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A CONCEPTUAL APPROACH FOR ESTIMATING RESILIENCE TO FUEL SHOCKS

IAN PHILIPS, GY09IP@LEEDS.AC.UK ITS UNIVERSITY OF LEEDS GB-LS29JT
DAVID WATLING, D.P.WATLING@LEEDS.AC.UK ITS UNIVERSITY OF LEEDS GB-LS29JT
PAUL TIMMS, P.M.TIMMS@LEEDS.AC.UK ITS UNIVERSITY OF LEEDS GB-LS29JT

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Ian Philips, gy09ip@leeds.ac.uk ITS University of Leeds GB-LS29JT

David Watling, d.p.watling@leeds.ac.uk ITS University of Leeds GB-LS29JT

Paul Timms, p.m.timms@leeds.ac.uk ITS University of Leeds GB-LS29JT

ABSTRACT

We examine a conceptual approach to the estimation of resilience of transport systems to fuel shocks, i.e. a severe and long lasting reduction in the availability of fuel for motorised transport. Resilience in this paper is defined as the persistence of the social, economic and environmental systems required for sustainable development following a fuel shock. Adaptive capacity is an element of resilience and is defined in the paper. We discuss the importance of indicators in transport planning and policy. They make use of conceptual approaches to report numerical estimates which can be applied to policy. There is currently no indicator of adaptive capacity of individuals in small geographies sensitive to a variety of policy measures, such as those affecting fitness, obesity, bicycle availability and bicycle infrastructure, whose impacts (at least in the short term) are on a smaller scale than large-scale land use and urban morphology change. We propose a conceptual approach for designing a method to estimate resilience. We make this the focus of our paper because it is an essential pre-cursor to selecting suitable data and calculation techniques to produce an applicable indicator. The indicator shows the proportion of the population of areas who would have the capacity to commute to work principally by bicycle or walking following the shock. Four groups of factors influence the indicator value; individual capacity to walk and propel bicycles, environment factors such as slope, supply factors such as bicycle availability and constraints such as time budget. It assesses capacity grounded in current data and avoids as far as possible the need for speculation about the future. We believe this makes progress towards producing a good indicator with relatively un-controversial, transparent simplifying assumptions. The indicator can be applied to different levels of fuel reduction, can compare the resilience of different areas and can be updated over time. We describe the indicator in a UK context but the indicator can be used in any nation where suitable data exists. Although we have focussed on the application of the method to fuel shocks caused by finite limits to resources, it would be possible to use this method to examine adaptive capacity to other shocks such as geopolitical crises.

Keywords: Resilience, adaptive capacity, sustainability, indicators, walking, cycling, peak oil, resource scarcity, disruption, system change, indicator functions

1 INTRODUCTION

There are finite limits to resources (Meadows et al., 1972). There are finite limits to fuel available for transport (Hubbert, 1956). Rockstrom et al., (2009) argue that certain natural resources have already been exploited beyond critical thresholds where there are likely to be consequences to which society will have to adapt. Peak-oil may lead to a gap between demand and supply of fossil fuels for transport (for example see Aftabuzzaman and Mazloumi, 2011). This means that there are a number of situations in which it is possible that fuel supply for [passenger] transport could be suddenly and dramatically reduced.

We are interested in the assessment of resilience to inform transport policy about sustainable futures. A resilient transport system is one which can continue to provide some social and economic benefits within the environmental limits imposed by a fuel shock. The question we will address is: how *resilient* is our current pattern of travel and transportation provision to such a sudden and unpredictable fuel shock? Resilience is important but there are problems considering it in policy because of a lack of satisfactory indicators. Authorities in the UK for example wanting to assess resilience do not have a suitable estimation method or indicator for doing so. In this paper we focus on the UK by way of example, but the principles of the indicator we develop can be applied internationally.

The focus of this paper is the development of the conceptual design of a method for assessing resilience. The conceptual design is necessary firstly in order to inform methodology and data selection and secondly as part of the communication of what to measure and why. These elements are pre-requisites of applying the methodology to an indicator which is instrumentally sound and applicable to policy and decision making. (Gudmundsson, 2010; Lyytimäki and Rosenström, 2008). Whilst reporting methods and results are important, we believe that this conceptual approach is an important starting point and should be explained clearly. For that reason methods and results will be reported separately.

In section 2 of this paper we first consider the definition of resilience, its importance and the need for indicators of resilience to inform sustainable transport policy. Then we go on to show that current indicators are not able to give a complete measure of the adaptive capacity element of resilience. Adaptive capacity being the ability to continue making journeys post shock. Particularly there are no existing indicators that are sensitive to a variety of policy measures affecting fitness, obesity, bicycle availability and bicycle infrastructure whose impacts (at least in the short term) are on a smaller scale than large-scale land use and urban morphology change. Sections 3 and 4 construct the conceptual approach by defining scope and the indicator design respectively.

Section 3 outlines the scope of the indicator proposed. For purely practical reasons the indicator is based upon a model of adaptive capacity the ‘morning after’ a shock which happens tomorrow. Whether this is a short term disruption to fuel supply or a permanent reduction in availability there is a ‘morning after’: a day after the shock when the population needs to attempt to carry on with life. On the ‘morning after’ the shock, the number of ways in which people can adapt is likely to be limited to changing modes. For example, people are unlikely to be able to move home to a better location or get a new job the morning after, nor can land-use and location of jobs and services be changed instantly. The 'morning after' is chosen not for policy reasons, but for the practical reason that a calculable, relatively non-controversial, and transparent indicator can be produced for this point in time. We provide a baseline for further work. Section 4 outlines the indicator designs. The factors considered are explained and examples are given of the type of existing data which could be used to populate the model. Section 5 summarises issues addressed developing a method which can be applied to calculating an indicator. Section 6 covers conclusions and further work.

