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Designing user-centric transport strategies for urban road space redistribution

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ABSTRACT

Cities worldwide are geared to promote economic growth, improve accessibility, address environmental issues, and enhance the quality of life. However, the processes that lead to the design of urban roads, particularly the space distribution, reflect the inequalities existing in the fabric of our society. Motorists often have shorter travel time and more space than passengers of other modes. Furthermore, the existing transport appraisal and planning tools that frame sustainable transport policies fall short of considering the dimension of social justice. Therefore, our urban transport systems are essential areas for advancing sustainability through a transport justice-based approach to planning that can pivot the distribution of infrastructure investments over different social groups and transport modes. This study proposes such an approach by which such suitable urban transport strategies can be identified, co-created with users and appraised while considering the commuters' needs. Specifically, the interaction between the multidimensional characteristics of sustainability and the principles of transport justice are investigated. The proposed approach is applied to London and Birmingham. The results show that a transparent and holistic approach to integrating users within transport planning is an effective way to reflect diverse needs and local circumstances and thereby ensure a just transition to sustainable urban transport policies. The results from the case studies highlight a strong rationale for the centrality of justice in any urban transport planning and policy making efforts, particularly in the allocation of road space.

1. Introduction

The global urban population is predicted to grow by 2.5 billion in 2050, reaching 66% of the total population (Population Division U.N., 2018). The urban transport industry needs to respond to this ever-increasing demand by providing more reliable, accessible, safe and sustainable services. Contemporary urban transport policies tend to favour and prioritise motorised private transport systems while mainly ignoring, or accepting as a necessary evil, their negative environmental and societal impacts. The increased and often ever-growing levels of motorised transport have resulted in cities still struggling with high levels of congestion, air pollution, noise and accidents (Gössling et al., 2016). Furthermore, the increased use of private vehicles has often pressurised the transport planners while allocating the available road space among different transport modes (Gwilliam, 2003). Motorised individual movements in relatively large boxes have residual issues, retaining the need for large amounts of road space for substantial, fast-moving objects that provide barriers to people's activity being one (James et al., 2017). This is underpinned by the truism that all infrastructures are, at their very essence, created and operated to deliver shared resources in towns and cities, and more widely regionally and globally. This need for sharing of resources has always been understood but was starkly illustrated by Hardin (1968) in his description of the 'tragedy of the commons' – an unregulated system defaulting to the benefit of the 'haves' rather than the 'have nots' (Hardin, 1968).

Governments have a responsibility to govern all resources to benefit everyone in, and perhaps outside, society (i.e., citizens and non-citizens); those who pay their taxes to enable the services to be provided and those who do not or cannot. Providing an adequate means to move for all falls squarely into this responsibility, providing as it does a plethora of opportunities that are not afforded to those with limited ability or capacity to move. Previous transport planning and engineering studies have

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explored a range of aspects including, quantifying the magnitude and extent of disruptions on the urban transport system to society due to infrastructure deterioration (Marsden et al., 2020) and extreme weather events (Jenelius and Mattsson, 2012; Pregnolato et al., 2017; Zorn et al., 2020); benefits of transport infrastructure projects and services to different areas within the city (Currie, 2010; Foth et al., 2013); the influence of transport policies on making services affordable to different income groups (Levinson, 2010); and measuring the exposure of different social groups to transport-related externalities like accidents and pollution (Feitelson, 2002). The accessibility of urban transport systems has also been investigated in line with issues such as gender, ethnicity, age, socioeconomic status and disability (Gössling, 2016; Lucas, 2012; Lucas et al., 2021; Martens and De Ciommo, 2017; van Wee and Geurs, 2011). Recent studies have highlighted the challenges associated with road space allocation for different transport modes (Nello-Deakin, 2019) and activities (Valença et al., 2021). While investigating the fairness of road space allocation, Creutzig et al. (2020) reported that car users have approximately 3.5 times more space than non-car users. Reallocating the space from cars to other modes is justified from environmental, social and economic contexts (Gössling, 2020). However, there are no academic attempts or systematic approaches from an infrastructure appraisal perspective to aid policymakers in addressing sustainably allocating/reallocating road spaces. Moreover, there is still little engagement within the theories of transport appraisal and planning to frame road space redistributions in the context of user-centric urban transport policies (Pereira et al., 2017).

Facilitating a fair distribution of road space and associated benefits requires a context-specific approach that considers different priorities and opportunities (Lee et al., 2021). Whence, co-creation methods offer a way of creatively engaging with users to provide a holistic perspective on a particular problem and potential solutions where the users are at the centre of the designed solutions. For example, co-creation methods were used to generate possible sustainable travel solutions (Mitchell et al., 2016) and investigate the expectations of bus users (Hildén et al., 2017). Moreover, co-creating provides a real-world comparison of the applicability of generated solutions by the end-users with those developed by planners and researchers (Trischler et al., 2018). However, contemporary urban transport policies have been developed based on differing principles favouring different transport modes, often depending on political visions, while often not fully considering the users' requirements. For example, consultation with transport users and communities is very limited outside of large transport infrastructure schemes in UK (Institute for Government, 2021). Considering the complex and overlapping responsibilities with other infrastructure services, decision-makers need to balance the value for money and efficiency of urban transport investments against the social equity (Martens, 2020) and justice that it might deliver (or not) (Lucas et al., 2021). Transport modelling and cost-benefit analysis (CBA) have been the two key tools used in the infrastructure appraisals (Sasidharan and Torbaghan, 2021). However, the recommended improvements are often based on current or future transport demand and not considering various user perspectives (Whittle et al., 2019); for example, arriving at a trade-off between the commuter requirements, costs of different strategies (e.g., segregated cycle lane, bus lane) and the associated impacts to the city from accessibility, safety, and environmental discourses.

A user-centric based approach would pivot the distribution of the investments over different social groups and transport modes. This could see a paradigm shift in transport planning to compliment the demand models with need-based or commuter-centric approaches that consider the needs of different population groups and transport mode users alongside the information on their travel behaviour and patterns. Raising this argument to a higher level, the needs and wants of people – their aspirations – should be synthesised with the aspirations of those who govern (for the benefit of their place as well as their citizens; justice comes into these judgements) and those of all other relevant actors (Rogers and Hunt, 2018). Adopting such an approach effectively sets the brief for co-creation: the joint problem definition and problem-solving activities needed for effective systems design and operation. To this end, this paper presents a theoretical framework for identifying sustainable urban transport strategies (focusing on infrastructure investment appraisal for road space allocation) while considering the commuters' preferences and their travel patterns; evaluating the cost-effectiveness of candidate strategies and suggesting a set of solutions aimed at solving infrastructure, service and behaviour related urban transport challenges (Section 4). The usability of the proposed framework was demonstrated by applying it to London and Birmingham (Section 5) where a travel behaviour survey was conducted to gather information on how, why, when and where people travel and factors influencing their travel (e.g., convenience, healthier lifestyle, safety). Following the survey, three semi-structured focus groups were organised with participants from both the cities to identify the transport-related problems in both the cities relating to behaviour (e.g., drunken driving, inconsiderate cyclists, drivers being inconsiderate of cyclists), services (e.g., the unreliability of bus services, inaccessible information) and infrastructure (e.g., potholes, lack of cycle lanes). The solutions to these problems were identified through focus groups, and the cost-effectiveness of their application to different urban road layouts (single and dual carriageways with two and four lanes) was evaluated using a CBA. The results from the case studies (Section 6) highlight a strong rationale for user-centric approaches to any urban transport planning and policy making efforts. The conclusions and recommendations for future research are presented in Section 7.

2. Sustainability in urban transport

The sustainability of transport systems generally refers to combinations of policies and technologies that influence infrastructure, services and travel behaviours that minimise adverse social and environmental impacts and retain economic benefits (Stephenson et al., 2018). The concept of sustainable development has been employed for identifying optimal resource allocation strategies for the management of infrastructure facilities and systems (Alam et al., 2017; Sabatino et al., 2015). While sustainability is about achieving a balance between economy, society, and environment (Sasidharan and Torbaghan, 2021), the term 'liveability' of cities has been drawn into the discourse on sustainability to raise the importance of people's needs and wants alongside economic and environmental concerns (Rogers, 2018). While there is universal agreement that achieving sustainable development is a global imperative, no universal set of practices can be applied. This is because the sustainable development priorities will vary across regions and cities, i.e., they are necessarily context-dependent (Rogers, 2018). Furthermore, these priorities for a given region are likely to change over time due to the region's attained level of development, reflected in the sophistication of the technologies that are progressively deployed. Additionally, these priorities will change with cities being compelled to respond to challenges associated with climate change, decarbonisation, inclusion, and resource depletion (Liang et al., 2022; Parkin et al., 2019; Sasidharan et al., 2023). Combined with this are concerns over the needs of an increasingly ageing population in many countries. The existing approaches to identify and appraise the urban transport policies can be argued to fail to meet these objectives.

Generally, transport systems aim to improve overall accessibility (to maximise uptake) and reduce transportation costs while serving as an essential ingredient for economic development and growth. From that perspective, *space* is a crucial element in urban transport designs (Kemmer et al., 2022). The area and infrastructure made available within the cities for different modes of transport will affect the transport options, volumes, and the residents' travel behaviour. The infrastructure provision for public transport and active travel can greatly influence mobility shifts. For instance, the introduction of cycle lanes in London and Birmingham has often been seen as an advancement in efforts to make cities 'liveable'. Gössling et al. (2016) reported that the traditional urban design approaches resulted in unevenly distributed road space with greater space allocated to cars, while bicycles were most disadvantaged. Driven by concerns of safety, air pollution, congestion, greenhouse gas (GHG) emissions and the inefficient use of limited space, the urban mobility narrative appears to be changing towards more sustainable transport practices. However, changes in the distribution of road space can take much time even in cities with far-reaching ambitions for urban transformation such as Copenhagen (Carstensen et al., 2015). More specifically, limitations on parking provision in new developments can encourage the use of more sustainable transport modes.

