Towards a conceptual framework of hard and soft behaviour change interventions in sustainable transport

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Abstract

This paper aims to identify effective strategies for promoting behavioural change towards more sustainable travel patterns, drawing on evidence from the literature and practice. Established objectives for behaviour change interventions include reducing emissions, alleviating congestion, and enhancing overall well-being through targeted interventions. Drawing on existing frameworks for behaviour change, the paper focuses on the key dimensions which are relevant to the design and evaluation of policy measures. A multi-dimensional conceptual framework of behaviour change interventions in transport is proposed to highlight the importance of combining 'hard' measures, such as road user charges and infrastructure investments, with 'soft' measures, like public awareness campaigns and incentive programmes. The other three dimensions cover the timeframe for change, the level of change impact and the "push" and "pull" change strategies. Evidence of previous impact is presented, distinguishing between marginal and non-marginal changes and, where appropriate, the longevity of impact. The evidence demonstrates that tailoring these strategies to specific population segments and geographic contexts is crucial for delivering impact, particularly given the diverse travel needs and socio-demographic factors that exist within different jurisdictions. The paper concludes with recommendations for advancing research to better understand the synergetic effects of various behaviour change interventions using the proposed framework.

Keywords: behaviour change, sustainable transport, TDM, interventions, infrastructure

1 Introduction

There is increasing attention paid to strategies and policies linked to reducing emissions and transforming people's lives in ways that align well with more sustainable patterns of behaviour. Over the last decade, there has been considerable discussion about achieving a net-zero economy (Logan, Hastings, & Nelson, 2022) and many countries have introduced detailed plans outlining their paths towards net-zero. Promoting active travel and decreasing dependence on motorised transport are becoming important priorities in many of these agendas,

although the growing support to transition to electric cars may go against the promotion of broad-based sustainability goals that include reducing traffic congestion.

Achieving changes in travel behaviour is considered a crucial demand-side measure for evaluating transport interventions which are aimed at sustainability. Evaluations of these interventions should be multi-disciplinary and long-term, utilising suitable measurement tools to assess the many outcomes related to travel behaviour. These outcomes should include positive changes in modal share, public health and wellbeing, and environmental health. Cleland et al. (2023) in a review of complex interventions to reduce car use, highlighted that there remains a significant gap in understanding the holistic impact of policies and interventions on travel behaviour change. Consequently, the challenge remains to determine how relevant interventions can trigger behaviour change towards more sustainable travel patterns considering the complexities in travel choice behaviour. The paper focusses on seeking an understanding from our current knowledge bank of the effectiveness of a range of interventions through the lens of behaviour change dynamics, to provide directions to policymakers in designing targeted and interconnected policies and interventions.

The paper is structured as follows: the next section outlines some of the key behaviour change theories considering their relevance in the context of developing effective transport interventions (including the Theory of Planned Behaviour, the Diffusion of Innovation, the Transtheoretical Model of behaviour change and Gamification). Subsequently, the paper proposes a new conceptual framework for the evaluation of transport interventions through the lenses of impact, longevity, and spatiality. Reference is also made to the importance of segmentation. Finally, we conclude with insights for future research and policymakers on designing and implementing effective travel behaviour change policies.

2 Previous research on travel behaviour intervention

Arnott et al. (2014) conducted a meta-analysis using multiple research databases in the transport field. They found that most interventions were not designed based on theory, and were less effective in achieving behaviour change, such as reducing car use or shifting to more sustainable alternatives. Crucially, transport interventions were often *ad hoc* and only provided information with some regulatory restrictions. Subsequent studies have shown that interventions guided and designed with insights from behavioural change (BC) theories are found to be more effective. One example is the case of Theory of Planned Behaviour (TPB) which has guided business-focused Transport Demand Management (TDM)[1] programmes, which significantly changed travel behaviour across the entire transport network during the 2012 London Olympics (Jones & Woolley, 2019). Studies have also shown that when people receive a new message from an intervention about switching transport mode, they are prompted to evaluate their current mode and make trade-offs on updated features and attributes of modes to decide whether to switch or not (De-Toledo, O'Hern, & Koppel, 2022). This illustrates the relevance of viewing behaviour change through the lens of the overall decision-making and choice process, since people make holistic decisions about their behaviour rather than behaviour which is related solely to utility maximisation, which in turn is related to non-

[1] The authoritative definition of Travel Demand Management is given by Meyer (1999) who described TDM initiatives as an 'action or set of actions aimed at influencing people's travel behaviour in such a way that alternative mobility options are presented and/or congestion is reduced' (p 576).

compensatory behaviour (Essen, Thomas, Berkum, & Chorus, 2020; Yusuf, O'Connell, Jordan, Chapman, & Anuar, 2022).

There are several well-known behaviour change theories which have been applied to transport. These include the Theory of Planned Behaviour (TPB), the Diffusion of Innovation (DOI), the Transtheoretical Model of behaviour change (TTM) and more recently, Gamification. All have been applied in transport studies to derive insights on critical factors which contribute to sustainable travel behaviour change. In parallel, there have been relevant developments in the policy-led literature, such as "avoid, shift, and improve" which is widely regarded when developing transport interventions. In mapping out the relevant behaviour change literature, it is evident that there is no single dominant behaviour change (hereafter abbreviated as "BC") theory in transport or other disciplines. Many BC theories have developed from different origins and foci. In reviewing the BC maintenance topic, Kwasnicka, Dombrowski, White, and Sniehotta (2016) identified some 117 theories covering behaviour, BC and BC maintenance. In a wide-ranging review informed by behaviour change in the fields of transport, health, energy and climate, Andersson, Hiselius, and Adell (2018) positioned four influential and widely adopted BC theories along four stages of behaviour change from adopting, shaping, changing and keeping changes. This is supported by the main BC theories, including the Theory of Planned Behaviour (TPB) (Ajzen, 1991), the Diffusion of Innovation (DOI) (E.M. Rogers, 1962; Everett M. Rogers, 2010), the Transtheoretical Model of behaviour change (TTM) (Prochaska & Clemente, 1982), and Gamification (e.g., Yen, Mulley, and Burke (2019). DOI and Gamification work at the stages of adopting and shaping behaviour change, and TPB and TTM focus on making and maintaining behaviour changes. Although it may not be entirely accurate of actual behaviour (for example, TPB also focuses on adopting and shaping change), this process is an effective way to build a holistic view to consider behaviour change as a whole picture and not just narrow it down to one method or aspect. This view is appropriate given the highly complex nature of human behaviour. Examples of travel behaviour initiatives/interventions promulgated through a particular theory are given below and in more detail in Section 3.

