monetary charge for making a trip by public transport may impact the level of demand for public transport and private cars	Depends on the magnitude and the direction of the fare level (changes). A reduction in fares could lead to positive impacts though some increases in active travel and physical activity and possible reduction in traffic and air pollution, heat island effect, noise and climate change effects and motor vehicle crashes. Further possible positive impacts through reduced inequalities
	Fare structures http://www.konsult.leeds.ac.uk/pg/73/	Depending on direction: profit or welfare maximization	Depends on the magnitude and the direction of the fare structure (changes). A reduction in fares could lead to positive impacts though some increases in active travel and physical activity and possible reduction in traffic and air pollution, heat island effect, noise, climate change effects and motor vehicle crashes. Possible positive impacts can occur through reduced inequalities
	Concessionary fares http://www.konsult.leeds.ac.uk/pg/31/	Providing discount fares for target groups using public transport. Increased public transport use for vulnerable and disadvantaged groups. Possible shift from car use	Positive impacts through slightly increased active travel and physical activity, reduction in inequalities, reduction in air pollution, heat island effect and noise and possibly motor vehicle crashes
	Integrated ticketing http://www.konsult.leeds.ac.uk/pg/70/	Increasing the convenience of public transport use. Possible shift from car use to public transport and reduction in congestion	Positive impacts through slightly increased active travel and physical activity, reduction in air pollution, heat island effect, noise and climate change effects and possibly motor vehicle crashes. Further possible positive impacts through reduced inequalities

infrastructure leads to a decrease in green space or biodiversity loss or an increase in community severance.

The third category of interventions: *management and service*, includes 23 individual policy measures. Many of the management and service policy measures can have a positive health impact mainly through the reduction of motor vehicle crashes (e.g. road maintenance, conventional traffic management, intelligent transport systems, accident remedial measures, traffic calming measures, road physical restriction, regulatory restrictions, bus service and priorities, cycling promotion measures, pedestrian crossing facilities, lorry routes and bans, road freight fleet management systems and new rail services), and some reduction of air pollution, noise and heat island effects (e.g. road maintenance using materials to reduce air pollution and noise, traffic management and urban traffic control, intelligent transport systems, high occupancy vehicle lanes, road physical restrictions, regulatory restrictions, low emission zones, parking controls, bus service and priorities, cycling promotion measures, lorry routes and bans and new rail services). Some of these measures such as physical road restrictions and parking controls may free up urban space that could be utilised for green or public space and may also reduce community severance. With the exception of improvements in cycle and pedestrian facilities, measures in this category often do little to increase levels of active travel and physical activity, and may have negative impacts through increases in inequalities.

The fourth category of interventions: *attitudinal and behavioral*, includes 10 individual policy measures. The health impacts of attitudinal and behavioral policy measures such as promotional activities, personalised journey planning and company or school travel plans are harder to predict and depend on the direction and content of the measures, but in general are likely to result in positive health impact through increased levels of active travel and physical activity, and reduction in air pollution, noise and climate change effects and possibly motor vehicle crashes. Similarly, ride and bike sharing, car clubs, flexible working hours and telecommunication are likely to result in positive health impacts and higher flexibility in mobility patterns. Promoting low carbon vehicles is a controversial measure and lessons learnt from the European diesel car boom indicates that this measure can negatively impact air quality and health through the increased exposure to nitrogen oxides and particulate matter. On the other hand, electric cars may have a positive contribution to air quality and health (via a reduction in tailpipe emissions but not from tyre, brake and road surface wear, corrosion and resuspension), provided that a target for clean electricity generation is jointly implemented.

The fifth category of interventions: *information provision*, includes nine individual policy measures. For some of the information provision policy measures the health impacts are unclear (e.g. crowd sourcing), while for others there may be positive health impacts

