Tools for addressing transport inequality: A novel variant of accessibility measurement

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Addressing transport inequality: a novel variant of accessibility measurement

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Highlights

- Few accessibility measures equip policy makers to choose policies that address transport inequality
- A new measure, Index of Personal Travel Impact (IPTI), is proposed, based on the journey time and relative cost of the journeys an individual would like to make
- Initial testing indicates that calculating IPTI is feasible and that it reveals differences across individuals
- IPTI could support decision makers interested in issues of transport inequality

Abstract

Accessibility is widely thought the most appropriate reference point when assessing transport inequality, a fundamental consideration of the liveable city. But definitions of accessibility vary and often either trivialise or overcomplicate the concept, with the result that decision makers lack a representation of it that is both sufficiently accurate and at the same time sufficiently straightforward. A response is offered in this paper: the *Index of Personal Travel Impact* (IPTI). IPTI is an estimate at the individual level of the relative impact of desired travel, reflecting the time taken and real financial effect, and is expressed as an amount per unit distance. It is calculated using the journeys an individual would like to make (as opposed to those they actually make or those that an authority might assume "important") and reflects the specific characteristics of the individual (e.g. car availability or mobility impairment) and of the journey (e.g. the need to arrive by a given time). It therefore serves as a good individual-level representation of the relative ease/difficulty of travelling.

The rationale for IPTI's formulation is described in detail and the measure's strengths and weaknesses discussed. The practical feasibility of calculating IPTI is explored through description of a small pilot which produced encouraging results and through a discussion of the potential efficiencies offered by the increasing availability of large data sources and online journey planning tools. IPTI's potential applications are then discussed: first, it could provide an intelligible way of demonstrating the differing extent to which people face mobility barriers, which could be useful where an attempt is being made to address inequality. Second, IPTI could inform the appraisal process by showing the distributional effects of a given scheme upon individuals' relative capacity to travel. The paper concludes with recommendations for further research.

Keywords

Justice; fairness; accessibility; quality of life; liveability; social sustainability

1 Introduction

"The bundle of rights and freedoms now available to us, and the social processes in which they are embedded, need to be challenged at all levels. They produce cities marred by inequality, alienation, and injustice" (Harvey and Potter, 2009, p. 45).

Harvey and Potter's rallying cry above plainly applies to transport at least as much as to any other aspect of urban areas – significant transport inequality is seen in both rich and poor cities around the world (as well as in non-urban areas). With this special issue's theme in mind, it is surely reasonable to assert that the liveable city (Southworth, 2016) is one in which such inequalities are managed down to an acceptable level. Meanwhile, in terms of quality of life (a fundamental component of a city's liveability), if a part of the community suffers poor quality of life, this should be seen as constituting poor quality of life for that community as a whole. This is because a community's overall quality of life is a matter of its distribution as well as its mean. But it also reflects the practical harm that such inequality imposes, in terms of lost economic opportunities, risk of crime, etc. And such a state of affairs also fails the test of (social) sustainability (Boström, 2012). In order to respond to transport inequality, though, we need to understand it, and measuring it is a crucial first step. But, as this paper shows, the measurement of transport inequality remains challenging.

Banister characterises transport inequality as having three forms: unequal distance travelled across social groups (e.g. rich and poor); observed daily variations in travel behaviour between different groups of people; and inequalities in the levels of transport accessibility (Banister, 2018). In this paper, we are most interested in the first and third of these. The first is well supported by data that show poorer people travel considerably less far than their richer counterparts (Titheridge et al., 2014; Moore et al., 2013; Bourn, 2012). And we argue that this is in large part explained by the third: the lower my level of accessibility, the less far I shall travel, *ceteris paribus*.

Having identified the link from accessibility to transport inequality, it is appropriate also to mention the concept of motility (Flamm and Kaufmann, 2006) (which Urry describes very simply as "potential for movement" (Urry, 2012, p. 38)), since we shall be exploring the differences in more detail later on. Both accessibility and motility connect with what Nussbaum calls "combined capabilities", being "a combination of personal abilities and the political, social, and economic environment" (Nussbaum, 2011, p. 20). Most accessibility measures are in fact designed to represent both the personal and environmental aspects (Geurs and van Eck, 2001; Geurs and van Wee, 2004; Hull et al., 2012; Papa et al., 2015), reflecting Nussbaum's observation of their combined influence on what people (are able to) do. Finally, we must mention a further flowering of research in the field of transport or mobility justice (van Wee, 2011; Martens, 2016; Pereira et al., 2017). More specifically, the evidence that transport "injustice" may beget or exacerbate more general forms of social injustice has stimulated various transport and mobility researchers to investigate what policies are needed to foster a more just transport system, or one that is likely to promote wider justice (this being a distinct goal).

A crucial part of tackling transport inequality is its measurement and that is the focus of this paper. As we shall argue, the extensive effort expended on defining and implementing accessibility measures appears not so far to have provided the community of transport practitioners and policy makers with a robust means of selecting transport interventions that would create a more just world. We therefore offer an approach to measuring the impact of travel upon individuals that departs in several ways from conventional approaches. We develop our index of personal travel impact (IPTI) in steps, setting out the rationale at each point and discussing the advantages and disadvantages of the approach taken. The final sections of the paper describe a small pilot designed to test the feasibility of calculating IPTI and discuss the practicality of making IPTI more widely operational before offering proposals concerning its contribution to addressing transport inequality in the pursuit of the liveable city.

1.1 Structure of the paper

The paper is structured as follows.

In Section 2 we offer a critical assessment of approaches to the measurement of accessibility;

Section 3 introduces our *Index of Personal Travel Impact*, explaining and discussing its formulation and considering its potential advantages and disadvantages;

Section 3.6 describes a small pilot exercise to test the feasibility of the Index and discusses making it operational on a larger scale, as well as ways in which it could be further developed; and

Section 5 discusses the possible use of the Index to promote the liveable city and offers recommendations for further research.

Further information concerning analysis of the cost of travel is provided in an appendix.

2 The concept and measurement of accessibility

Having established above that the standard quantity considered when responding to transport inequality is accessibility, we need now to explore this in more depth. Specifically, what is actually meant by accessibility and what has so far been learnt from attempts to measure it?

2.1 Accessibility as a concept

According to the Oxford English Dictionary, the word *accessibility* was first used in the 18th century to mean the quality or condition of being accessible. It came to have a specific meaning in transport planning in the 20th century, with Hansen's definition from a 1959 paper (cited over 3,000 times) shown to be enduring: "accessibility is defined as the *potential* of opportunities for interaction" (Hansen, 1959, p. 73). Here, Hansen was parting ways with more basic interpretations of the term, explaining his definition further as being "a measure of the *intensity of the possibility of interaction*" (Hansen, 1959, p. 73).

We argue that this approach to the concept established the notion of accessibility as a three-sided relationship between people, opportunities and the transport system. That is, in being centred on *interaction*, the concept of accessibility is thereby obliged to address:

1) the locations and circumstances of people;
2) the locations and characteristics of opportunities; and
3) the detailed nature of the transport system that (to a greater or lesser extent) connects them.

So, of necessity, accessibility is a function of all three: a change in any implies a change in accessibility. The simplicity and coherence of this interpretation help to explain its durability. We mention in passing the scope to include a fourth dimension – timing – in the concept, as proposed in another widely cited paper: Hägerstrand's (1970) concept of time-geography was intended to incorporate the reality of scheduling into understandings of accessibility. Though influential, this approach has proven especially difficult to apply (Curl et al., 2011).

Hansen's conceptualisation of accessibility explains its importance to questions of transport and mobility justice, given the predominant characterisation of transport as being a derived demand: if we are concerned about transport inequality, this is because of its effects on individuals' capacity to take advantage of opportunities (or "interaction", to borrow from Hansen); hence discussion of social exclusion in the Introduction. And here we can draw an important distinction between accessibility and motility, also introduced above. We may have good reason to be interested in motility but it is not our primary concern when thinking about transport inequality, because the ability simply to move is of much less importance than the ability to reach destinations of value. We present this distinction in visual form below in Figure 3 as part of the explanation of IPTI.

