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Review article

Safety accessibility and sustainability: The importance of micro-scale outcomes to an equitable design of transport systems

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ABSTRACT

This paper discusses the potential conflicts that can arise when trying to design a transport system to be sustainable, safe and accessible. The paper considers first the overarching vision that drives such an aim and how that determines choices for design and implementation of such schemes. Using the example of a shared space project, Exhibition Road in London, to illustrate how these issues come to arise and how research could help to resolve them, the paper then considers how science is able to support better design and implementation. This raises questions for scientific methods that could support better consideration of such issues, learning from the small-samples analysis of transport safety research to be amplified to include the detailed research that drives accessible design.

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1. Introduction

In the desire to achieve safe and sustainable outcomes from transport decisions, it is important to ensure that people with restricted mobility are included in the analysis and their needs incorporated in the design of the systems that are implemented as a result. This presents a challenge because sometimes the needs of people with restricted mobility conflict with the design approaches directed to safety or sustainability – and sometimes with both. There is therefore a necessity for a method to consider all three elements together so that transport systems can be truly safe, sustainable and accessible.

This paper considers first the context in which such decisions are made and describes some models that help to frame the questions that need to be addressed by transport decision-makers. It then discusses these in the example of a shared space scheme implemented in London in 2012. This involved exploratory experiments in a laboratory and consideration of conflicts between groups with different outcomes and this has given rise to a reconsideration of the way in which the science used to support transport decisions might be deployed so that such conflicts are highlighted and resolved before implementation.

2. Context

The three terms in the title each has potential for confusion, so it is important to frame the discussion in this paper with a statement about

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what each is taken to mean in the present context. So, for the purposes of this paper:

1. Safety is the ability of society to provide an environment in which risk is acceptable to individuals in pursuance of their desired activities, while ensuring that the risk to any individual does not increase involuntary risk to others. Security is a particular sub-branch of safety: security is the state engendered by society so that people can move freely without risk caused deliberately by the actions of others. In the context of this paper, security is considered within the overall concept of safety.
2. Accessibility is the ability of a person to reach and undertake the activities they desire and need, such that such accessibility is available in an equitable manner to the whole of society.
3. Sustainability is the ability of a society to thrive, given the interactions between the equity it affords its population, the impacts on the environment it causes and the ability of its economy to support the needs of the people into the foreseeable future.

Sustainability, accessibility and safety are thus all issues which are routinely conceived, considered and measured in societal terms, yet are the results of cumulative but quite separate actions performed by individuals. This gives rise to a disconnect between the actions of an individual and the development of societal measures and policy, which are necessarily posed at the macroscopic scale. This disconnect reveals itself in three ways. Policy failure is where policies do not work or are not taken up. Unintended consequences arise where policies are different, or result in different actions, compared with what was intended. Hyper-successful policy describes the situation where a policy is taken up much more strongly than anticipated, with unfortunate results. Sustainability, accessibility and safety can very easily conflict with each other – a clear example in current city planning is that of shared space, where sustainability drivers lead a city to want to introduce a shared space, accessibility brings desires to remove obstacles (some of which are there, notionally at least, to provide a safe environment), and the safe mix of vehicles and pedestrians relies on confidence that drivers and pedestrians come to an understanding on an individual basis about who has precedence in a particular space at a particular time.

Fig. 1 shows how the three drivers come together in a Venn diagram, and indicates that the sweet spot of an accessible, safe and sustainable outcome requires very specific conditions for each driver. Beyond that point, there are compromises – for example, a scheme could be 'safe and accessible', but not necessarily sustainable, or 'safe and sustainable' but not necessarily accessible. As always, the issue is not one where everything can be satisfied, but where compromises need to be made – how to determine how far away from the ideal it is possible to move for a particular scheme. The nub of this paper is how to appraise or evaluate a scheme that is, by its nature, prone to such conflicts of interest, in a way which depicts the situation in an appropriately objective way. This, of itself, is not new. Allsop [1] discussed the issue of how to find the compromises that can be made to mitigate these conflicts, and the OECD produced a comprehensive report [2] on the difficulties of finding and implementing compromises to enhance the safety of vulnerable road users without an attendant change in perception by all parties involved. However, the combined issue of all three factors, in light of newer policy approaches relating to the rights and responsibilities of citizens within an urban context highlights the need for a deeper consideration of the issues.

When considering suboptimal outcomes (i.e. where the outcome means some reduction from optimality in one or more elements), it is crucial to consider how a scheme fits with the overarching vision of the society and city in which it is being implemented. It is this vision that drives the choice of compromises that need to be evaluated and these compromises need to be evaluated as a whole set, not just individually – hence the importance of Fig. 1.

