

Chapter 6

Network planning and infrastructure design

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Abstract

Purpose: The chapter reviews planning and design approaches for cycle traffic in order to direct future thinking towards the critical aspects of network design that will have a beneficial impact on the utility and nature of the environment for cycling.

Approach: The chapter provides a critique of the approach of adopting a so called hierarchy of solutions frequently adopted in western countries with low levels of cycling use.

Findings: The guiding principle for designing routes for cycle traffic is that the bicycle is a vehicle capable of speed and, as a consequence, links and junctions need to be designed according to appropriate geometric design standards. In addition, owing to the nature of the cycle and rider combination, the oft repeated Dutch characteristics for good design for cycle traffic of coherence, directness, attractiveness, safety and comfort remain firm.

Practical implications: The practical implications of the outcomes from the chapter are a method of approach for planning infrastructure for cycle traffic which starts with an analysis of demand and works through to the creation of suitable networks for cycle traffic which are grounded in, and extended from, suitably regulated existing highway networks.

Social implications: An extensive transport system suitable in nature for cycle traffic will attract a wide base of users and consequently allow for the benefits of cycling to be captured.

Value of chapter: The value of the chapter rests in its emphasis on the need to treat cycling as a distinct transport mode and, consequentially, planning and engineering needs to be undertaken in a way conducive to providing the basic necessary infrastructure for such a distinct mode.

Keywords

Cycling, cycling infrastructure, traffic engineering, traffic management, risk, spatial planning, demand modelling

Introduction

Cycling is wonderfully liberating and enervating in the right environment: it is difficult and unpleasant if the environment is not suitable. Programmes of activity to promote the values and benefits of cycling encompass elements of what are sometimes called the four 'Es': engineering; education, enforcement and encouragement. While such a range of interventions, perhaps particularly with a strong emphasis on cycling skills training, may assist in promoting cycling, it is not easy to achieve significant uptake in cycle use without the development of a physical environment right and proper for the particular characteristics of cycle users.

The appropriate balance between promotional activities and infrastructure provision to maximise levels of cycling, however, remains elusive. For example, in a review of evidence from the UK Cycling Demonstration Towns project, it has only been possible to conclude that the sustained investment had an effect, and it has not been possible to determine more closely defined effects from specific interventions (Sloman et al., 2009). A longer historical view (see Chapter 2) suggests an interesting interweaving of infrastructure provision and cultural development of cycling. What remains clear, however, is that the planning, design and construction of any route that cycle traffic is expected to use must be directed towards making the route fit for its purpose.

Strategies for promoting infrastructure for cycling have sometimes only considered the specification of engineering upgrades to particular localised areas or supposed problematic features of the existing road network. However, a strategy that is more likely to succeed will

consider a whole settlement or a whole network, and such a strategy, as with the construction of motorway networks in many western countries, for example, may take decades to complete successfully.

Although not the focus of this chapter, it is worth discussing the nature of cycle users and the range of non-infrastructure interventions that are available. Road users in charge of motorised vehicles are adult or near adult, have usually had to pass a test after having been trained, and may be subject to health checks to avoid them driving after the onset of dotage. By contrast, cycle users exist from an age after which they can balance on two wheels, which typically may be four years old. The health benefits of cycling allow for a user to continue cycling, if he or she so wishes, easily into a tenth decade. Training of cycle users, where it exists and where it is taken up, is typically less rigorous than that for motorised vehicle users, and in any event not compulsory. A cycle user provides the motive power and the distribution of speed of cycle users ranges from the lowest speed possible to retain balance (around 12 km/h to avoid significant lateral movement, CROW, 2006) to speeds exceeding 40 km/h for fast commuters (Parkin and Rotheram, 2010). The kinematic envelope of a moving bicycle and rider combination is typically taken as 1.0 metre (DfT, 2008) and the rider's body is exposed to the environment through which he or she is passing. Overall, cycle users are heterogeneous in terms of their physical characteristics, have a wide range of cognitive abilities and are, owing to their relative exposure, vulnerable in hostile environments.

Non-infrastructure interventions used by those promoting cycling in countries with low cycle use relate to the enhancement of an individual's knowledge and skill (for example cycle training, provision of information through maps and signs), and behaviour (for example relating to safety, road sharing and road traffic violations including enforcement), and also extend to celebration of cycling (for example through rides and festivals, marketing and promotion including tourism promotion). In addition, other actions relating to good planning and governance have also been used including the monitoring of use and opinion, the establishment of reference groups of cycle users, and professional training in provision for cycling. Necessary infrastructure developments that are not intrinsically part of the transport network include the provision of high quality cycle parking and the development of appropriate carriage and integration arrangements with public transport.

There has been an increase in the amount of guidance published by and for road authorities relating to infrastructure design for cycle traffic and Parkin (2010) provides an evaluative review on the most prominent of these. The review discusses levels of service for cycle networks and particularly considers the issue of the effort of the rider, and includes a discussion on design speed. We take the opportunity here to extend the discussion to consider issues surrounding the contention that exists between protagonists of on-road provision and off-road provision (the integrationists and segregationists introduced by the authors of Chapters 2, 4 and 5). To do this we use a framework based on an analysis of risk. Finally, and importantly, we critically assess the currently promulgated so called 'hierarchy of provision', which purports to guide planners and designers to specific types of action in an ordered way. We propose a distinctive new approach for planning the creation of any physical infrastructure needed to promote cycling based on an appropriate analysis of the needs of cycle traffic. We conclude the chapter with some rumination on the path to sustainability for transport through infrastructure provision for cycling.