2 BACKGROUND

2.1 Explaining resilience

Resilience in this paper is defined as the persistence required of the social, economic and environmental systems for sustainable development. Sustainable development in this paper means economic and social systems functioning within finite ecological and resource limits. There is much debate over the definition of sustainable development used in transport (for a summary see Ramani et al., 2011). Resilience has several elements which will be defined below including adaptive capacity and transformation (Folke et al., 2010). Specified resilience (Carpenter et al., 2001) is the resilience of one system in response to specific changes. Using specified resilience is a simplification which may make analysis tractable. We pick as our system of interest the transport system. In this context we can examine the resilience of people to a fuel shock in the transport system. Adaptive capacity in this context is the ability of people to keep making journeys [primarily by walking and cycling] post shock, so that they can continue to have a 'way of life'. This holds if we assume that people need to make journeys in order to have any form of 'way of life'. People need to access goods, services, other people, education and employment wherever they exist.

Figure 1 shows that all systems of interest exist within a global social-ecological system (SES) constrained by finite resources. Definitions of SES include those by Berkes, (2003), Gallopín, (2006) and Glaser et al. (2008). The concept of SES acknowledges a finite limit to resources and that depletion of a resource can force changes to systems. The shaded boxes show the initial current state of transport and connected systems. There may be a fuel shock in the current state. From the current state, policies may have been implemented (a) or insufficient preparations for the coming shock will have been made (b). If insufficient preparations have been made then the nature of the shock determines the outcome. A short duration shock (c) risks disruption. After the disruption the system may return to the initial state until the next shock (d). If insufficient preparations have been made and the shock is the beginning of permanent change there is a risk of system collapse (e). If policies have been implemented before the shock (a) there is a chance adaptive capacity has been built (f), so that when a shock occurs the system adapts (g). The effects on transport and connected systems depend on the level of adaptive capacity. Policies could also be implemented to transform the system (h). In the event of a shock the system would be resistant; would not be dependent on fossil fuels and thus unaffected by a fuel shock (j).

Resilience as defined above is important to achieving sustainability. More precisely it is part of sustainability defined within an eco-centric worldview or as ecological economists would call it "Strong sustainability" (Daly, 1994). Strong sustainability notes that there are finite limits to some resources. Weak sustainability does not consider finite limits to resources. Instead it views the environment, social and economic dimensions of sustainability as interchangeable; environmental capital can be replaced by economic capital. There is agreement that resilience is an aspect of strong sustainability (Teigão dos Santos and Partidário, 2011, Gunderson and Holling, 2002, Lebel et al., 2006). Tight (2010) asserts that current transport planning and thinking maintains an unsustainable approach. Referring again to Figure 1; if transformation has not occurred before a shock happens then adaptive capacity would be required to avert negative consequences. Within the transport literature there is support for strong sustainability underpinning the development of transport policy (e.g. Banister, 2008, Gudmundsson and Höjer, 1996, Schiller et al., 2010). There is then a clear justification for attempting to increase adaptive capacity to transport fuel shocks.

We have given a high level definition of resilience of a transport system to fuel shocks above. In this section we have specified the scale of interest and the interest in adaptive capacity. Operationally we are examining the resilience of the transport system to fuel shocks at small geographies through the adaptive capacity of individuals and the "small" scale factors which influence them immediately after the shock.

Table 1: After (Gudmundsson, 2010, Boulanger, 2007) *Learning will contribute to understanding the functioning of systems.

Boulanger's groups of functions	**Indicator functions**
1. A "Rational – positivist" set of functions. Objective measures of phenomena, a technical tool.	Describing the situation– What is going on? Assessment - How are we doing? Prioritizing and deciding – What should we do? *
2. A "Discursive – constructivist" set of functions. Framing problems, encouraging discussion of issues.	Focus the attention – discuss what is important? Accountability function – Discussion of change to accountability functions to emphasize what is important. Prioritizing and deciding – What should we do? Communicating - how do we tell others? *

2.1 Indicators in transport policy

2.1.1 Indicator functions

Indicators exist within a context of governance. The decision on whether an indicator will be used in policy making is subject to social and political influence. For example one political group may reject the use of an indicator for purely ideological reasons, another may reconsider its position on an issue when presented with evidence from an indicator. This is an idea from Pastille Consortium, (2002). They suggest that the uses of indicators can be grouped based on a political science approach such as that of Boulanger, (2007). Boulanger gives a political science based classification of indicator use. There are two useful groups; a "Rational – positivist" set of functions and a "Discursive – constructivist" set of functions. The former is associated with objective description and assessment of phenomena which allows it to be used as a measurement tool. The latter are the functions of indicators which allow them to frame problems in discussions, these are almost always qualitative.