2.1. The Five Cities model

In setting up and evaluating city visions, we have used a technique developed from the analysis of cities that have been through stark transformations [3,4], which we call the 'Five-Cities Model'. This views a city through five lenses and sets the framework for choosing between compromises when making both macro and micro decisions. The vision acts as a 'pull factor' for all decisions to be taken by the city, including the strategy for implementation. The test is to satisfy the five criteria as completely as possible, recognising that there could be imperfect solutions in which all five are not completely satisfied, but that such suboptimal outcomes need to be recognised and dealt with in another way. Fig. 2 shows a conceptual diagram of the five city model, indicating (1) that the primary aim of the city is directed towards the people – usually expressed in a form such as 'improve the quality of life of the people', (2) the five criteria that need to be satisfied in order to be able to achieve that aim. These are deliberately not sectoral, but are based on the achievement of a quality life: a city in which people have mutual respect for each other (the Courteous city), a city in which there are sufficient activities (economic, educational, leisure…) to satisfy the needs of the people and that these must be accessible to all (the Active & Inclusive city), a city which people enjoy and feel that they own – with all the responsibilities that this implies (the Aesthetic and Public city), a city which actively delivers good health (the Healthy city), and a city in which change is designed-in, recognising that the needs of future generations will almost certainly be different from the needs of present generations and that we should be making decisions now that recognise that such change is inevitable and facilitate that change when it occurs (the Evolving city).

Fig. 2 is important, because it shows how the desire to have sustainability, accessibility and safety as key drivers in transport projects helps to drive towards the overall vision. This applies throughout – each of the five cities has calls on this desire, although some might be more prominent in some of these cities than in others. Accessibility, for example, clearly figures in the Active and Inclusive city, but it is also a major player in the Courteous city, the Aesthetic & Public city, the Healthy city and the Evolving city. Safety is a key player in the Aesthetic & Public city and in the delivery of the mutual respect in the Courteous city, but also in reducing both mental and physical health issues in the Healthy City and ensuring that access to the activities is safe in the Active & Inclusive city. Decisions taken now and in the future can deliver safety in the Evolving City. Sustainability clearly has a role to play in the Evolving city, but without economic and other activities available to all in the Active & Inclusive city, and the societal cohesion required for Courteous and Aesthetic & Public cities, sustainability will not be delivered. Sustainability also requires healthy outcomes from the Healthy city to deliver a sustainable future.

Having established the set of priorities emanating from the overarching vision, it is then necessary to establish how sustainability, safety and accessibility can work together within these boundaries to create a satisfactory outcome. As shown in Fig. 1, each has sub-themes – the three pillars of Equity, Economics and Environment in the case of sustainability, Personal and Systemic in the case of safety and the consideration of the Person, the Environment and Activities in the case of accessibility. The least familiar of these are the ones related to accessibility and these will be considered further now.

2.2. The Capabilities Model

The Capabilities Model [5,6] was developed in response to the Social Model of Disability, following the principles of capabilities and functioning outlined by Amartya Sen [7]. For Sen [7], functionings are 'the various things that [a person] manages to do or be in leading a life' and the Capability of a person 'reflects the alternative combinations of functionings the person can achieve, and from which he or she can choose one collection.' Sen [8] explored the relationship between a person's capabilities and their well-being and the point to emphasize here is that there is a

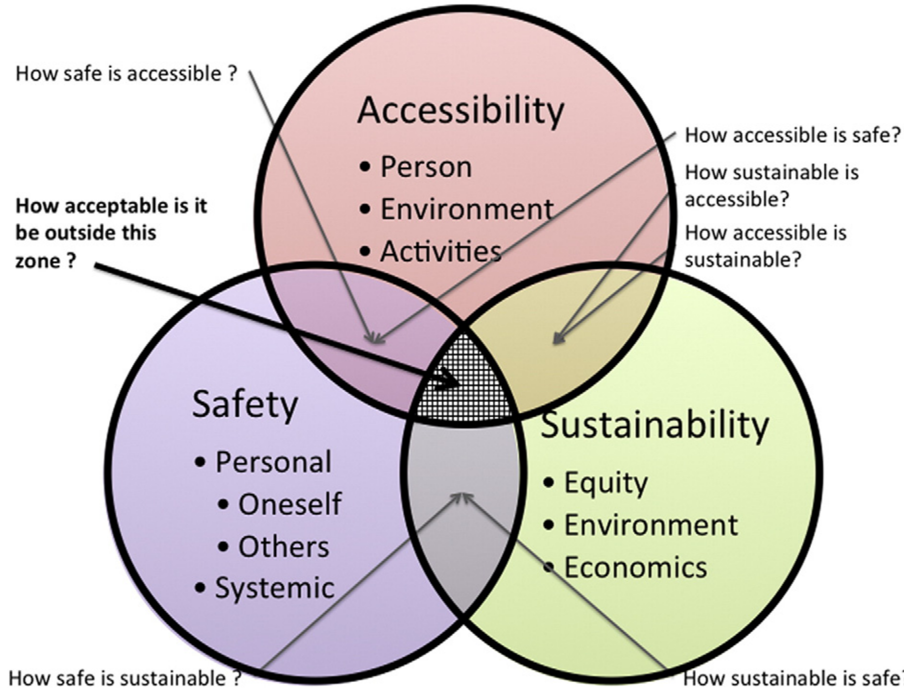

Fig. 1. The relationship between safety, accessibility and sustainability.