Principles for Design

On the basis that the approach for designing routes for moving vehicles is well established in design manuals for highways, and is based around a design speed, it should be clear that the guiding principle for design for cycle traffic ought also to be that the bicycle is a vehicle capable of speed. For routes designed as transport corridors only for bicycle traffic, designers need to ensure that they apply appropriate principles of highway and traffic engineering in a similar way as they would apply those principles for motor traffic. Geometric features of the route alignment need to be designed according to the selected design speed, and these include curve radii in the vertical and horizontal planes, sight distances required for stopping and overtaking, and lengths of tapers for lateral movements within the route.

In addition to the engineering essentials of highway and traffic engineering, however, the designer needs to be aware of the special characteristics of the bicycle and rider, which in turn influence the design characteristics appropriate for cycling infrastructure. These are suitably defined by the Dutch (CROW, 2006) as being coherence, directness, attractiveness, safety and comfort. These guiding characteristics have been adopted by authors of guidance across the globe in varying forms. While also being important for all types of transport network, there is significant added weight placed on many of these attributes for the reason that the rider is very much part of the embodiment of the bicycle as a vehicle. Directness is more important than for other types of transport because of the added personal cost of effort, and perceived safety is paramount because of potential feelings of vulnerability when passing through certain types of environment. Relative to more sedentary forms of travel, comfort will already be compromised because of the nature of the vehicle and the balance required riding it, and so issues such as surface roughness become even more important.

There has been room for a significant amount of opinion amongst traffic engineering professionals and advocates around the specific 'working out' of traffic engineering relating to the bicycle. Some contrasting approaches include: provision of on-road cycle lanes; provision of segregated cycle paths in the road corridor, usually behind the kerb line; provision of cycle paths completely away from road corridors, e.g. through parks or utility corridors. 'Bicycle boulevards' and 'neighbourhood greenways' have been popular in North America, and the Dutch pioneered the 'woonerf' shared space concept in residential areas. More globally there are contentions about whether 'providing for cycling' is the same as 'providing cycle facilities', with lower speed limits and/or lower traffic volumes often being sufficient to create a cycle-friendly environment. Forester (2001) provides an exposition of the argument that there is little by way of provision that ought to be made for cycle traffic as distinct from other types of vehicle, although this relies on riders undertaking fast and sometimes necessarily assertive 'vehicular cycling' in relatively hostile environments in order then safely to co-exist with other road users.

These different viewpoints often arise because of the different perspective of the protagonist, who may either assume that a person cycling always wants to achieve the highest speeds possible and is comfortable mixing with motor traffic, or that cycle users are 'afraid' of traffic and wish to avoid motor traffic at all costs (for a fuller discussion of the role of the informed citizen as a protagonist, see Chapter 4). For authorities trying to provide for the widest cross-section of existing and potential cycle users, it can seem difficult to reconcile these conflicting viewpoints. In particular, much of the concern can often centre on the perceived quality and level of service that would be afforded by the alternative options of 'on-road' cycling and 'off-road' cycling. We argue that this dichotomy is false so long as designers adhere to the engineering principles of route design and the five Dutch characteristics for cycle networks. Clearly, a lot of the contention has been linked with the extremely poor consideration given to cycle traffic in some developed countries to date, and this can be associated with poor knowledge amongst traffic engineers of the characteristics of cycle traffic, comprising as it does of vehicles travelling at speed (see Warrington Cycle Campaign, 2007 for some cringingly poor manifestations of 'design' for cycle traffic). Critical issues for design are: a smooth bound surface; suitable geometry for the design speed; suitable speed management of all traffic; suitably constrained gradients; adequate width; properly designed crossings and transitions from on-road to off-road; full and proper route maintenance.

For reasons connected with a well developed sense of urban design, and for reasons connected more with a desire to manage traffic appropriately, many urban areas have central zones that have had vehicle traffic excluded, i.e. they have been 'pedestrianised'. Allowing cycle use to penetrate into areas designed more specifically with pedestrians in mind (street malls, squares and so on) has been a contentious issue in some countries, but is relatively common in many parts of Northern Europe.

Insert Figure 1 here
Bicycle street in an otherwise pedestrianised area in Munich

Frequently, the effect of prohibiting cycling in pedestrian areas is to 'force' cycle users onto longer, busier traffic routes, designed specifically for motor traffic management purposes.

Davies et al. (1998) confirmed this by finding that many alternative routes involved high capacity roads, additional hazardous junctions, additional distance and the majority required cyclists to dismount at some stage. In many cases, there is adequate capacity in motor-free areas to safely cater for all non-motorised users. Trevelyan and Morgan (1993) analysed video and questionnaire responses from sites in England and Wales and examined conditions in other countries and found that people cycling respond to pedestrian density and modify their speed, dismount, and take other avoiding actions where necessary. Collisions between pedestrians and cyclists were very rarely generated in the areas studied; in fact only one pedestrian/cyclist collision was noted in fifteen site-years. This is supported by similar findings from German surveys with initial public reservations being significantly reduced after a year's experience, and evidence of the adaptation of cycling behaviour, including dismounting, when high densities of pedestrians were present (CROW 1993). There was no evidence that cyclists rode more quickly once legally allowed in pedestrian areas, and pedestrian-cyclist collisions were small in number and not too serious.

Overall, routes for cycle traffic without the presence of motor traffic can be advantageous where such routes allow for access much closer to the final destination, where they allow for a more direct route to be taken, and where they are designed to be attractive and comfortable for cycling use. However, the network offered for use by cycle traffic should be fit for purpose based on guiding characteristics of coherence, directness, attractiveness, safety and comfort.

Before outlining an approach for developing networks suitable for cycle traffic, we review an area of discussion that arises frequently when considering cycle use, the question of risk to users.

The question of risk

Movement and risk are inextricably linked, and this linkage results from the high probability of collisions between moving objects in close proximity and the physics of momentum transfer and force created in collisions. Clearly, where human and animal life is involved in such collisions, the issue of risk becomes an ethical one, and of great significance to society as a whole. Road safety engineering has approached the subject by analysing data to assess and develop engineering interventions to assist in reducing the incidence and severity of collisions. Enforcement of appropriate behaviour plays a role (for example, the enforcement of speed limits), but more recently added to the armoury of road safety practitioners are encouragement (of a safety culture whereby individuals accept responsibility for their own and others safety) and education (through training and publicity) (ROSPA, 2003).