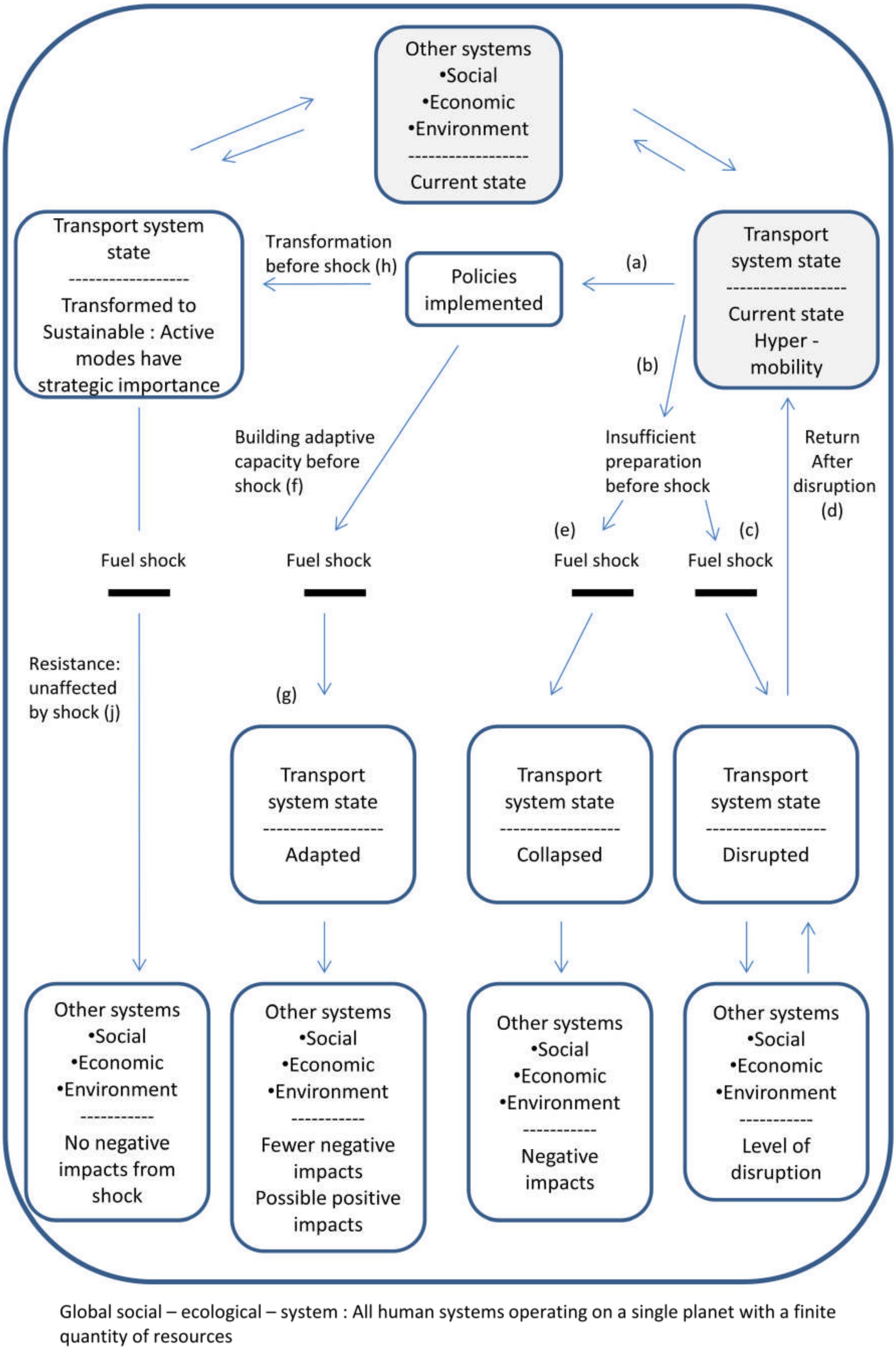

Figure 1: Elements of resilience in the context of transport fuel shocks.

Table 1 summarises indicator functions. Pastille Consortium, (2002) assert that it is important that both these groups of functions be considered when trying to produce effective sustainability indicators.

Quantifiable indicators are more common. In a review of definitions of indicators quantifiability and measurability were key features (Gudmundsson, 2010). For example Marsden and Bonsall, (2006) explain the development of a culture within the UK public sector which relies upon performance targets measured by indicators. They note that issues which are not covered by indicators and targets are ignored or sidelined. In a UK context indicators which can be used as objective, robust, quantifiable, statistically sound tools are more likely to gain entry into the policy discourse. These are all statements which are associated with quantitative measures. It shows that quantitative measures are preferable in UK policy making (Marsden, 2008). Litman, (2007) appears to echo this internationally. A list of indicators of sustainable transport in Mihyeon Jeon and Amekudzi, (2005) covering economically developed nations and international bodies also showed quantitative indicators dominate.

2.1.2 Good indicator criteria

Indicators have to be ‘good’ in terms of their “Rational- positivist” functions in order for them to be accepted into the policy debate and fulfil their other useful functions. If the methods used to develop an indicator are sound, it increases the credibility of the indicator (Mitchell et al., 1995). Marsden et al., (2006) summarise features of good indicators which could be used as criteria for inclusion in Table 2. Though it is not explicitly mentioned, it is inferred in Table 2 that indicators should be transparent. It should be clear what data is used, how it is used and the method to calculate the indicator value should be open. Methods should be open so that any assumptions can be made clear and results can be reproduced.

Table 2: Characteristics of good indicators after Marsden et al 2006

Good indicators are:

1. Useful – have clear functions
2. Clearly defined – no ambiguous terms
3. Non-corruptible – no way of twisting reporting of data to suggest more positive values
4. Controllable – reflecting transport’s contribution to wider issues
5. Measurable
6. Responsive - able to show change over a specified time period or at a particular spatial resolution. They must also be sensitive to policy measures.
7. Easy to understand – by practitioners, politicians and general public – relevant to experience
8. Cost effective to produce

2.2 Current indicators of resilience

Active modes are key to resilience to fuel shocks. Adaptive capacity in this context is the ability of people to keep making journeys [primarily by walking and cycling] post shock focussing on "small" scale factors influencing individuals in small geographies. The UK guidance on indicators for transport appraisal does not directly consider resilience of people to a fuel shock in the transport system as we define it in Section 2.1 (DfT, 2007). The current indicators used in appraisal of the environment objective do assess effects on physical fitness. This is a factor of adaptive capacity but on its own it cannot give a measure of adaptive capacity. Current mode share does not indicate capacity for people to use active modes post shock. It would appear from the literature that other countries do not explicitly examine resilience. For example Mihyeon-Jeon and Amekudzi, (2005) give examples of indicator sets used in economically developed nations and international bodies and Miranda and Rodrigues da Silva, (2012) in Brazil. The indicator sets examined do not collect the range of information which would be needed to give a measure of adaptive capacity to transport fuel shocks. For example they do not collect the fine grained information about people's capacity to travel by bicycle such as ownership at small geographies and individuals' ability to propel a bicycle.

Proposed indicator sets for sustainable urban mobility, such as those suggested by Litman and Burwell (2006) or Toth-Szabo and Várhelyi, (2012) include some indicators which measure some factors of adaptive capacity but it is not considered explicitly. For example Marletto and Mameli, (2012) consider walkability and cyclability as measures of the propensity to use active modes under current conditions. These measures do not give an adequate measure of adaptive capacity after a shock. Accessibility statistics and indicators use assumptions about trip length by active modes based upon current circumstances and behavioural preferences. Dodson and Sipe, (2007) suggest an indicator of vulnerability of the populations of different areas to fuel price rises in Australian cities. It identifies areas which may have to change if there are price rises. It does not measure the capacity of the individuals there to adapt.