distinct relationship between what a person could do and what they choose to do. In the world of infrastructure and transport systems, we defined Capabilities as having two parts: (1) the Capabilities that an infrastructure or systems element requires the person to be able to achieve in order to create the possibility of the functioning, and (2) the Capabilities provided by the person in response to this requirement. Capabilities are required by the environment in order for a person to be able to function in it – for example, a kerb *requires* a person to be able to step up at least the height of the kerb – and the person *provides* capabilities which relate to that environment – in this case the ability to lift the foot more than the height of the kerb. Of course, the relationship between required and provided capabilities must only be resolved in a safe manner. This means that if the only way for the provided capabilities to exceed the required capabilities is for the person to undertake some dangerous act, the test has not been passed. Thus the 'functioning' (what a person manages to do to lead a life) is only possible if the person's Provided Capabilities at least equal the Required Capabilities of the infrastructure/system in a safe and acceptable manner. Fig. 3 illustrates the process.

The key is that if the person lacks sufficient capabilities, the end objective – undertaking a desired activity – is impossible in that environment. The importance for this paper is that the objective is to

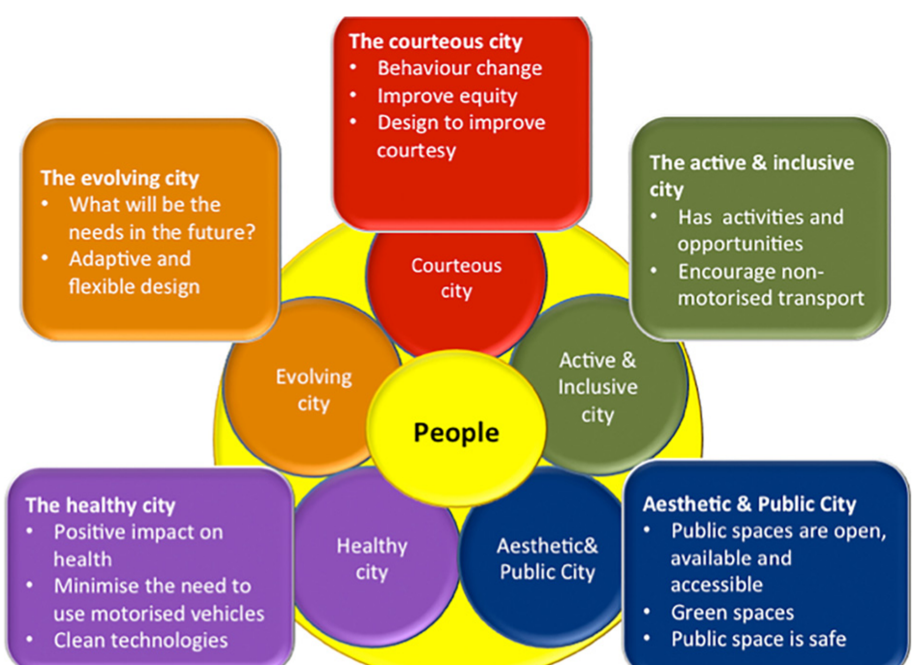

Fig. 2. The Five Cities model.

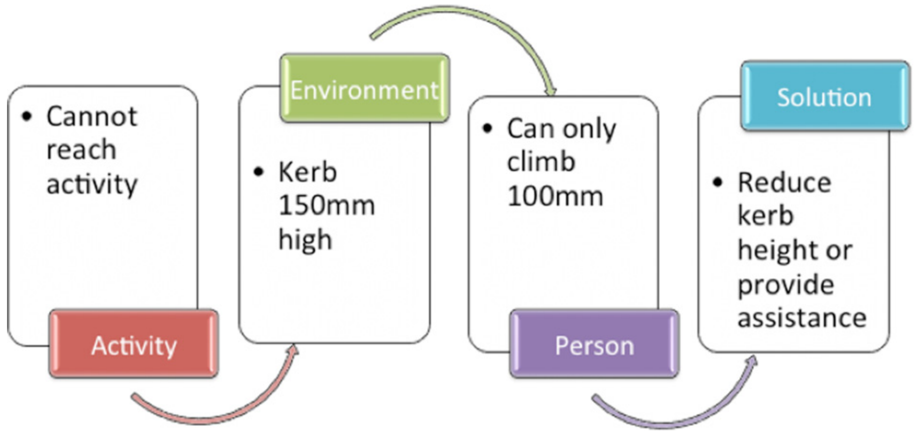

Fig. 3. The Capabilities Model.

undertake the activity, not just to mount the kerb, and so the failure of the provided capabilities to meet the required capabilities of the environment makes the activity impossible. This limits the potential ability of improving the person's quality of life. Therefore this 'systems failure' places a barrier to the overarching aim of improving the quality of life of the people. The barrier can, of course, be overcome – by altering either the required or the provided capabilities – in order to make the activity reachable. This could be achieved by altering the environment – for example, reduction in the kerb height or improved lighting – or enabling the person to overcome the obstacle – for example, the provision of a suitable walking aid.