While physical mobility is critical to the functioning of many urban systems, stating that the social impacts of urban transport must embrace all impacts (positive and negative) on people is usually considered too broad. Health and safety often impact the decision-making process in the transport planning (Martens et al., 2012). *Health* impacts of conventional motorised transport are associated with the emissions of harmful substances such as carbon dioxide (CO_2), nitrogen oxides (NO_x) and particulate matter (Sasidharan et al., 2020b). Air pollution-related health risks are the highest while commuting in traffic (Karanasiou et al., 2014) with cyclists being the most exposed as their respiration rates can be up to 4.3 times higher than those of car users (Int Panis et al., 2010). Half of the air pollution-related mortality in Europe is attributed to motorised transport (Künzli et al., 2000). Willingness to pay (WTP) for health services is often used to measure the health impacts of transport systems in monetary terms within transport appraisals (de Dios Ortúzar et al., 2000; Haddak, 2016). Additionally, noise exposure is a considerable health and wellbeing problem in cities with more than 50% of Europe's urban population exposed to alarming noise levels from road traffic that often exceeds the safe limit of 55 dB (European Environment Agency (EEA), 2018). Exposure to traffic noise is reportedly damaging to health (Wrótny and Bohatkiewicz, 2021) and is mainly related to motorised transport (Pathak et al., 2008). On the other hand, safety is also a key priority for people's wellbeing and an important social indicator. Apart from the human cost, accidents also hinder sustainable development and place considerable psychological, social, and economic burdens on commuters and wider society. The situation is exacerbated particularly in developing countries where the costs associated with accident-related fatalities and injuries amount to approximately 3% of GDP (Kopits and Cropper, 2003). The corresponding figure for developed countries ranges from 2.2% to 4.6% (Torbaghan et al., 2022). While most traffic accidents are associated with cars, pedestrians and cyclists are disproportionately often the victims of such incidents (Torbaghan et al., 2022).

From an environmental impact perspective, there are significant differences in fuel efficiencies between various modes of transport, with the energy consumption of conventional cars being the greatest among urban transport modes. The GHG emissions associated with the transport sector have increased (+14%) between 1990 and 2012 in the EU-28 and this is particularly high (+17%) for road transport (Statistical Office of the European Communities (Eurostat), 2015). Moreover, the urban transport developments also have adverse impacts (e.g., biodiversity). The inverse, of course, is true: promoting walking and cycling through the development of the required infrastructure, such as green infrastructure corridors and blue–green infrastructure, can significantly decrease the negative primary impacts while improving biodiversity (Fairbrass et al., 2017; Sadler et al., 2011).

3. Appraising sustainable urban transport strategies

Drawing parallels with principles of social justice, transport justice argues that '*governments have the fundamental duty of providing every citizen with adequate transportation and thus mitigating the social disparities*' that have been created over time (Verlinghieri and Schwanen, 2020). Transport investment appraisal processes are often hierarchical and demand discrete decision making in uncertain and risky environments. In practice, when decision-makers face many alternatives that are governed by political, economic, socio-cultural, technological, environmental, and other external influences, they often resort to short-term strategies, which not only ignore a 'transport ecosystem' perspective (or commuters' needs) but also fail to deliver transport justice. It can be argued that transport justice should take a centre stage of infrastructure appraisal and transport planning while aiming to achieve social and environmental goals. Such an argument is mainly attributed to the fact that urban transport systems and associated infrastructure have traditionally been designed based on industrial interests and do not necessarily represent broader societal goals (Beyazit, 2011; Lucas, 2012). There is also growing evidence that motorised urban transport increasingly burdens other modes concerning space allocation (e.g., road layouts, parking) and traffic congestions (Banister, 2007; Levinson, 2010; Mullen et al., 2014).

The current design of urban transport systems (both services and infrastructure) is no longer reflective of the changing needs of urban commuters, the requirements of different transport modes and their use, or the quality of life in cities (Gössling et al., 2016). However, some studies argued strongly against the practical implementation of justice within transport (Martens, 2011; van Wee and Geurs, 2011) with the assumption that it is very challenging to consider the cost and benefit of transport policies. On the other hand, other studies consider justice as a pillar of consequentialism, sufficientarianism and egalitarianism, contributing to the ex-ante evaluation of transport policies that consider social exclusion, accessibility and equity constraints (Lucas et al., 2021; Van Wee and Roeser, 2013). As outlined in previous sections, one way of facilitating a fair distribution of resources and space between transport modes and population groups can be through the co-creation of urban transport strategies followed by evaluating the cost-effectiveness and sustainability evaluation of the candidate strategies.

Transport modes can be categorised into more sustainable (walking and cycling, bus, light rail transit) and less sustainable (motorcycle, car) transport modes. Each mode makes uneven contributions to transport systems' social, environmental, and economic outcomes. The effects of transport systems can be summarised in three dimensions, namely, exposure (accident risks, air and noise pollution), space (distribution and access to infrastructure facilities), and time (delays due to congestions) (Gössling et al., 2016). The underlying principles associated with these three dimensions can be said to be captured within the three pillars of sustainability, i.e., the economic, social, and environmental aspects of each transport system (Table 1). Evaluating the sustainability of a transport strategy can provide some insights into its contributions to achieving justice. Transport justice can be introduced as a distinct benefit for urban transport users, aiming to reduce socio-spatial inequalities and provide more accessibility for vulnerable groups.

4. Methodology

We propose a theoretical framework that advocates a sustainability evaluation approach (summarised in Fig. 1) to compare the economic, social, environmental implications of adopting a particular urban transport strategy, such as those outlined above, so that the most viable can be selected based on its corresponding implications for road space allocation. *Establishing a clear vision and objectives* for the transport strategy that aligns with the long-term goals to be achieved in terms of sustainability, accessibility, and mobility is often dictated by the national and local transport policies. Identifying and engaging with key stakeholders, including government agencies, local communities, environmental organisations, transportation providers and businesses is necessary to understand their *needs, concerns, and expectations regarding transportation* (i.e., services, infrastructure, user behaviour). *Identifying potential alternative solutions* to urban transport strategies involves a systematic approach that considers the challenges and goals of a specific area including population density, traffic levels, pollution levels, existing infrastructure and future growth projections alongside budgetary and environmental considerations. Consideration needs to be given to the interconnectedness of criteria when evaluating the sustainability

Table 1
Transport objectives and their contribution to sustainability and transport justice (ECMT, 2000).

Transport objective	Sustainability			Transport justice		
	Economic	Social	Environmental	Exposure	Space	Time
Reduce greenhouse gas emissions		●	●	●		
Reduce noise		●		●		
Reduce congestion	●		●			●
Reduce social exclusion		●		●	●	
Improve air quality		●	●	●		
Improve transport safety	●	●		●		
Improve access	●	●			●	
Create wealth	●	●		●		
Support the local economy	●	●		●		
Protect landscapes & biodiversity			●	●	●	

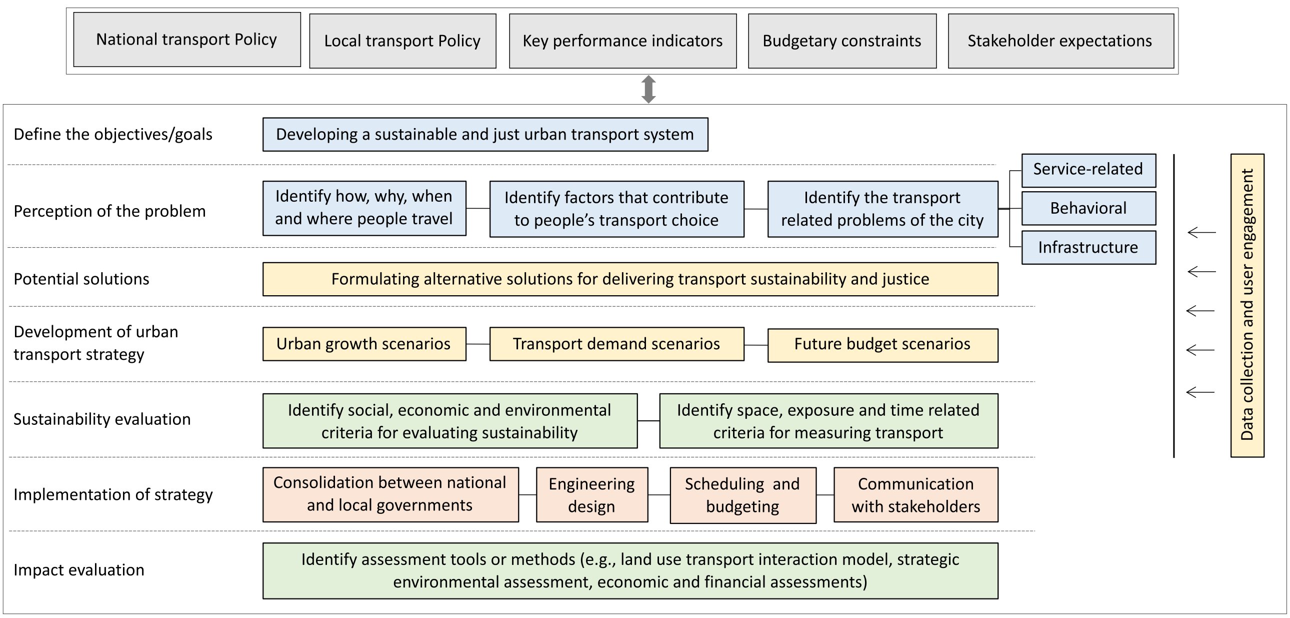


Fig. 1. Theoretical framework for identifying sustainable and just urban transport strategy for road space allocation.

impacts, i.e., changes in economic, social or environmental criteria can have ripple effects on each other. Cost-benefit analysis (CBA) is often used to compare different strategies and solutions to achieve the desired performance targets within the budget limitation. In such an approach, monies spent on redesigning and rehabilitating existing urban road layouts are considered investments, with financial returns. In principle, CBA can compare the transport strategies using economic decision rules that consider the costs and benefits accruing from the strategy over a given period of analysis. The most appropriate strategy is the one that provides the greatest return on investment. For example, creating segregated bus/cycle lanes is likely to have higher initial investment costs. However, this may subsequently lead to lower user costs due to the shift from cars to public transport and active travel, resulting in lower emissions, less time delay and reduced accident costs.

Implementation of the strategy requires coordination between national and local governments and the transport authorities. The national government could provide financial assistance and technical supervision for developing the local transport master plans. Further to guide improvements to its implementation, impact evaluations of the transport strategies seek to test whether the anticipated benefits have been generated when delivered in the real world, identify any unintended consequence and allow for the value for money assessment to be reviewed in the light of the evidence post-implementation. A set of key performance indicators (KPI) are often devised to set targets and assess the impact of initiatives in achieving them. These KPIs could include metrics such as carbon emissions reductions, mode shift towards public transit and active travel, traffic congestion reduction, and air quality improvement (European Conference of Ministers of Transport (ECMT), 2000; Mihyeon Jeon and Amekudzi, 2005; Nag et al., 2018; Ngossaha et al., 2017; Rao et al., 2018; Umer et al., 2016). Together with the available budget levels and potential sources of funding, including government grants, public–private partnerships and revenue generation mechanisms like tolls or congestion pricing, these KPIs influence the urban transport strategy that is to be adopted.