Rendall et al., (2011) provide an indicator of resilience as defined in Section 2. They use the notion of active mode accessibility to suggest changes to urban morphology and land-use to increase adaptive capacity in the event of a reduced supply of fuel due to peak-oil. The mitigation strategies considered changes to land-use which are high level changes. These are useful mitigation strategies to be implemented in anticipation of a shock. Other land use and transport interaction models would also be suitable for examining high level mitigation strategies. However we believe that there are also non land-use "small" scale factors which influence the ability of individuals to adapt after a shock. As Table 2 states, indicators need to be sensitive to policy measures. Different indicators are needed at different scales. For example; land-use focussed indicators are too high level to examine localised, individual and community oriented interventions. It would not pick up the effects of policy interventions aimed at changing obesity or bike availability on adaptive capacity.
There is currently no indicator which shows adaptive capacity of people to transport fuel shocks which would be sensitive to policy interventions at the scale of interest.

2.3 Summary of position in Section 2

To summarise our position so far: Our definition of transport resilience in Section 2.1 illustrates its importance. Section 2.2 shows indicators are essential to represent issues in transport policy. This justifies a need for indicators of resilience and the subset we are interested in – adaptive capacity indicators of "small" scale factors that is those not involving large scale land-use and urban morphology change which influences individuals in small geographies. Section 2.3 demonstrates a lack of suitable indicators which justifies the production of a new indicator. This application requires development of a method of calculation.

3 INDICATOR SCOPE

The indicator we shall subsequently define uses a fairly simple idea, commonly found in transport planning. We calculate the adaptive capacity of the area now. That is, we consider a shock which happens tomorrow and the adaptive capacity immediately after the shock. Then we suppose: what if a particular policy intervention had been implemented before the shock – what would the current adaptive capacity be? For pragmatic reasons we choose to concentrate on a hypothetical situation on the first day after a sudden shock, i.e. before society has had any opportunity to make a 'post-shock' adaptation. We can offer evidence from the current situation to suggest adaptive capacity at this point. However if our measure is calculated some weeks or longer after the shock we have no evidence of how people may change. In reality a shock might not be so sudden. However this indicator gives a clear simplification rather than speculating about how rapid the onset of the shock would be. We wish to avoid speculation where possible. The indicator is then sensitive to policy interventions before a shock. These policies affect the adaptive capacity immediately after the shock.

We hypothesise that the adaptive capacity 'the morning after' at a local scale will affect longer-term and larger scale adaptive capacity and overall resilience. Thus, while *predicting* the longer-term adaptive capacity is beyond the scope of our work, we believe our calculated measure to be a useful indicator for both the shorter and longer term. We feel that the most important application of this indicator is to address issues of resource scarcity, because as argued in Section, 1 fuel shocks are possible and in Section 2 because resilience needs to be considered to deal with barriers on the path towards sustainability. However we notice that the indicator could be used to assess adaptive capacity to other transport shocks and disruptions caused by other events such as geo-political crises and natural disasters as shown in Figure 1.

It is important to state that the guiding approach of this work is to produce an *indicator of capacity to adapt* rather than a *predictive model*. Calculating capacity tells us an upper bound of what might be possible. Capacity measurement on its own is perfectly valid as an output. Indicators and proxies of capacity are common in science, decision making and policy. We cannot predict the exact number and type of journeys people will need to make after a shock. So, for example, we could investigate the ability of people to continue making the journey to work. This is clearly a rather artificial situation but it captures a key aspect of resilience of the present transport system, and the journey to work is a journey type that is easy to understand. The guiding approach throughout involves making maximal use of pooling existing data sources, one might call it an 'empirically-grounded indicator', which will lead to ease and cost effectiveness of the production of an indicator for a wide variety of areas. The purpose of the indicator is to assist in decision making by firstly assessing the effect that specific policy interventions would have on adaptive capacity to fuel shocks, and secondly by fulfilling discursive functions. A good indicator (see Table 2) capable of performing its Rational-positivist functions may then be accepted into the governance discourse as explained in Section 2.2.1.

The scope of the indicator is tightly focussed on transport fuel shocks, but the consequences could be wide. Ramani et al., (2011) suggest that indicators which affect generic sustainability issues are more important than those only relevant to a specific domain such as transport. Indicators of resilience and adaptive capacity to fuel shocks are relevant beyond the transport domain in two ways. Firstly, if there is a shock and there is insufficient adaptive capacity then the transport system will collapse. Such a collapse would as Figure 1 shows have serious consequences for social, economic and environmental systems. The proposed indicator illustrates a specific case of a generic issue. Secondly, it is novel in transport to consider resilience as an element of sustainability. This allows us to see the journey to sustainability not just in terms of mitigating and changing currently unsustainable practices. It also acknowledges that in the journey towards sustainability there may be barriers and shocks which hinder progress.

As the indicator is quantifiable is is more easily used in existing appraisal frameworks. The indicator could be used in a Multi-Criteria Analysis (MCA) where a weighting is given to achieving resilience objectives. The nature of the indicator means it could also be monetised. This means it could also be utilised in a Cost Benefit Analysis (CBA) based appraisal framework. The current transport appraisal guidance in the UK contains some elements of both of these systems (DfT, 2007). In recent times there has been a debate on the relative merits of using CBA and MCA individually or combining these approaches (Browne and Ryan, 2011; Gasparatos et al., 2008; van Wee, 2012). However as Gühnemann et al., (2012) point out both MCA and CBA appraisals tend to be compensatory. This means that if a scheme has a poor environmental score then it can be compensated for by a good economic score. This is a key feature of weak sustainability and is at the heart of the problem of strong sustainability being hindered by appraisal frameworks. So, the indicator could be used in existing appraisal frameworks perhaps achieving some of its Constructivist-discursive functions such as raising awareness. However we have not taken this step. The indicator would be most effective in showing the value of promoting resilience and strong sustainability objectives if the appraisal system used were non-compensatory. Martinez-Alier et al., (1998) argued for a non-compensatory MCA appraisal. There are examples of non-compensatory approaches in UK indicators. For example the aggregation of the different domains of the Index of Multiple Deprivation uses a non-compensatory system (McLennan, 2011).