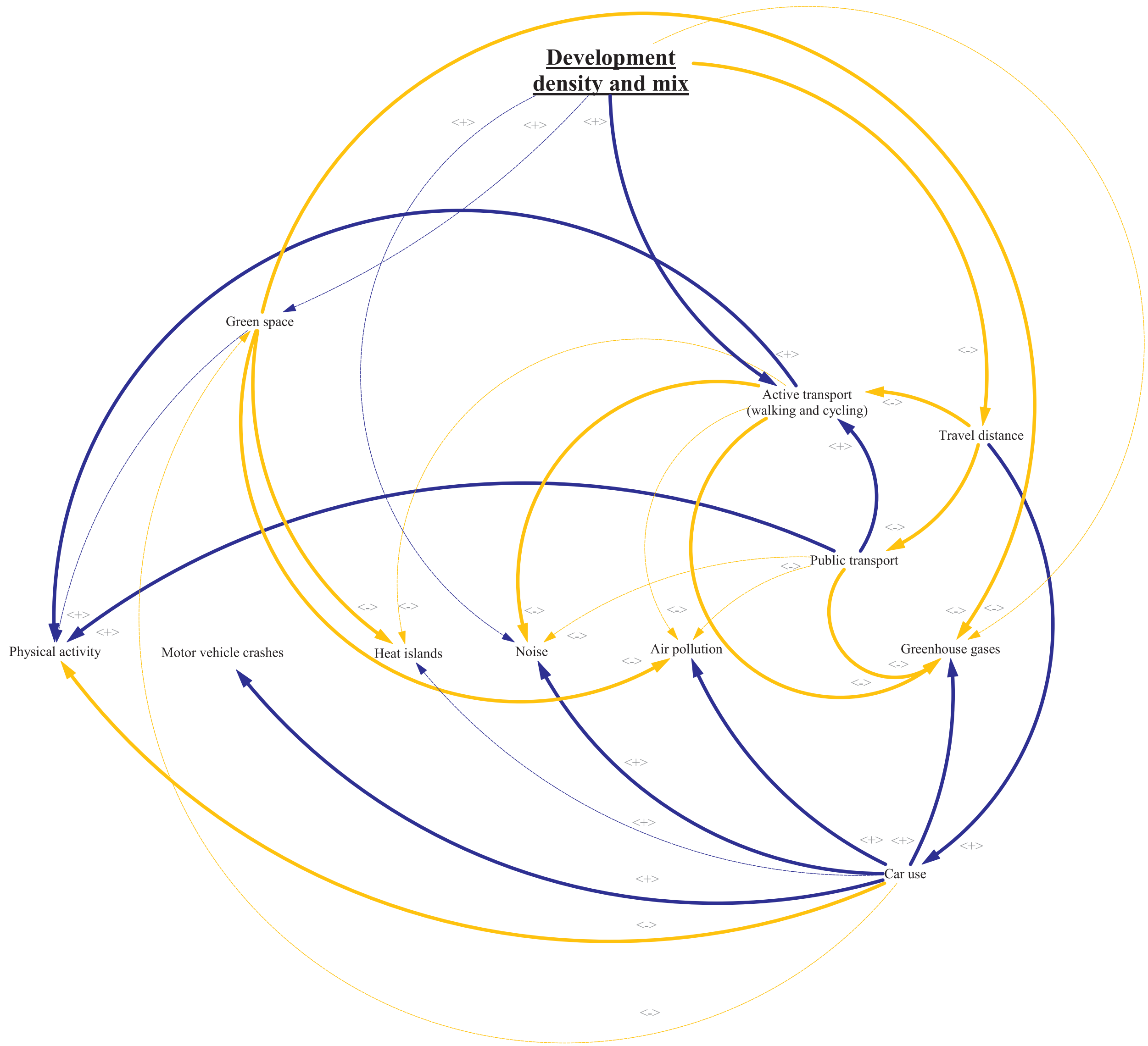

Fig. 2. Mental model for the interactions between a KonSULT transport policy measure (e.g. development density and mix) and pathways leading to premature mortality and morbidity. The blue arrows indicate that a change in independent entity is associated with a change in the dependent entity in the same direction (i.e. an increase associated with an increase, +). The orange arrows indicate that a change in independent entity is associated with a change in the dependent entity in the opposite direction (i.e. an increase associated with a decrease, -). The thicker arrows indicate effects for which the evidence is stronger than the thinner arrows. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

through a reduction in motor vehicle crashes (e.g. conventional signs and marking, variable message signs, barrier-free mobility) and air pollution and climate change effects via reducing stop start driving and idling and encouraging and facilitating the use of public transport (e.g. in vehicle guidance systems, conventional time tables and service information, trip planning systems).

The final category of interventions: *pricing*, includes nine individual policy measures. Pricing policy measures are often likely to have positive health impacts through general reductions in car use and traffic levels, taxing the most polluting fuels, regulating the age of the vehicle stock, reducing the convenience of motoring and parking, decreasing public transport fares to increase patronage and providing integrated ticketing that allows passengers to transfer within or between different public transport modes with ease and convenience. These measures can possibly slightly increase active travel and physical activity, reduce levels of air pollution, noise, heat island effect, climate change effects, motor vehicle crashes and community severance. Further positive impacts can occur if inequalities are reduced by for example decreasing fares for public transport which may improve the mobility and accessibility of vulnerable and low socioeconomic groups.