Whilst accessibility is a crucial reference point for transport inequality, we must acknowledge that it has other "customers". Accessibility is, for example, a major part of transport forecasting: the more accessible a destination is made by a change to the transport system, the more journeys to it can typically be expected (Glaister, 1981). Accessibility equally informs land-use planning for similar reasons, and this in fact was the focus of Hansen's seminal 1959 publication. The range of applications of accessibility as a concept may help to explain that its definition has tended to remain abstract (Handy and Niemeier, 1997), with Ingram claiming (in another influential paper) that "the term is rarely defined or given an operational form" (Ingram, 1971, p. 101). Since Ingram wrote, there has been no shortage of operational forms (as we shall discuss), but their very diversity militates against the development of a more concrete definition of accessibility. So we are left with a concept that is very important to many in the transport world, including those concerned with inequality, but which lacks a self-evident means of application. We argue that this arises in part from the tripartite relationship on which accessibility is founded: because accessibility is a function of three sets of variables, each inherently complex in itself, there is unlikely to be a "natural" formulation of the quantity (Miller, 2018). And, as we shall go on to claim, a pragmatic response is to seek a formulation that is suited to the specific application to which accessibility is going to be put.

2.2 Measuring accessibility

Numerous approaches are offered to the explanation and classification of accessibility measures (Geurs and van Eck, 2001; Geurs and van Wee, 2004; El-Geneidy and Levinson, 2006; Vandenbulcke et al., 2009; Hull et al., 2012; Papa et al., 2015). For example, consistent with the tripartite relationship we posit above, Hull et al. find three "key" elements in the characterisation of accessibility measures in the scientific academic literature: "(1) a determined geographical 'origin' location or category of people or freight that is being considered for accessibility, (2) a set of relevant destinations that might be weighted by the size or quality of associated opportunities, and (3) a measure of physical separation between (1) and (2) that is usually expressed in terms of time, distance or generalised cost" (Hull et al., 2012, p. 4).

Geurs and van Eck, for their part, divide measures into three types – infrastructure-based, activity-based and utility-based. Geurs and van Wee (2004) provide a taxonomy that develops that of Geurs and van Eck and which has been taken up extensively in the literature. Their category of *infrastructure-based* measures is centred on network performance and therefore does not comply with our tripartite conception of accessibility as it does not take account of origins and destinations; their *location-based* measures "describe the level of accessibility to spatially distributed activities, such as the number of jobs within 30 min travel time from origin locations'" (p129); their *person-based* measures are those that capture accessibility at the individual level, reflecting the work of Hägerstrand in analysing capacity to participate in activities at a given time, reflecting environmental constraints; and their *utility-based* measures arise from the field of economics and analyse "the (economic) benefits that people derive from access to the spatially distributed activities" (p129). Within the location-based and utility-based categories, they identify a number of sub-types that reflect the detailed approaches taken to measure design. For example, in the location-based category, so-called "isochrone" measures enumerate the number of opportunities within a given journey time, without assessing their usefulness or relevance. Other measures introduce the concept of competition to reflect the role of supply and demand: a hospital's services will be more or less saturated (and therefore more or less available to the individual) depending on the number of individuals within its catchment.

Returning to our discussion above of the conception of accessibility, the various measures considered in the work of Geurs and van Wee and others differ considerably in a) the *extent* to which they capture the three elements (people, opportunities, transport system), b) the ways in which they *characterise* the elements captured, and c) the *interpretation* offered. For example, on *extent* of capture, we have already asserted that Geurs and van Wee's infrastructure-based measures miss out people and opportunities, concentrating exclusively on the system. In terms of *characterising elements*, many measures are based only on journey *time* and do not therefore reflect the cost (absolute or relative) of travel, whereas others are designed to include both. Here, the main issue is of detail: as discussed, each of the three sets of variables is individually quite complex so a measure can reflect the minutiae of an individual's circumstances such as their inability to climb stairs or need to reach a destination by 6am; it can equally gloss over such details and treat individuals as homogeneous, with most measures falling somewhere between these extremes. Finally, with respect to *interpretation*, measures tend to express opportunities available in terms of impact of travel, or *vice versa*. As mentioned, isochrone measures produce a number of opportunities associated with a given travel time. Most other measures estimate the impact associated with reaching a given opportunity or set of opportunities. (We return to the meaning of the term "impact" below.) A utility-based measure, meanwhile, may present the utility of obtaining an opportunity *net* of the disutility borne in travelling to it but this approach is not common; the majority of measures quantify the impacts of travel without estimating the benefits derived at the destination.

2.3 Representing impact

Given the breadth of the term, we should begin by saying that we use *impact* in this paper to describe the impact of travel *on* the traveller and, more specifically, the consumption at the individual level of finite resources caused by the act of travelling. This is, of course, a narrower use of the term than is seen in other settings, where *impact* might embrace externalities such as road injuries or emissions of greenhouse gases. We return to a potentially broader interpretation in our final section.

The question of how the impact of travel is interpreted by accessibility measures requires further examination, as impact lies at the heart of any accessibility measure of potential value to the study of transport inequality. We have noted that simpler measures rely on travel time alone. More sophisticated measures include the financial costs of travel alongside the time required. Whilst the financial impacts of travel have been extensively studied from the perspective of transport inequality, we are not aware of any so-called accessibility measures that include cost but exclude time. Meanwhile, the "gold standard" of impact estimation within accessibility measures is found, we argue, in utility-based measures, as these will be based on generalised cost (Koopmans et al., 2013).

Generalised cost has long been used to support forecasting and appraisal, though its popularity is not universal (Grey, 1978). The quantity can take a range of forms but, at its most basic, it is a linear combination of the cost and time associated with travel (Searle, 1978). More sophisticated versions of generalised cost differentiate between time spent in a vehicle and time travelling to or time waiting for it; they may place a value on reliability and/or include quantities such as an "interchange penalty" to reflect the fact that people generally prefer direct journeys if they are available.[1] But the simplest formulation reflects the fact that the dominant elements of the personal impact of travel are the time it takes and the money it costs. Though of course a simplification, this version of generalised cost captures the reality of travel reasonably well. It also reflects the perennial tension between the resources required to estimate impact and the accuracy that will be attained.

Regardless of the number of its constituents, one of the strengths of generalised cost is that the elements are converted into a single unit of account and then summed, which enables simple comparisons to be made between journeys and/or individuals. Those elements that are initially measured in units of time are translated into monetary values (and *vice versa*) using the so-called "value of time". This quantity has been extensively researched (e.g. Wardman et al., 2016) and continues to be debated (e.g. Lin, 2012) but it has become more or less an accepted part of transport planning.

2.4 Discussion

We start by pointing out that the variety of accessibility measures now in existence is certainly attributable to innovation on the part of transport analysts, but is also a result of the range of uses to which measures might be put. A major retailer will want to know how many shoppers might visit a new store and its forecasts will be based on accessibility calculations but the nature of these calculations will naturally differ from those carried out to support an analysis of transport equity. So, whilst the fundamental concept of accessibility tends to be consistent across instances of its measurement, it is clear that not all measures will suit all applications. Indeed, to return to Geurs and van Wee, they assess measures' usability for evaluation across two broad categories – economic impacts and social impacts. We would go further, arguing that it is legitimate to start the selection of a measure by setting out what is wanted of it. With that in mind, we now turn to three specific issues.

First, it is common for accessibility measures to be based on the set of destinations/opportunities meeting a number of criteria, e.g. the number of jobs that can be reached within thirty minutes' travel. This is understandable at the aggregate level and can be useful when comparing candidate interventions. For its part, when the UK Department for Transport released guidance on accessibility planning, it listed the following categories of trip destination: primary and secondary schools, further education establishments, "work", hospital, general practitioner, and major centres (Department for Transport, 2006). At face value, this is reasonable: health, work, education and the opportunities available at a major centre all appear high priorities for individual travel. But it is easy to imagine an example that shows the limitations of this method. A person may live in the centre of a major city and have easy access to all of these essentials but at the same time be isolated from their loved ones who are in a neighbouring city, joined by a rail link that is exorbitantly expensive. The point here is that, for accessibility to be measured at an aggregate level, it becomes necessary to make blanket assumptions concerning which destinations are desirable, meaning that a considerable amount of highly relevant individual-level detail is lost. Moreover, this approach smacks of paternalism: the authority decides on behalf on the individual which destinations should matter to them.