4 INDICATOR DESIGN

The indicator is designed to measure the effect of interventions which could be made before a shock (as shown at the top of Figure 1) which would improve adaptive capacity after a shock. As stated in Section 3; for purely practical purposes we measure adaptive capacity immediately after the shock. This is so that there is transparency in terms of calculation. If there were a time lag of weeks or months from the shock to the time adaptive capacity were measured, then consensus would be lost because uncertainty about people's actions would lead to speculation.

4.1 Fuel situations considered

Three simple situations are considered each with a little more fuel available but all with much less fuel available then at present. These can be seen on the right hand side of Figure 2. The following simplifying assumptions are made regarding fuel availability:

1. Fuel availability stops or is reduced suddenly at a point in the very near future.
2. The government controls and rations any fuel which is available and already has contingency plans for implementing rationing in such a situation.
3. Freight is not considered.
4. It is assumed people need to get to work.

In situation 1 there is no fuel at all available for personal transport. The only modes available are walking and cycling. In situation 2 there is a very limited supply of fuel. This fuel is only available for the transport of essential workers to and from work by some form of motorised transport. In situation 3 there is slightly more fuel available. There is fuel available to transport essential workers as above, but there is also some fuel available to power some public transport; commuter trains would operate and a bus service would operate to move workers to and from work. Even in situation 3 the amount of fuel available is far less that at the current time and many people are expected to have to rely on walking and cycling. The discussion below concentrates on factors in situation 1. There is a brief overview of situations 2 and 3.

4.2 An indicator of the proportion of the population able to get to work after a fuel shock – design overview

Indicators are a trade off between realism and simplicity. The aim is to make non-controversial simplifications and assumptions which are transparent and easy to understand. Simplifying assumptions we made in the design of our indicator are shown in table 3:

Table 3 simplifying assumptions

1.This is an indicator of adaptive capacity immediately after a shock.
2. The health and age characteristics are the same as the current population.
3. Post shock – walkers and cyclists can use all of the road network in situation 1 but have to share with motor vehicles in situations 2 and 3.
4. Cyclists are free flowing and not subject to congestion or delays at junctions.
5. The population could achieve the level of adaptive capacity proposed by the indicator safely and without risk to health.
6. Spatial distribution of activities does not change the morning after the shock.
7. People cannot migrate or change jobs the morning after the shock.
8. A policy has to lead to safe and healthy outcomes. It cannot encourage or direct people to behave in an unhealthy or unsafe way. For example; estimates of how far people can walk and cycle should not be based on work rates [whilst walking or cycling] and time budgets which lead to illness and injury.

This indicator is given as the proportion of an area's population which *could* maintain their current commute by changing to active modes. It is an indicator of one form of adaptive capacity following a fuel shock. As seen on the left of Figure 2 the calculation of the indicator is based on four groups of factors. Firstly, individuals have a maximum capacity to walk and cycle based upon their physical characteristics. Secondly, location features such as topography affect this physical capacity. Thirdly the supply of resources such as bike availability and the permeability of the transport network due to barriers and infrastructure also affect the maximum distance which individuals can walk or cycle. Finally individuals have constraints on the time they can spend commuting. The conceptualisation of the indicator is shown using influence diagrams (Figure 3). The reason for using an influence diagram is to clearly define the relationships between variables in the indicator in an easily understandable way (Clemen, 1991). Figure 3 shows the factors which determine the value of the indicator in the three fuel situations considered. Factors with no superscript are common to all three situations. Factors considered in situations 2 and or 3 are marked with a superscript.

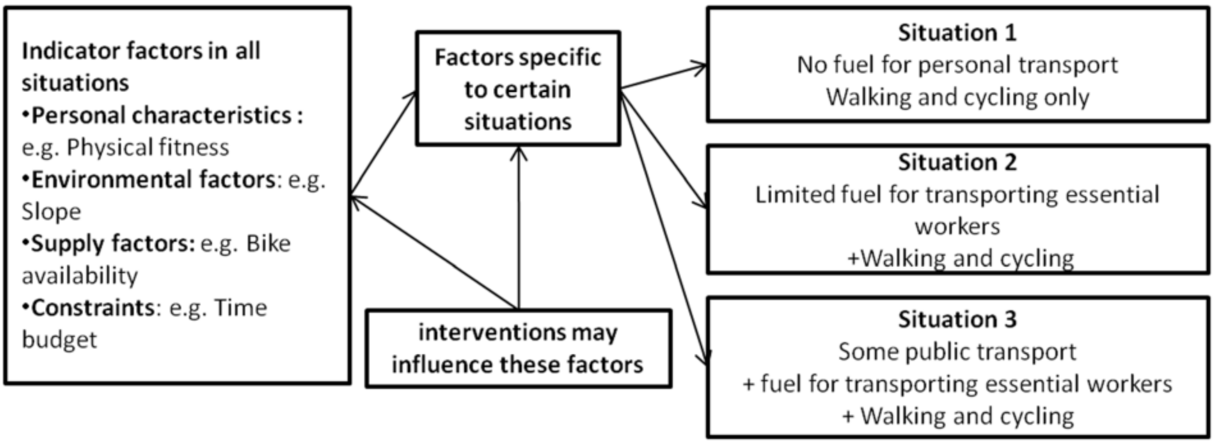

Figure 2: The main components of the indicator and factors considered in 3 different fuel availability situations

Table 4 gives examples of specific interventions which could be tested for their influence on adaptive capacity.

Table 4: Policy and intervention table. The indicator can test the effect of interventions on the value of the indicator.