The brief assessment above suggests that to improve public health, there may be a need for more focus on land use policy measures which underlie travel levels and patterns and a better integration of land use and transport planning. Further, some of the urban transport policy measures may have negative impacts on equity and community severance and any new infrastructure propositions need to be examined as it can feasibly introduce an additional way by which wealthy neighborhoods deviate and become fragmented from poorer areas. Measures such as developer contributions, new road construction, trams and light rail, new rail services, regulatory restrictions, low emission zones, parking controls, new rail services, lorry and heavy vehicle bans, and crowd sourcing may increase inequalities and measures such as land use to support public transport, bus rapid transit, cycle networks, high occupancy vehicle lanes, bus services, bus priorities, bus regulation, ride sharing, car clubs and concessionary fares may decrease inequalities.

4. Discussion and conclusions

In this study, we describe how transport related exposures and lifestyles impact health through motor vehicle crashes, traffic-related air pollution, noise, heat island effect, green space exposure, physical activity through active travel, social exclusion and community severance. These exposures/lifestyles, and their associated impacts, are not equally distributed in the populations, further contributing to health inequalities. There are further health impacts through climate change. These pathways impact health through increasing premature mortality and morbidity and, in the case of climate change, through second order effects on food crops, water, poverty, mental health, stress and post-traumatic stress.

These pathways and impacts are broader and bigger than previous documentations. For example, Khreis et al. (2016) did not make an explicit link between transport-related climate change or community severance and health and Cohen et al. (2014) did not make an explicit link between transport-related noise, heat-island effects, green space exposures and health (beyond mental health and stress). The evidence linking these exposures to transport and to adverse physical health outcomes such as risk of cardiovascular disease and premature mortality is relatively new and has not been a common inquiry area in contemporary health and transport research. However, as shown in Table 2, this evidence base has strengthened and further research and synthesis are underway. Emerging evidence suggests that the impact of noise on premature mortality for example is comparable to Mueller et al. (2017a) and independent of Stansfeld (2015), Tétreault et al. (2013) the impacts of air pollution on premature mortality. Furthermore, when morbidity is considered, the health burden of noise is even higher than that of air pollution or physical inactivity (Mueller et al., 2017b). In comparison, very little quantitative evidence is currently available for the health impacts of transport-related heat, green space and community severance.

The list of pathways and impacts we provide in this paper is still, however, not an exhaustive list and practitioners are encouraged to think about their local contexts and other pathways and health impacts they become aware of. There are other indirect pathways by which transport can impact health which have been documented elsewhere and not in this paper or the literature we identified. For example, Widener and Hatzopoulou (2016) identified the indirect health impacts of transport which occur if/when communicable disease is spread through transport networks whilst Abu-Lebdeh (2017) identified the adverse impacts of transport on water and soil quality which can reach humans and other living species through the food chain, public water supplies, trees and vegetation.

An addition of this paper is the linkage made between 64 specific transport policy measures and the expected pathways of actions and subsequent health outcomes. KonSULT is a well-established and a unique knowledgebase that synthesizes numerous urban transport policy measures and offers evidence on their performance. The knowledgebase has also been used by many European cities and is undergoing constant updates, testing and developments (May et al., 2016). With the large and continually increasing number of available transport policy measures, and the improved knowledge of the many interactions between transport policies and health, it is essential that the pathways and the health impacts of these policies are stated, updated and synthesized for them to be considered by transport practitioners. On the other hand, it is also useful to be able to pin point relevant policies based on pathways of actions cities want to target and find readily available documentation on relevant measures (e.g. which policies are worth considering if a city wants to reduce traffic noise and associated health impacts).

We report that many, but not all urban transport policy measures, can have a positive impact on health, the magnitude and scale of which remains unknown as there are few studies quantifying it and no synthesis reporting this evidence as a whole. Some of these impacts may have not been widely recognized until the 1990s, yet evidence of the numerous health impacts associated with transport is not new (Transport and Health Study Group, 1991; Dora and Phillips, 2000), but is now better developed and documented in academic circles (Khreis et al., 2016; Mueller et al., 2017a), and includes more impacts than previously acknowledged. Although health research has made significant advances in demonstrating the health impacts of urban transport, and particularly of the caroriented planning approach many cities have adopted over the past decades, such work has yet to cross to the practice realm and contribute to a more evidence-based approach to urban policy and practice. This paper also shows that a wide range of transport policy measures is currently available for cities to consider and many of those can be adopted to promote and protect public health. Health professional and health impact assessors can also benefit from this summary to identify and become acquainted with feasible policy measures at the urban scale.