Provided Capabilities are highly individual. They relate to that person in *that* place at *that* time in *those* circumstances. It is to understand the significance of this point that the Pedestrian Accessibility & Movement Environment Laboratory (PAMELA) was set up, in order to find out what exactly causes an obstacle to be an obstacle for individual people, and thus what might be done to eliminate or at least to mitigate it, so that they can reach their chosen activity (http://www.cege.ucl.ac.uk/arg/pamela). This requires detailed data collection and analysis in an environment that is sufficiently realistic to represent "that place" and "those circumstances" that the individual person can experience them under controlled conditions so that we can analyse where and when the problem occurs – and, importantly, when it does not.

As indicated in Fig. 1, we are looking for urban design in which accessibility, safety and sustainability can all be tackled, where the three 'pillars' of sustainability – equity, economics and environment – can be served, and the capabilities satisfied in a way that is safe for both the individual and society. We have to address the issue of conflicts – where do safety and accessibility conflict for example – and how we resolve these. The final contextual model to bring into this question is that of equity – the solution needs not only to be sustainable, accessible and safe, but it must also be fair.

2.3. The Difference Principle

Tyler [9] shows that a useful approach to the study of fairness was developed by John Rawls [10], and is his concept of the Difference Principle. To understand the Difference Principle, consider two groups of people, X1 and X2. This change in expectation of benefits is shown graphically in Fig. 4, where the equal (and increasing) change in the expectation of benefits is also shown for comparison. Fig. 4 shows Rawls's example of increasing the wealth of Group X1. In our case, we can use the same approach to consider a transport-related decision. We intend to implement a decision – for example, to close junctions along an avenue – to reduce delays to through traffic. This decision will have impacts on both X1 and X2 (for example, X1 could be users of the avenue and X2 could be people living away from the avenue but needing to access it through these junctions). What the Difference Principle proposes is that, in order to be fair, the expectation of benefits to X2 must at least not be worse than they were before the implementation of the decision. So the expectation of benefits to X1 increases after the decision – e.g. reduced delay – and although to start with X2 could expect increased benefits, as, for example, the first junction closure reduces through traffic in their residential area, this soon reduces and eventually the expectation becomes less than it was before the decision, as the closure of junctions makes it become increasingly difficult – and then impossible – to access the avenue.

The Difference Principle is very important when considering the sustainability-safety-accessibility issue, because it allows us to check the extent to which the difference obtained when a decision results in an inequality – for example, where a decision made to benefit safety makes the street inaccessible to some people in the community. The question then becomes one of comparing the difference in expectations and determining how to establish fairness. This dilemma can be seen in Fig. 5, where the differences are highlighted. The fair resolution to this problem has to be driven by the achievement of the activities resulting from an equitable and fair (Rawls would say 'just') resolution of the provided and required capabilities in the context of the achievement of a safe, sustainable and accessible outcome and all in the context of the overarching aim.

Considering both macro- and micro-scale issues in determining the appropriateness of an intervention in the transport system is a challenge that has to be faced, not only in the design and implementation, but also in the analysis, both before and after the implementation.

In order to resolve the disconnect between macro policy desires and micro responses, it is a good idea to look at the science which drives the individual's responses to stimuli – whether these emerge from policy impetus (such as price) or physical/sensorial sources. This becomes an important issue where the separate strands of sustainability, accessibility and safety come together, for example in the issue of the promotion of active travel and shared space, in relation to the development of autonomous vehicles. This can also raise questions about the methods by which schemes are appraised or evaluated. When using methods that produce some form of summary statistic, great care has to be taken to ensure that the summary is able to capture both the overall outcome seen from the perspective of an interested observer, and the individual outcome seen from the perspective of the individual people involved, whether this involvement is active or passive. This is very difficult because there is no defined end point. Nothing is perfectly and unambiguously safe or accessible or fair. They might be as close to the ideal as can be managed now, in a given place and under current circumstances, but even the improvement they offer could simply reveal another desire. For example, a new accessible bus service could reveal the existence of a new activity that was unknown before. Any one of these can change in the future, and it is more than possible that an individual can live longer than these conditions pertain, so change is highly desirable. Progress often yields simply yet another challenge to be faced and resolved.

Fig. 4. Rawls's Difference Principle.

3. Micro-scale outcomes from experiments under controlled conditions

To explore this topic in more detail, an example is used to illustrate how individual and general issues combine to create potential challenges in the implementation of transport projects which aim to make the world safer, more accessible and more sustainable.

3.1. Exhibition Road, London

Childs et al. [11] discusses some experiments that were conducted for Transport for London in relation to the (then) proposed scheme to make Exhibition Road into a shared space [12]. Exhibition Road is a major south-north corridor in London, about 1.2 km long, and leads directly to one of three roads which cross the 'barrier' of Hyde Park/Kensington Gardens, the other two being Kensington Church Street, which is narrow, bendy and low capacity, and Park Lane, which was a dual carriageway wide and highly congested. Exhibition Road, lying to the south of the parks, provides access to the central route between the two parks and is thus a fairly busy traffic corridor. It is also the street on which a number of museums are located and so has a high pedestrian flow. [12] shows traffic counts in the shared space scheme ranging from 13 to 15,000 vehicles per day, nearly 10,000 pedestrian movements and 1000 pedestrian crossing movements per day, including many school students visiting the museums. This is therefore not a typical shared space scheme – it is much longer than most and carries more traffic than would normally be considered for such a scheme.