[1] In fact, Transport for London (2013) has one of the most sophisticated sets of journey parameters, including the value placed by customers on the absence of graffiti. The quantities are, however, small in comparison with travel time and cost.

Second, to the extent that accessibility measures include the financial cost of travel, they treat this as an absolute number. References are made in the accessibility literature to the affordability of travel (e.g. DHC and University of Westminster, 2004) and work on transport inequality extensively acknowledges the importance of the issue (e.g. Banister, 2018; Lucas, 2012; Guzmán et al., 2013). Indeed, our own research throws this into relief. Figure 1 shows analysis of the National Travel Survey (explained more fully in the Appendix), with costs of travel per mile shown against income, revealing a nearly monotonic positive relationship. This is no surprise: those with more money can afford to purchase more convenient, comfortable, reliable and/or speedy forms of transport, most of which will cost more. But Figure 2 instead shows the result of dividing cost per mile by household income for each of the bands (indexed to the poorest five per cent), thereby showing the approximate true financial impact of travel. There is one "kink", with the 16th band having a slightly higher value than the 15th, but the pattern is otherwise uniform and very clear: the real financial impact of travel is over twice as great for the poorest five per cent than for the next five per cent; and the impact felt by the wealthiest semi-decile is less than a tenth of that of the poorest. What this demonstrates very effectively is that any positive correlation between wealth and cost per mile (as shown in Figure 1) is more than outweighed by income effects: wealthy people may choose slightly more expensive ways of travelling but they still feel less impact per mile. Despite this stark fact, however, we have not succeeded in finding any accessibility measure that adjusts financial impact for income. This may reflect the diversity of applications for accessibility measures, as discussed – many applications will rely quite properly on absolute cost – but it appears to vindicate our claim that measures should be designed to suit the use to which they will be put.

Third, accessibility measures appear universally to deal with the whole journey (or, in more sophisticated cases, journey tours (e.g. Fransen and Farber, 2019), recalling the work the work of Hägerstrand). This is perfectly understandable but it has a very important consequence which we explain in the context of the relationship between transport and land-use planning. The integrated planning of land use and transport has long been considered the ideal (Banister, 2008) and its absence is one reason that accessibility planning faltered in England (Kilby and Smith, 2012). It is almost self-evident that "good" planning should embrace both where people and services are located and the means of travelling between them. But, with few exceptions, land-use planning and transport planning have remained stubbornly unintegrated. Yet, in being based on whole journeys to destinations, accessibility measures conflate the weaknesses of both land-use planning and transport planning and thus present the policy maker with a set of dilemmas: attempt to relocate activity X or modify the transport links to its current setting? These dilemmas are hard to address at any time but will typically be confronted by someone who has some control over either transport or land use but not both. We argue, therefore, that there is a case for building an accessibility measure that takes land use (with all its imperfections) as a given, thereby enabling a transport planner to make transport decisions.

To conclude our short survey, we note that, whatever the strengths or weaknesses of accessibility measures, scholars have identified several problems with their use. In their survey, te Brömmelstroet et al. detected increasing complexity in "planning support systems" (including accessibility measurement tools) which, as a result of a desire for scientific rigour, lead to a "black box effect" (te Brömmelstroet et al., 2014, p. 4). They found this helped to explain a mismatch between supply and demand, and a lack of mutual understanding between the developers of accessibility measures and their users, resulting in potential users being confused by the tools offered to them. These problems are further exacerbated by perceptions that accessibility measurement tools can produce "information overflow" (te Brömmelstroet et al., 2014, p. 178) whilst also being expensive to use.

In summary, the huge importance and potential value of measuring accessibility have not yet been matched by the emergence of measurement tools that are fit for purpose, thus leaving transport practitioners (and those working on transport justice in particular) somewhat stymied. For this reason, we introduce in the following section a different approach to measuring accessibility, intended to avoid some of the problems discussed here.

3 The index of personal travel impact (IPTI)

Recalling our comment above concerning designing accessibility measures to fit a specification, we should repeat that our aim here is to arrive at a measure that provides policy makers with practical assistance in responding to transport inequality. The use of the term “transport inequality” is intentionally specific: we are not here concerning ourselves with spatial justice (in the sense of the relative locations of individuals and the services they need or desire).

3.1 A measure based on money and time

Taking the typical complexity of accessibility measurement as a useful reminder, we seek a measure which strikes a successful balance between precision and ease of application. The more data that are included, the more accurate we might expect the measure to be, but also the more laborious to develop and implement. We have claimed above that financial cost and time are the dominant components of impact and we therefore limit our measure to these elements.

One area in which we part ways with conventional versions of generalised cost is its treatment of money. The absolute cost of travel is used in formulations of generalised cost and this reflects its roots in microeconomics. From a policy perspective, we argue that the real impact of travel needs to be shown and that this is a function of disposable income (as shown in Figure 1 and Figure 2), for which total gross income is likely to be the best available proxy. We therefore estimate the real financial impact of travel by calculating the ratio of the financial cost of travel to the person’s estimated total income.

Because we have adopted a deliberately simple formulation of generalised cost, we require a single measure of journey time. We select door-to-door journey time as this seems the best way to capture the different and often overlooked aspects of travel such as walk access/egress and parking search. This glosses over the fact that travellers dislike certain aspects of travel (such as waiting for a vehicle) more than others, which more sophisticated formulations of generalised cost reflect through weighting but, again, we feel this omission is justified by the need to limit the complexity of the measure.

3.2 Adjusting financial impact for income

Because we are using income-adjusted financial impact in our measure, we carry out the following conversion. The raw financial impact of a journey is multiplied by the ratio of the mean personal income of the area of interest (perhaps an entire country or a region within it) to the individual’s income. For example, suppose Jane Bloggs has an annual income of £20,000 and lives in an area where the mean annual income is £25,000. A journey costing her £10 in cash has an adjusted impact of £12.50 (£10*£25,000/£20,000).

3.3 Combining money and time for an estimate of journey impact

We now seek a way of bringing the time and money elements of our measure to a single unit of account. We use the prevailing general value of time as estimated for the community in question in order to achieve this.

To continue the example above, let us assume that it would take Jane Bloggs 40 minutes, door to door, to make the above journey (including any time for access, egress, walking, waiting, parking search etc). Supposing the current value of time is £0.10 per minute, we can convert the adjusted (financial) cost of the trip (£12.50) into time by dividing by the value of time to give 125 minutes. We sum this and the door-to-door journey time to produce a total of 165 minutes[2] – the impact of this journey on Jane Bloggs.

3.4 Deriving a value at the person level

It is now necessary to move from the impact of a single journey to an estimate of the impact of travel at the level of the individual. This requires a suitable number of representative journeys to avoid the estimate being skewed by one or two journeys that have disproportionately low or high impact. Whether this is 10, 15 or 50 journeys is a matter of trading off the additional data collection burden against the additional accuracy it would bring. The representative set should reflect not just the range of journeys but their likely frequency, with journeys made annually therefore contributing less to the overall picture, *ceteris paribus*, than those made daily.

It is important to emphasise at this point that the journeys used should be those an individual *would like* to make, whether or not they are currently realistic (given the individual's circumstances and the nature of the transport network). This is crucial in order for the measure not to be determined by an individual's current, possibly constrained, travel habits. Instead, the use of journey *aspirations* ensures that the measure for personal travel impact correctly gauges the match between the individual's ability to travel and the destinations that are important to her. See Figure 3, which contrasts this approach with others commonly seen in accessibility measures.

For each of the journeys in the set, the time and financial impacts need to be estimated. These will reflect the individual's circumstances: if she has access to a car and is able to drive, this is treated as a feasible mode (unless parking at the destination would be impossible); if she must arrive at her destination by 5am and does not have access to a car, this may mean that the journey has to be made by taxi/private hire; if she is a wheelchair user, this too will be reflected in the set of feasible options. Ordinarily, the estimate should be based on using the lowest-impact feasible option, where "impact" is the combination of time and (income-adjusted) financial cost as described above. This "bespoke" approach allows new options such as ride-hailing (and, in due course, automated vehicles) to be considered immediately they become available.

In the final step, the income-adjusted financial impacts and total journey time of a set of representative actual/desired journeys are first combined into a single total. Then, in order to derive an index at the individual level, we divide this total by the combined distance of the set of journeys, thus producing an impact per unit distance. The measure used is crow-flies[3] distance. We call the resulting ratio the Index of Personal Travel Impact, or IPTI.