4.1. *Cost-benefit analysis*

Various economic parameters can be considered when evaluating the sustainability of transport systems, including both direct and indirect and monetised and non-monetised benefits. Changes in the total operational costs, i.e., those of owning and operating vehicles resulting from a transportation improvement project are often considered within an analysis (Victoria Transport Policy Institute (VTPI), 2017) since considerable savings could be achieved by reducing private vehicle ownership and/or use. For example, better walking and cycling opportunities or public transport services may encourage urban households to switch to more sustainable transport modes or avoid purchasing cars. Similarly, the provision of new or enhanced intermodal transport systems in a city has beneficial impacts on travel time, vehicle operating costs and parking costs, while walking, cycling and bus travel have relatively low travel costs. Several decision rules could be used to evaluate the sustainability of transport investment strategies while framing it from an economic perspective through cost-benefit analysis. The most common ones are the Net Present Value (NPV), the Benefit-Cost Ratio (BCR) and the Internal Rate of Return (IRR) (Sasidharan et al., 2020a). The BCR ($\widehat{BCR}$) is the ratio of discounted benefits and costs accruing over a given analysis period (Eq. (1)). Transport investment strategies with a BCR of more than 1 have greater benefits than costs; hence they have positive net benefits. The higher the BCR, the greater the benefits relative to the costs.

$$\widehat{BCR} = \sum_{n=0}^{N} \frac{\widehat{B}_n / \widehat{C}_n}{(1+\widehat{r})^n} \tag{1}$$

Where ($\widehat{C}_n$) is the discounted infrastructure costs, ($\widehat{B}_n$) is the discounted benefits, $\widehat{r}$ is the discount rate, N is the analysis period, and n is the individual years of the analysis. The discounted infrastructure costs ($\widehat{C}_n$) associated with a transport strategy consisting of different transport modes, m, is made up of costs related to employing staff ($\widehat{C}_{Em}$), procurement of materials ($\widehat{C}_{Mat}$) and deployment of machinery ($\widehat{C}_{Eq}$) of type, u, during the year, n. $\widehat{C}_n$ can be obtained from Eq. (2):

$$\widehat{C}_n = \sum_{m=1}^{M}\left[\widehat{C}_{Mat} + \left\{\sum_{u=1}^{U}(\widehat{C}_{Eq}\times\widehat{N}_{Eq}) + (\widehat{C}_{Em}\times\widehat{N}_{Em})\right\} + (\widehat{UC}_{M_n}\times\widehat{J}_{M_n}\times\widehat{P}_{M_n})\right] \tag{2}$$

where the required number of machinery ($\widehat{N}_{Eq}$) and employees ($\widehat{N}_{Em}$) for constructing or setting up the infrastructure is also considered. Where $\widehat{UC}_{M_n}$ is the user cost, $\widehat{J}_{M_n}$ is the number of journeys, $\widehat{P}_{M_n}$ is the number of passengers per journey using a transport mode, m, during the year, n.

The discounted benefits ($\widehat{B}_n$) accrued from each transport strategy are the sum of the direct and indirect economic, social, and environmental benefits associated with each transport mode, m, during the year, n can be estimated using Eq. (3).

$$\widehat{B}_n = \sum_{m=1}^{M}\sum_{n=0}^{N}(\widehat{Eco}_{M_n} + \widehat{Soc}_{M_n} + \widehat{Env}_{M_n}) \tag{3}$$

where $\widehat{Eco}_{M_n}$ is economic, $\widehat{Soc}_{(TM)n}$ is social and $\widehat{Env}_{M_n}$ is environmental impacts of a transport mode, m, for the given year.

The direct and indirect economic impact of a transport mode ($\widehat{Eco}_{M_n}$) is traditionally considered to be associated with the cost of and time to complete a journey (Eq. (4)). The economic impacts thus calculated serve as transport justice indicators of accessibility and time associated with each transport mode (Albacete et al., 2017; Bok and Kwon, 2016; Doorley et al., 2015; Koopmans et al., 2013; The International Transport Forum (ITF), 2017).

$$\widehat{Eco}_{M_n} = (\delta\widehat{UC}_{M_n}\times\delta\widehat{J}_{M_n}\times\widehat{P}_{M_n}) + (\widehat{T}_{M_n}\times\widehat{VOT}_n) \tag{4}$$

Where $\delta\widehat{UC}_{M_n}$ is the change in user cost, $\delta\widehat{J}_{M_n}$ is the change in the number of journeys and $\widehat{T}_{M_n}$ is the average journey time using a transport mode, m, during the year, n. $\widehat{VOT}_n$ is the economic value of time during the given year.

The direct and indirect social impact of a transport system ($\widehat{Soc}_{M_n}$) is associated with health, safety and noise (Eq. (5)). This, in turn, acts as the transport justice indicator for exposure associated with each mode of transport (Doorley et al., 2015).

$$\widehat{Soc}_{M_n} = (\widehat{WTP}_n\times\delta\widehat{J}_{M_n}\times\widehat{P}_{M_n}) + (\widehat{RA}_{M_n}\times\widehat{C}_{Acc_n}) + (\widehat{N}_{M_n}\times\widehat{C}_{No_n}) \tag{5}$$

Where $\widehat{RA}_{M_n}$ is the risk of traffic accidents and $\widehat{N}_{M_n}$ is the noise caused by transport mode, m. $\widehat{C}_{Acc_n}$ is the accident impact cost and $\widehat{C}_{No_n}$ is the impact cost of noise during the year, n. $\widehat{WTP}_n$ is the maximum price that a user is willing to pay for healthcare during the given year.

The environmental impact associated with each transport mode is determined using Eq. (6), which provides another insight into the transport justice indicator of exposure. $\widehat{C}_{P_n}$ is the marginal social cost for pollutant emission, p and $\widehat{E}_{PM_n}$ is the pollutant emission factor of a transport mode, m, during year n (Sasidharan et al., 2020a).

$$\widehat{Env}_{M_n} = \sum_{p=1}^{p}(\widehat{E}_{PM_n}\times\widehat{C}_{P_n}) \tag{6}$$

5. Implementation of the proposed approach

The methodology proposed in the previous section has been implemented to identify user-centric urban transport strategies for London and Birmingham. To this end, information was collected on users' travel behaviour, transport-related problems were identified, and solutions co-created. The value for money of the identified solutions was evaluated using the CBA proposed in the earlier section.

5.1. Research design: Travel behaviour

An online survey was conducted to identify users' travel behaviour and perspectives towards different urban transport policies in UK. The questions (Table A1 in Appendix A) were arranged into three sections: subjects (conveying the socio-economic background and mobility groups); valued activities (work, leisure, and study classified in terms of categories and frequency) and the locations where activities occur; and travel practices (preferences on travel modes, and commuters' considerations for modal alternatives, services, travel costs and time, reliability, safety, environmental impacts). The questions were aimed to explore the contribution of mobility to achieving valued opportunities. Participants were recruited using email and social media campaigns to engage with participants from across the UK. Responses were received from 114 participants from different socio-economic backgrounds living in 18 UK cities (Table 2). For instance, 31% of the respondents from Birmingham are students, while 56% are employed full time, and 13% are retired/not employed. On the other hand, 20% of the respondents from London are students and 80% are employed.

Table 2
Participation in the study (% by categories).

Category		Participants (%)		
		National	Birmingham	London
Age	18–24	6	13	13
	25–64	88	87	87
	65+	6	—	—
Gender*	Female	39	44	30
	Male	56	56	60
Ethnicity*	Asian	26	56	47
	Black	8	6	—
	Mixed	2	—	—
	White	55	32	47
	Other	9	6	6
Education level	High school	4	—	—
	Graduate	14	19	13
	Post-graduate	82	81	87
Employment status	Employed	71	56	80
	Not employed/ Retired	10	13	—
	Student	19	31	20
Salary range	< £15,000	20	44	—
	£15,000–£29,999	18	—	13
	£30,000–£49,999	42	38	61
	£50,000–£74,999	13	18	13
	> £75,000	7	—	13

Note: Some participants preferred not to disclose this information.

The results from the survey shed light on travel behaviour in UK and particularly for London and Birmingham, the two most populous cities nationally. The commuters' travel behaviour is influenced by their socio-economic background and where they live (i.e., based on the availability of transport services and modes). Furthermore, factors such as time and cost of travel, safety, reliability, convenience, and accessibility to transport infrastructure (e.g., parking, cycle lanes) were found to contribute to a person's choice of transport mode. These factors were grouped into six socioeconomic levels (Fig. 2). Both the cities show very different levels of factors influencing transport mode choice from the national baseline level. One notable exception to this is the users' consideration of the environmental impacts of their transport choice, which was ranked the lowest both nationally and regionally. Safety was ranked higher in both cities (6 in Birmingham and 5 in London). There is a significant variation in the contribution of reliability of the mode to the users' choice across the chosen spatial locations. For example, reliability was ranked to be the most important factor contributing to mode choice at a national level, yet it was ranked ~33% less important in Birmingham and ~70% less important in London. Similarly, affordability had the same importance as reliability in London as a contributor towards mode choice while it was ranked ~17% less important in Birmingham and ~33% less important at the national level.

Fig. 3 shows a summary of key findings on the 'ease' with which respondents were able to use a car, cycle, and public transport in UK. The factors that could potentially contribute to measuring the 'ease' were grouped, with 1 being the easiest and 5/6 the most difficult. As expected, cycling was ranked as the most cost-effective. When it comes to the availability of segregated cycle lanes, London is reportedly performing ~50% better nationally and compared with Birmingham. However, safety for cyclists remains a concern among respondents both at the national and regional levels. The respondents were more satisfied with the connectivity offered by public transport while feeling that the frequency of operation needs to be increased. However, cars were ranked more accessible (e.g., frequency of taxi services) within the cities. A range of difficulties with transport in general (not just public transport) was highlighted by the participants. The respondents also reported that the cost of owning and operating a car is slightly higher than using public transport costs.

It was also reported (Fig. 2) that the journey cost is the highest contributing factor for encouraging commuters to use public transport frequently, across all levels (i.e., national, London and Birmingham). This might also explain the lack of concern for environmental impacts amongst the participants when choosing their mode of transport (Fig. 2). However, environmental benefits and travel/journey costs were highlighted as important both nationally and in London (Table 3). Furthermore, when quizzed on the factors that encourage a shift from car to public transport (Table 3), travel cost was shown to be one of the main motivations for all participants. At the same time, they were motivated to

Fig. 3. Ease of using (a) car, (b) cycle, and (c) public transport in UK (1: the easiest to 5/6: the most difficult).