Many studies and implementations integrate BC theories and apply them jointly, such as TPB with the Technology Acceptance Model (TAM), TTM with TPB, DOI with TAM, and the combination of TAM, DOI and Gamification (Yen, Mulley, & Meza, 2023a, 2023b). For instance, the combination of TTM and TPB has been employed in health interventions, such as fitness or diet-tracking applications, to capture readiness to change alongside behavioural intention, thereby improving predictions of lifestyle modification (Boonroungrut & Fei, 2018). In the transport sector, for instance, TAM and TPB have been integrated to explain the adoption of sustainable mobility options, such as public transport apps and bike-sharing systems, by combining usability perceptions with subjective norms and perceived behavioural control (Shaaban & Maher, 2020). Likewise, the integration of DOI and TAM has been employed to study electric vehicle adoption, where innovation characteristics such as relative advantage and compatibility are linked with perceived usefulness and ease of use to capture drivers' acceptance behaviour better (Rezvani, Jansson, & Bodin, 2015). Further, several researchers have provided comprehensive reviews of BC theories and their roles in various fields of transport. Andersson et al. (2018) linked TDM to voluntary travel behaviour change which has been successfully achieved by application of personalised travel plans (PTP). De-Toledo et al. (2022) highlighted the role BC theories should play in providing the guidelines for developing policies, interventions and tools based on a scientometric review of over 300 papers published on transport behaviour.

Another important aspect that BC theories highlight, but which has been less focused on in transport interventions, is traveller heterogeneity. Traditional choice models, for example, often rely on observable variables while neglecting attitudes, beliefs, and other unobservable factors that shape behaviour, leading to biased estimations, although the developments in hybrid choice models has recognised and accounted for such influences in a more behavioural appropriate way (Greene and Hensher 2026). Other studies (e.g., Hunecke et al., 2008; Anable, 2005) emphasise that attitudes toward car use and specific motivations are stronger predictors of behaviour than demographics, supporting the idea of using segmentation approaches that account for diverse preferences. Various frameworks illustrate this, such as Anable's six traveller types, Portland's four cyclist categories, and stage-based models of behaviour change (Sunio et al., 2018), all of which underline the need for targeted strategies rather than blanket "one-size-fits-all" policies. Personalised travel planning further demonstrates the value of segmentation by tailoring interventions to workplaces, schools, or residential areas, with evidence showing that such strategies can significantly increase active travel (Ogilvie et al., 2007). Overall, recognising and addressing heterogeneity enables more effective policy design, as individuals' attitudes and behaviour may shift depending on context and trip purpose.

The International Energy Agency promotes a triple policy approach of "avoid, shift, and improve" (see Figure 1) to foster sustainable transport. The framework, proposed by the Transformative Urban Mobility Initiative (Leroutier and Quirion, 2023; TUMI, 2019), is designed to minimise travel, whether by reducing trip distances or promoting remote work and online shopping; transitioning from private cars to active and public transport options, as well as carsharing; and enhancing vehicle and fuel efficiencies. This can be achieved through a combination of incentive-based strategies ("carrots"), such as enhancing safety for cyclists and pedestrians, and punitive measures ("sticks"), such as reducing the allocated space for cars in urban areas (Xiao et al., 2024). It is important to integrate insights from the BC literature to ensure that avoid–shift–improve strategies translate into lasting shifts in mobility behaviour. Beyond financial incentives and regulations, people's choices are shaped by habits, norms, identities, the neighbourhood in which they live and perceptions of convenience and safety, which can be influenced through nudges, framing, and social feedback (Leroutier and Quirion, 2023). Embedding these behavioural insights helps align infrastructure and policy with everyday decision-making, making sustainable mobility the more natural and attractive option. AITPM (2024) have recommended the approach as a means to rapidly decarbonise Australia's transport sector.

Taken together, the theories and evidence presented above highlight both the complexity and the multi-layered nature of travel behaviour change. While the existing "avoid–shift–improve" framework provides a valuable policy foundation, its effectiveness depends on grounding interventions in behavioural insights, accounting for heterogeneity among travellers, and informed by behaviour change theories where they support actionable change outcomes. What becomes clear is that no single theory or segmentation approach can fully capture the diversity of motivations, barriers, and contexts that shape mobility choices. This underscores the need for a more comprehensive framework that not only draws on behavioural theories in sustainable transport but also considers key dimensions of intervention design and implementation. In the following section, we propose a multidimensional conceptual framework that incorporates these dimensions, including distinctions such as "push" versus "pull" measures, "hard" versus "soft" levers, the timeframe of change, and the scale of impact, thereby offering a more holistic scope to guide sustainable transport policymaking and practice.