We present an expression for this quantity (I) below:

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2 In this instance, the common unit chosen is minutes; journey time could equally be multiplied by value of time in order to arrive at a combined quantity expressed in money terms but the effect would be the same.

3 More precisely, it is the crow-*flies/tunnels/swims* distance. This reflects situations where there is a topographical barrier to a direct journey (e.g. a mountain between origin and destination) but intervention (e.g. tunnelling through the mountain) is a feasible response.

$$I = \frac{\sum_j t_j + \frac{N}{V.i}\sum_j c_j}{\sum_j d_j}$$

Where:

t_j is the door-to-door journey time of the lowest-impact feasible option for trip j

c_j is the absolute financial cost of the lowest-impact feasible option for trip j in terms of fares/tolls paid, vehicle running costs etc[4]

N is the mean (annual) personal income of the area under consideration

V is the prevailing value of time (expressed as a quantity of money per unit time)

i is the individual's (annual) income

d_j is the crow-flies distance between the origin and destination of trip j

3.5 Distinctive characteristics of IPTI

Various aspects of the formulation of IPTI deserve a degree of examination, as follows.

3.5.1 The role of time in IPTI

The somewhat trite assertion that we all have 24 hours per day is nonetheless an accurate one. This can be countered with claims that some people are relatively "time-rich" or "time-poor", reflecting the commitments in their lives. Such claims of course have some foundation and a case could be made for calculating the time taken by a person to travel a unit distance relative to their "time budget" in much the same way that we adjust financial impact to reflect disposable income. If Person A (working full-time with two young children) has one hour available (not already committed to another activity) per day whereas Person B (retired) has four, this would suggest that ten minutes' travel would have four times the impact for A as for B. Leaving aside the very considerable data requirements associated with adding this dimension into the analysis, we demur on the grounds that choice plays a significant part in the structure of our lives. Being time-rich or time-poor can of course be greatly affected by factors beyond our control (the need to care for a sick relative, say) but it is also largely a product of decisions made autonomously. If I choose to volunteer with three charities as well as working full-time, I can expect to be busier than my neighbour, also employed full-time but with no volunteering commitments. Given the motivation for developing the Index of Personal Travel Impact – addressing inequalities in the capacity to reach destinations of importance – it is far from obvious that the person undertaking more activities should expect to enjoy a higher quality of transport options, as would be implied if the measure were based on "disposable time".

3.5.2 Dividing by distance

Why create an "index" rather than simply use the sum of impacts across the representative journeys selected by the individual? This is best demonstrated by picturing an individual whose selected journey aspirations include a trip from the UK to the Caribbean. First, we must emphasise that the method we set out in this paper explicitly does not question or criticise such a choice – for some people, periodic trips to exotic locations are highly prized. But it must immediately be acknowledged that the personal impact of travelling to such destinations (reflecting journey time and the cost of flying to such destinations) would

[4] The estimation of IPTI could be rendered more accurate by including additional cost elements (e.g. vehicle depreciation) but at the expense of simplicity.

probably make such individuals' "impact total" considerably higher than those of people whose travel aspirations did not involve international aviation. Remembering, as with the discussion of time above, that the motivation for creating this measure is to address inequalities in *ability* to travel, it would seem perverse to treat someone who desired long-distance travel as intrinsically deserving of assistance, *ceteris paribus*. There is the additional risk that, if a sum of the sort discussed were used, individuals would be inclined to "game" the system when listing their desired journeys, a point revisited below in discussion of making the system operational.

A more minor, instrumental benefit of creating an index based on a ratio is that it would remove the need to stipulate the number of journeys on which an individual's "score" might be based. If Person A's index is based on 10 journeys and that of Person B based on 50, we would expect the value for Person B to be more accurate but the two quantities should nonetheless be broadly comparable.

It seems reasonable to use distance as the denominator since we travel in order to cross territory and there is a natural logic to the idea that, the further we go, the greater the impact will be, on average. But its use has an important consequence which we discussed earlier in the context of the relationship between spatial planning and transport planning.

To illustrate, let us consider two similar individuals who live one mile and ten miles from their doctors' surgeries, respectively, and imagine that their transport options are similar in terms of speed and cost per unit distance. If we adopted a goal of equalising the travel impact of reaching one's doctor across individuals, it would be likely to produce unwelcome consequences: at the extreme, it may require the provision of supersonic transport to those living in the most remote areas. Not only would this be unsustainable in a variety of ways, it would also provide a perverse incentive to those contemplating a move to a location of low density, with sprawl a likely result. Instead, using the approach we are setting out, the two people's trips to their doctor would have the same value in terms of IPTI because the Index controls for distance. By expressing personal travel impact as a quantity per unit distance, we exclude issues of development density and where services are located, thereby ensuring that IPTI informs the analysis of *transport* inequality specifically. This is not least because it should not fall to the transport sector to compensate for deficiencies in the planning of health, education etc, nor for the idiosyncrasies of a market-based system that may create food deserts through the closure of life-line shops.

3.5.3 Crow-flies distance as the denominator

Having argued for the use of distance as the basis for deriving the IPTI ratio, we must now justify using *crow-flies*[5] distance rather than the perhaps more familiar choice of distance travelled (as used in the National Travel Survey). Here, whereas we argue that it should not fall to the transport sector to compensate for the peculiarities of where services are located, we claim that it very definitely does behove the transport sector to respond to the fact that some journeys are considerably more *circuitous* than others. The use of crow-flies distance will ensure that, the more a journey departs from a straight line between origin and destination, the higher its contribution to an individual's IPTI. In some cases, this will reflect topography – island-dwellers who depend on the mainland for key services will be greatly affected by the directness of any links between the two – but it will also frequently be a function of the differing densities of the various modes' networks. For example, the rail network in the UK is for the most part much sparser than its highway counterpart. Journeys by rail will therefore in general involve greater distance, especially as the traveller is not at

[5] As above, actually crow-flies/tunnels/swims.

liberty to charter a train to follow the shortest path along the line but must instead accept the train services available, which may mean travelling into and out of a centre in the absence of orbital services. Thus, those who rely on public transport will typically exceed the straight-line distance between origin and destination by a higher proportion than those who have private transport, all other things being equal, and this will (correctly) be reflected in a higher IPTI.

Those who have the use of private transport may equally be forced to divert considerably from the straight-line route in locations where the highway network is itself relatively sparse. Again, this will (properly) be reflected in a higher IPTI for people in such areas compared with those living in areas with denser highway networks. See Figure 4 for a graphical representation of these arguments.

3.6 IPTI's potential advantages

We base IPTI on individuals' personal journey *aspirations*, rather than either their actual travel or generic assumptions about destinations of importance. Doing this reduces the risk that an individual's travel horizons might be defined in a circular fashion, based on current activities or, for that matter, on motility. The latter quantity, despite being more than current mobility, is clearly informed and perhaps constrained by current mobility (Flamm and Kaufmann, 2006). Our approach also avoids the situation where blanket assumptions are made (by a public body) about the journeys an individual may wish or need to make.

IPTI is also based on the time and financial impacts of *feasible* options for making journeys and thus implicitly reflects individuals' personal circumstances such as a mobility impairment or the need to travel at times when public transport may not be running. By not assuming "one size fits all", this means that the time and cost calculated for a given journey are accurate for the individual given their situation.

By adjusting for household income (as a proxy for disposable income), IPTI estimates the real financial impact of travel, thereby removing the need to make separate assumptions concerning affordability.

The use of crow-flies distance as the denominator means that the measure enables comparisons of the directness of the transport network between locations with reference to the journeys people wish to make. Directness can obviously be gauged in morphological terms but, without reference to journey desires, this is bound to be an abstract exercise.

IPTI is *relatively* simple in that its formulation is straightforward and its calculation requires two data items per journey (total cost and door-to-door time) and depends on a single parameter (value of time). This should mean that the measure avoids the "black box effect" identified by te Brömmelstroet et al. But we do not for a moment suggest that IPTI is a panacea. We therefore turn next to some criticisms.