A network of roads and road users forms a system for movement, and the premise underlying interactions between users is that they 'drive on sight'. There is a distinction between the objective 'visibility' of a vehicle (for example car, or bicycle and rider) and the ability, for whatever reason, of road users to appropriately perceive other moving objects or people in the road. In countries with relatively low cycle use, like the United Kingdom and New Zealand, cultural emphasis has been placed on the responsibility of the person cycling to be 'visible', which simultaneously and implicitly reduces the perceived need of other road users to properly use their senses to 'perceive' the other vehicle or person. To some extent, a rebalancing has been recently attempted by Transport for London in a series of advertisements that suggest to the general public and road users in particular that 'the more you look for something, the more obvious it becomes'. Cycle users generally take up less road space, although they are frequently taller than most private motor vehicles. On the basis of their relatively smaller size, it could be argued that they are relatively less visible. However, a difference in relative visibility is not an argument that a 'lazy' road user should be able to make for not having perceived a person cycling: it comes back to the principle that the road network is offered on a 'drive on sight' basis.

The risk of a collision is related to absolute speed and the relative direction and relative speed between moving objects. An absolute increase in speed does not necessarily increase the risk of collisions if the road system is designed to minimise differences in the direction and relative speed of vehicles. For example, a system of motorways segregates directions of travel,

provides appropriately angled merges and diverges at junctions and bans slower moving vehicles. However, in mixed traffic conditions often found in urban areas, an increase in speed results in a higher risk of collision and higher consequential damage because of the presence of many slower moving road users. Risks of collisions are enhanced by the relative differences in speed between road users, and failures to yield priority appropriately in accordance with the usual rules of the road. Behaviour and interactions between road users will vary and depend on the attitudes of the individuals involved, the road space available, the form of infrastructure and traffic management and environmental conditions, such as the degree of light and the weather.

Existing modern transport networks and traffic management regimes were often built with limited or no thought being given to cycle users. The provision of retro-fitted 'facilities' for cycle traffic has often been undertaken to attempt to address this issue. While these facilities may often ostensibly have the aim of reducing one or more perceived risks of cycling, they may also have other undesirable effects such as reducing priority for cycle users, or the speeds that they would otherwise wish to travel at.

Adams (1995) differentiates between risks perceptible and controllable by the individual as a result of their actions (in his example, climbing a tree) and risks that are perceptible only with the help of science through an analysis of the evidence (for example, the prediction and control of diseases). He suggests that an individual will make decisions based on an inherent propensity to take risk, but influenced by rewards and experiences of losses due to accidents. On the other hand, governments take action based on an attempted analysis of the objective probabilities of 'risk and reward', and it is eminently debatable the extent to which reasonable decisions are made based on such 'corporate' analysis of risk on behalf of the individual (this is why debate continues about nuclear power and military action, for example). Adams also points out that the management of risk will modify the risk and hence change behaviour. An important distinction is behaviour that changes a risk to oneself and behaviour that changes risk for another, for example driving with inappropriate speed for the condition may be relatively safe for oneself, but not for a third party. On this basis, it could be argued that a constraint placed on a driver as a result of a 'facility' for cycling (e.g. a narrower traffic lane) may in fact result in the driver seeking to compensate in some way and taking more risky action in order to produce the same reward (at the most banal, being 'home in time for tea'). Such compensation may have more significant detrimental consequences than if no perceived 'constraint' had been placed in his or her way.

Perceptions about risk are frequently quite different than an analysis of the accident record might suggest. For example, pedestrians may avoid crossing a road at a certain place, even though it may lie on a desire line, because of their perception of the hazard of crossing at that place. This reduction in pedestrian use will be reflected in fewer collisions involving pedestrians. Such feelings of insecurity are just as 'real' as the forces experienced in a collision. So far as cycling is concerned, a major issue is concerned with the conditions in which it is appropriate for cycle traffic to mix with motor traffic. A common misconception about off-carriageway routes is that they are inherently safer than their on-carriageway counterparts simply because of the absence of motor traffic. Other risk factors, such as other cycle users and pedestrians, and objects at the side of the route, still require cycle traffic to behave on motor traffic free routes in a disciplined way and to 'ride on sight'. People new to cycling in particular have a strong fear of collisions with motor traffic, so routes for cycle traffic off the carriageway are, seemingly, attractive to them. As evidence to support this, Kingham et al. (2011) found in New Zealand a preference for separated facilities (separate from both motor vehicles and pedestrians) across a sample of people interested in cycling but currently not regular utility cyclists.

The majority of cycle collisions do not involve motor vehicles: people fall off or hit objects for various reasons, and they also have many collisions on routes shared with pedestrians, dogs, and other people cycling. Munster et al. (2001) estimated from New Zealand hospital data that four times as many cyclists are injured from 'cycle-only' crashes on the carriageway or on footways and other routes than those involved in motor vehicle collisions (note that these data do not include off-road mountain-biking track accidents). When considering children specifically, Safekids (2007) concurs, and suggests that 90% of New Zealand hospitalisations for bicycle-related injuries to children during 1999-2003 did not involve a motor vehicle. Similar findings have been found elsewhere (Moritz, 1998; Carlin et al., 1995; and also Franklin, 1999).

It is also worth observing that conflicts with motor vehicles may not be reduced by off-carriageway riding; cyclists will typically still have to cross side roads and driveways, where most conflicts occur. Forester (2001) points out that a key assumption for advocating off-road paths is that same-direction motor traffic is the greatest danger to cycling (e.g. being hit from behind). With American data, he showed that these types of collision made up only 1% of all cycle collisions both on-road and off-road.