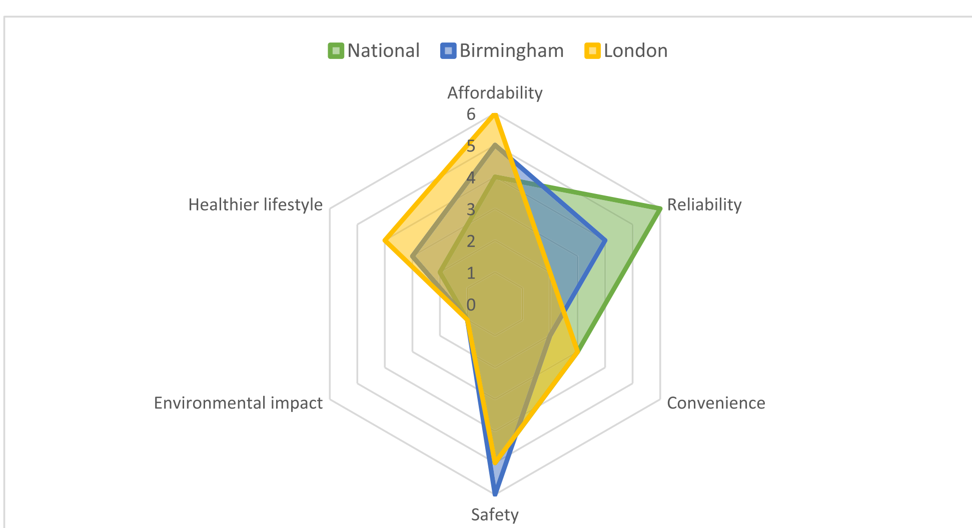


Fig. 2. Factors contributing to the transport mode choice in UK (1: the least contributing to 6: the highest contributing).

Table 3
Top three factors encouraging participants for a mode shift.

Mode shift	National	Birmingham	London
Car to public transport	Environmental benefits, Convenience, travel costs	Reliability, travel costs, convenience	Travel costs, convenience, environmental benefits
Car/public transport to active travel	Health & wellbeing, trip length (< 5 miles), environmental benefits	Travel costs, travel time, health & wellbeing	Health & wellbeing, trip length (< 5 miles), travel costs

shift from public transport/car to active travel for health and wellbeing benefits, provided that the length of the trip was less than 5 miles for work, study or leisure (Figs. 4(a), 4(c), and 4(e)). It can also be observed from Table 3 that the factors contributing to participants' motivation for mode shift are very similar nationally and in London.

The transport mode choices are represented in Fig. 4, broken down by travel behaviour (the average journey length and the number of trips) and reasons for travel (i.e., work, study, and leisure) at the national and regional scales (i.e., London, Birmingham). While public transport is the preferred mode in London for 5–10–mile–long journeys (Fig. 3(c)), cars were chosen as a means of transport for the same journey length in Birmingham (Fig. 4(e)). However, participants tend to use public transportation at the national level irrespective of the length or reason for the journey (Fig. 4(a)). All the respondents mainly use cars to travel for leisure with ~68 %, 67% and 77% for national, London and Birmingham respectively (Figs. 4(a), 4(c), and 4(e)). It is also noteworthy that participants in London who use cars are more likely to travel relatively long distances (over 20 miles) (Fig. 4(c)) for work and leisure than in Birmingham (Fig. 4(e)), where the average leisure-related journey length is up to 10 miles. Figures 4(b), 4(d), and 4(f) show the percentage of weekly trips for each primary mode of transport for the national, London and Birmingham regions. Respondents tend to make ~18%, 16%, and 30% of their weekly trips (< 5 miles long) on public transport and 13%, 4% and 51% by car for work, study and leisure, respectively (Fig. 4(b)). In London (Fig. 4(d)), both cars and active travel are used for leisure-related trips that are usually < 5 journeys per week. In contrast, respondents living in Birmingham make these journeys using cars and public transport (Fig. 4(f)). Unsurprisingly, students in universities and further education are largely associated with active travel and public transport.

Commuting distances between home and locations of work, leisure and study primarily depend on the distance from the dwelling to the main or secondary urban centres (Fig. 5). The central dwellers make a higher proportion of their trips by cars and active travel in London (Fig. 5(a)) and Birmingham (Fig. 5(b)) and a lower ratio by public transport. On the other hand, those living away from the centre tend to rely more on public transport for work trips in both the cities, while preferring cars for leisure trips. This is likely influenced by the wide spatial coverage and availability of public transport services in London and Birmingham.

The economic background of the residents also influences their travel behaviours and their chosen mode of transport, as might be expected (Fig. 6). Most of the participants who earn < £15,000 (per annum) in this survey results were full-time students, and those who earn > £15,000 were studying part-time (Fig. 6(c)). It can be observed that participants who earn > £15,000 drive to work more often if they live in the outer regions of a city. On the other hand, participants who earn over £75,000 often live in the outer part of the cities (Figs. 6(a)–6(c)) and prefer cars as their primary mode of transport for work, leisure, and study (assumed to be a part-time study). While public transport seems to be widely used by all economic groups for work, leisure and study-related trips, cars are mainly attributed to work and leisure related trips. Participants tend to use public transportation and active travel irrespective of their economic backgrounds (Fig. 6(c)). In contrast, they mainly use different means of transport (i.e., car, public transport, and active travel modes) for leisure trips. Although (Fig. 3(c)) the frequency of operation is a commonly

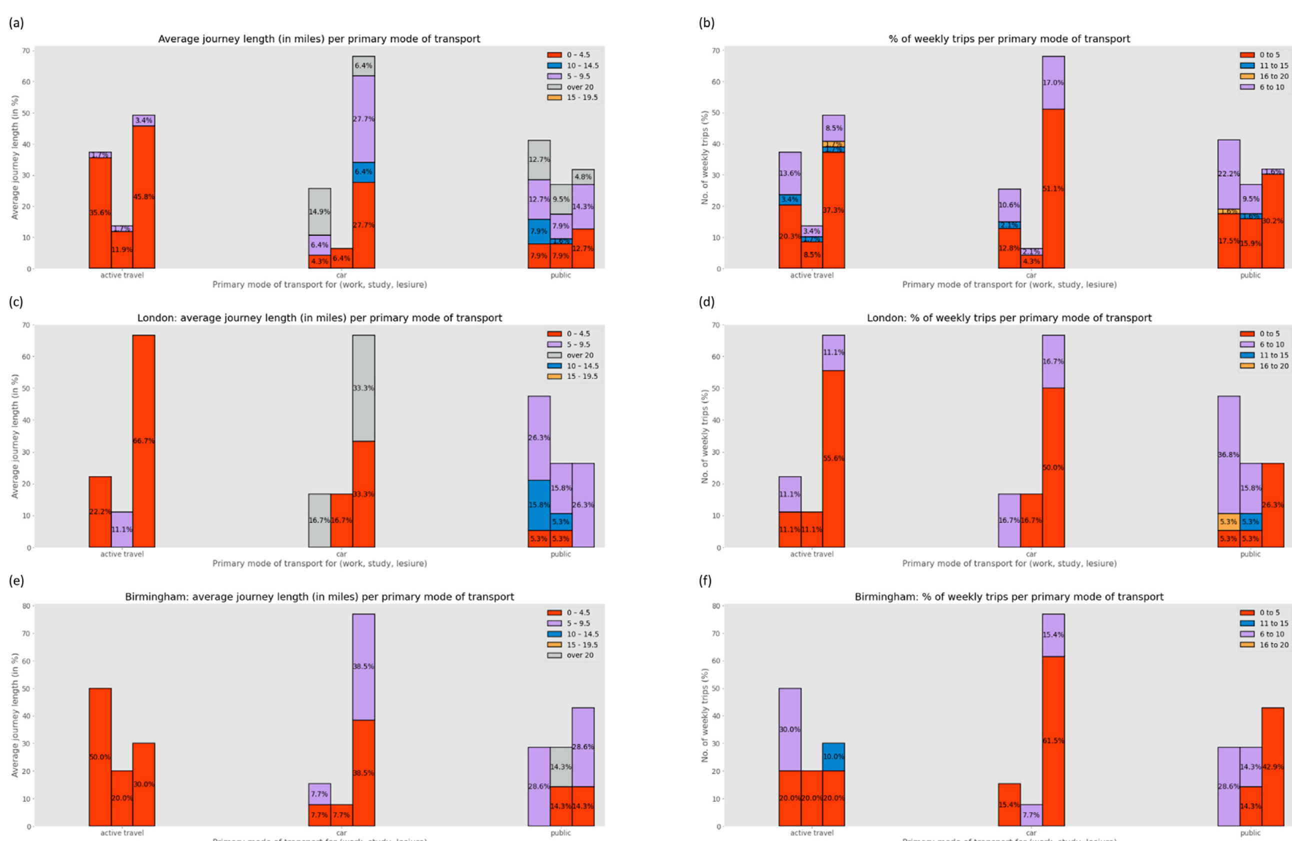


Fig. 4. (a) Average journey lengths and (b) weekly trips per primary transport mode nationally, in (c, d) London and (e, f) Birmingham.

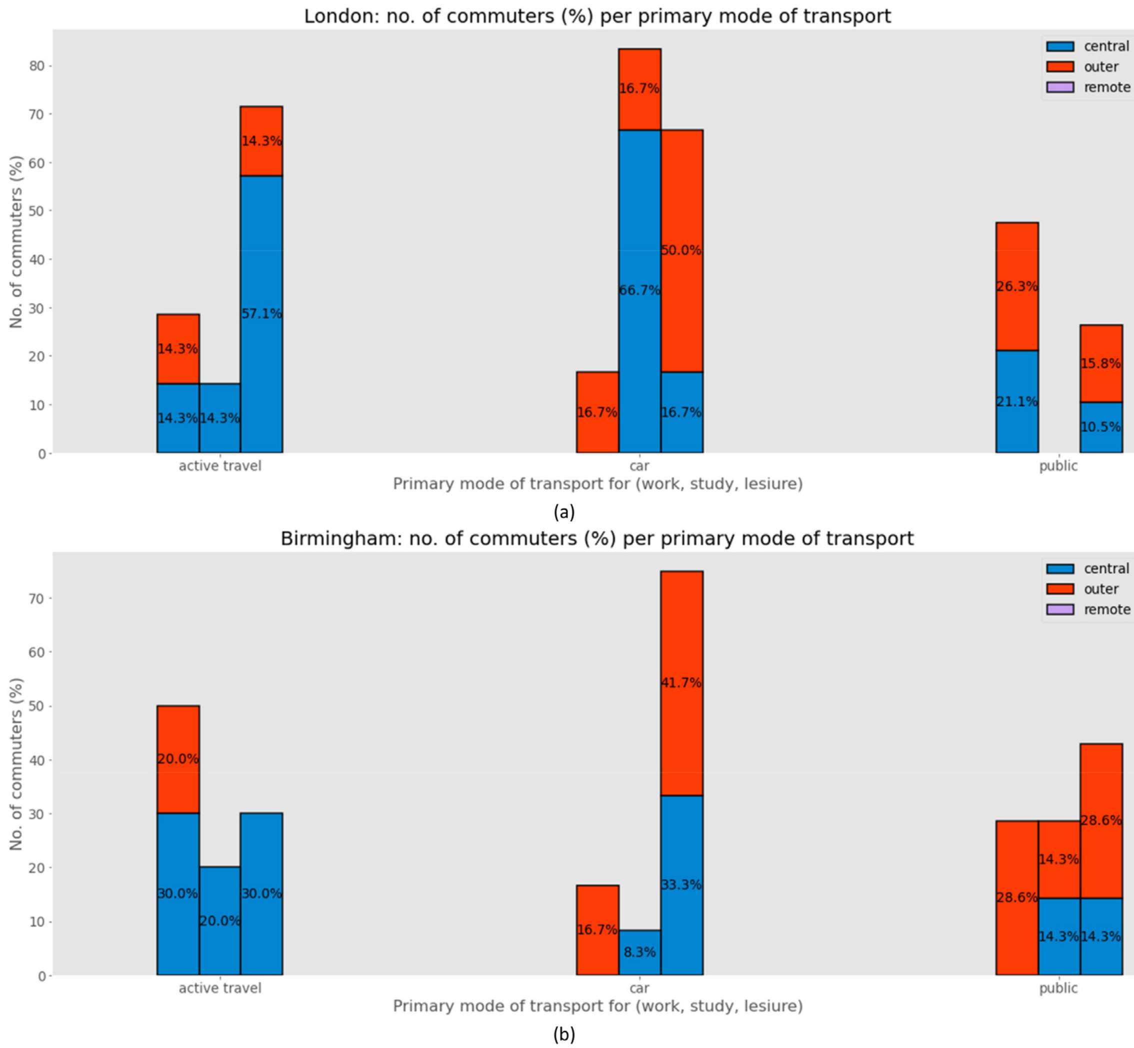


Fig. 5. Influence of residence location and travel reason on the transport mode choice in (a) London and (b) Birmingham.

reported problem associated with public transportation, people tend to use it frequently regardless of their economic backgrounds and their location of residence.