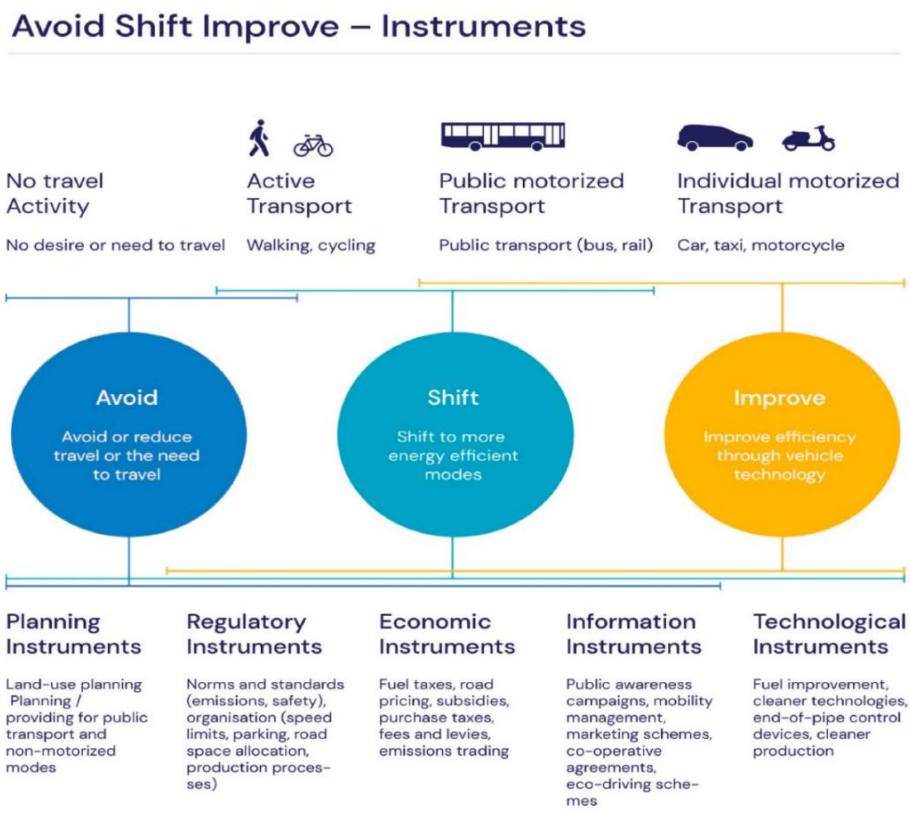

Figure 1. Illustration of the Avoid, Shift, Improve framework proposed by Transformative Urban Mobility Initiative (TUMI, 2019)

3 A New Conceptual Framework for Behavioural Change Intervention in Sustainable Transport

Behaviour change is a complex domain that interrelates with multiple disciplines and theoretical traditions. Building on the consideration of Behaviour Change (BC) theories presented in Section 2, the proposed conceptual framework (Figure 2) draws from insights gained from the TPB, TTM, DOI and Gamification principles. Each of these theories offers complementary insights into how and why individuals adopt, maintain, or resist changes in transport behaviour. For example, TPB highlights the role of attitudes, subjective norms and perceived behavioural control in shaping travel intentions; TTM underscores the staged process through which people move from pre-contemplation to maintenance of new behaviours; DOI explains the spread of innovations such as bike-sharing or electric vehicles through social networks; and Gamification taps into intrinsic motivation through feedback and rewards. Informed by these theoretical perspectives and previous research on transport behaviour change, the framework situates interventions along the four dimensions which influence their effectiveness, namely: time frame (short v long), impact levels (small to high), the push and pull nature of interventions, and whether they can be classified as "soft" or "hard". A fifth dimension is to consider the impact of interventions across different locations (spatial). In essence, the framework operationalises the mechanisms described by BC theories: it links

individual-level psychological drivers (e.g., attitudes, readiness, motivation) with structural and contextual levers (e.g., policy strength, infrastructure, incentives[2]).

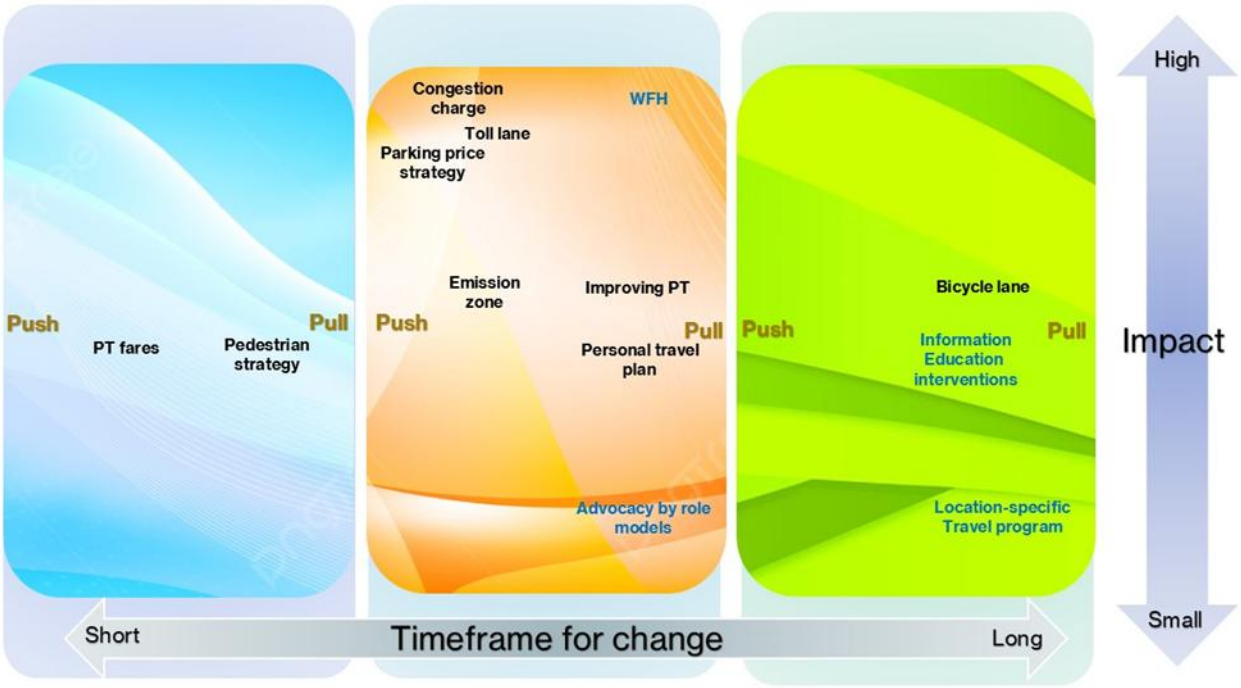

Figure 2. A new conceptual framework of behaviour change interventions in transport considering timeframe, impact and push / pull (Note: Blue text = soft measures and black / bold = hard measures) (Source: authors own)

There are some further important distinctions associated with Figure 2. The framework captures both transport and non-transport interventions, it can be used to highlight both successes and failures in behaviour change initiatives, to illustrate both marginal vs non-marginal changes, the temporal (short vs long term) and spatial impacts (national, urban, regional). As an illustration, measures introduced during the pandemic such as Working from Home (WFH)[3] (Hensher et al. 2026) would be classified as non-transport, long-term, national, high impact; providing "green infrastructure" (parks and green corridors) to promote active travel is urban and rural, long-term, moderate to high impact; and parking pricing strategies are transport, urban, medium term, moderate impact. Of relevance here Hensher and Nelson (2025) highlight the role of non-transport providers who can contribute to mobility management with examples including bonus shopping points via a supermarket app if you visit a store using a shared bike or public transport or a discount on your restaurant bill because you got the bus.