Policy area	**Specific intervention**	**Units – what is the intervention output**
Increase fitness / Decrease obesity	Sustrans Luton 10 week active travel programme	% of people active for more than 30 minutes 5 days per week
Cycle infrastructure & speed limits	Construction of segregated cycle routes.	Km of segregated cycle route
Bicycle availability.	Community bike hire and hub mirroring Velo-Campus bike hire.	Number of bikes that become available to population of area
Commute distance	Workplace travel planning to increase telecommuting	% increase in telecommuting and corresponding decrease in commuting by distance
Public transport	Increase rail mode share	Percentage of an area's population which can travel by rail
Reduce network barriers	Bridge and route construction similar to Sustrans Connect2 type schemes	Effects on circuity in specific areas
Reducing number of stops on cycle journeys.	Change traffic signals and priorities(optimise for cycles instead of cars)	Average number of stop-start per cycle km – affects maximum distance travelled

4.3 Indicator design situation 1

4.3.1 Time budget

Two factors constrain the time budget: a *physical constraint* and *a social constraint*. The *social constraint* comes from the pattern of daily life. Governments may issue travel times those seeking work should be willing to travel, for example in the UK it is set as 90 minutes in each direction (DWP, 2012). Not everyone can be expected to do this. This base expectation is modified by aggregating individuals into households, and taking data about the proportion of people escorting children to school and other activities which constrain the commuting time budget. This along with mobility impairment will be considered.

The *physical constraint* is the body's system of muscles and joints. Any individual who is not already a regular cyclist may be affected by saddle soreness, muscular and joint pain. There is some evidence to suggest that after riding for two hours many experienced riders would express discomfort when using a normal bicycle saddle (Keytel and Noakes, 2002). Discomfort is likely to be felt sooner by those beginning cycling. Christiaans and Bremner, (1998) reported that almost 60% of 453 Dutch volunteers testing cycling comfort complained of soreness of some type when riding their own bicycles on journeys of less than one hour's duration. It is assumed that the effect of aches and pains could be compounded over several days leading to injury. The physical constraint assumes that individuals would be physiologically capable of travelling to work and back five days per week without injury. Mobility and disability is also considered part of the physical constraint.

4.3.2 Factors influencing pedalling power

Age, weight, height, BMI and fitness are related and affect the ability to propel oneself by walking or cycling. The cardio-vascular systems of a non-athlete, working age adult could work at an exercise intensity called Lactate Threshold (Jones and Poole, 2004; Pringle and Jones, 2002; Whipp and Rossiter, 2005). Practically, above lactate threshold blood lactate accumulates faster than it can be dissipated meaning a non-athlete would soon have to stop and rest. This could be maintained for several hours at a time each working day, provided the adult eats a suitable diet. If the following individual characteristics are known (or, in our case, are simulated), then they can be used as parameters to estimate the *pedalling power* at Lactate Threshold: a*ge, weight, BMI, height and fitness*.

4.3.3 Bicycling speed and maximum distance

Once *pedalling power* is known, the speed of travel can be calculated. *Bicycle speed* is a function of the *pedalling power*, *weight* of the rider, *bike weight* and various frictional constants (Wilson, 2004). *Bicycle speed* and the known *time budget* are multiplied to give the maximum distance an individual could cycle.

4.3.1 Bicycle availability

The UK National Travel Survey table NTS0608 (DfT, 2010) lists the percentage of individuals with access to bicycles by age. This could be used in the indicator. It must be noted though that it would not differentiate between availability of cycles to men and women. The other limitation of the data is that it is a national level figure and does not show variation between areas. Other approaches can be taken to better account for spatial variation in bike availability, for example relating studies of bike ownership to socio-demograpic data (e.g. Anable, 2010).

4.3.1 Slope

Cycling uphill is significantly slower than on the flat for a given power input. A route which has an equal amount of uphill and downhill will also have a different power requirement to a flat route for a given average speed. Different hypotheses of how people choose to expend energy when cycling uphill, or accelerating after stopping, are available (Parkin, 2008; Graham, 1998); for example people's motivation may lead them to work at higher rates to maintain speed. Working at Lactate Threshold is highly sustainable, while working at a higher rate for part of a journey might reduce the ability of people to be able to cycle for the whole of their time budget, or to recover and repeat trips. It is assumed in our approach that when riding uphill, people can maintain a constant rate of pedalling power at Lactate Threshold. They will then have a slower average speed than a non-stop journey on the flat. The topography of an area is an important determinant of the maximum distance people could cycle. There are numerous GIS methods which can be used to estimate the slope of an area. Sample routes can be used and the average slope calculated. This may work well for a small study area but would be very time consuming for large study areas. A raster grid of digital elevation data is available for anywhere in the UK in 1km, 50m and 10m squares. The slope is derived from the difference in height between two adjacent squares (ESRI, 2011). The average slope of the area can be calculated. However there are problems: the slope of road and path surfaces may not follow the fall line; the elevation grid covers the whole area not just the roads and paths; and the coarser the resolution used, the more small undulations are missed. Parkin (2008) deals with some of these issues and uses a 1km grid in an estimation of effort along cycle routes. Finer 50m and 10m grids may be better for examining small areas.

4.3.1 Network permeability

Route directness varies in areas of different morphology and network type. Route directness or the level of circuity of a network is the ratio of the on road distance to the Euclidean distance between origin and destination (Levinson and El-Geneidy, 2009). For example, the value for Pedestrian Route Directness is lower for curvilinear than grid street patterns (Dill, 2004). Also if there are barriers to connectivity such as rivers without bridges at convenient points, this forces people to take a more circuitous route. Following an extreme shock in situation 1, the entire road network would be available for use by those walking and cycling. An estimate has been made using analysis of randomly selected origins and destinations that suggests a 'circuity' of around 1.2 on the road network (Newell, 1980). This is quite crude. For example, a study of Portland, Oregon and Minneapolis St Paul revealed that circuity also varies depending on journey distance (Levinson and El-Geneidy, 2009). Interesting as this is, the exact values from this study are perhaps not applicable in a UK context as urban morphology in the US and UK differs.