Road injury collision data for 2006-2010¹ in New Zealand shows that 58% of reported urban cycle collisions are at intersections, with a further 19% occurring at driveways; it is difficult to avoid those, even on a footway. Considering specifically collisions that could probably be avoided by cycling adjacent to, rather than in, the carriageway (e.g. overtaking, hit car door, rear-ended), fewer than 30% of all on-road cycle collisions appear to be likely candidates.

In moving cyclists to a separate route, however, additional collision opportunities may be introduced, especially if the route is within the road corridor. Nearly 10% of all reported cycle collisions in New Zealand note that the cyclist was (illegally) riding on the footway (sidewalk); with more than half occurring at driveways. Depending on the location, frequent conflicts with pedestrians are possible and there may be less perception and reaction time for conflicts that occur at driveways or side-roads. While the geometry and physics point towards such additional collision opportunities, the extent to which they may in fact manifest themselves in reality will be a function of the way that riders and drivers interact, and this is an artefact of behaviour.

Insert Figure 2 here

Separation means additional side road conflicts have to be managed

A number of studies in North America have found that collision rate involvement when cycling on footways is higher than on the carriageway or on off-road cycle routes (Aultman-Hall and Hall, 1998; Moritz, 1997). An interesting finding by Aultman-Hall and Adams (1998) was that regular footway cyclists also had higher on-road crash rates than non-footway users. This raises the possibility that footway riders are either less confident or lack the skills and training of on-carriageway riders (although they did find that regular commuters had similar collision patterns on footways). The different problems faced at intersections compared with mid-block locations are highlighted by Danish research (Jensen 2008) that found that, while off-road cycle tracks were safer in general than their on-carriageway counterparts, they were less safe at intersections. SWOV (2010) therefore recommended that cycle tracks parallel to roads should either rejoin roads ahead of intersections or be taken further away to cross the side roads.

A concern remains amongst cycle users that a collision with a motor vehicle is more likely to lead to serious injuries, hence perhaps the preference to use the footway. Certainly most bicycle-related deaths involve a collision with a motor vehicle. Over the ten-year period 1998-2007, typically six out of every seven children killed in bicycle-related incidents in New Zealand resulted from a collision between the child and a motor vehicle². But, while moving the cyclist off the carriageway may result in a lower incidence of severe injuries, it may result in transferring injuries to pedestrians that are hit by cyclists (albeit rarely fatally). Aultman-Hall and Hall (1998) found that the likelihood of 'major' cyclist injury remained about 1.7 times greater on footways than carriageways.

By contrast, neighbours to off-road cycle routes sometimes express concern about crime, vandalism and litter, and these risks of public disorder may affect their property's value. A review of 300 off-road routes in North America by The Rails-to-Trails Conservancy (1998) suggested these misgivings were unjustified and the Trails and Greenways Clearinghouse (2003) identifies potentially significant economic benefit that can arise from popular new trails to small communities. A range of surveys (see for example, Lagerway and Puncochar, 1988; Macy and Alexander, 1995; Sustrans, 1999, Racca & Dhanju 2006) suggest the majority of local

¹ Data from New Zealand Crash Analysis System (CAS) database, 2006-10; only 923 out of 4032 reported injury collisions involving cyclists were not at intersections or driveways.

² Data from the New Zealand National Injury Query System; only 6 out of 43 cycling fatalities for children under 15 did not involve a motor vehicle.

residents consider off-road routes to be a useful additional local amenity and an advantage for, or at least a neutral effect on, property values and public safety. Sustrans (1999) note that visual appearance of the finished product will have an effect on the perceived and actual benefits and this fits in with the core Dutch characteristic of attractiveness.

One of the problems with many existing off-carriageway facilities, at least in New Zealand and the United Kingdom, is that they have been poorly designed and maintained (if at all) for cycling. Indeed, a lot of the above research focused on cycling on existing roadside footways designed for pedestrians. The central point is that when routes for cycle traffic have been created off-carriageway, cycle traffic has been expected inappropriately to fit into an unsuitable environment for such traffic, with little or no design consideration having been given to the bicycle as a vehicle capable of speed, and this has contributed to the collision problem.

An important way of managing risk on the road network has been to ensure that every aspect of geometric design is related to the design speed. In order to manage the risk on any route that is deemed appropriate for cycle traffic, an appropriate design speed must be considered by the designers. Such a design speed is relevant whether the path of the cycle traffic is within a carriageway used by other motor vehicles, whether it is along a route dedicated to cycle traffic but intersecting with roads and pedestrian routes, or whether it is along a route that also serves pedestrians. In this latter case there are two possibilities: routes are divided into a carriageway for cycle traffic and a footway for pedestrians, or, in a manner akin to country lanes that have no footway, there may be a single shared surface. The design speed dictates forward visibility envelopes for stopping and overtaking, curves in the horizontal and vertical planes, and the tapers over which vehicles are expected to make lateral movements within the space available to them. The use of public roads is well codified in law and in user guidance, such as, in the United Kingdom for example, the Highway Code (DfT, 2007). In some limited instances it may be appropriate for routes to be shared by pedestrians and cycle traffic without the pedestrians being offered a footway adjacent to the carriageway dedicated to cycle traffic use. However, when remote from motor traffic, it would appear that the good sense promulgated in the guidance is not adhered to. In particular, the UK Highway Code suggests to pedestrians that they walk towards oncoming traffic on the right hand side of the road (the UK has a left hand rule of the road for driving) in order to face oncoming traffic. This rule is not widely promoted as a 'rule of the route' for routes that cater for both pedestrian and cycle traffic, but would, if implemented, provide a suitable codification for behaviour on such routes. Alternatively, many North American and Australasian shared pathways mark and sign the path like a road, with all path users in the same direction keeping to one side unless overtaking.