This section discusses aspects of the framework in more detail including the characteristics of hard vs. soft measures and their impact, push / pull (noting also that these two dimensions may be blended), followed by consideration of impact and of temporary vs. long-term behaviour

[2] It is acknowledged that some levers may have what might be interpreted as negative behavioural outcomes such as EV drivers increasing their weekly km and thus contributing to congestion. Social norms and networks may also work against measures designed to effective desirable change.

[3] For recent WFH and hybrid work evidence see: https://www.sydney.edu.au/business/our-research/institute-of-transport-and-logistics-studies/transport-opinion-survey.html

change, acknowledging relevant influences from the BC theories. Some other considerations such as geographic influence and socio-cultural context are also discussed.

3.1 Hard vs. soft measures

Transport policies introduced as part of TDM can be divided into 'push' and 'pull' instruments (see 3.2) which can be implemented in the form of 'hard' and 'soft' measures (Kitamura, Fujii, & Pas, 1997). 'Soft' transport interventions are schemes that encourage health-promoting behaviours. From a TPB perspective, 'soft' interventions such as personalised travel plans, public-transport marketing, or walking-bus schemes, target attitudinal and normative components, seeking to increase perceived behavioural control and positive intentions toward sustainable modes. Similarly, TTM explains their effectiveness through progressive engagement: personalised feedback and self-monitoring help as individuals move from contemplation to action. Previous narrative reviews (Brög, Erl, Ker, Ryle, & Wall, 2009; Cairns et al., 2004; Richter, Davis, Apse, & Konrad, 2011) have found that 'soft' transport policy measures such as personalised travel plans, behavioural nudges through incentives, and competitions, are as effective as voluntary travel behaviour change programmes (Taylor & Ampt, 2003; Williams, Spotswood, Parkhurst, & Chatterton, 2019). Some of the pioneering studies on voluntary travel behaviour change were completed in Australia by Taylor and Ampt (2003), Ampt (2003) and Stopher et al. (2009). Table 1 summarises various 'hard' and 'soft' measures, categorising them based on their applicability over time (temporal) and across different locations (spatial).

'Hard' transport policy measures modify the physical environment, potentially prompting changes in travel behaviour to these modifications (such as limited use of freeway lanes for car users, and improved pedestrian lighting). This awareness may lead travellers to consider the implications for their travel choices, such as increased car travel time, and decide that alternatives like public transport offer a faster service. For instance, infrastructure changes or toll lanes modify external constraints, which aligns with TPB's emphasis on control beliefs and DOI's focus on the adoption of innovations once barriers are reduced. Findings of a stated preference exercise conducted in Abu Dhabi, indicate that individuals across various socio-economic levels are prepared to pay for High Occupancy Toll lanes to avoid congestion, with their willingness to pay rising as travel conditions deteriorate (Abulibdeh, 2018). A study conducted in the USA in Texas on the toll-managed lanes (ML) found that overall ML use was not affected by the change in toll rates, as anticipated (Burris & Ashraf, 2019). Contrary to the belief that raising toll rates would reduce ML use, their results indicated that the impact varies by type of ML user, namely, *choosers*, *frequent ML users*, and *infrequent ML users*. Burris and Ashraf (2019) note that the choosers category increased their ML use, except for very frequent ML users (10+ trips per month), who reduced their usage. This phenomenon is not unprecedented when increases in tolls leads to greater congestion in general-purpose lanes, prompting additional users to choose the ML. Understanding the effectiveness of designed and implemented "hard" measures such as ML is crucial in identifying interventions that yield significant versus marginal outcomes (Bamberg and Rees, 2017; Gaborieau and Pronello, 2021) which aligns with TPB's emphasis on control beliefs and DOI's focus on the adoption of innovations once barriers are reduced.

3.2 Pull vs Push

The push–pull lens concerns how uptake is driven and implemented, whereas the hard–soft lens (3.1) concerns the nature of the measure. Push instruments discourage undesirable actions through restrictions, while 'pull' instruments encourage desirable behaviours via incentives

(see Figure 3 and Babb, Smith, Moniruzzaman, and Biermann (2014) for a detailed review). Within BC theory, pull measures are typically underpinned by positive reinforcement and motivational constructs drawn from gamification, fostering intrinsic motivation and sustained engagement. Conversely, push measures can be interpreted through the TTM as external stimuli that move individuals from inertia to contemplation or preparation stages by altering perceived costs or dissonance. The goal of 'soft' transport policies within the pull space is to influence car users' decisions by shaping perceptions, helping them assess alternatives, and motivating and empowering switches (Bamberg et al., 2011). On the other hand, the goal of 'hard' transport policies within the push space is to prevent car users driving more, such as using cordon-based pricing for entering certain zones (e.g., in Singapore, London and Stockholm) Table 1 gives examples of hard and soft interventions. Effective transport policy often integrates these elements, consistent with DOI's proposition that diffusion accelerates when innovations are accompanied by both supportive incentives (pull) and enabling policies (push).