4.3.1 Indicator design situation 2

Parkin et al., (2007) present a logit model of acceptability of cycling; the probability that an individual will find it acceptable to cycle. The parameters in Parkin's model are: proportion of the network with cycling facilities, as well as age and gender distribution of the population. Parkin's model is independent of changes in speed, volume and ratio of bicycles to motor vehicles, which would change immediately after a shock. In situations 2 and 3 there are some motor vehicles on the road so it is assumed that bicycles will have to stop at intersections. Because it requires more energy to accelerate after stopping it reduces the distance which can be covered within the time budget (Parkin, 2008; Wilson, 2004). It is assumed that approximately 10% of the workforce would be classed as essential workers. Whilst this is quite arbitrary, it is beyond the scope of this study to determine which workers would be deemed essential.

4.3.1 Indicator design situation 3

We make a number of assumptions about public transport for situation 3. We assume the operation of rail services because:

1. Trains are fuel efficient when running full.
2. Electrified parts of network potentially run on renewable energy sources.
3. Users would be the same, as rail capacity would not change much immediately after the shock.

In situation 3 there is enough fuel for a bus service. The current bus fleet is available. A proportion of the bus fleet is employed transporting children who live beyond their maximum travel distance to the nearest school. The rest of the bus fleet can be used to transport adult workers.

5 THE METHOD APPLIED TO AN INDICATOR

In this section we summarise issues which have been addressed in developing a method which can be applied to calculating an indicator. We reflect upon indicator design in Table 5. Progress is made towards all the criteria of good indicators, though we feel there is scope for further development of the data sources and the way they are used. The indicator and design proposed represent a good first step with room for further progress.

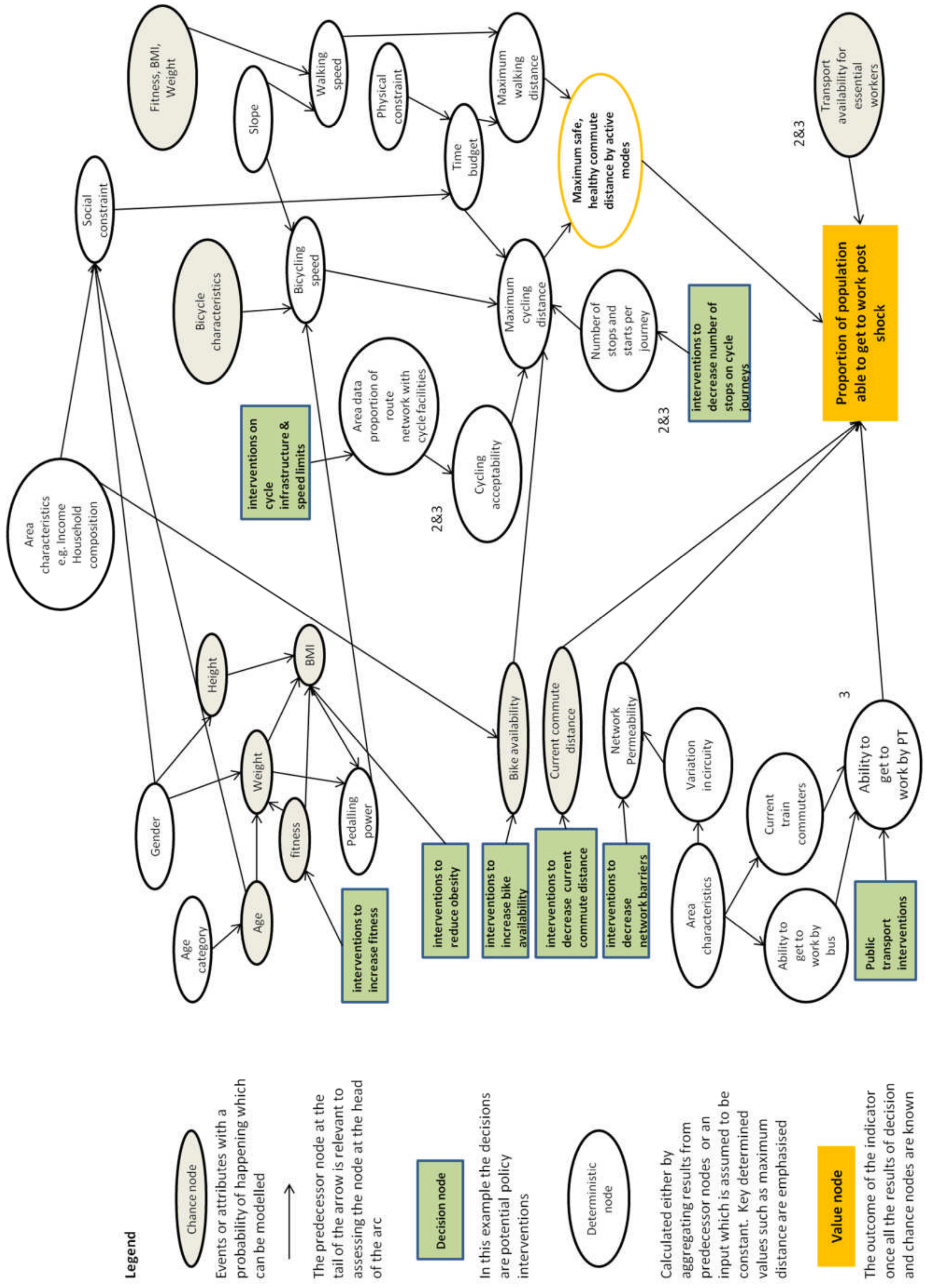
Legend
Chance node
Events or attributes with a probability of happening which can be modelled
The predecessor node at the tail of the arrow is relevant to assessing the node at the head of the arc
Decision node
In this example the decisions are potential policy interventions
Deterministic node
Calculated either by aggregating results from predecessor nodes or an input which is assumed to be constant. Key determined values such as maximum distance are emphasised
Value node
The outcome of the indicator once all the results of decision and chance nodes are known
Age category
Age
Gender
Weight
Height
fitness
BMI
Pedalling power
interventions to increase fitness
interventions to reduce obesity
Area characteristics e.g. Income Household composition
Social constraint
Fitness, BMI, Weight
Slope
Walking speed
Bicycle characteristics
Bicycling speed
Physical constraint
Time budget
Maximum walking distance
Maximum cycling distance
Maximum safe, healthy commute distance by active modes
interventions on cycle infrastructure & speed limits
Area data proportion of route network with cycle facilities
Cycling acceptability
2&3
Number of stops and starts per journey
interventions to decrease number of stops on cycle journeys
2&3
Bike availability
Current commute distance
Network Permeability
Variation in circuity
interventions to increase bike availability
interventions to decrease current commute distance
interventions to decrease network barriers
Area characteristics
Current train commuters
Ability to get to work by bus
Ability to get to work by PT
3
Public transport interventions
Transport availability for essential workers
2&3
Proportion of population able to get to work post shock