Figure 3 Rules for cycle route user behaviour are required

Milton Keynes is one of the so-called New Towns in the United Kingdom that was developed through the 1960s to the 1980s based on a concept of easy motor vehicle access and relatively low development densities. In the case of Milton Keynes, the transport network comprises a grid pattern of roads connecting at large roundabouts with cycle and pedestrian traffic banished to separate 'redways' that dip beneath the road network through underpasses. Franklin (1999) identifies reasons for a high accident record on the redways as being poor design and very poor user discipline, for example the flouting of basic practices such as cycling on the left (mirroring the left hand driving rule of the road) and not using lights at night. He also notes increased conflict between pedestrians and cycle users as a cause for concern, and this suggests that where routes are designed for speedy cycling progress they should, in a similar manner as for 'normal' roads, be kerb separated from adjacent footways. Despite the network of cycle routes, cycling has never achieved a significant proportion of use and this is likely to be as a result of the town having been designed around and for the car in particular (rather than the bicycle), a lack of priority for cycle traffic and a general lack of cultural support for cycling.

Finally, it is worth returning briefly to the theme of 'safety in numbers' already introduced in Chapter 5. A range of studies (see for example, Ekman, 1996 and Jacobsen, 2003) demonstrate reduced risk associated with greater numbers of bicycles within the traffic mix which have spawned the idea of 'safety in numbers'. In an excellent commentary, Bhatia and Wier (2011) point out that the literature consistently supports non-linear models in which

increases in injury collision frequency are proportionally less than the increase in the volume of the road user being considered. However, they suggest that greater clarity of argument is required, particularly where public policy intervention is being considered, in order properly to recognise the difference between reduced individual risk and overall total number of injury accidents, which, for changes in mode share to more benign modes of a low magnitude, will still result in an overall increase in injury accidents. They also point out that confounding may occur (for example safer environments will increase both numbers and safety) and that adequate evidence of the causal direction is lacking (in other words increased safety could be producing increased numbers) in current 'safety in numbers' studies. They do suggest, however, that plausible causal mechanisms could exist, such as more users being more visible, more users forming larger groups, which in turn may have some sort of collective vigilance. Overall they ask why streets should not be designed for adequate safety regardless of the number of users.

Now having gained an appreciation of the issue of risk and cycling, we turn our attention to the sort of networks that would support cycle use.

Networks for cycle traffic

This section provides guidance for developing comprehensive transport networks suitable for cycle traffic. Individual links and junctions in the network may or may not happen to be coincident with routes over which motor traffic also has a right to pass, but it is likely that they are coincident in the majority of cases. The guidance offers direction to those promoting cycling, providing transport, and planning and undertaking spatial planning and land development. Taken together they may be regarded as a set of values to help position cycling appropriately within the whole transport system for a twenty first century sustainable society.

Despite the ubiquitously quoted engineering requirements and characteristics, their operationalisation has frequently been left wanting. A favourite approach has been to create a hierarchy of provision of treatments to existing routes (for example IHT, 1996; DfT, 2004), which may first attempt to reduce motor traffic volumes, followed by reducing speeds, followed by intersection treatment and traffic management, followed by reallocation of carriageway space, followed by the introduction of specific facilities such as additional bridges. This was introduced in Chapter 4.

Parkin (2010) has argued that such a hierarchical approach to implementation leads the designer down the path of making adjustments to the existing network at the individual route and corridor level without initially considering properly the higher-level introductory processes of understanding demand, and then providing for that demand with a suitably constructed network defined by engineering parameters and the Dutch network characteristics. The hierarchy of provision is not helpful in outlining the processes of route and network planning that must precede scheme implementation.

Virtually all cycle trip ends will be on the road network, that is to say most trip ends will also be accessible by motor traffic. This may be quite acceptable if one end is a residential road, but, based on the planning and engineering approaches of the latter part of the twentieth century, the shopping or business end of the journey may be surrounded by high volume, high speed roads which may not be conducive to an attractive and comfortable environment in which to cycle. This leads to the realisation that, unless constructing a completely new town or suburb, the introduction of suitable networks for cycling needs to be retrofitted into an existing well established and frequently heavily used road network. Retrofitting may require no action at all: the existing road routes may be fully suitable and attractive for cycling. However, they may on the other hand benefit from specific forms of traffic management that may provide more appropriate movement space for cycle traffic as a distinct type of vehicle within the traffic mix. We suggest below actions in a procedure for the implementation of infrastructure to assist in promoting cycling.

1. Spatial planning
2. Demand modelling
3. Traffic and speed management and the creation of enhanced permeability
4. Construction of links to complete a permeable network

5. Integration with public transport

Action 1 would normally precede or be undertaken in association with Action 2 and these are the usual steps in a local authority's approach to managing the physical development of its jurisdiction. Actions 3 to 5 are interconnected and complementary and may be undertaken in parallel with each other. Not all actions may be as desirable and necessary as other actions, and this will depend on the nature of the areas being considered.

1 Spatial planning

The rate of change of land use varies between cities and countries across the world, but is generally slower paced in older established communities and nearer the centre of larger communities. However, spatial planning determines the geographical end points of journeys and this geographical relation, and the intervening transport network, help determine the demand for transport and the modes and routes used.

The nature of the relationship between land use and transport demand has been discussed in Chapter 5. Cervero et al. (2009) summarise the five relevant spatial planning attributes in an interestingly alliterative style as being:

- density;
- destination accessibility;
- design;
- distance to public transport; and
- diversity.

In a consideration of integrated transport, Hickman et al. (2010) expand these five attributes to eleven themes including:

1. settlement size (with larger settlements offering more mixed land uses and less need to travel);
2. location of major growth areas;
3. the nature of the strategic transport network for medium and long distance travel;
4. density of land use;
5. the balance between employment opportunities and housing;
6. the accessibility to key facilities;
7. development site location;
8. the extent of a mixture of land uses;
9. neighbourhood design and street layout;
10. approaches to travel demand management; and
11. policy on car parking.