Land use policy measures such as development density and mix and land use and many infrastructure policy measures are likely to have a larger impact on health because they may not only affect air pollution levels, heat island effects, noise levels, climate change effects and possibly the amount of green and public space in cities, but they importantly impact on the levels of active travel and physical activity which may be the pathway with the largest positive health impacts. Many of the management and service policy measures may not affect physical activity levels, but can have a positive health impact mainly through the reduction of motor vehicle crashes, air pollution, heat island effect, noise and climate change effects. The likely health impacts of attitudinal and behavioral policies, information provision and pricing measures are harder to predict, but generally beneficial health impacts are expected, depending on the direction and content of information and nudging. We also report that some of the urban transport policy measures can have negative health impacts through the nine pathways identified. These warrant further consideration when designing transport plans or projects. Both positive and negative health impacts of transport policy measures may not be first order effects; for example, the construction of a new road can increase car use directly increasing air pollution, noise, heat island effect and decreasing active travel but a second order effect would be that new construction takes up land that was or could have been used differently, e.g. by providing more green or public space. The health impacts associated with climate change are also considered distal impacts, which take significantly longer time to manifest (see Table 1). Yet, these are particularly important as transport is a key sector of greenhouse gas emissions, not only through motor vehicle emissions, but also through associated building construction, operation and car manufacturing.

Linking potential health impacts to specific transport policy measures, as we have done in this work, can aid planners and transport professionals to think systematically about and account for the health impacts of transport policies; which is perhaps not so obvious for professionals who are trained in systems that focus on the functional quality of infrastructure (Khreis et al., 2016). We also showed that there are synergies between the different measures and the different interventions categories, especially the land use interventions. As such, there may be a need for a closer focus on land use policy measures and better integration of land use and transport planning to achieve health objectives. This call is in line with previous calls to integrate transport with other sectors; importantly with land use – if system transformations are to be made towards sustainable development (Hall et al., 2014).

We found that the potential effects on social exclusion and inequalities were harder to establish but we report that measures such as regulatory restrictions, low emission zones, parking controls, new rail services, crowd sourcing, lorry and heavy vehicle bans, may increase inequalities and measures such as bus and public transport services, bus priorities, and concessionary fares may decrease inequalities. Further, community severance can result from infrastructure policies (particularly new roads and rail lines) and from heavy traffic (which can arise from conventional traffic management). Conversely, severance can be reduced if heavy traffic flows are reduced, which can result from some of the traffic reduction policies (e.g. physical restrictions and road pricing).

This work offers a brief assessment of the potential health impacts associated with urban transport policy measures. Its main limitation is that it only provides a general indication of the direction of the potential health impacts associated with KonSULT's policy measures, based on a rapid literature review and expert knowledge and assessment, rather than good scientific evidence on interventions related to each policy measure examined. Currently, the peer reviewed literature for health effects of the implementation of many policy measures is scarce. Future research needs to better monitor, evaluate and build a new evidence base for the effectiveness and feasibility of healthy urban and transport interventions as they happen. Future syntheses should aim at bringing this evidence together in a systematic manner.

It is planned to add Public Health as an objective in the KonSULT knowledgebase in the near future. In the meantime, it appears that land use and pricing measures offer the greatest promise for enhancing public health by reducing the need to travel, enhancing green space and facilitating shorter distance travel by active modes. The only measures in doubt in this category are parking standards and developer contributions, where the impacts will depend critically on how these standards and contributions are used. The second most effective category appears to be pricing, particularly in the case of low and integrated fares which facilitate greater public transport use and help reduce social exclusion, and congestion and parking charges, which can help reduce car use. The categories of management and services, awareness and information all contain measures which can be effective provided that they are appropriately designed. On balance, infrastructure measures appear the least likely to assist in a public health campaign and are and the most likely to aggravate problems of air pollution, climate change, loss of green space, and social exclusion.

As it stands, transport is still responsible for a large mortality and morbidity burden and policy measures need to be implemented to mitigate these adverse impacts. Urban and transport planners, economists, environmentalists and health professionals need to work together on this using systemic and systematic approaches and find optimal measures with the largest benefits and the smallest health risks.

Acknowledgement

The work was conducted without any specific funding source.

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