3.7 Possible limitations and shortcomings of IPTI

Any measure of accessibility is bound to involve simplification and IPTI is no exception. The use of only door-to-door time, for example, glosses over details such as waiting and interchange, which trouble people to differing degrees and ought, therefore, to be included if a comprehensive understanding of the impacts of travel is to be obtained. Door-to-door time also leaves in doubt the issue of frequency: if I must travel (for reasons of cost, say) at a time when there are fewer buses, then longer waiting times *within* the journey will be captured by door-to-door time but the fact that I may have to arrive *early* for an appointment will not. Nor does IPTI capture the relative comfort of a journey and this of course varies greatly between locations and forms of transport. IPTI is also based on a number of approximations. For example, estimating real financial impact using gross income can, at best, be seen as providing a rough estimate of the true personal cost of travel; it cannot account for the very significant differences across individuals in terms of financial commitments that determine their true disposable income.

We have argued that using journey aspirations rather than actual travel reduces the risk of reinforcing mobility patterns that may be a result of underlying inequalities, in terms of income, say. And there is evidence that those on low incomes do forgo certain trips as a result (e.g. Moore et al., 2013). But it would be naïve to assume that travel aspirations are not informed by one's actual travel: as motility researchers have demonstrated, people develop their "access rights portfolios" (Flamm and Kaufmann, 2006) partly on the basis of their initial endowments. IPTI is at risk of creating a different form of circularity, with the "transport wealthy" setting much more ambitious journey aspirations than those of the "transport poor". This may not actually mean that the transport poor are practically disadvantaged – longer journeys will not necessarily have higher impact per unit distance – but it is nevertheless a relevant consideration, even if only in philosophical terms.

Rather different is the question of externalities. As currently defined, IPTI does not account for any impacts that may fall on someone other than the individual traveller or for benefits (e.g. physical fitness) that the individual might derive from travelling in a certain way; it does not privilege sustainable- or active-transport modes or capture the severance or safety impacts on third parties, for example. In this respect, IPTI does not differ from most other accessibility measures but we should be mindful that our starting point was transport inequality and that unequal accessibility is only one facet of this.

If these weaknesses are allowable, this still leaves us with the task of calculating IPTI, a far from trivial matter, as discussed next.

4 Making IPTI operational

Having defined and discussed IPTI at a conceptual level, it is necessary next to investigate the practicality of making it operational. In particular, how much information needs to be collected in order for an individual's index to be calculated with sufficient accuracy, how much resource is required to process this information, and how much can be estimated reliably using proxies? As more and more data concerning travel behaviour enter the public domain and journey planning becomes increasingly easy using online tools, the burden should be considerably less than would have been the case a decade ago. But there is a presumption that the individual will nevertheless need to be involved in the calculation process to at least some extent: only they know exactly which journeys they would like to be able to make, and it is probably necessary for now to rely on them to say which travel options are actually feasible given any relevant constraints.

4.1 A pilot of the IPTI estimation process

We investigated some of the above questions by running a small pilot. The process is presented in graphical form in Figure 5.

A self-completion questionnaire (https://opinio.ucl.ac.uk/s?s=63218) was created using survey software called Opinio. It collected some personal information (access to a car, powered two-wheeler and/or bicycle; household structure; any special travel needs) and then sought data concerning a minimum of five journeys, with prompting to encourage respondents to think of different journey purposes – work/education; leisure activities; shopping/other personal business; visiting friends and family; and other. For each trip, the respondent was asked to provide an origin and destination. To reduce response burden, it was possible to select "home" as the origin for any trip. The respondent was also asked to provide an approximate frequency, using categories taken from the National Travel Survey (NTS). Finally, there was a free-text box in which respondents were asked to write "anything relevant about this journey that might affect your travel options".

The issue of income was dealt with slightly differently than as described in Section 3, in order to be consistent with the NTS and take advantage of pre-existing income categories used in its questionnaire. Respondents were asked to provide their gross *household* income (as opposed to their *personal* income) and personal income was subsequently estimated on the basis of the numbers of adults and children in the household, using the OECD equivalence scale (OECD, n.d.).

The survey was circulated amongst a small number of the authors' colleagues and students with the request that they complete it as fully as possible and report any difficulties encountered.

A total of seven individuals completed the survey and six of the responses were usable (the seventh respondent seemingly having misunderstood the completion instructions). No difficulties were reported. The extent to which relevant additional trip-level information was provided varied across respondents. For the most part, these responses had the effect of fixing the mode of the journey in question, which slightly lessened the analysis task described below.

The authors processed the responses, estimating time and financial cost for each trip. In summary, this involved the following steps:

- Assign mode, based on general information given by the respondent, trip-specific information provided and/or an assessment of the relative time and financial cost associated with the obvious private- and collective-transport options;
- Derive crow-flies distance, using on-line calculators
- Estimate financial cost, using various publicly-accessible journey-planning tools and making necessary assumptions about time of travel, vehicle type (if applicable) and route preference;
- Estimate journey time, using a similar set of tools and assuming standard walking and cycling speeds.

Carrying out this task took between 30 and 45 minutes per respondent, depending on the number of journeys recorded and their complexity.

Aggregate travel times, financial costs and crow-flies distances were calculated for each respondent by applying annual rates derived from respondents' answers concerning frequency. These numbers were then combined, using the formula set out in Section 3.4, to produce an estimate of IPTI for the six respondents included.

4.2 Findings from the pilot and discussion

The minimum of the set of IPTI values calculated is 2.32 and the maximum 8.02. Whilst the numbers do not have any meaning in themselves, it is striking that the range is so large despite the small number of respondents and their relative homogeneity (as researchers or practitioners), thereby giving some confidence that the IPTI measure will serve as a means of understanding differences between individuals' relative ease of movement.

The process of assigning mode, time of travel and route involved making a number of assumptions and it is not clear how much this will have affected the values derived. For example, peak and off-peak fares on public transport can be very different. Equally, no attempt was made to allow for the savings that could be achieved through season tickets for frequent journeys. Further testing could establish a better understanding of an appropriate trade-off between the detail sought from respondents and the accuracy thereby achieved.

Notwithstanding these considerations, the pilot seems to have provided some evidence to suggest that the data collection process is viable, *provided respondents are willing*. But this leads to questions about resource requirements and motivation of respondents: why should a typical individual take the trouble to provide this information? In the short term, it will be possible to calculate IPTI for small samples of individuals using a method similar to the pilot, compensating respondents for their time if necessary. At such time as IPTI became part of the policy-making process, we would need to have information for much larger groups, making payment for providing the information unworkable. The solution may lie in the prospect of IPTI acting as a mechanism for people to obtain assistance with their travel. Those whose IPTI is likely to be high (because of low income, lack of access to private transport, disability and/or remote location) could be invited to provide this information in the form of an "application for support".

As to the reliability of the self-completion process, we raised above the risk of its being "gamed" by individuals seeking to increase their IPTI in order to receive benefit. There would therefore need to be certain safeguards in place to manage this risk and future research could investigate and appraise the options.

A separate consideration is whether there is scope for any aggregation. At first sight, this is not possible given what has been said about allowing for each individual's particular circumstances and preferences. But, as a dataset began to emerge, it may be possible to discern patterns amongst the responses such that it became feasible to estimate IPTI using a subset of the questions initially posed of respondents. Certain information, such as the set of public-transport options, will be common to individuals across a number of households, for example. A filtering process could then be applied to establish whether a specific person could fulfil a given journey requirement using available services. There is also scope to consider expanding existing established survey processes to collect data that would support calculation of IPTI. The National Travel Survey, for example, involves a large sample and the marginal cost of incorporating into it IPTI-relevant questions would probably be far smaller than running a bespoke data-collection exercise.

Our tentative conclusion, then, is that the calculation of IPTI across potentially quite large groups seems feasible. We now turn to how IPTI might be used.

5 The potential use of IPTI to promote the liveable city

In this paper we have provided a critical analysis of the current state of the art in accessibility measurement, supported by some additional analysis of the differing impact of travel on individuals. This has contributed to the definition of IPTI, intended to be a useful decision-support tool for transport policy makers. We note in passing that IPTI does not, strictly speaking, conform to our own definition of accessibility measures, since it in effect measures the relative ease of *moving towards* opportunities as opposed to actually *reaching* them, and we have explained the rationale for taking this approach. In addition, as explained, the formulation has been designed to strike a balance between accuracy and the resources required for calculation. In this regard, its relative simplicity may be a benefit in terms of making it intelligible to the non-expert.