Owing to the effort required, cycling is better suited to short journeys. Evidence from the UK National Travel Survey (DfT, 2011, Table NTS0308), for example, shows that 85% of bicycle trips are for distances up to 5 miles, and this contrasts with 56% of trips by car as a driver being up to 5 miles in length. The themes identified by Hickman et al. that act as particular reinforcement for cycling include higher land use densities, mixtures of uses, and good juxtaposition of housing with jobs and services. In addition, cycling could be further supported through appropriate management of travel demand for other modes and suitable policies to constrain car parking (and at the same time provide sufficient bicycle parking). In much larger settlements where distances are greater, and for journeys between settlements, planning can be used to encourage cycling as an access and egress mode from public transport.

At a more strategic level, the planning framework should be used to provide and protect corridors for cycling related infrastructure. Frequently, routes for cycle traffic have been created opportunistically based on the availability of, for example, disused railway corridors. While these may be appropriate for leisure purposes, they are of limited value for transport purposes unless they happen to lie on desire lines that satisfy a demand for movement. New Zealand guidance (LTSA, 2004) points out that a cycle route separate from a motor traffic route may only be practical when planning new suburbs and townships. Such practicability is, though, in essence a political question. Historically, it has been deemed appropriate to use planning and highway laws for the compulsory purchase and construction of highways for motor traffic. In more recent times, there is evidence that these powers have been used for marginal road widening for

junction improvements linked with bus priority. Ultimately, a decision about the nature and layout of a transport network in an urban area is related to public policy. It is implicit that adequate and timely transport planning needs to be undertaken to ensure that routes with a suitable level of accessibility and which may be constructed to suitable standards for cycle traffic are identified and protected through the appropriate legal processes.

Strategies to promote cycling do not exist in isolation from other policies and actions. The success of cycling strategies is greatly influenced by what is done elsewhere; other policies and programmes must be consistent with the promotion of cycling. This integrated approach also helps to emphasise the fact that the cycling strategy is not an 'add-on', but an integral part of the activities of road authorities and other agencies. Therefore, agencies need to review and implement other pro-cycling policies. These include road projects that should take full account of cycling needs and the use of other routes and corridors, which may or may not be in existing public open space but may have value as transport corridors for cycle traffic. An example of developing integrated thinking has emerged in London and is evident through the requirement that those engaged in designing or maintaining the street network are all well versed in the London Cycle Design Standards (TfL, 2005).

The ability to develop appropriate approaches for provision for cycle traffic will be influenced by variations in local conditions, for example in terms of topography, climate, compactness of land use and historic settlement structure, and social and cultural attitudes to cycling. The extent and quality of infrastructure may also be constrained by local economic and political priorities in the allocation of often scarce urban realm and road space and other transport policies and investments such as public transport investments. To ensure continued progress, spatial and transport planning requires long term commitment to a policy direction and sustained commitment from a range of public authorities, private organisations and non-governmental organisations at different levels (local, regional and national). These organisations may include local employers and health, education and leisure agencies. A further constraint on the ability to achieve success may be the availability of appropriately qualified and experienced professional staff and this deficiency may to some extent be overcome by appropriate training and professional development.

2 Demand modelling

While spatial planning is an on-going process punctuated by a particular timescale (usually dictated by a legislative need for renewed land use planning policies on perhaps a quinquennial basis), the planning of specific infrastructure such as a transport improvement, will happen at a particular point in time and be related to a particular project as part of a scheme of investment. Demand modelling is therefore an activity that would be undertaken at a specific point in time relative to a planned programme of investment as a result of a policy initiative.

Erstwhile provision of infrastructure for transport has frequently been caricatured as being a process of 'predict and provide' with roads 'filling up' with motor traffic because of rising car ownership and use virtually as soon as they have been constructed. Based on the experiences in the late 1980s and early 1990s in the UK, a detailed analysis of this phenomenon of seemingly relentless growth was investigated (DoT, 1994) and evidence of traffic being 'induced' as a consequence of the provision of infrastructure was revealed. This resulted in significant changes to the way the forecasting demand was undertaken. So far as cycling is concerned, the approach presently adopted may perhaps be described as 'provide and promote', and this makes the bold assumption that whatever is being provided is fit for purpose. Infrastructure interventions to promote cycling have not always resulted in a hoped for increase in use of cycling. This is linked with the extent and quality of provision, but also with the reluctance of a population to switch from other modes while the provision for cycle traffic remains, in their eyes, incomplete.

Cycle demand modelling is still in relative infancy and Bamberg in Chapter 9 provides an overview of a series of emerging methods for modelling choice for cycling. Methods that have been used for investigating the level of use of cycling have otherwise been related very closely to a study of its relationship with the extent of provision of infrastructure. For example, Nelson

and Allen (1997) examined cycle pathway length and its relation with cycle commuting in eighteen cities in the USA. Each additional mile of cycle pathway per 100,000 population was associated with a 0.07% increase in cycle commuting. However, based on the data being cross-sectional in nature, it was not possible to infer a cause-and-effect relationship.

Extending the work to thirty five large cities, Dill and Carr (2003) found that the percentage of people commuting to work by bicycle correlated significantly with various cycle infrastructure variables, but not with any other transportation, environmental or demographic variables. The strongest correlation was with the number of on-road bicycle lanes per square mile. Each additional mile of bicycle lane per square mile was associated with a 1.0% increase in the proportion of workers commuting by bicycle. (It should be noted that such an increase in bicycle lanes is significant as the cities in the study averaged only one third of a mile of bicycle lane per square mile). Again, no cause-and-effect relationship may be claimed, but it does imply that some commuters will adopt cycling if the infrastructure is appropriate and this has been discussed more fully in Chapter 5.