The proposed design for the scheme was to create a pleasant environment for people in the street by eliminating kerbs and vertical infrastructure and removing the overt separation between traffic and pedestrians. The issue brought to the attention of the local authority was that visually-impaired people would find it very difficult to have confidence in the safety of the street, as they would not know where the traffic would be. Researchers in the PAMELA facility were asked to test possible methods for differentiating zones where traffic might be and zones where traffic would not be present, where these methods did not involve a vertical obstruction to the vista of an open space. Accordingly 24 different designs of tactile paving were installed in the laboratory and tested by two groups of people: visually-impaired people and mobility-impaired people. The laboratory was set up with a set of delineators arranged so

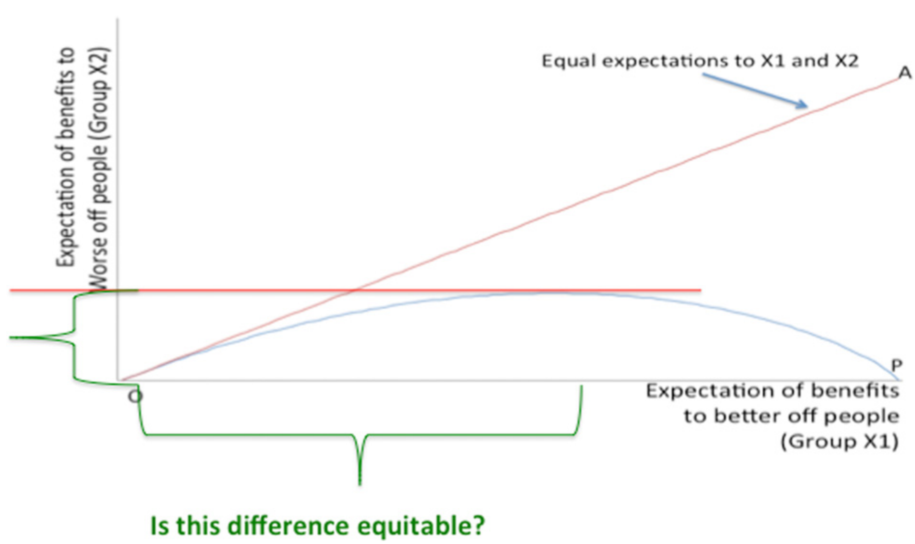

Fig. 5. Differences in expectations of benefits that follow a decision.

that participants could approach them at right angles or at an angle, and they were instructed to stop when they believed they had detected the change in surface. The results of these experiments are reported in detail in [11]. None of the 24 delineators worked very well and some were very poor. More interestingly, it was generally true that delineators that worked for visually-impaired people were problematic for mobility-impaired people and vice versa. There was no surface that performed well for both groups. The research suggested some further experiments to help with the decision, including testing the performance of the more satisfactory delineators on-street in a less-controlled environment than the laboratory, but this was not taken up.

The scheme was implemented with corduroy paving (which was one of the better performers in the laboratory tests) used to distinguish between the part of the street where traffic was encouraged to pass and the rest of the street. Corduroy paving was both reasonably well detected by the visually-impaired group and reasonably possible to cross by the mobility-impaired group – but some members of each group failed the detection/mobility test, so it is not a fully successful solution. Corduroy paving is one of the UK's standard tactile surfaces [13], but this application is not typical. Normally corduroy paving is set at the top and bottom of a stairway to alert visually-impaired people of the presence of the stairs. In Exhibition Road, it is laid along the whole length of the street, thus can be approached at any angle. In fact Exhibition Road is not really a 'shared space' as such – the traffic largely stays in one part of the street and pedestrians in the other, with some incursion for parking, and thus some vehicle movement, in the 'pedestrian' part of the street. Anecdotally, mobility-impaired people seem to keep firmly to the 'pedestrian' part of the space, well away from the traffic, and there is a feeling that visually-impaired people stay away.

The Exhibition Road scheme was put in place as part of an environmental improvement, to reduce the presence of traffic in the area, to make it more pleasant for people and to provide a safe space. It is an example of a project aiming to create a sustainable, accessible and safe space. Has it done so? Undoubtedly a large number of people use the space and pedestrians enjoy the freedom to wander in most of the available space, keeping clear of the traffic lanes. Traffic seems to move reasonably freely – [12] reports some quite high speeds – up to around 27 mph (45 km/h) during the day, which suggests that there is little, if any, pedestrian incursion of the traffic lanes, even with high pedestrian flows and crossing movements. In sustainability terms then, the delay to traffic has not been increased, and the reduction in queuing means that pollution should be less than it would be with continual stationary traffic. In safety terms, segregation has been sufficient to keep pedestrians and traffic apart.