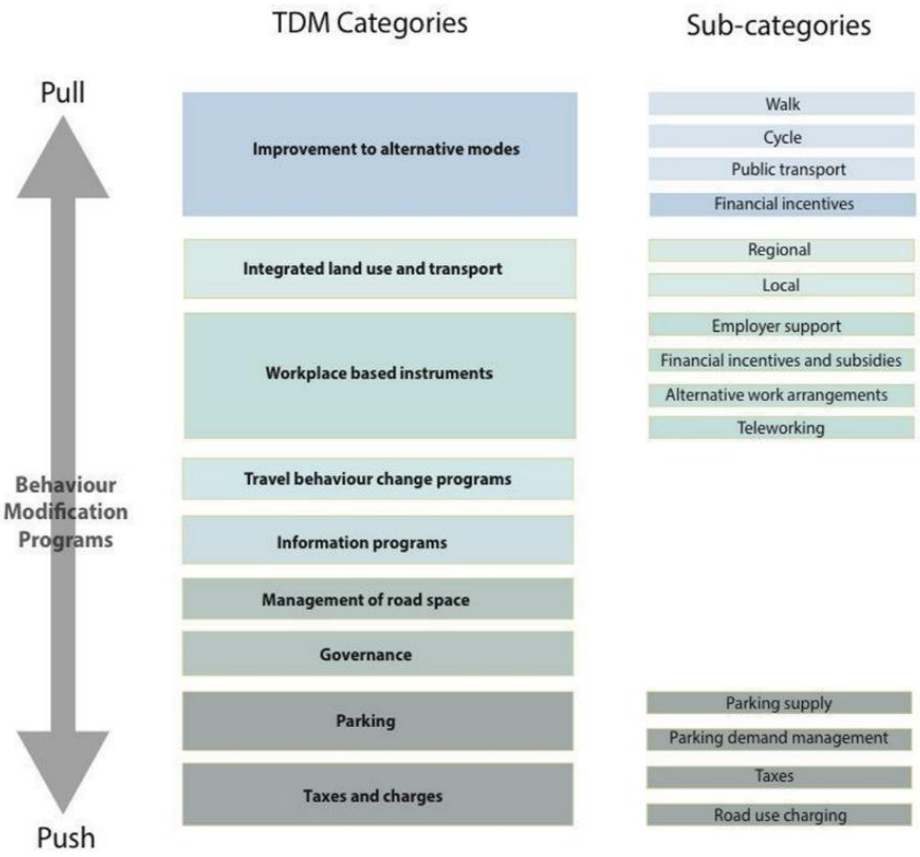

Figure 3. The Travel Demand Management Matrix (Babb et al., 2014)

Table 1. Summary of examples hard and soft interventions

Intervention measures	Push/ Pull	Hard /Soft	The time frame of behaviour change	Spatial Scale	Impact	Example References
Bicycle lanes	Pull	Hard	Long	Urban, regional	Small, moderate	Cleland et al., 2023
Road pricing (e.g., congestion charges and cordon-based charges)	Push	Hard	Short, medium, long	Urban	High	Börjesson et al., 2012, Hensher and Puckett, 2007, Santos and Shaffer, 2004
Parking pricing strategies	Push	Hard/ soft	Medium	Urban	Moderate, high	Kirschner and Lanzendorf, 2020
Toll lanes	Push	Hard/ soft	Short, medium	Urban	Moderate, high	Burris and Ashraf, 2019, Abulibdeh, 2018
Improving public transport	Pull	Hard	Medium	Urban, regional	Moderate	Fan et al., 2023
Personalised travel plans	Pull	Soft	Short, medium	Urban	Small, moderate	Chatterjee, 2009, Rye et al., 2011
Emission zones	Push	Hard	Medium	Urban	Moderate	Nelson et.al., 2022
Information/education interventions	Pull	Soft	Medium, long	National	Small, moderate	Bamberg and Rees, 2017, Gabrieli et. al., 2013
Working from home (WFH)	Pull	Soft	Medium, long	Urban, regional	Moderate, high	De-Toledo et al., 2022, Hensher et al., 2023
Location-specific travel programmes	Pull	Soft	Medium, long	National	Small	Spack et al., 2010, Petrunoff et al., 2016
Advocacy by role models	Pull	Soft	Short, medium	National	Small	Hanna et al., 2018
Pedestrian Strategies	Pull	Soft	Short	Urban	Small, moderate	Nelson et al., 2022, Salón et al., 2012
Public transport fares	Push	Hard/ soft	Short	National	Small, moderate	Nelson et al., 2022

Note: Table 1 should be read in conjunction with Figure 2.

Accordingly, measures such as information dissemination, communication, and education are used to generate behavioural change (De-Toledo et al., 2022). This includes strategies such as personalised travel planning (PTP) (Chatterjee, 2009; Geoffrey Rose & Ampt, 2001); travel plans tailored to specific locations like schools, universities, workplaces, and residential areas (De Gruyter, Rose, Currie, Rye, & van de Graaff, 2017; Petrunoff, Rissel, & Wen, 2016); persuasive technologies such as mobile apps (Anagnostopoulou, Bothos, Magoutas, Schrammel, & Mentzas, 2018); events (Geoff Rose & Marfurt, 2007); and advocacy by role models (Hanna, Demond, & Kelsey, 2018). Individualised travel marketing, or a travel feedback programme (Chatterjee, 2009; Parker et al., 2007), is found to be useful in encouraging individuals to voluntarily decrease their car usage (Bamberg & Rees, 2017), with appropriate implementation leading to a shift to more sustainable modes (Table 2). Pricing-based push (e.g., congestion charging) can work in tandem with pull measures: The London congestion charge, introduced in 2003, was a landmark policy aimed at reducing traffic congestion and improving air quality. By implementing a daily fee for driving in central London during peak hours, the charge effectively reduced car traffic volume by 30% in the

first year with around 9% of motorists transferring to public transport, thus contributing to lower emissions (Hensher & Puckett, 2007; Santos & Shaffer, 2004).

Table 2. Summary evidence on personalised travel planning and other soft interventions

Intervention measures	Location	Impact	Study
Personal travel planning – residential	England	Consistent reductions in car travel with an average of 11%, 4% increase in walking and 2% increase in cycling and public transport	Chatterjee, 2009
Personal travel planning – office	United States	Average vehicle trip generation was 36%-37% lower compared to other areas. Average peak parking generation was 21% lower than published parking generation rates	Spack et al., 2010
Personal travel planning – university	United Kingdom	Reduction in car trips by staff and students of 11 %	Rye et al., 2011
Personal travel planning – hospital	Australia	Driving to work among employees decreased by 13%	Petrunoff et al., 2016
Persuasive technology – Apps	Italy	14% of the participants adopted sustainable choices	Gabrieli et. al., 2014
Special events - Ride to Workday	Australia	27% continued to ride to work, 80% of first timers indicated a positive impact on their readiness to ride to work, 57% indicated an influence on their decision to ride	Rose and Marfurt, 2007