5.2. *Research setting: co-creating user-centric solutions*

Respondents to our survey (discussed in Section 5.1) from London ($n = 21$) and Birmingham ($n = 19$) were selected randomly to be part of semi-structured focus groups. The number of participants per focus group may vary (Rabiee, 2004). A small number of participants (< 4) might limit the discussion, while many participants (> 10) could limit the interaction (Cameron, 2005). Focus groups have been used in different research designs, including designing public transport systems (Ramos et al., 2019). A focus group allows deriving multiple benefits from participants. It is a fast and efficient way for obtaining data from multiple participants(Onwuegbuzie et al., 2009), creating the possibility of spontaneous responses and comments and providing their experiences or situation within the context of transport choices (Duggleby, 2005; Onwuegbuzie et al., 2009). With this in mind, the number of participants in our focus groups was 8. Each participant was interviewed individually first to gather information on how, why, when and where people travel and factors influencing travel (e.g., convenience, lifestyle, safety).

Three-focus group were conducted with participants from London and Birmingham. The process involved linking key factors in locations and infrastructure that promoted and compromised mobility to participant-generated solutions and combining complementary options. Two semi-structured focus groups were then organised with participants from both cities separately to identify their transport-related problems for four different transport modes: car, bus, metro, and active travel. The reported problems were related to user behaviour (e.g., drunken driving, inconsiderate cyclists, drivers being inconsiderate of cyclists), services (e.g., infrequently bus services, inaccessible timetable information) and infrastructure (e.g., lack of cycle lanes, potholes; see Fig. 1). The participants provided a set of road-based solutions (e.g., segregated cycle lanes, bus lanes) and their top three motives for suggesting these solutions from five criteria: accessibility, affordability, reliability, safety, and environments (Table A2 in Appendix A). The transport solutions for London are summarised in Fig. 7 and detailed in Table A3 in Appendix A, while those for Birmingham residents are summarised in Fig. 8 and described in Table A4 in Appendix A. Figures 7 and 8 also present the participants' perspective (i.e., commuters' perspective) on the contribution of the proposed solutions' economic, social and environmental impacts.

The applicability of these solutions to different participants-chosen road layouts (for single and dual carriageways with two and four lanes, as shown in Table 4) was also discussed in the final focus group, including all participants from both cities. It was assumed that the roads have sidewalks on both sides and the strategies adopted (Table 4) are influenced by the UK's Manual for Streets (Department for Transport, 2009). Strategy 1 (S1) considers introducing bus lanes where cyclists and taxis are allowed to travel. S2 presents a scenario where segregated lanes

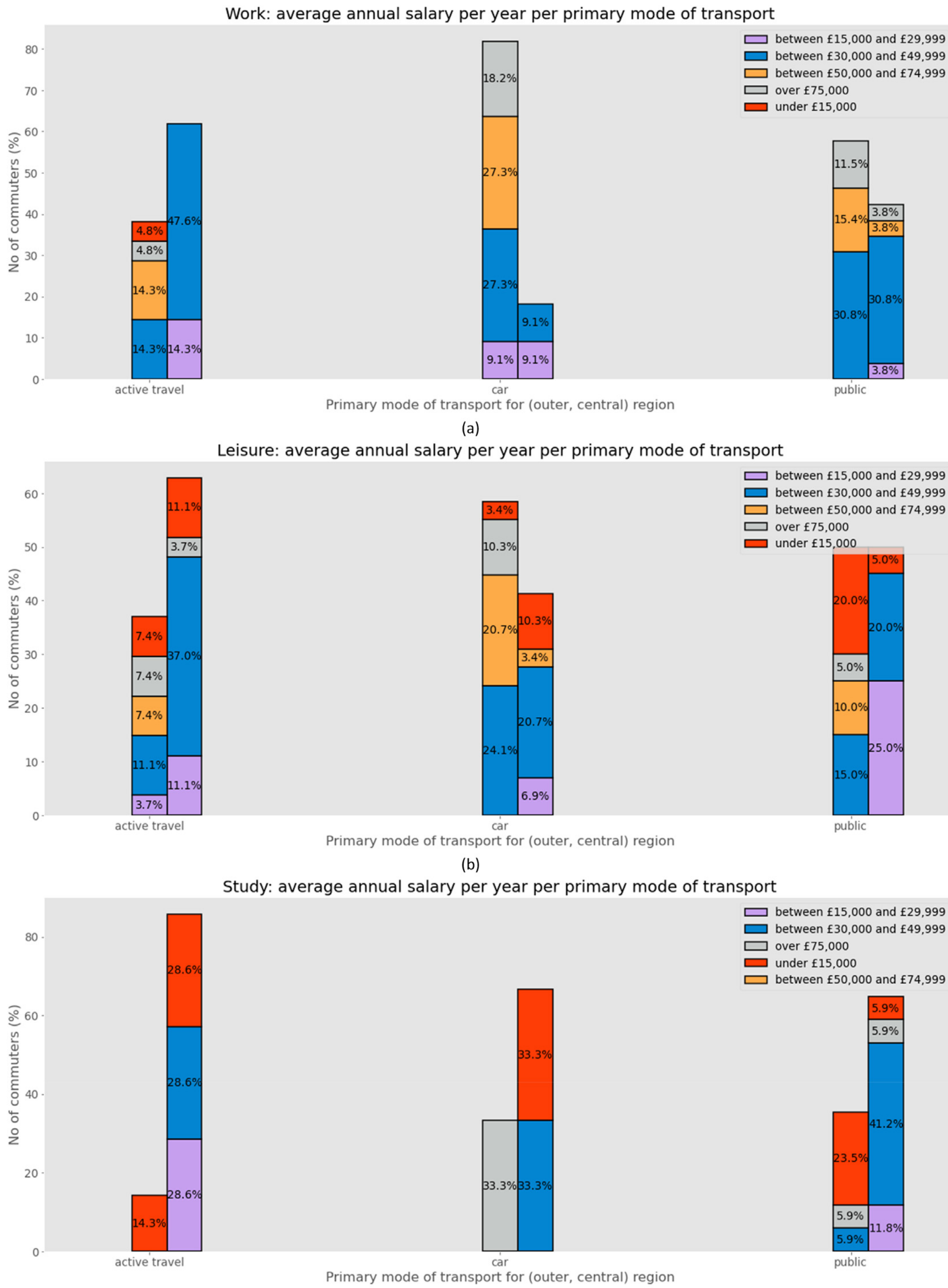


Fig. 6. Influence of salary and region of residence on the travel mode choice for (a) work, (b) leisure, and (c) study at the national scale.

for both cycles and buses. S3 represents a strategy where segregated cycle lanes are provided while the motorists and buses share the same lane. S4 suggests introducing traffic calming measures (e.g., 20 mph speed limits, road humps, lane width restrictions) without any changes to the road layout. It should be noted that the participants selected the candidate strategies for each of the road layouts (Table 4) for which further cost-effectiveness analysis was carried out.

5.3. *Evaluation: Cost-benefit analysis of road space allocation strategies*

The data from the survey were analysed to understand the users' travel behaviour and the current state of urban transport in the two cities. Focus groups generated a set of potential design solutions for urban road layouts. These solutions were systematically analysed for comparing benefits, costs, and implications. The proposed CBA approach was used to calculate the BCR for the strategies outlined in Table 4 for the candidate urban road layouts in London and Birmingham. This UK government's transport appraisal guidance, WebTAG (Department for Transport

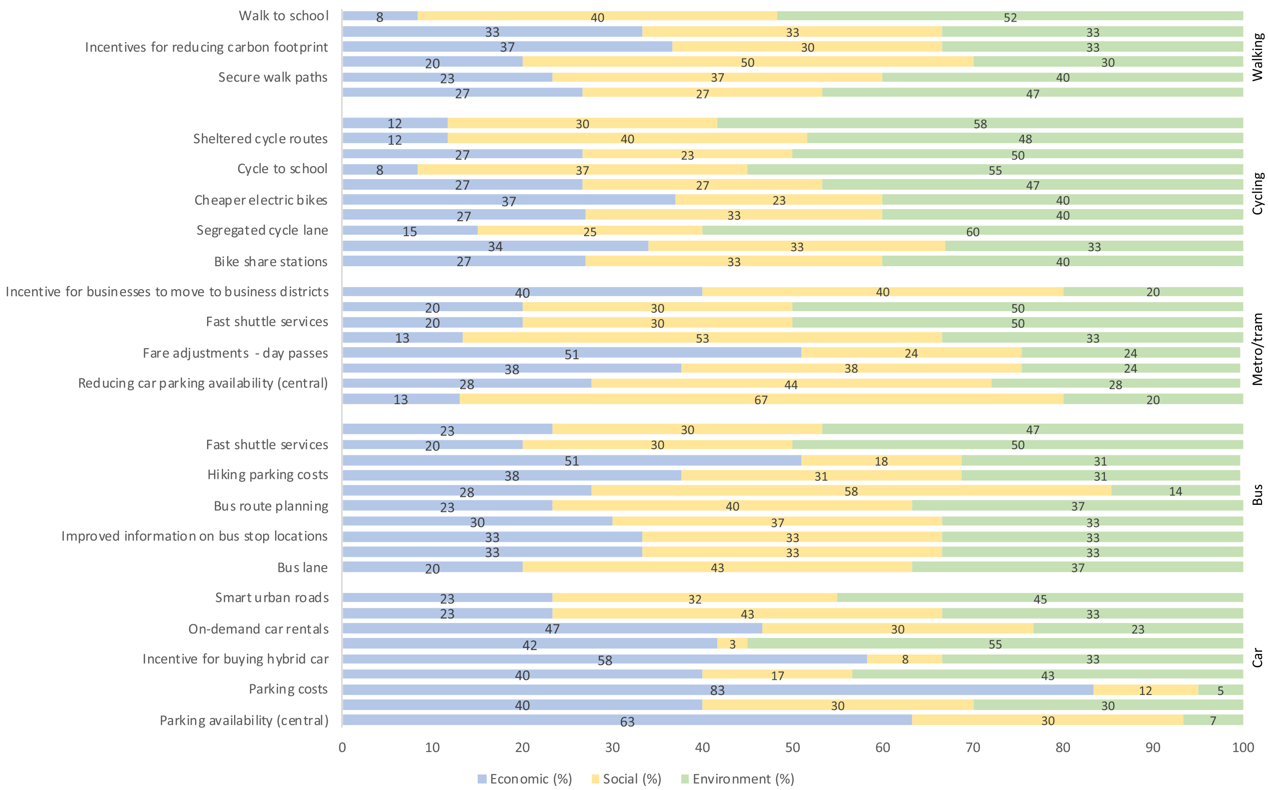


Fig. 7. Sustainability scores provided by focus group participants for transport solutions in London.