There have been collisions involving pedestrians and traffic. Fig. 6 and Table 1 show respectively that collisions and casualties have been in decline since 2006, especially since 2012, when the scheme was implemented. In accessibility terms, accessibility has been achieved for most of the population, both pedestrians and vehicle occupants. However, whether it has worked well for people with mobility problems is much more in doubt and further research is needed to establish who is – and, importantly, who is not – using the space. That this involves researching people who do not do something, rather than counting those who do, raises a real analytical problem: it is impossible to prove a negative, yet somehow we have to identify people who would have used the space under different conditions, but who do not us it in its present form. This is a hard sample to find.

4. Stimuli and responses in shared space environments

4.1. General issues

We could look at other ways to establish what is happening, by looking at the neurology of interactions, driven by the way a person sees and perceives objects in an environment. Safety in shared space is based on the idea that by obtaining eye contact with the driver, a pedestrian communicates their intention to move in a certain direction, such as entering the path of the car, and the driver responds by slowing down and becoming prepared for the style of movement of pedestrians – which is less predictable than that of vehicles. The pedestrian's difficulty in obtaining eye contact is well-known, especially when the vehicle windscreen is compromised by awkward lighting, reflections and so on, and it is really left to the driver to determine contact with the pedestrian. The driver has many other objects potentially requiring attention, but it is easier to see out from within a car than it is to see into a car from the outside. Whether a mutual eye-contact is obtained, where each acknowledges the other, is less clear. There is quite a risk that the driver and pedestrian do not 'make eye contact' with each other – so that the chance of stimulating a response in either person is not guaranteed.

It takes a determined time for a visual stimulus to achieve a neuronal response – around 250–300 milliseconds and a few (about 10) milliseconds to stimulate a neuronal reaction. This means that a person is seeing as if the world is there 'now', but actually this is a pre-conscious prediction made on the basis of how it was when the last 'data' was received a quarter of a second before. An incorrect prediction could easily place a pedestrian in the path of a car (a quarter of a second is sufficient to commit to a footstep in a certain direction) and the car could move nearly 2.4 m in that time (if travelling at 20 mph (33 km/h)). For visually-impaired people, who would find visual stimuli and eye contact difficult, and sometimes impossible, they must rely on other sensorial stimuli, such as hearing and touch to drive their response. The neurological response will be similar for these senses, perhaps longer for touch, but the driver might well be unaware that the person is visually-impaired and will be basing their predictions on the presumption that the pedestrian can see them. So these predictions are based on an assumption that the 'other' person has a full range of capabilities. Any correction would have to be made in the conscious mind, which is much slower and would cause further delay in actual motion response (e.g. to apply the brakes or sound the horn).

Shared space is a compromise between a fully pedestrian space and one with traffic segregated from people. The only way this can be achieved safely is to slow the traffic down to an extent where it is easier to respond to pedestrian movement and if a collision were to occur, the level of injury would be slight. At such speeds, the vehicles run more quietly, with neither motor nor tyres creating disturbing noise, so the aural stimulus of the presence of a vehicle is reduced. There is concern about electric vehicles in these environments for this reason, but actually the noise levels from modern vehicles are really quite low at these speeds. In most shared space schemes the speeds are reduced so ambient noise is lower (around 50 dBA rather than around 70 dBA) and the traffic is slow. Some drivers find alternative routes that are less frustrating or slow, so the traffic volume falls and speed is reduced towards a pedestrian level. Exhibition Road is unusual because the traffic is in no way achieving anything like a pedestrian pace, yet the normal means of separating traffic and pedestrians have been removed. The reducing trend shown in Fig. 6 suggests that care is being taken by both drivers and pedestrians to ensure that collisions do not happen, so it could be said to be working. What is not so clear is whether it is being accessible.

4.2. Autonomous vehicles

Into this stimulus-response challenge rolls the autonomous vehicle. In this case there will be no possibility of 'making eye contact' and the role of the driver in the interaction will be taken over by the computer systems on the vehicle. The question will be whether the vehicle will be able to interpret the detectable signals emanating from the pedestrian. Humans can detect an amazing array of signals from other people – even through a car windscreen (if they can see the person on the other side). The sensors in autonomous vehicles will be able to detect the presence of a person (or at least an object) near the vehicle, but would be much less likely to be able to infer 'intent'. The vehicle would need to play safe and be prepared to stop, if collisions are to be avoided. This