Katz (1996) used a stated preference approach to estimate an elasticity of demand of 0.6 for cycling based on changes in the proportion of a journey served by some sort of bicycle 'facility'. This finding suggests that a 25% increase in facilities would increase the numbers of cycle commuters by approximately 15% ($25\% \times 0.6$). Parkin et al. (2008) used UK census data and revealed that the proportion of people who cycle to work was most affected by the geographical factors of hilliness (elasticity -0.893), rainfall (-0.665) and temperature (+0.703) with the proportion of bicycle route that is off-road displaying a low elasticity of +0.049. The point is made that revealed data contrasts with larger elasticities usually found in models constructed from stated preference data. McDonald et al. (2007) examined ten case studies in New Zealand and derived predictive equations for cycle numbers on on-road and off-road facilities. The equations were based on existing cycle mode share and growth in the local district and, in the case of off-road facilities, the adjacent motor vehicle volumes. While an estimation method was developed, the researchers acknowledged that further case studies would help improve the model.

The field of estimating cycle use is still evolving, and there are now some useful guides available to help predict likely future cycle numbers using a variety of techniques (including FHWA, 1999; Katz, 2001 and DfT, 2010). The methods range from simple comparisons of similar facilities previously built, through the use of elasticities, to full scale trip demand models. In addition, as already mentioned, Bamberg in Chapter 9 introduces a wider range of socio-psychological models and Zuidgeest and Brussel in Chapter 8 describe geographically based techniques for defining and overcoming barriers through cycle network construction.

3 Traffic and speed management and the creation of enhanced network permeability

The geography of the transport an urban area is defined by not only the layout of the road network, but also by the way traffic speeds and volumes on the road network are managed through area wide strategic traffic management. Historically traffic management has been implemented usually only with a view to 'smoothing the flow' of motor traffic and what is now required is the creation of systems for easy movement for all classes of traffic which recognises the very different nature of different types of vehicle, in particular the bicycle.

Future area wide and strategic schemes will need to be thoroughly operationally appraised using fully specified transport models and junction analyses such that different scenarios of layout and priority may then be compared. Additional regulation by the creation of, for example, one way streets and banned turns may be one outcome, but also it may be appropriate to construct new links within the network specifically for cycle traffic, for example, in the same way that hitherto perhaps 'ring roads' or 'relief roads' have been built for motor traffic in the past. New links are discussed further in the section below.

Insert Figure 4 Streets with cycle traffic only allowed in one direction

While specific traffic management measures may be necessary for the size and volume of motor traffic, these measures may not be necessary for cycle traffic, which is much more agile in nature and has much less impact on the urban environment than motor traffic. An alternative network, more advantageous to cycle traffic should always be considered, and may be regarded as being 'interleaved with' the network as defined for motor traffic. This will create enhanced permeability (sometimes referred to as 'filtered permeability', see Melia, 2007) for cycle traffic. The creation of such preferential networks would rely on traffic regulation and also, again, in some instances, on the creation of specific new links.

Insert Figure 5 here
Banned turns except for cycle traffic

It is technically quite feasible to manage the physical infrastructure of the highway in a variety of ways which provide priority for different classifications of vehicle. The greater difficulty is in ensuring that the priority is being appropriately considered for cycle traffic from a political point of view: funding only follows for such traffic management schemes with such support.

As discussed in Chapter 4, advocacy for cycling has played an important role in shaping thinking, even if sometimes it has established antagonisms between 'users' and 'providers'. The consciousness of the importance of creating civilised urban environments through speed management has been significantly raised in recent times by international campaigning around the theme (see for example 20splentyforus, 2011). 20s Plenty For Us suggests that 'total', that is town-wide or settlement-wide, zones with speeds of 20mph (30km/h) would create a new 'societal norm' for speeds in urban areas and reduce the need for expensive physical measures to 'calm' traffic to appropriate speeds. Ownership of such an approach, it is suggested, would be enhanced because most drivers would benefit in their home street, a consistent message that 20 mph is 'plenty' where people live can be easily promulgated and accepted, and that, being based on a democratic process, an additional collective community commitment to road danger reduction can be created. Evidence, for example, from the early adopting City of Portsmouth in the UK suggests a 22% reduction in road collision casualty numbers (20splentyforus, 2011) and such town specific evidence is supported by a recent review of the literature (Reid and Adams, 2011), which points to speed limits as being an important risk factor in multi-vehicle collisions involving cycle traffic.

Interestingly, based on a conception that the European Commission's 2010 road safety strategy paper was too vague, timid and inadequate, Members of the European Parliament Transport and Tourism Committee provided democratic support for reduced speed limits in urban areas by endorsing a report that calls for a 30km/h speed limit in all residential areas and on single-carriageway roads without cycle tracks. Specifically they see this as a road safety measure to help cut the number of children aged less than 14 years old killed on roads by 60% and those seriously injured by 40% (European Parliament, 2011). There is hence, therefore, also evidence of political will in support of technical strategies to create more hospitable transport environments.

Even without a corresponding speed limit reduction, traffic calming on its own can provide useful safety benefits. Mao & Koorey (2010) investigated nineteen streets in Christchurch, New Zealand, that had been reconstructed with various vertical and horizontal traffic calming devices. They found that the average collision frequency decreased by 17%, despite the general trend of increasing collision numbers on Christchurch's local roads.

The Dutch guiding characteristic of coherence addresses the point that everyone capable of cycling should be able to use the road network to access all of their desired destinations by bicycle. A significant challenge is the often difficult issue of maintaining attractive and comfortable sections of the network at locations where it intersects with or runs parallel with roads that carry significant volumes of motor traffic. Therefore, consideration needs to be given to treatments that ensure adequate provision for cycle traffic. Such provision may include a degree of lateral separation from motor traffic to reduce the impact on the cycle user of the negative impacts of moving traffic, with air pollution and noise perhaps being the most important amongst these. It may also include specific measures to manage conflict at junctions, such as

marked space for cycle traffic through to the provision of distinct waiting areas (for example, dedicated approach lanes, or advanced stop lines to create a 'box' area) or times during a signal cycle only for cycle traffic.