But we started with the themes of injustice and inequality and we need to return to them. We also cited various writers who have concluded that the measurement of accessibility has not in general enabled the identification of policies that address accessibility problems identified – that is, accessibility measurement has proved helpful in identifying the problems but less so in identifying the solutions. In order for IPTI to be useful, then, we need to be confident that it could provide policy makers concerned about transport inequality with the means to select interventions in an informed way. To address this point, we briefly discuss the potential application of IPTI.

The rationale of IPTI is that it should allow meaningful inter-personal comparison: if my IPTI is higher than yours, this means that the journeys I wish to make would have a larger (negative) impact on me (per unit crow-flies distance) than yours would on you. This implies that IPTI can be used to provide a baseline showing the distribution of this impact across a community. In the first instance, then, a transport policy maker should be able to identify the members of that community whose accessibility (measured in this way) is most limited. This may be enough, in terms of taking action. But a possible additional step would be the identification of a value of IPTI that should be considered the maximum acceptable. Once this number had been obtained, transport planners could develop interventions designed to reduce the IPTI of those exceeding the limit.

We can imagine IPTI being used within a cost-effectiveness exercise: a range of interventions could be developed to bring the IPTI of a community within the limit; the intervention that achieved this at the lowest cost would then be taken forward for further analysis. But it is probably more realistic to imagine IPTI being used in conjunction with traditional appraisal tools such as cost-benefit analysis (Martens, 2011). Here, alongside conventional information such as an intervention's benefit-cost ratio, its IPTI performance could be shown. We envisage this being a matter of calculating the simple aggregate reduction of "excess IPTI" achieved by the intervention; the quantity could alternatively reflect a weighting scheme that gave more priority to those whose IPTI exceeded the threshold by the greatest amount. We can also imagine the valuation of "bonus" IPTI – improvements in the index of individuals who did not exceed the threshold.

To return to the theme of the role of quality of life in promoting the liveable city, IPTI could be a useful weapon for the policy maker eager to address inequality. This reflects our earlier assertions that ability to move is an important component of quality of life and that, if a proportion of a community does not enjoy good quality of life, this constitutes a lack of quality of life for that community as a whole.

To conclude, IPTI may prove useful to policy makers who are interested in questions of transport and mobility justice. It should provide a readily understandable way of seeing the differing extent to which people face mobility barriers. And, in terms of transport planning, it should enable useful analysis of the spatial distribution of people who face the greatest obstacles to travel. Combined with a method of application, it could inform a fresh approach to transport planning.

5.1 Recommendations for further research

Given that the pilot described above produced encouraging results, a fuller trial of the feasibility of calculating IPTI is in order. Such a trial would enable the following questions to be investigated:

- Do respondents understand the questions as intended?
- Do respondents struggle with any aspect of completing the survey, such as describing journeys they wish to but do not currently make?
- Are there significant economies of scale available as the number of respondents increases?

- What level of remuneration, if any, would be necessary to motivate completion?

A second strand of activity would involve testing the concept of IPTI with policy makers, perhaps using real or dummy data to support the process. Questions to be addressed might include:

- Do policy makers sympathise with the formulation of IPTI?
- Would they/how would they wish it to be incorporated into decision-support systems such as appraisal frameworks?
- Would they/how would they wish to see a maximum level of IPTI defined to inform policy making?

The data collected from such an exercise could be used to specify a set of activities to increase the relevance of IPTI and/or the accuracy and efficiency of calculating it.

A third strand is more prospective and would address the possible inclusion of transport externalities in a future variant of IPTI. This would require the reconciliation of personal impacts ("what do I experience when I travel?") with wider impacts ("what does my travelling impose on others and my environment?")

A final strand would return to the broader questions that motivated the development of IPTI: does a measure designed to isolate transport from land use empower transport policy makers? If so, what does it mean for spatial planning and the prospects of integrating land-use and transport planning? Might addressing transport inequality in isolation lead to unplanned and perverse land-use consequences?

Declaration of interest

None

Funding

This research was supported by a grant from UCL Public Policy.

Acknowledgements

This work began with the UCL Policy Commission on Transport and Ethics, whose members were Dean Machin (Chair), Nicole Badstuber, Emily Crampton, Daniel Durrant, Sapfo Lignou, Anna Plyushteva and the author. Data analysis that informed the development of IPTI was carried out by John Shrewsbury. The author additionally thanks the anonymous reviewers whose comments enabled him to improve the manuscript significantly.

Author statement

Tom Cohen: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Visualization; Roles/Writing - original draft; Writing - review & editing

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Appendix – the National Travel Survey and our use of it

The National Travel Survey

The National Travel Survey (NTS) first took place in Great Britain in 1965 and was repeated sporadically until 1988, when it began to be carried out on a continuous basis. In 2002, its sample size increased to over 15,000 households. It has undergone numerous changes since[6] but it continues to support analysis of trends in travel behaviour in England (Morris et al., 2015).

The NTS uses two data collection methods: face-to-face interviewing using computer-assisted personal interviewing (CAPI) and self-completion of a seven-day travel record. The *Household* questionnaire provides household-level information about income. It is completed face-to-face with the Household Reference Person (HRP), being the householder with the highest income, or their spouse or partner. Amongst other things, the HRP is asked a question about the household's total gross income which is answered using a show-card[7]. This places the respondent's household income in one of 20 bands. The McClements scale is subsequently used to adjust the raw answer to reflect household structure: the income of a two-adult household without children is not weighted; the incomes of households with more occupants are scaled down and those of households with fewer are scaled up to create an estimate of "real household income equivalent". Answers are then deflated to 1990 values for comparison purposes (Department for Transport, 2015) which results in a degree of re-banding.

All individuals within a surveyed household are asked to complete the travel record (diary). For each trip made, they are asked to record a range of information, including purpose, origin and destination, departure and arrival times. For multi-stage trips, details for each stage are requested. Long trips (of 50 miles or more) are recorded over two weeks and are logged separately from shorter trips.

Method

We used a dataset from the National Travel Survey (NTS) supplied to us by the UK Data Archive (Department for Transport, 2016a). The NTS is a long-established rolling survey based on large samples, now covering England (rather than the whole of Great Britain). In addition to collecting a large quantity about the characteristics of individuals and households, it gathers a week's detailed journey-making information from all members of participating

[6] The most notable of these is the omission, since 2013, of Scotland and Wales from the sample. The sampling level for England has remained the same as before, enabling longitudinal comparisons for England to continue to be made.
[7] Income data are not collected at the individual level in the NTS.

households. The dataset supplied to us is an anonymised collation of cleaned data collected over the period 2002 to 2014.

For the analysis we wished to carry out, the key data we needed on trips made related to mode, distance, time and cost. For journeys made by private motorised modes, we needed distance and time (and we imputed operating cost, using a flat quantity per km). For public transport modes, we additionally needed fare paid.

For public transport cost, we selected the variable "Stage Cost" as the best available proxy because it is a sum of the responses for single and return tickets, one-day travelcards and pre-pay costs. Of the various samples within the dataset, we used the "diary sample" because this matches best with those who completed the travel record (diary). With respect to household income, the variable we used for our analysis is "Household Income Semi-deciles diary sample".

Of the 103,222 household records in the original set, those that had reported no travel were omitted, leaving 100,684. In doing our work, we complied with the guidance provided with the NTS data concerning use of a series of sample weights (Department for Transport, 2014).

To enable the analysis we wished to carry out, we aggregated data on journeys made to the household level because this is the unit at which income is recorded.

Limitations of analysis

The NTS dataset is both very large and quite complex. In order to have a manageable analysis task, we were obliged to omit some detail and to make a number of blanket assumptions, as follows:

- We did not attempt to capture the effective cost of public-transport trips made using season tickets. Survey respondents are asked to provide details of any such tickets they hold and to identify public-transport journeys made using them during the seven days of the travel record. But attempting to distribute the cost of such a ticket across journeys made using it is not possible given that the ticket's validity may be much greater than the seven days during which travel is recorded. We therefore excluded public-transport trips made using a season ticket.
- We omitted long-distance journeys (categorised in the NTS as 50 miles or more).
- Whilst the National Travel Survey gathers information about vehicles held by the household and respondents are asked to identify which vehicle is used for a given journey made by private motorised transport, there was not sufficient resource to estimate operating costs at a vehicle level. We therefore applied a blanket rate for vehicle operating costs per kilometre.
- We restricted our analysis of private motorised transport to car and light van, excluding motorcycle. Given how small a proportion of total vehicle distance is travelled by motorcycle,[8] we believe this to have been a justifiable simplification.
- The nature of our data licence meant that we were not provided with information about the cost of parking.