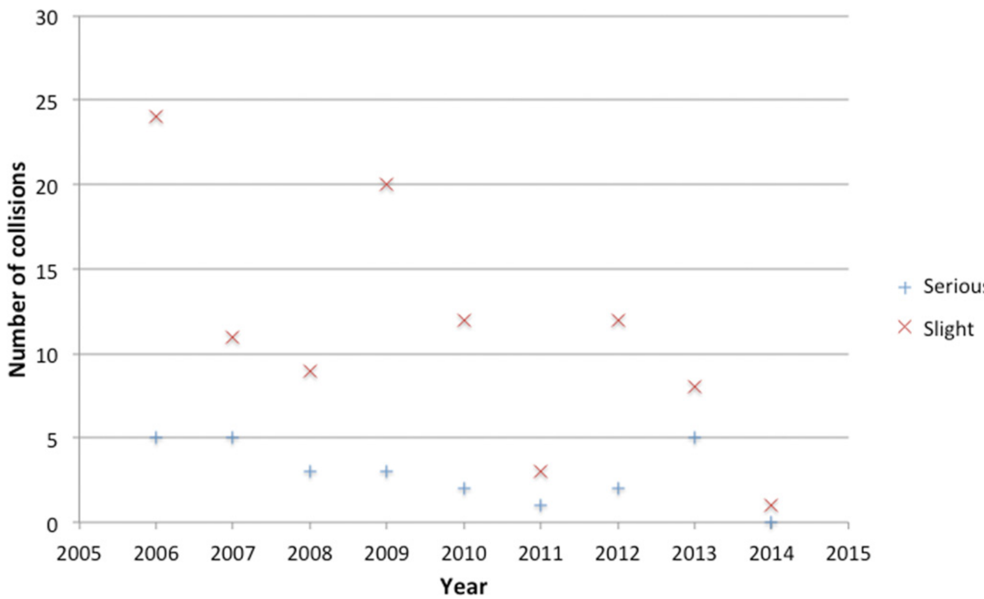

Fig. 6. Collisions in Exhibition Road 2006–2014 [14].

could result in many non-useful stops by the vehicle, but relaxing from the 'stop if unsure' model could result in too many collisions. There needs to be a much better understanding of how to detect intent in order to incorporate that in the control algorithms.

To achieve accessibility in this environment, then, the design of the shared space needs to enable the pre-conscious predictions to be as good as possible, while permitting full accessibility and maintaining sustainability. This means studying them in detail. However, until now, this has been difficult because such study has rested in the domain of the medical research laboratory. In these facilities, the emphasis is on detecting and understanding disease and developing treatments. The conditions are highly controlled, sometimes sterile, and often removed from any external intrusion of unwanted light or noise (or vibration in some cases). These conditions are so removed from the reality of walking in Exhibition Road that, important though they are, they are of limited help for this problem. The PAMELA facility, however, is well-placed to undertake studies of this nature in an environment which is controlled in terms of physical appearance and feel, noise and lighting, but which can yet appear like a real environment, such as a street, railway station, airport or building interior. This enables us to see how people respond to elements of the urban infrastructure and changes in stimuli. Because it can deal with multiple stimuli under these conditions, it is possible to carry out multisensorial research and to see how, for example, different lighting makes it easier or harder to detect a change in the surface of the footway, how resilient such detection might be under other conditions, such as a loud noise, and so on. It is also possible to explore how people with particular capabilities manage in different environments. The facility uses a combination of engineers, architects, psychologists, ophthalmologists, audiologists, and neurologists to learn about this world of sensorial interaction between people and the environment and it seems to be increasingly important to have this understanding in order to achieve the desired level of safety, accessibility and sustainability in the future.

As with safety, accessibility design requires careful attention to be paid to the micro-scale design elements. A few millimetres here or an angle there can make all the difference to the outcome. Our analytical methods need to pay attention to how and why such small differences have such large effects. This is why the detailed work in facilities such as PAMELA is so important.

5. Conclusions

The application of the Rawls Difference Principle to the Exhibition Road example is an interesting case. An expectation of general enjoyment of greater pedestrian space for one group comes at the price of a limited

Table 1
Exhibition Road - all casualties by mode of travel & severity 2006–2014 [14].

Exhibition Road - all casualties by mode of travel & severity - 01 January 2006 to 31 March 2014 (provisional)											
Casualty severity	Mode of travel	No. of casualties									
		2006	2007	2008	2009	2010	2011	2012	2013	2014	Sum
2 Serious	1 Pedestrian	0	2	2	1	0	0	2	2	0	9
	2 Pedal cycle	1	0	0	0	0	0	0	1	0	2
	3 Powered 2 wheeler	2	3	1	1	2	1	0	2	0	12
	4 Car	1	0	0	1	0	0	0	0	0	2
	5 Taxi	1	0	0	0	0	0	0	0	0	1
	Sum (serious)	5	5	3	3	2	1	2	5	0	26
3 Slight	1 Pedestrian	3	1	2	3	3	1	3	2	1	19
	2 Pedal cycle	4	5	1	5	4	1	4	2	0	26
	3 Powered 2 wheeler	7	5	2	4	6	1	2	3	0	30
	4 Car	9	1	12	9	2	0	1	4	0	38
	5 Taxi	2	0	1	1	0	0	1	0	0	5
	6 Bus or coach	1	2	1	2	0	0	1	0	0	7
	7 Goods vehicle	2	0	0	0	0	0	0	0	0	2
	Sum (slight)	28	14	19	24	15	3	12	11	1	127
Sum (slight and serious)		33	19	22	27	17	4	14	16	1	153