3.3 Impact Level

Understanding the effectiveness of designed and implemented measures is crucial in identifying interventions that yield significant versus marginal outcomes (Bamberg & Rees, 2017; Gaborieau & Pronello, 2021). BC theories such as the TPB and TTM help explain why impact levels differ across interventions that change attitudes, subjective norms, and perceived control (TPB). Interventions which move individuals through readiness stages (TTM) are more likely to generate non-marginal and sustained outcomes. For instance, in public transport, introducing a new bus route is a designed intervention aimed at improving accessibility. If passenger numbers increase significantly, indicating improved accessibility and reduced congestion, the intervention is deemed effective with non-marginal outcomes. Conversely, if there's only a slight improvement, the outcomes are marginal, highlighting the need for further intervention or adjustments. Such evaluations help in aligning the interventions with the overarching objectives, like enhancing public transport efficiency or reducing environmental impact. Without these measurements, it is challenging to discern the true impact of the intervention, potentially leading to wasted resources or missed opportunities for greater improvements (Bamberg & Rees, 2017). Another example of impact can be drawn from the COVID-19 experience, where WFH policies significantly lowered personal vehicle usage, reduced traffic congestion, and lessened environmental impacts. In some cases, encouraging a four-day workweek, with one day spent WFH, could result in a 20-40% reduction in commuting (Hensher, Beck, & Nelson, 2023).

Effects vary by user segment. A study conducted in China (Fan et al. (2023) comparing information provision and public transport improvements found limited effects of information on some groups, but reductions in car use with public transport improvements for others (Fan et al., 2023). These differentiated outcomes are consistent with DOI, which highlights how adoption rates differ across user groups depending on their openness to innovation and perceived advantages. Users were categorised into three groups: Group A (travel in low-frequency and prefer multimode), Group B (travel in middle-frequency and prefer the car) and Group C (travel in high frequency and prefer green modes). Group B's preference for car use and exclusion of bicycles was decreased with information but little change was exhibited with information on Groups A and C, but a reduction in car use B and C was seen with improvements in public transport Fan, Chen, Yu, and Li (2023).

It is also essential to consider the impact of such policies across multiple dimensions. For example, in the case of the London congestion charge, with the exclusion of environmentally friendly vehicles from the charge, as individuals replaced their older vehicles, the incentive to purchase environmentally friendly cars led to an increase in congestion, albeit with a higher proportion of greener vehicles. This situation underscores the importance of clearly defining objectives: if the goal was to reduce congestion, then all vehicles, regardless of their environmental impact, should be subject to regulation. Conversely, if the aim was to improve air quality, then environmentally friendly vehicles should not be penalised. The case also illustrates how measures intended to address one issue can have unintended consequences on other aspects, such as congestion. Elsewhere, Stockholm's congestion charge, introduced in 2007, has successfully decreased traffic volumes and improved air quality. Milan's Area C scheme, launched in 2012, has also led to reduced traffic and enhanced environmental conditions (Börjesson et al., 2012).

3.4 Temporary vs. long-term behaviour change

Two critical criteria in judging the success of behaviour change in transport are the effectiveness of the interventions and measures and maintaining achieved behaviour change. The TTM and TPB provide useful perspectives here: TTM emphasises that change occurs progressively across stages, from action to maintenance, while TPB explains that sustained change depends on reinforcing attitudes, norms, and control beliefs over time. Murray et al. (2017) conducted a systematic review using a meta-analysis of interventions to promote physical activities in achieving behaviour change and change maintenance. Self-monitoring and follow-up prompts worked better for interventions introduced in workplaces, universities, and other community-based settings (Cleland et al., 2023). Moreover, as tactics, these aspects of the intervention provided better maintenance of travel behaviour change. This shows that, while certain interventions may produce benefits for a few months before requiring additional funding or adjustments to maintain their effectiveness, others may have enduring effects. Hence, recognising the duration of these impacts is crucial for identifying which interventions provide lasting advantages and support the long-term sustainability of transport programmes.

Figure 2 indicates the timeframe (short, medium, long) of some of the 'hard' and 'soft' measures of interest. While the aim of the behaviour change measures is to achieve lasting changes in behaviour, the duration of impact is not always uniformly reported in studies, leaving ambiguities related to the temporality of the interventions (Austroads, 2024). Some studies have favoured long-term policies over short-term ones when combined with appropriate tools to assess the intended outcomes of such interventions such as modal share, public health and environment.

For example, working from home (WFH) emerged as a popular measure during the COVID-19 pandemic and has proven effective in fostering what are likely to be longer-term behavioural changes with potential for incorporation as a TDM tool. From a DOI perspective, the widespread adoption of WFH illustrates how behavioural innovations spread once their relative advantages become visible and compatible with existing lifestyles. Similarly, Gamification and motivational feedback mechanisms, such as recognition or rewards for sustainable choices, can reinforce habit formation and sustain change beyond initial adoption. The mental and physical comfort that WFH offers compared to traditional commuting patterns has significantly contributed to this shift (Balbontin et al., 2023). With reduced reliance on car travel, both employers and employees have become more accustomed to the benefits of WFH. These structural changes are gradually becoming a permanent feature of the mobility and land-use landscape, as the convenience and comfort of remote work continue to reshape traditional work and transportation patterns (Hensher et al., 2023).

Cleland et al. (2023) highlight a comprehensive strategy for promoting healthy and sustainable travel behaviour across the life course. This approach advocates for active travel in schools during childhood, enhancing teen mobility during adolescence, implementing organisational travel plans during working adulthood, and promoting walking for transport in older adulthood. Their findings underscore the necessity for longitudinal studies to ascertain the initiation and sustainability of these behaviours throughout life. Similarly, Pronello and Camusso (2011) discovered that an educational policy could significantly encourage a positive behavioural intention to increase the use of bicycles and buses (by 40%) and foster a commitment to act differently in alignment with general beliefs, thereby enhancing behavioural control.