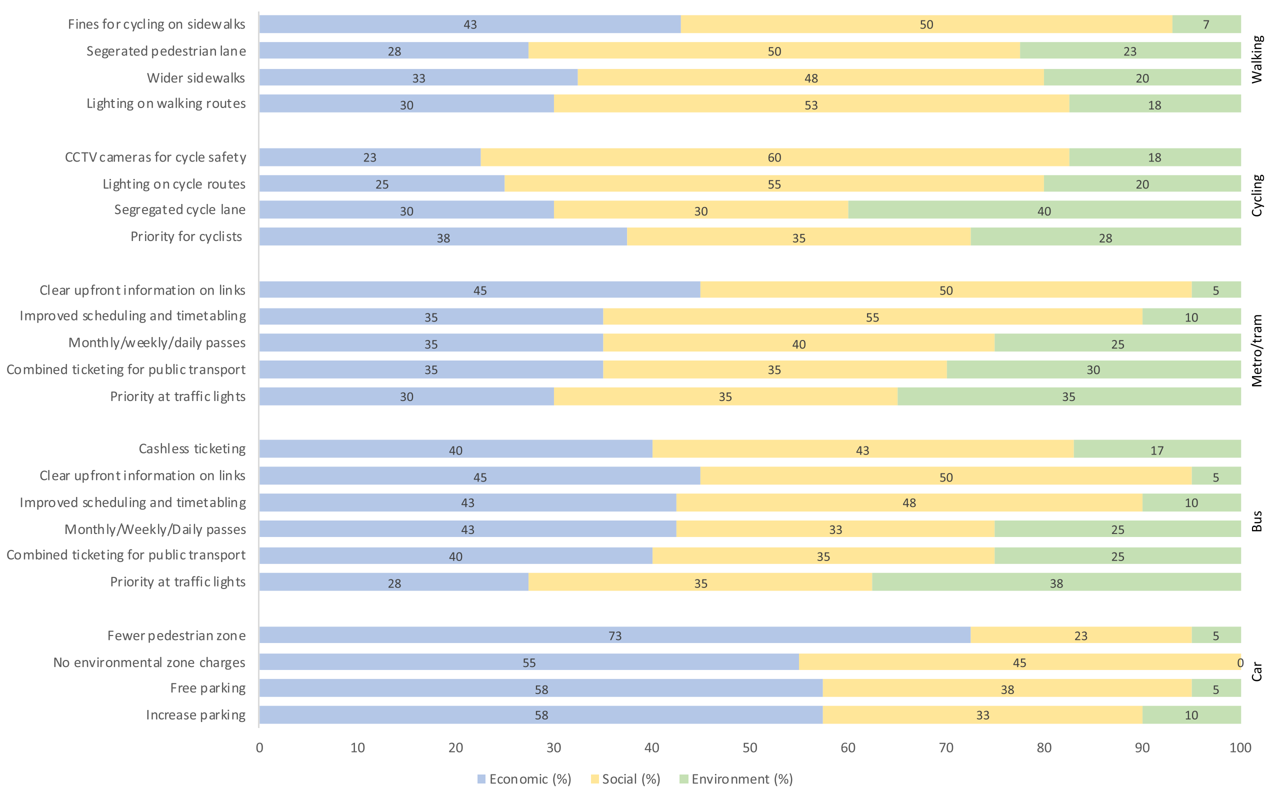
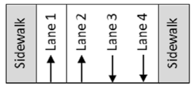
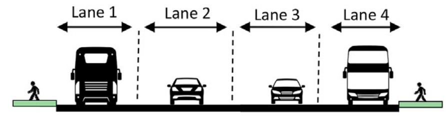
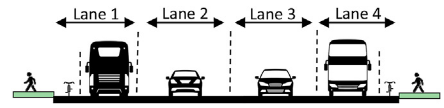
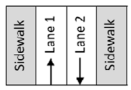
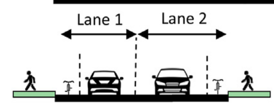
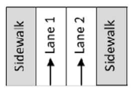
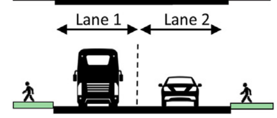
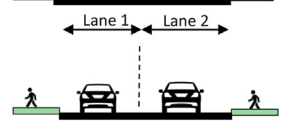
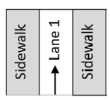
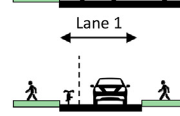
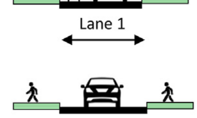


Fig. 8. Sustainability scores provided by focus group participants for transport solutions in Birmingham.

Table 4
Road space allocation strategies selected by focus groups for different road layouts in UK.

Road layout		Proposed urban transport strategy	
4-lane double		S1	
		S2	
2-lane double		S3	
2-lane single		S1	
		S4	
1-lane single		S3	
		S4	

(DfT), 2004), was used to categorise the value for money of the transport strategies based on their BCR as poor (BCR < 1.0), low (BCR 1.0–2.0), medium (BCR 2.0–4.0) and very high (BCR > 4.0). Ten years of analysis (2010–2019) and a discount rate of 3% were used following the UK Department for Transport (DfT) guidelines (DfT, 2004). The DfT's road count point data from 2010 to 2019 were used to estimate the traffic on routes representing the selected road layouts in London (A4 for four-lane dual carriageway, A3216 and A302 for two-lane single carriageways, Clifton Terrace for one lane single carriage way C road) and Birmingham (A38 for four-lane dual carriageway, B4124 and Heeley Road for two-lane single carriageways, Anglesey Street for one lane single carriage way C road). The introduction of bus lanes is expected to increase bus usage by 4%–6% annually (National Infrastructure Commission (NIC), 2018). Similarly, at least a 5% annual increase in cyclists are expected following the setting up of segregated cycle lanes (Sloman et al., 2019). For each route, one-mile-long representative sections were used for the analysis. Monte Carlo simulation (MCS) was used to analyse the costs and benefits, including assessing the uncertainties with the data, to identify the BCR of each strategy. The data employed for the CBA is presented in Table 5 discounted to present-day prices. The probability distribution for each input value was modelled as a pert distribution and 10,000 iterations were performed using the @RISK software. Figure 9 presents the BCR of the different strategies considered for London and Birmingham (Table 4).

6. Discussion

This study proposed a theoretical framework that advocates the need for user-centric sustainable transport strategies. The proposed CBA provides a tool to evaluate and compare the cost-effectiveness of different road space allocation strategies. The proposed approach was employed to identify the strategies that provide the greatest return on investment for different road layouts in London and Birmingham. For example,

Table 5
Parameter values used for the Cost-benefit analysis.

Item	Minimum	Most-likely	Maximum	Source
Infrastructure related (per mile)				
Segregated cycle lane	£715k	£800k	£900k	Taylor and Hiblin (2017)
Bus lane	£150k	£160k	£170k	NIC (2018)
Traffic calming measures	£920k	£960k	£1m	Harvey (2000)
Social impact (per passenger mile)				
Cycle	£0.06	£0.09	£0.12	(European Local Transport Information Service (ELTIS), 2019)
Bus	£3	£3.8	£4.2	(Mott MacDonald, 2013)
Car	−£0.02	−£0.05	£0.08	ELTIS (2019)
Value of Time (per passenger hour)				
Cycle	£8.42	£9.62	£10.02	(DfT, 2011)
Bus	£15.64	£16.64	£17.64	
Car	£15.85	£16.74	£17.69	
Journey capacity (passengers/journey)				
Cycle	1	1	1	NIC (2018)
Bus	60	90	96	
Car	1	1.2	2	
Emissions (gCO_2e per mile)				
Cycle	0	0	0	Shorter (2011)
Bus (London)	1,500	1,600	1,700	
Bus (Birmingham)	9,000	10,000	11,000	
Car	240	246	250	
User cost (per passenger mile)				
Cycle	£0.20	£0.25	£0.28	Sustrans (2019)
Car	£0.67	£0.70	£0.72	
Bus (London)	£0.15	£0.20	£0.30	Transport for London (TfL) (2021)
Bus (Birmingham)	£0.25	£0.30	£0.35	National Express WM (2021)