expectation of these benefits for another group. Did the tactile paving solution improve this situation? One outcome from the laboratory experiments was that there was a definite difference between the responses of visually-impaired people and mobility-impaired people – both of whom would be within the group of people with a smaller expectation of benefits (see Fig. 5). This suggests that even within this group, there is not only an accessibility issue, but also a challenge to the equity of the scheme – which would strike at one of the three pillars of sustainability. How would equity be delivered? The first response is to recall that in the Capabilities Model, the primary objective is to undertake an activity – such as visiting the museums. Is access achievable to the museums on Exhibition Road in the shared space scheme? Well, if the person could arrive in a car or by the accessible bus that operates on Exhibition Road, then they could reach the museums, as they could park in the shared space near to the museums and there is a bus stop nearby – although if arriving on a bus, they would have to cross the traffic stream in order to reach some of the museums, which might present a problem. But this limits the access to those who have access to either a car or a bus (or who could navigate along the shared space). The sense, noted above, that some people are not going to Exhibition Road because they feel uncomfortable there, suggests that for these people, the museums are no longer reachable and their ability to enjoy them is thus depleted. This is why it is important to establish the extent to which this occurs – in order to establish whether the delivery of equity is actually achieved by the scheme. The introduction of autonomous vehicles will add a further challenge for this analysis.

Studying the individual responses to environmental stimuli is important because it informs the Capabilities Model about what the thresholds are and the extent to which people can find ways to cope or not with difficulties. It is these thresholds that determine the design limits for accessible infrastructure. Understanding how people cope near to the thresholds is crucial and we know, for example that the body has considerable systems to enable a person to cope. [15] showed that older people's gait changed as soon as their eye fixated for the first time on a raised step in their path. A similar response was found by [16], where people moving inside a moving bus changed their gait in order to improve support when the bus was accelerating. Both of these examples exhibit pre-conscious changes as a response to a stimulus. A study by Wang [17] showed that there was a strong possibility that people would misinterpret the unevenness of a footway and that under certain lighting conditions, this possibility increased substantially. In all three cases, it is clear that the interface between the environmental stimulus and the way a human being responds to it is not well understood.

The physiological and neurological responses are normally examined in order to determine problems or disease in the associated senses, but not the relationship to the stimuli to which they have to respond beyond the clinical environment. This also means that much of the research undertaken hitherto has been directed towards people with diseases or other conditions which affect their performance – the research undertaken in PAMELA has also involved people with no such disease or condition. Also, the way in which the medical research has been conducted has influenced the ability to apply it to the real environment. Ophthalmologists tend to test the outcome of their therapies through eye tests before and after the treatment. Bainbridge et al. [18,19] used PAMELA to test a gene replacement therapy in a simulated conceptualised street environment, to determine if the therapy was sufficient to enable an improvement in quality of life. Wang's study [17] was novel because it looked at the detection of rough surfaces, not in a computer screen simulation, but with real surfaces located on the footway surface, horizontally, from the eye-level of a pedestrian, under controlled conditions. So the science has had to adapt to the challenge of understanding capabilities (both required and provided) and the means of analysis needs to adapt as well. How can we decide on the equitable thresholds which deliver a difference in accessibility, a safe and a sustainable outcome, when the samples involved in examining these thresholds are necessarily small and particular?

The imminent arrival of autonomous vehicles is hugely important in shared space. The concept of 'making eye-contact' which drives the principle behind shared space has problems when examined at a neurological level. Is it enough that the driver makes contact with the pedestrian but the opposite is less successful? The driver's response might be to slow down – which is a good thing – but the lack of two-way contact is still an issue in terms of the feeling of safety, even if the fact of safety might have been resolved. Autonomous vehicles are very unlikely to be equipped with sensors which are sufficient to detect or deliver eye-contact with pedestrians. The interaction will therefore only be conducted on the basis of the detection of physical movement. Unfortunately the physical movements that indicate understanding of interpersonal understanding are tiny and often quite late in the stimulus-detection-response process. The challenge for autonomous vehicle manufacturers and operators will be how to deliver the confidence that it is safe to interact with them in shared space.

Safety research over the past few decades has developed rigorous methods of analysis to explore the meaning underlying rare events and to determine the significance of these for subsequent design of safe transport systems. The enormous reduction in traffic accidents and related injuries and deaths over this period bears witness to the success of this approach. In order to incorporate accessibility into this work, it will be necessary to include considerations of the accessibility thresholds in the analysis and subsequent design. This also means the exploration of evidence from small data samples and the consideration of how these might justifiably affect design, implementation and operational decisions. The main difference between the safety issue and the accessibility one is that safety failure can result in death or debilitating injury, whereas accessibility failure can result in a loss of equity. Even where death is not involved, both can have lasting effects on the individual, but both also reflect on the societal view of what is a 'good' society. A society that designs-in (whether explicitly or by failing to act) death and injury is often perceived to be an uncaring or poor quality society. The desire to curate a society in which quality of life is enhanced drives decisions from the macroscopic level of policy through to the micro scale of the detailed design of tactile paving and this connection needs to be explicit in the science and analysis that drives design, implementation and operation of transport systems. A society that designs in a way that means (whether explicitly or by failing to act) that some members of society are excluded from accessing their chosen activities is also an unfair, incomplete and poor quality society. An outcome that is not safe and accessible is not sustainable, not least because why would society want to sustain such an inequitable outcome? This is a question that should touch us all.

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