[8] In 2015, approximately 2.8 billion miles were travelled by motorcycle in Great Britain. In comparison, 247.7 billion miles were travelled by cars and taxis, and 46.9 billion by light van (Department for Transport, 2016b).

Discussion

Of these simplifications, we believe those relating to season tickets and long-distance trips are likeliest to be significant. With respect to the first, there is evidence that season-ticket ownership is more prevalent in higher-income groups (Beige and Axhausen, 2006). A season ticket offers a saving over the walk-up fare in most cases so the consequence of omitting these trips will be to exaggerate the absolute cost of travel to a greater extent for rich travellers than for poor.

With respect to long trips, whilst they may be a small proportion of all reported trips (somewhat less than four per cent of the set[9]), they are by definition longer than most trips captured in the general travel record, whose average distance in 2015 was 7.3 miles (Department for Transport, 2016e). Given that overall distance travelled is positively correlated with income (Department for Transport, 2016f), it seems reasonable to assume that wealthier people will make more long-distance trips than those from poorer backgrounds. Without analysing the speed and cost characteristics of the long-distance journey data, it is not possible to say with confidence what their omission means for this analysis. But it seems reasonable to assume that long-distance travel is both comparatively speedy and comparatively cheap per unit distance. We therefore suggest that the absence of these data from our analysis is likely to exaggerate the cost and time expended on travel and to do this to a greater extent in the case of wealthier individuals.

As can be seen, both discussions indicate that the simplifications made are likely to exaggerate the costs borne by wealthier travellers. Our findings are such that more comprehensive analysis would only strengthen the conclusions we are able to draw.

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[9] There were 48,921 reported long-distance trips in the NTS across 2011 to 2015 (Department for Transport, 2016c); over the same period, 1,377,572 trips in all were recorded (Department for Transport, 2016d). The matter is complicated by the fact that data on long-distance journeys are collected over two weeks in comparison with a single week for shorter trips.

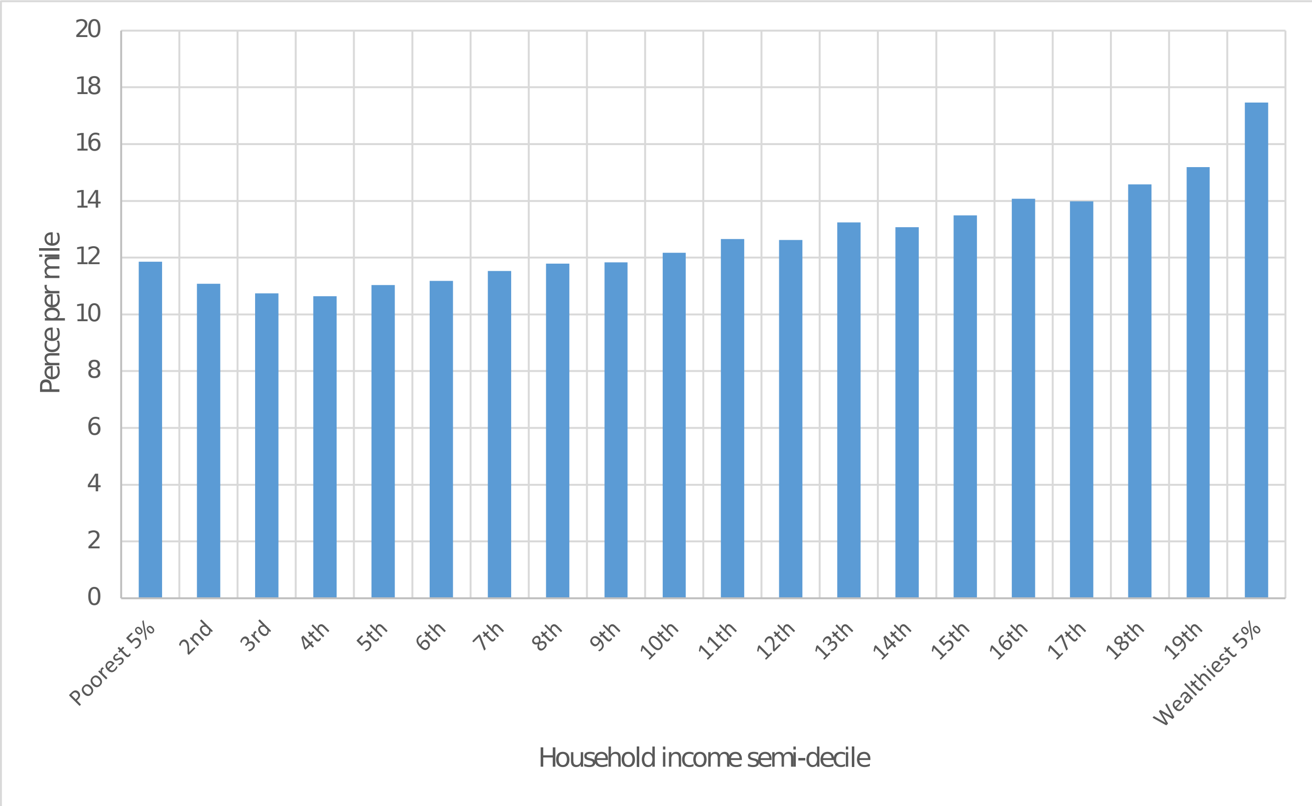


Figure 1: Mean cost of travel per mile by income band (source of base data: National Travel Survey)