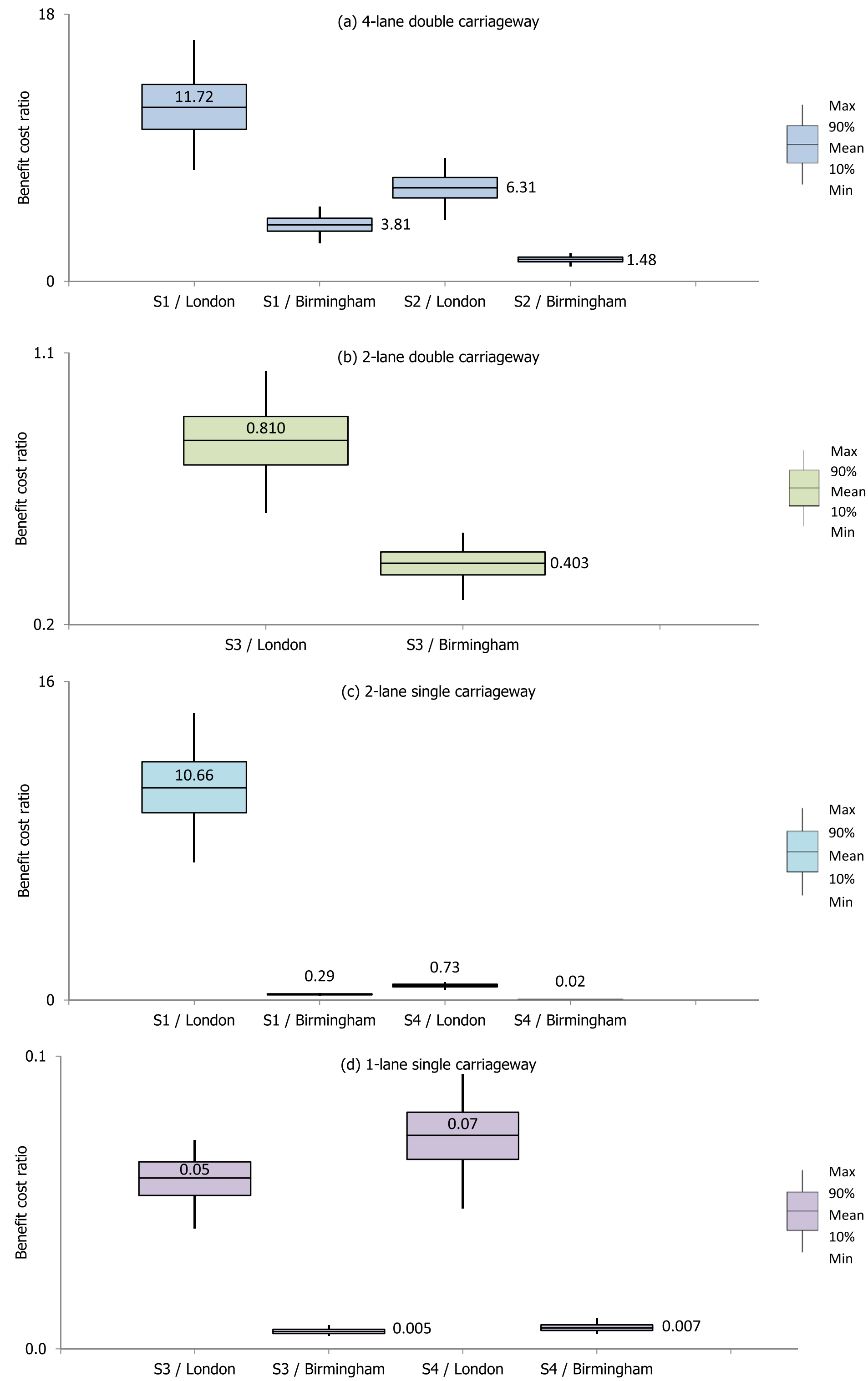


Fig. 9. Benefit-cost ratios of the selected strategies for (a) 4-lane double carriageway, (b) 2-lane double carriageway, (c) 2-lane single carriageway and (d) 1-lane single carriageway in London and Birmingham.

introducing a bus lane (S1) provides the highest BCR in both cities for a four-lane double carriage; a better option than providing separate lanes for buses and cycles (S2). While the bus lanes (S1) have a higher BCR in comparison to traffic calming measures (S4) for a two-lane single carriageway, the value for money argument is varied across both cities (very high BCR in London and medium BCR in Birmingham), demonstrating the previously articulated argument regarding context-dependency. The introduction of cycle lanes (S3) on two-lane double carriageways and one-lane single carriageways delivered poor value for money in both cities in comparison.

6.1. User-centric transport systems

One of the possible solutions for dealing with justice anomalies in urban transport is to plan and design the infrastructure in a user-centric way. The inherent difficulty in planning such systems is accurately predicting users' demand and travel behaviour. Without this, even the smallest change in the transport system is only informed guesswork. The growing pressure on urban passenger transport systems has increased the demand for new and innovative solutions to increase its efficiency. Traffic calming measures including variable speed limits for motorists, segregated cycle lanes and increased lighting on cycle lanes can be implemented in the short term. Providing clear information on bus arrivals, bus stop locations, interchanges, and ticket charges can also constitute immediate actions to realize the benefits of introducing bus lanes. However, increasing bus frequency and charges for congestion/environmental zones generally require detailed planning and hence are potential solutions for the longer term. Similarly, installing physical dividers between cycle and vehicle lanes requires re-designing the road layouts, although examples of retrofitting exist and have increased in popularity during the COVID crisis across Europe (Campaign for Better Transport, 2020; Hadjidemetriou et al., 2020). Despite their cost-effectiveness, the adoption of these solutions varies in different cities as they depend on budget availability, infrastructure, users' travel behaviour, transport demand and planning. Another solution is the use of shared space, which has received mixed reviews and appears to be very region-specific (Kim et al., 2019; Pearson et al., 2019).

The UK's Public Sector Equality Duty under the Equality Act 2010 places elderly and disabled people at the top of the list (Government Equalities Office, 2010). The user hierarchy is paralleled in the UK's National Planning Policy Framework and National Design Guidance (Ministry of Housing, Communities & Local Government (MHCLG), 2021). This approach contradicts the perception of the participants of this study, i.e., that pedestrian walkways, cycle lanes and public transport did not appear to be considered by planners as a priority despite that many concerns were raised about safety, lighting and access. This is reflected in the recently revamped hierarchy of road users within the UK's Highway Code to improve the safety of people walking and cycling (DfT, 2022).

6.2. *Shift to sustainable mobility*

Another approach for tackling the urban transport injustice challenge has been the slow but steady shift towards shared mobility services (car-sharing, bike-sharing, etc.), especially in combination with traditional public transport can serve as a substitute to private vehicles. Of particular relevance here is the willingness of people to walk to access public transport, since the connection with people's places of residence can often determine people's wider choices (van Soest et al., 2019, 2020). There is also an interesting connection to the idea, articulated earlier, of infrastructure systems' core function of enabling a sharing of common resources. The typical resources in cityscapes and townscapes include pedestrian, cycle and vehicular routes – notably the interconnected pattern of streets. The inherent willingness, or lack of willingness, to share these resources, either intimately in terms of physical co-location or more generally in terms of occupying larger quantities of space (e.g., in personal vehicles), greatly influences travel choices. This is one of the major sources of uncertainty in providing different modes of transport provision.

Beyond commuters' needs and encouragement for using active travel, public transport, and car-sharing, the possibilities of disruptive technologies and the generational shifts in travel preferences should also be considered while shaping urban mobilities plans. With 90% confidence, the introduction of bus lanes (S1) provides the highest BCR for four-lane double carriageway (Fig. 9(a)) and two-lane single carriageway (Fig. 9(c)) in both cities. The value of investing in bus lanes is significantly higher in London (~200%), which might be attributed to more frequent buses and a higher number of bus users than in Birmingham. In comparison to S1, the introduction of both cycle and bus lane (S2) delivers a lower BCR on the four-lane double carriageway in London (~46% less) (Fig. 9(a)) and Birmingham (~61% less). For both cities, introducing segregated cycle lanes (S3) on a two-lane double carriageway realises poor BCR (Fig. 9(b)). The introduction of bus lanes (S1) is recommended on London's two-lane single carriageway as they deliver a very high value for money in comparison to traffic calming measures (S3) (Fig. 9(c)). However, the same strategy realises a poor BCR in Birmingham (Fig. 9(c)). It can also be noted that the BCR of segregated cycle lanes (S3) and traffic calming measures (S4) on the one-lane single carriageways in both the cities (Fig. 9(d)) is negligible, and neither strategy is recommended. On the other hand, policymakers often have to deal with a 'chicken-and-egg-problem' regarding the relationship between transport demand and the availability of transport infrastructure and services. These demands tackle some challenging questions such as "does the provision of cycle lanes result in increased cycle usage? and "does increase usage dictates the necessity for cycling infrastructures?", among others.

6.3. *Travel behaviour*

The role of sustainability in governing people's choice of transportation modes remains somewhat unclear. Inevitably, some of the tendency towards greater active travel results from individuals making choices to contribute to a more sustainable future. The growing awareness of the need to reduce CO_2 and GHG emissions more generally, and the now oft-quoted UK and international Government aspirations to move to net-zero by 2050 or earlier, might be expected to dominate people's choices. However, there is a spectrum on which any individual sits: from awareness of the need for changing perceptions to fundamental adjustments in individuals' attitudes towards such change, through to altered behaviours to deliver that change (Topal et al., 2021). Improvement in changing attitudes and behaviours is provided, of course, if the changes being sought have been co-created with the end-users using techniques such as the methodology of the aspirational future (Rogers and Hunt, 2018). This spectrum demonstrates the complexity of creating and implementing transport policies and practices, hence reinforcing the need to 'advance by learning' (Rogers, 2018) and being both responsive and nimble in implementing actions towards improved sustainability. This, in turn, requires a process of monitoring and adjustment to refine the actions and practices; when physical changes to streetscapes and transport routes are involved, this becomes more complicated though not necessarily difficult or impossible if appreciated at the outset.

6.4. *Limitations and future research*

The applicability of the proposed framework (Fig. 1) for comparing different transport planning strategies were conducted using a simplistic version of CBA. Considering the wider impacts of transport, the CBA can be extended to capture the health and safety impacts, social equity considerations, land use and development effects, induced demand and mode shift, multi-modal integration, and the potential for the strategies to stimulate economic development, create jobs, and boost economic activity in the region. It is important to note that CBA is not the only tool that can be employed for evaluating different transport strategies. Other approaches such as multi-criteria analysis (Broniewicz and Ogrodnik, 2020; Dean, 2021) and life cycle assessment (Al-Thawadi et al., 2020; Jakub et al., 2022) can also be used to incorporate social and environmental factors into the evaluation process, as well as weighting and aggregating the different factors (Yedla and Shrestha, 2003).

The sample size of the participants of the travel survey ($n = 81$) and focus groups ($n = 8$) conducted within this study is a limitation as it might not be representative of the overall population. This can be augmented by engaging with a wide range of stakeholders, including community groups, to get their input into the evaluation process. This could also involve using stratified sampling (Shi, 2015) to ensure that the complex and heterogeneous needs of different stakeholders are adequately represented, and that the benefits of transport planning options are distributed equitably. Data on travel behaviour can also be collected using innovative digital technologies such as smartphone applications, social media, Internet-of-Things, GIS and GPS (Torbaghan et al., 2022). The proposed case study can be further improved by conducting a land-use modelling (François et al., 2017) for the urban scenario. For further research, a carbon footprint model (Yang et al., 2016) resulting from urban transport could also be employed to consider the transport system's actual physical footprint and the equivalent urban tree cover required to offset the direct and indirect transport-related CO_2 emissions. Lastly, it is important to note that the data collected were in a pre-COVID-19 scenario, and the relevance of any findings to post-pandemic travel behaviour needs to be explored further.

7. Conclusions

The depiction of everyday travel behaviour and mobility practices allows better addressing urban transport justice concerns. These include the different and often unequal access available to different transport modes and social groups and the differentiated individual preferences that transport policy makers often overlook while designing cities and transport systems. The proposed approach within this paper can provide a significant conceptual advancement for placing transport justice in the context of sustainability for designing user-centric transport strategies: sustainability can be interpreted as mainly related to the pursuit of broader transport justice aims that every stakeholder has reason to value.