Figure 3: Previous page. Influence diagram – factors and relationships modelled in the indicator. Personal physical characteristics such as fitness influence pedalling power. Environmental factors such as slope, supply factors such as bike availability and constraints such as time budget affect the maximum distance people can travel by active modes. Maximum travel distance is compared to an individual's current commute distance to determine whether they can make the journey to work Maximum distance an individual can travel is also dependent upon the fuel situation and whether the journey can be made by motorised modes. The notation used here is based on that used in (Clemen, 1991).

It is particularly worth noting the points that follow. The method lends itself to application as an indicator because is useful, not only instrumentally but because of its relationship to the broader issue of sustainability and resource scarcity. It has potential for having impact through its discursive function. As can be seen in the discussion of the practice of construction and use of indicators above; the attempt to be transparent about limitations and simplifying assumptions increases the robustness and applicability of the method to be used as an indicator. The attempt throughout to develop a method for estimating adaptive capacity which is non-controversial contributes towards all the good indicator criteria.

Table 5: The design of the indicator follows the criteria set for good indicators shown in table.

Criteria for good indicators	Steps towards fulfilling criteria
1. Usefulness	Indicator can have "Rational – positivist" and Discursive – constructivist" functions. Trial use with stakeholders would further refine the functions. Indicators can measure the resilience to fuel shocks. The issue of resilience to transport fuel shocks is a specific example of the generic issue of resource scarcity threatening sustainable development.
2. Clarity	We have tried to be clear in terms of definitions of terms and presentation of the design.
3.Non-corruptibility	Users would have to be clear about what data is input to the model. As the journey to work is used in the indicator, areas with high unemployment could artificially increase the adaptive capacity. This has to be accounted for in construction of the indicator.
4. Controllability	It is not possible to totally isolate transport systems from other real world systems so simplifications have to be made.
5. Measurability	A quantifiable indicator of adaptive capacity is produced. Speculative assumptions are avoided as much as possible. Relationships between factors rely on established relationships evidenced in literature. Simplifications have had to be made, such as assuming that the social constraints on time budget (Section 4.1) remain the same immediately after the shock rather than speculating how it might change. We also assume relationships from sports science literature which determine the link between level of physical activity reported in a survey and the pedalling power (Section 4.2). Data sets suggested may be current, but may be out of date - for example census data. We see these as good measures for a first iteration of the indicator but new data sets may make the measurement of the indicator more precise.
6. Responsivity / comparablity	The indicator shows the response that particular interventions would have on the indicator value. A do minimum calculation of the indicator can be made for the current time. Next year if updated data are collected a do minimum calculation could be made. This would give the opportunity to show progress. However not all data sets would be updated annually such as the census. The indicator is spatially responsive: The indicator is comparable between locations.
7. Understandability	The indicator is intended to be straightforward: The output units can be understood by

	non-specialists. The influence diagram goes some way to making the factors modelled understandable to a non-specialist. However this could be made clearer. The functional relationships between variables and the data sources do require more explanation and may be difficult to convey to non-specialists. Trial use with stakeholders will help determine how understandable the indicator is.
8. Cost effectiveness	This first iteration indicator uses existing nationwide secondary data sets. If the indicator were developed further by collecting new primary data it would be more difficult to establish the cost effectiveness of this indicator over the first iteration.

6 CONCLUSIONS

We examine a conceptual approach to the estimation of resilience of transport systems to fuel shocks. The reason for doing so being the finite limits to resources. The importance of considering resilience and particularly adaptive capacity to fuel shocks is explained. Transformation before a shock or adaptive capacity at the point of shock are required to avoid negative consequences (as explained in figure 1). Adaptive capacity would be required to maintain options for sustainable development after a shock. Section 2.2 explains the need for indicators of resilience and the subset we are interested in – adaptive capacity indicators of "small" scale factors (not strategic land-use and urban morphology change) influencing individuals in small geographies. Section 2.3 demonstrates a lack of suitable indicators which justifies the production of a new indicator. Section 3 defined the scope of the indicator and the design of the method to estimate it in section 4. The conceptual framework allows assessment of the impact of policy interventions which could influence adaptive capacity such as health and fitness, bicycle availability and reduction of network barriers as explained in table 4. The indicator illustrates generic issues of sustainability and are not limited to the transport domain. The paper gives an example of indicator design using practices recommended in the literature.

A number of choices were available in developing this conceptual framework. Principal of which was estimating capacity rather than attempting to predict future behaviour. This was driven by the need of indicators to be uncontroversial in the assumptions used in their calculation. The decision to estimate adaptive capacity immediately after a shock avoids the need for controversial assumptions about attitude and behaviour change (or not) resulting from shocks. The choice of model scale was made because the literature points to an absence of indicators of small scale factors influencing individuals at small geographies. As explained above we felt important to give a full explanation of the conceptual framework for this method of estimating the adaptive capacity element of resilience to transport fuel shocks. Because it is a pre-cursor to model development and application as an indicator the next steps in further work are clear.

In the longer term further work may include development of data sets to enhance the model, and evaluation of the usefulness of the indicator amongst policy makers and practitioners. The model might be also usefully expanded to look at the movement of freight by active modes following fuel shocks. The integration of this indicator into suitable indicator frameworks also presents an opportunity for further work.

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