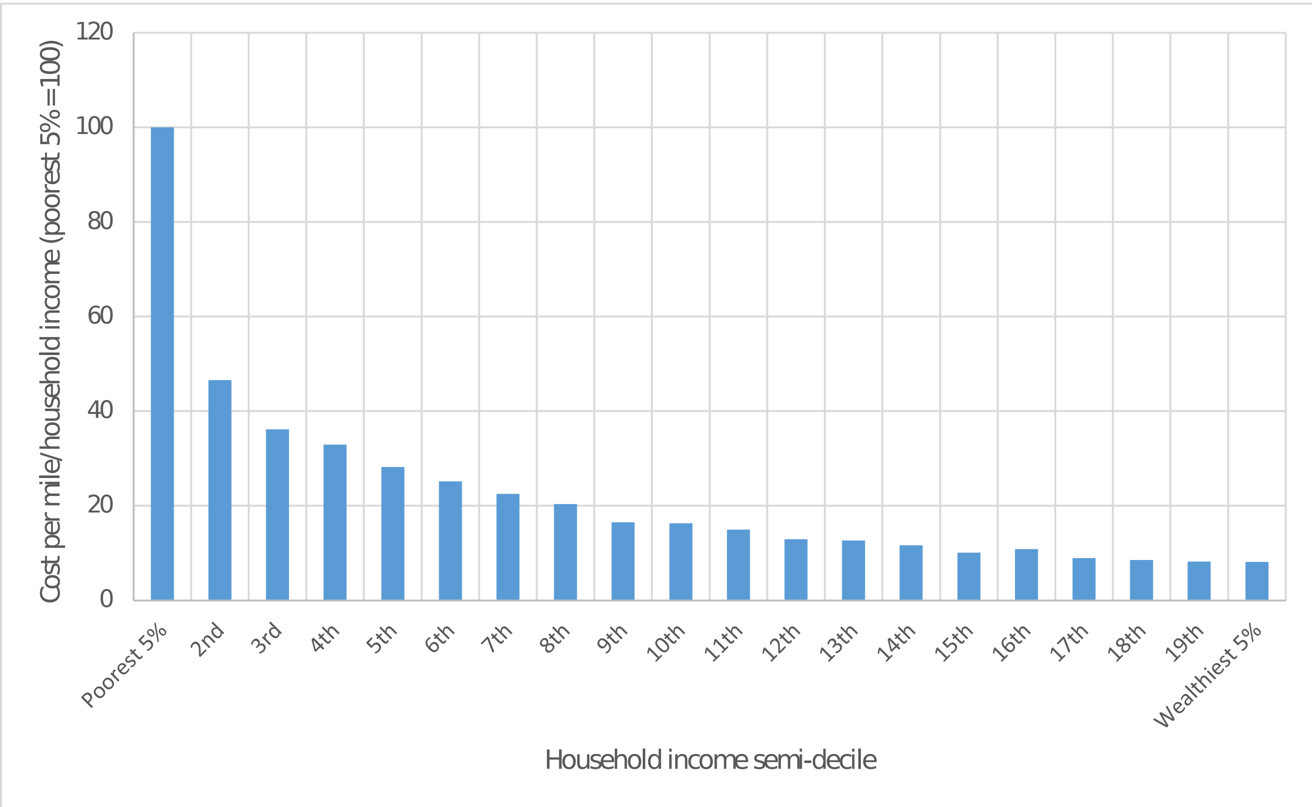
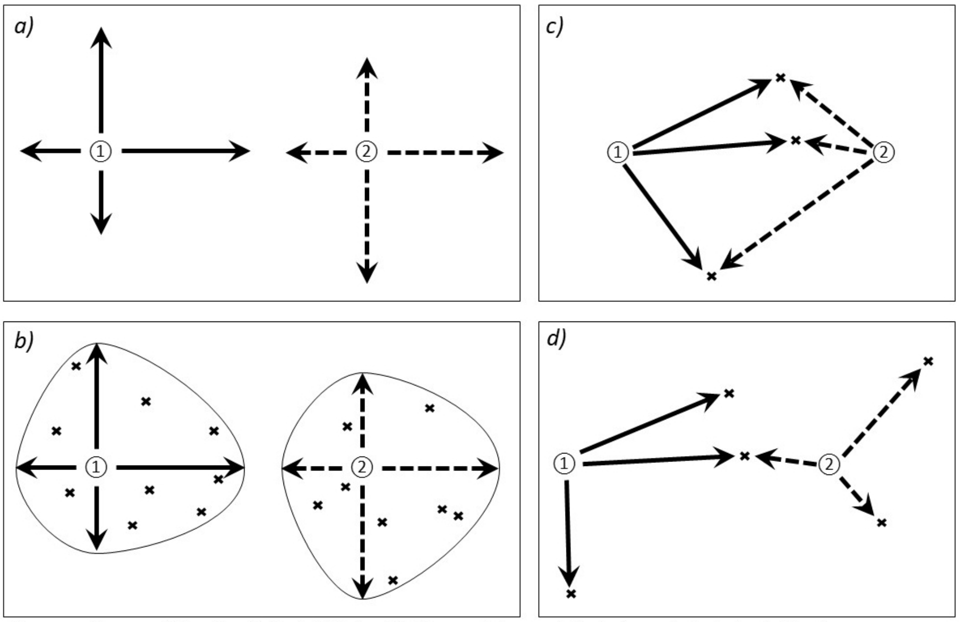
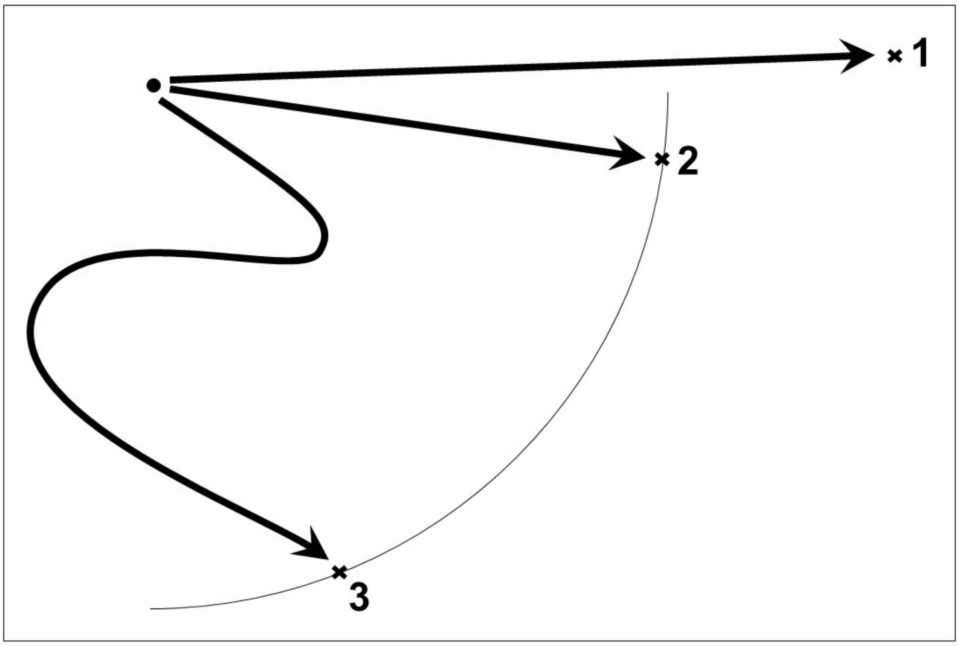


Figure 2: Mean cost of travel per mile as proportion of household income, by income band (source of base data: National Travel Survey)



The comparative accessibility enjoyed by two individuals. *a)* Motility: capacity to move (without reference to destinations); *b)* Isochrones: opportunities/destinations (represented by crosses) within a certain travel time are enumerated; *c)* Comparative impact of travel to pre-determined (fixed) destinations; *d)* Comparative impact of travel to destinations prioritised by individuals.

Figure 3: Four contrasting approaches to comparing accessibility



Destination 1 is further than Destination 2 as the crow flies; Destination 3 is the same crow-flies distance as Destination 2 but the path is much less direct.

Figure 4: Contrasting crow-flies distance with distance travelled

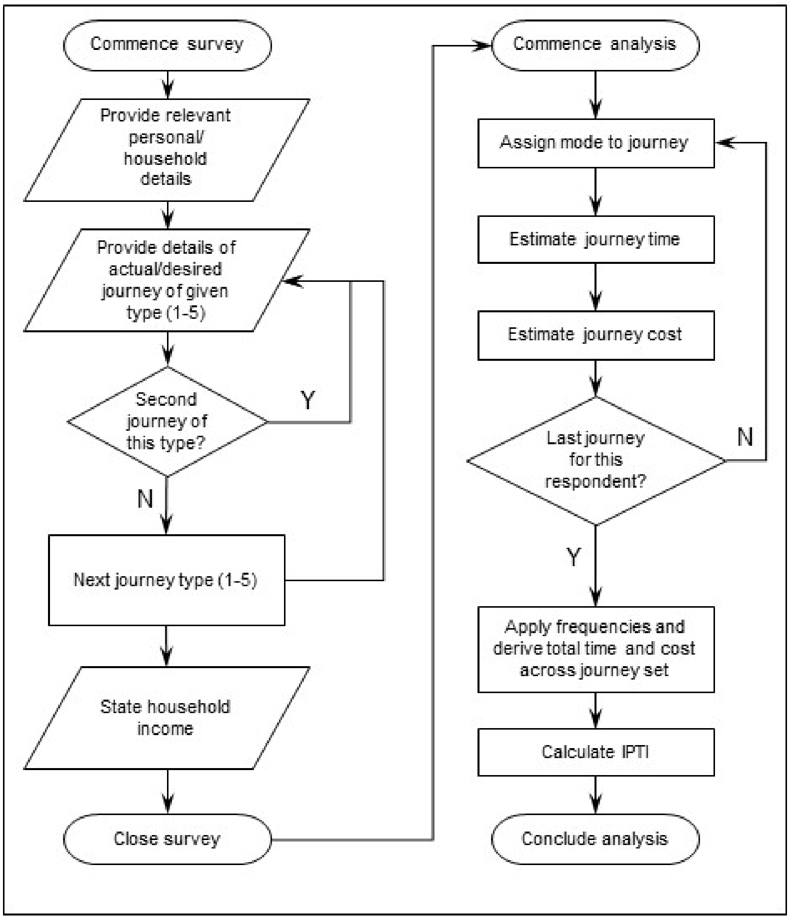


Figure 5: Pilot survey - data collection and analysis process