3.5 Combining measures

In practice, cities often blend push–pull and hard–soft interventions. For example, in Oslo, 20% of the investment scheme of the city is allocated for public transport and then, ‘soft’ measures such as congestion charging are used to ensure a reduction in traffic volumes (Lian, 2008). According to TPB, effective policy mixes target multiple determinants of intention and action, attitudes through communication and education, norms through social visibility and diffusion, and perceived control through structural improvements. Similarly, TTM suggests that individuals at different readiness stages respond differently to push or pull measures, while DOI supports combining complementary innovations to accelerate adoption. In Singapore a combination of high quality public transport, vehicle ownership limitations and road pricing has been successful in alleviating congestion (although not increasing traffic speeds) notwithstanding population growth and increasing incomes (Cheng, Watkins, & Anciaes, 2024). Studies conducted in Norway, Stockholm, Singapore, Milan, and Gothenburg have shown long-term beneficial effects are noted where combining congestion charging with improvements to public transport, even if there are negative effects per se from implementation of congestion charging, particularly for low income individuals and individuals living in areas where traffic diverts onto adjacent arterials as well as concentrating near key public transport corridors and stations (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012; Börjesson & Kristoffersson, 2015; Givoni & Banister, 2012; Lian, 2008; Percoco, 2014). WFH likewise spans operates as a pull when enabled through flexible policies, information, and IT support, and approaching a harder or push form when codified in organisational rules or paired with commuting disincentives (e.g., parking cash-out, peak-hour pricing) (Barrero, Bloom, & Davis; Hensher, 2020). Recent experience with WFH is expected to result in long-term behaviour changes as a result of the benefits that it can yield for both employer and employee perspectives (Hensher et al., 2023). Structural (hard) changes are also commonly complemented by soft, pull-oriented interventions such as information, education, and training, to encourage

behaviour change towards public transport and other sustainable modes (Gov.UK, 2021). Figure 4 illustrates how the three pillars of behaviour change, capacity creation, and network management, can be leveraged to influence travel patterns and foster synergies among various interventions, leading to significant, non-marginal impacts within a given context. Hensher et al. (2025) investigated the one-way trip and arc elasticity impacts of stand-alone policy initiatives and compared the two elasticity effects when push and pull policy initiatives are at play. They find not only that there are asymmetric effects according to whether the policy involves an increase or a decrease, but that the combined policy initiatives suggest very different mean arc elasticity impacts, opening up opportunities for behavioural changes that are not obtained to the same extent from a stand-alone policy initiative. Each policy by itself generally, although not always, has a lower relative elasticity compared to when it is combined with another policy.

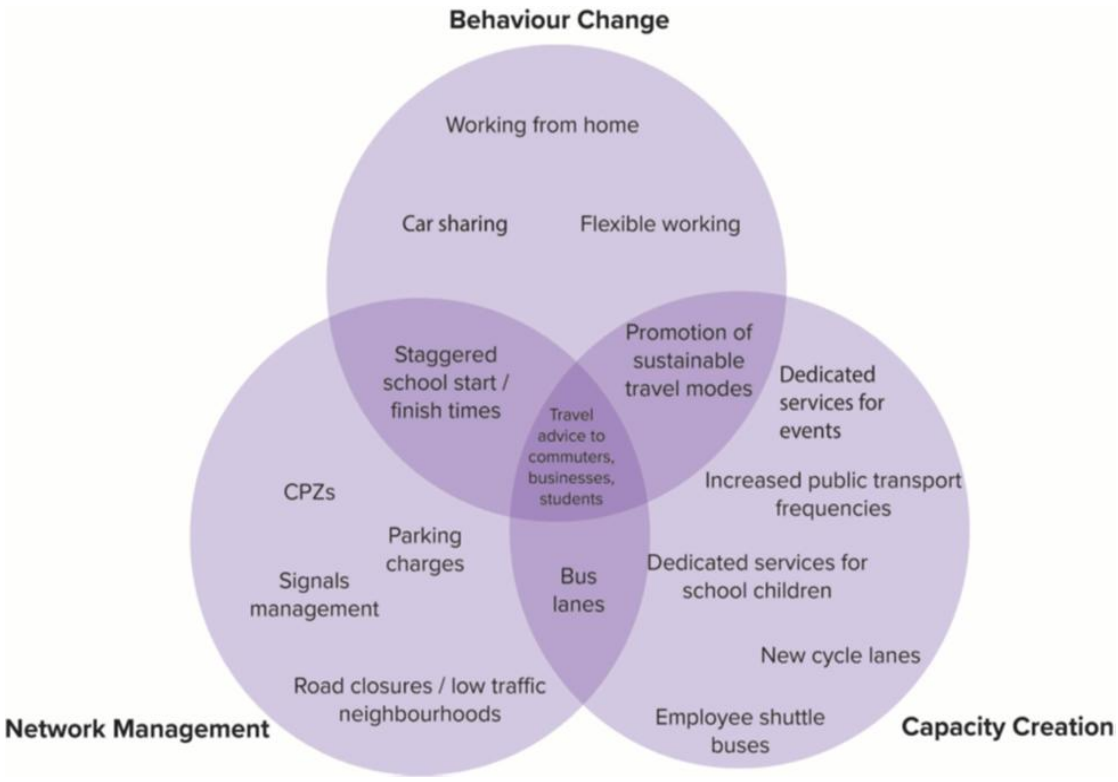

Figure 4. Structural Change and Policy Initiatives that can Impact Public Transport (Gov. UK, 2021*)*

3.6 Other considerations

Beyond the four dimensions depicted in Figure 2, additional considerations are worthwhile to be noted for completeness. It is important to develop behaviour change measures focusing on different localities and geographies such as cities, suburbs, regional and rural to cater to the transport requirements of the individuals living in such areas (Zhu, Guan, Han, & Li, 2020). Based on a study conducted in England, Wadud, Adeel, and Anable (2024) observe that just 2.7% of a person's trips involve long-distance travel (over 50 miles one way), yet these trips account for 61.3% of the total miles travelled and 69.3% of the greenhouse gas emissions (CO_2 equivalent) from passenger travel. This highlights the importance of having a separate focus

on long-distance travel to effectively decarbonise passenger transport. Long-distance travel, particularly flying, can provide significantly greater emissions reduction sensitivity compared to urban travel, indicating the need for a balanced policy approach.