To ensure sustainable development in cities, it is suggested that transport planning needs to take an integrated approach that considers both commuter needs and transport demands. Governments have actively encouraged user engagement in transport decision-making but have not always practised because of the inherent difficulty in doing so. To this end, a co-creation approach was used to identify different urban road layout allocation strategies that can enhance users' experience and meet their travel demands. The co-creation results further highlight that the design of potential transport solutions needs to move beyond the generic; the solutions should instead be selected based on rules that consider the costs and (multiple societal) benefits accruing from the strategy. A government's investments in the transportation sector and urban road layouts should provide some financial returns in terms of benefits and costs to satisfy the economic pillar of sustainability; however, equal importance should be placed on the societal consequences (the social pillar) of these investments, both positive and negative. This in turn requires the issue of transport justice to be integrated into decision-making so that all individuals are provided with the means of travelling and the access to opportunities that this affords. The importance of the third (environmental) pillar of sustainability is now not in danger of being lost because of the universal aspiration to move towards net-zero; the danger from this perspective lies in a narrow focus on this one goal rather than an appreciation of all of the environmental consequences of the actions taken.

It was shown that involving users in designing urban transport solutions effectively identifies sustainable and just transport systems. This is also aligned with the initiatives by the municipal and national governments for constructing more greener infrastructure and promoting more sustainable modes of transportation such as active travel, affordable and pervasive public transport, car-pooling, ride-sharing and other such initiates that recognise the need to share the common resource of space and means of movement in urban areas without harming other sections of the population. The proposed approach could also be extended to consider a transport demand model to cater to the mode shifts trend. The results further highlighted that the solutions thus devised need to move beyond the generic and placeless; instead, they need to embed specific locally relevant solutions in the context of specific geographic and demographic groups, and systems in question to ensure they respond to the 'intricacies of place' (all places being different in some way).

Replication and data sharing

The data of the travel survey collected within this research can be made accessible upon request via email to the corresponding author.

Author contributions

Manu Sasidharan: Conceptualisation, Methodology, Formal analysis, Investigation, Visualisation, Writing - original draft, Writing - review & editing, Funding acquisition. **Mehran Eskandari Torbaghan**: Conceptualisation, Methodology, Investigation, Writing - original draft, Writing - review & editing, Funding acquisition. **Yasmin Fathy**: Formal analysis, Data curation, Visualisation, Writing - original draft. **Christopher D.F. Rogers**: Conceptualisation, Methodology, Writing - original draft, Funding acquisition. **Nicole Metje**: Investigation, Writing - review & editing. **Jennifer Schooling**: Writing - review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that the are no declaration of interests for our paper titled 'Designing user-centric transport strategies – a codesigning approach to urban road space redistribution'.

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Appendix A

Table A1
Structure of the survey.

Sections		Questions
Subjects	A1	What is your age?
	A2	In what city or town do you live in the UK?
	A3	Which part of your city or town do you live in?
	A4	In what city or town do you work in the UK?
	A5	What is the highest level of education you have completed?

(*continued on next column*)

Table A1 (*continued*)

Sections		Questions
	A6	What is your job title?
	A7	What is your salary range per annum?
	A8	Which of the following categories best describe your employment status?
	A9	Which ethnic group best describes you?
	A10	What is your gender?
	A11	Do you have a smartphone?
Valued activities and places	B1	How many work-related trips do you make on average per week?
	B2	How far is your commute for work (in miles)?
	B3	What is your primary mode of transport for work?
	B4	What is your secondary mode of transport for work?
	B5	Do the environmental impacts of your chosen transport mode shift your primary mode of transport for work?
	B6	Does your chosen mode of travel change during peak and off-peak times while commuting for work?
	B7	How many study-related trips do you make on an average per week?
	B8	How far is your commute for study (in miles)?
	B9	What is your primary mode of transport for study?
	B10	What is your secondary mode of transport for study?
	B11	Do the environmental impacts of your chosen transport mode shift your primary mode of transport for study?
	B12	Does your chosen mode of travel change during peak and off-peak times while commuting for study?
	B13	How many leisure-related trips do you make on average per week?
	B14	How far is your commute for leisure (in miles)?
	B15	What is your primary mode of transport for leisure?
	B16	What is your secondary mode of transport for leisure?
	B17	Do the environmental impacts of your chosen transport mode shift your primary mode of transport for leisure?
	B18	Does your chosen mode of travel change during peak and off-peak times while commuting for leisure?
Mobility practices	C1	Do you own a car?
	C2	How often do you drive your car?
	C3	How often do you travel in a car as a passenger?
	C4	How often do you carpool?
	C5	Rank the following based on how easy (1) to difficult (6) you find using cars in your city/town?
	C6	Do you own a cycle?
	C7	How often do you cycle?
	C8	Rank the following based on how easy (1) to difficult (5) you find cycling in your city/town?
	C9	How often do you use public transport (bus, train, trams, underground or metro)?
	C10	Rank the following based on how easy (1) to difficult (5) you find public transport in your city/town?
	C11	What are the top three factors that encourage you to choose active travel (walking/cycling) modes over a car or public transportation?
	C12	Does the weather forecast affect your choice of transportation?
	C13	What are the top four factors that encourage you to choose public transport over a car?
	C14	Please rank the following factors from low (1) to high (6) importance that contribute to your decision of the transport mode
	C15	Would you prefer to cycle/e-bike for a part of your journey?
	C16	As a motorist, would you prefer to have a segregated cycle lane over having cyclists share the road with you?

Table A2
Justice related indicators.

Justice indicators	Definition
Affordability (J1)	Cost of making a journey
Reliability (J2)	The time, usage, speed and capacity of the transport system
Accessibility (J3)	Availability of service/mode to get access to the locations of activity
Safety (J4)	Protection of life while commuting
Environment (J5)	Impact of the transport system to the environment (Noise, Air pollution)

Table A3
Sustainability rankings and justice indicators for transport solutions in London.

Mode	Solution	Ranking allocation			Justice indicators
		Economic (%)	Social (%)	Environment (%)	
Car	Parking availability (central)	63	30	7	J1, J2, J3
	Parking location	40	30	30	J5
	Parking costs	83	12	5	J1, J2
	Electric charging facilities	40	17	43	J1, J3
	Incentives for hybrid car	58	8	33	J1, J5
	Congestion charges	42	3	55	J1, J5
	On-demand car rentals	47	30	23	J1, J2, J3
	Segregated cycle lane	23	43	33	J1, J4, J5
	Smart urban roads	23	32	45	J3, J4
Bus	Bus lane	20	43	37	J2, J3, J5
	Frequency	33	33	33	J2, J3, J5
	Bus stop location/info	33	33	33	J3, J5
	Number of seats on buses	30	37	33	J3, J5
	Bus route planning	23	40	37	J2, J5
	Reduce car parking (central)	28	58	14	J1, J3
	Increase Parking costs	38	31	31	J1, J5

(*continued on next column*)

Table A3 (*continued*)

Mode	Solution	Ranking allocation			Justice indicators
		Economic (%)	Social (%)	Environment (%)	
	Fare adjustments-day ticket	51	18	31	J1, J2
	Route based shuttle services	20	30	50	J3, J5
	Shuttle services for business districts	23	30	47	J3, J5
Metro/Tram	Frequency	13	67	20	J2, J3
	Reduce car parking (central)	28	44	28	J1, J2
	Increase parking costs	38	38	24	J1, J5
	Fare adjustments-day ticket	51	24	24	J1
	Size of station per population	13	53	33	J2, J3
	Fast shuttle services	20	30	50	J3, J5
	Shuttle for business districts	20	30	50	J3, J5
Cycle	Segregated cycle lane	18	32	50	J3, J4
	Bike-share stations	27	33	40	J2
	Cycle parking	10	33	23	J3
	Sharing electric bikes	27	33	33	J1, J3, J5
	Cheaper electric bikes	37	23	40	J1, J5
	Incentives for reducing the carbon footprint	27	27	47	J1, J5
	Cycle to school	8	37	55	J5
	Incentives for cycling	27	23	50	J1, J5
	Sheltered routes for cyclists	12	40	48	J3, J4
	Cycle highways	12	30	58	J2, J4, J5
Walking	Well maintained pavement	27	27	47	J3, J4, J5
	Security of walk path	23	37	40	J4, J5
	Travellators in difficult terrains	20	50	30	J2, J3
	Incentives for reducing the carbon footprint	37	30	33	J1, J5
	Incentives for walking	33	33	33	J1, J5
	Walk to school	8	40	52	J4, J5

Table A4
Sustainability rankings and justice-related reasonings for transport solutions in Birmingham.

Transport mode	Solution	Ranking allocation			Justice indicators
		Economic (%)	Social (%)	Environment (%)	
Car	Parking availability (central)	58	33	10	J1, J2, J3
	Free parking	58	38	5	J1, J2, J3
	No environmental zones	55	45	0	J1, J2, J3
	Fewer pedestrian zone	73	23	5	J2, J4
Bus	Priority at traffic lights	28	35	38	J2, J3
	Combined ticketing for public transport	40	35	25	J1, J2, J3
	Monthly/Weekly/Daily pass	43	33	24	J1, J3
	Better scheduling and timetabling	43	48	9	J2, J3
	Clear information on links	45	50	5	J2, J3
	Cashless ticketing	40	43	17	J3
Metro/Tram	Priority at traffic lights	30	35	35	J2
	Combined ticketing for public transport	35	35	30	J1, J2, J3
	Monthly/Weekly/Daily pass	35	40	25	J1, J3
	Better scheduling and timetabling	35	55	10	J2, J3
	Clear information on links	45	50	5	J2, J3
Cycle	Priority for cyclists	38	35	28	J2, J3
	Cycle lanes	30	30	40	J2, J3, J4
	Lighting on cycle routes	25	55	20	J4
	CCTV for cycle safety	23	60	17	J4
Walking	Lighting on walking routes	30	53	17	J4
	Increase the width of sidewalks	33	48	20	J4
	Segregated pedestrian lanes	28	50	22	J4
	Fines for cycling on sidewalks	43	50	7	J4

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Jennifer Schooling OBE is Director of the Centre for Smart Infrastructure and Construction (CSIC), at the University of Cambridge, UK and Co-Director of the Research Hub for Decarbonised Adaptable and Resilient Transport Infrastructures (DARe). She is passionate about changing the way of the infrastructure and construction industries viewing data, to become a vital asset in its own right, and as an engineering tool for tackling the key challenges facing our industry, including climate change, resource constraint and resilience. She leads CSIC's Digital Cities for Change project, and is a member of the UK's Digital Framework Task Group (DFTG) and the Infrastructure Client Group's Digital Transformation Task group (DTTG).