4 Construction of links to complete a network

It is not self-evident that the existing layout of a road network is ideal for cycle traffic. While some very old established routes may lie on obvious desire lines between specific settlements, there are many newer roads that have been constructed specifically with motor traffic management in mind, for example inner 'ring' roads. Bearing in mind the shorter average journey lengths and the need for directness for cycle journeys, these routes may or may not lie on useful desire lines for cycle traffic. As with management of the network for motor traffic where new build is deemed appropriate, there is the possibility that new build specifically to cater for cycle traffic could be required. This may connect, for example, housing estates via an area, such as a green swathe, which may easily be able to accommodate cycle traffic, but would be detrimentally affected by motor traffic. The construction of such additional links may require crossings of geographical barriers such as rivers and railways (where it may be too costly to provide a motor-vehicle carrying structure) and this affords civic society the opportunity of adding value to their neighbourhoods through the elegant design of walking and cycling bridges.

Insert Figure 6 here

Flagship schemes such as bridges may be valuable additions to the network

As mentioned in the section on spatial planning, it may be necessary to protect possible routes for cycle traffic with appropriate planning policies, and this needs political will and a desire to match the aspiration with funding. Conversely, such schemes may catch the imagination of local politicians and become 'flagship' schemes which may garner wide public support and the opportunity for kudos and the all important future vote of constituents.

5 Integration with public transport

Cycling coupled with public transport can provide a powerful alternative to the private motor vehicle. The door-to-door capability of cycling can be combined with the long-distance range and speed of public transport (especially where dedicated public transport corridors are available). Public transport can also provide a useful backup for cycling in bad weather. To achieve this, public transport systems need to allow for both good-quality cycle parking at stops and stations (DfT, 2008). Debrezion et al. (2008) found in the Dutch context that the availability of bicycle parking has a positive effect on the choice of railway station for the start of a journey. Ensor et al. (2010) determined that the provision of cycle and public transport integration in six major urban New Zealand centres would collectively generate more than 1.7 million trips per annum, with individual cities having benefit-cost ratios between 2 and 10.

Rietveld (2000a) found in The Netherlands a higher percentage use of the bicycle as an access mode to the railway than for the share of bicycle use more generally. However, a lower percentage uses the bicycle as an egress mode and he suggests policy to provide more secure parking provision at the destination end of a journey for a second bicycle, public bicycle schemes or better facilities for the carriage of bicycles on trains. The carriage of bicycles on public transport may be possible depending on the nature and capacity of public transport vehicles and the loading characteristics. It is usually not possible for bicycles to be carried on peak time trains on commuter routes, but limited carriage may be possible at off-peak times. Long-distance passenger services provide a desirable service for cycle tourists. Rietveld (2000b) further contends that overall journey speed, including the access and egress legs of the journey, is the main criterion that railway companies should consider when assessing rail journeys against alternatives.

The path to sustainability

The chapter has reviewed the principles for design of cycle networks and considered the question of risk. It has also argued for a more sophisticated and comprehensive procedure for planning and designing for cycle traffic than is offered by a hierarchy of provision, and which begins with spatial planning, adopts appropriate demand modelling, and then carries out schemes based on appropriate new build where required, and traffic management at a strategic and area wide level.

A common problem for politicians is the need for relatively quick results from investment. Any less-than-significant or visible change to the number of people cycling in an area may lead to calls for a moratorium on investment in cycling. Cycling England, a relatively short-lived quasi-autonomous non-governmental organisation established between 2005 and 2011, was aware of this issue and successfully concentrated its resources on the Cycling Demonstration Towns where concerted action did produce results and hence provided the evidence to seek additional funding for an expansion of the programme (see Sloman et al., 2009).

Koorey (2003) considered the state of the cycling network in Christchurch, New Zealand where considerable investment had occurred over the previous decade. While the rhetoric may sound impressive to some that over 60 km of streets had cycle lanes, with another 60 km of off-road cycle paths being available, it has to be remembered that there were approximately 1500 km of urban roads overall in Christchurch. There remained about 200 km of busy arterial routes that many potential cyclists would avoid and there were in many localities cases where there are limited opportunities to cross routes carrying significant volumes of motor traffic. The cycle 'network' was no more than a series of 'islands' isolated from each other. Clearly, if the general road network were comprised of such an isolated grouping of sub-networks, it would have a significant detrimental impact on motor vehicle trips. (One of the authors asks his students to consider how the volume of traffic on the M6 motorway may be affected if a link is missing say between junctions 16 and 17.)

Growth in cycling numbers will only become significant when networks suitable for a wide range of cycle users reach completeness and maturity. The fact that often the most difficult (and yet crucial) elements of cycle networks are left until last because of financial or political pressures only exacerbates this problem. The 'easy' and less necessary and influential components are often completed first, but it is generally not these aspects that are limiting the potential for growth in cycling numbers. More than minimal investment of time and resources is required to overcome these problems.

Many of the perceived problems with cycle facilities, both on-road and off-road, have been due to inadequate design or maintenance standards rather than the choice of facility. This of course can (and should) be resolved. Design that minimises risk is of concern for all transport networks and there are safety issues with both on-road and off-road cycle 'facilities'. Obviously it is desirable that all types of provision for all types of traffic are made as safe reasonably practical.

Even with appropriate design, the general public or local politicians may still develop incorrect perceptions about the relative merits of some 'treatments' designed to improve cycling. Education campaigns may be useful to inform these parties of the true value of such treatments in terms of safety and level of service. Some of the best solutions to promote cycling may not involve 'remedial' facilities, but involve the overall presentation of a network as suitable for use merely through good promotion.

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