Neighbourhood design is found to have a profound impact on travel behaviour. At the local level, using data from 547 individuals residing in four traditional and four suburban neighbourhoods in Northern California, Cao, Mokhtarian, and Handy (2007) used structural equation modelling to examine relationships between the built environment, car ownership and travel behaviour. Results show that land-use policies can effectively lead to reduced driving and increased walking. Based on a study conducted in North East England, Aditjandra, Mulley, and Nelson (2013) found that mixed-use developments, where residential areas are closely integrated with commercial and recreational spaces, encourage residents to engage in active travel modes like walking and cycling. These environments reduce the need for car travel by providing amenities within a walkable distance, making short trips by foot or bike more practical and appealing. This aligns with findings by (Cervero & Kockelman, 1997), who identified density, diversity, and urban design as key factors in reducing car dependence and promoting sustainable travel behaviour.

The availability of various transportation options, along with social and cultural factors and community influences, affects an individual's travel behaviour (Cheshmehzangi & Thomas, 2016). De-Toledo et al. (2022) suggest that given the diverse experiences of transport accessibility across a city, there is a need to contextualise travel behaviour interventions to specific local areas. This requires local travel behaviour information and better understanding of the barriers to realise opportunities for change, before creating and testing interventions tailored to these local contexts.

Haustein and Nielsen (2016) categorised the European Union's population into eight distinct mobility styles based on variations in travel choices, socio-economic factors, IT affinity, and life satisfaction to create six regional clusters. These distinct clusters together with the varied cultural backgrounds suggest that different policy approaches are required for the development and implementation of Sustainable Urban Mobility Plans (SUMPs)[4] (Gaborieau & Pronello, 2021). Some researchers have utilised the socio-ecological model to analyse the factors influencing active travel (Buehler & Pucher, 2021). This model includes a focus on the social-cultural environment, where social and cultural influences are often subtle and not immediately obvious. Frater and Kingham (2020) found that societal perception of cycling is a key social factor affecting how people consider active travel options. In a study conducted in New Zealand, it was found that a driver's license carries socially constructed meanings that can pressure young people to learn to drive regardless of their actual intention to drive. While some participants understood the environmental impacts of driving, this knowledge influenced their desire to own a vehicle and drive less than other factors, such as employability.

4 Conclusions and recommendations

This paper has proposed a conceptual framework, incorporating key dimensions relevant to the design and implementation of transport interventions to drive behavioural change for more sustainable transport. Although there exists a plethora of studies focusing on behaviour change

[4] Sustainable Urban Mobility Planning (SUMP) is a strategic framework aimed at creating efficient, inclusive, and environmentally sustainable urban transport systems.

interventions in transport, there is a notable lack of understanding regarding how the combination of these strategies can create systemic effects encouraging behaviour change within a given context. Understanding how various strategies interact could provide insights into creating more effective, integrated approaches to influence transport behaviour at a systemic level.

This paper has proposed a framework (Figure 2) informed by key BC theories including TPB, TTM, DOI and Gamification, which together explain how individuals and groups adopt, modify and sustain new transport behaviours. These theories provide the conceptual basis for situating behaviour change interventions alongside the dimensions which influence their effectiveness, namely: time frame (short v long), impact levels (small to high), the push and pull nature of interventions and whether they can be classified as soft or hard. Based on the discussion several key recommendations emerge to effectively promote sustainable travel behaviours. First, adopting a multi-faceted approach that combines both 'hard' and 'soft' measures is crucial for long-term success. While infrastructure improvements and policies like congestion pricing can directly influence travel behaviour, they should be complemented by personalised travel planning, public awareness campaigns, and incentive programmes. This combination ensures that individuals are not only motivated but also empowered to adopt and maintain sustainable transport modes (Santos & Shaffer, 2004). Second, tailoring interventions to specific populations through segmentation and recognising context is essential for maximising impact. Given the diverse responses to transport policies based on socio-demographic factors and geographic contexts, a one-size-fits-all strategy will most likely be ineffective. Instead, interventions should be segmented to address the unique needs and behaviours of different groups. For instance, targeting urban commuters with public transport incentives while offering customised travel plans in suburban or rural areas can effectively cater to varied travel demands. Additionally, aligning transport policies with the socio-cultural context of different communities can enhance their acceptance and effectiveness, ensuring that strategies resonate with the values and practices of the target population.

Cleland et al (2023) note that due to the complex nature of travel behaviour and given the intricate interconnections between transport, planning, and environmental systems, as well as the broader economic context and the many forms that travel behaviour can take, argue that is difficult to achieve a shift away from the current car-dependent system. A similar point is made by Argyriou and Barry (2021) in the context of the bus system. Proposed changes should be considered within the context of the entire land-use / transportation system and reviewing their potential impacts would be expected to benefit the broader sustainable transport agenda. Implementing certain interventions may have trade-offs, such as segregated bicycle lanes potentially reducing space for public transport or pedestrian sidewalks. But these same bicycle lanes could also be seen as beneficial to the community if they take space away from car lanes, aligning with sustainable transport goals (Cleland et al., 2023; Xiao, Liao, Wu, Tian, & Sun, 2024). To be effective, interventions should aim to shift people's attitudes and beliefs, encouraging voluntary changes in travel behaviour rather than imposing them. These insights enable the design of context-sensitive interventions tailored to specific populations and circumstances. Understanding the effectiveness of 'hard' versus 'soft' measures aids in selecting appropriate tools for achieving policy goals. Ultimately, the intention is to capture the strategies available to address current transportation challenges, foster long-term behaviour change, and advance environmental sustainability and social equity.

To advance the field of travel behaviour change, research needs to go beyond simply summarising the outcomes of interventions to identify their effectiveness (De-Toledo et al.,

2022). Nevertheless, as Arnott et al. (2014) suggest, there is currently insufficient evidence on the effectiveness of implemented measures for promoting travel behaviour change. Many prior studies have primarily focused on car reduction strategies without evaluating interventions to promote alternatives to car use (Piras, Sottile, Tuveri, & Meloni, 2022; Roaf, Lawlor, & Larrington-Spencer, 2024). Additionally, studies have often inadequately distinguished between interventions that create only marginal change from those making a substantial difference. This detailed information is crucial for policymakers designing travel behaviour change programmes.

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Declaration of interest

Declarations of interest: none.

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