## Measure No.20: Cycling


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### Provision of on-road and off-road infrastructure to facilitate cycle use

Cycling infrastructure interventions aimed at promoting cycling in a city can be developed at all scales, from alteration of a single junction, to entire networks of routes. They may also focus on the necessary infrastructure needed to facilitate more effective routes (such as a new bridge).

## 20.1 Context and background

This review is a review of cycling infrastructure and its role in sustainable urban transport. This includes provision along existing road links, and at road junctions. It also includes routes away from motor traffic and specific infrastructure, such as bridges.

The scope does not include wider issues about the general layout of general infrastructure within an area, for example relating to land use density and the relative location of land uses. It also does not relate to wider programmes to promote cycling. These matters are dealt with in the following reviews: No.4 access restrictions; No.5 roadspace re-allocation; No.6 environmental zones; No.7 congestion charging; No.9 site-based travel plans; No.10 personalised travel planning; No.11 marketing and rewarding; No.14 integration of modes; No.16 traffic management and control; No.17 travel and passenger information; No.22 bike sharing; and No.23 inclusive urban design.

Cycling infrastructure is designed to make cycling for a specific journey quicker, safer, more comfortable and more attractive. It is a necessary but insufficient condition

Key messages:

- Positive Benefit-Cost-Ratios (BCRs) are seen for networks of cycle paths, based on journey time savings and lower health and fuel costs.
- Positive BCRs at the lower end of the scale derive benefits mainly from the value of time; health benefits contribute the additional value at the top of the BCR range.
- Leisure-based networks can also bring benefits in respect of new job creation and additional economic activity.
- Appropriate infrastructure provision for cycle traffic, forming comprehensive networks of routes, is essential to encourage cycling.
- These networks need to be built up from components such as safe junctions and bridges which create suitably direct routes for cycle traffic. There is some lack of clarity, however, as to what specific links, or provision at junctions, would be deemed most suitable by users and potential users.
- There is a perception that it is safer to separate cycle traffic from motor traffic, and that off-road paths are therefore required.

Potential interventions

- Integrated networks of bikeways with intersections that facilitate cycling;
- Individual engineering improvements, and
- Good quality bike parking at key destinations and public transport stations.

- provide a comprehensive package of integrated measures;
- build a network of integrated bikeways with intersections that facilitate cycling;
- provide good bike parking at key destinations and public transportation stations;
- implement bike sharing programmes;
- provide convenient information and promotional events;
- introduce individualized marketing to target specific groups;
- improve cyclist education and expand bike-to-school programmes;
- improve motorist training, licensing and traffic enforcement;
- restrict car use through traffic calming, car free zones and less parking;
- design communities to be compact, mixed use and bikeable.

**Box 1:** Activities to promote cycling as a mode choice

that appropriate infrastructure is provided for cycle traffic. Multiple, reinforcing interventions covering a wide range of activity is required. Pucher and Buehler (2012), in a book which summarises some of the literature we present here, list ten areas of such activity. These activities are listed above in Box 1.

This review specifically considers issues in connection with points 1, 2 and 3 above. Aspects of the other seven activities can be found across the range of other Measures reviewed for EVIDENCE.

## 20.2 Extent and Sources of Evidence

There has been a much published work in relation to cycling in recent years, with almost one hundred documents selected for initial review here. The characteristics of this source material are summarised below in Box 2.

## 20.3 What the Evidence Claims

### *20.3.1 Overview of what the evidence shows*

The nature of much of the evidence is at aggregate level. It is concerned with area or city wide effects and hence is related to comprehensive treatments for cycle traffic based on networks for cycle traffic. We discuss first aggregate data analysis and models constructed at the aggregate level which have explanatory variables for infrastructure. We then turn our attention to components of infrastructure. We then consider cost benefit evidence before finally considering wider issues in relation to infrastructure. However, as a pre-amble, we discuss the issue of cycling and safety because the perception of risk is often reported as a reason why people may not cycle.

- This review has drawn on 20 source documents, and has also referenced Handy et al. (2014) in relation to gaps in the knowledge.
- Two of the references are in the nature of reviews of evidence (Pucher et al., 2010 and Yang et al., 2010)
- Implementation of cycling infrastructure is receiving ongoing scrutiny and research
- Evidence is drawn from Australia, Denmark, Germany, The Netherlands, Sweden, UK and USA
- All bar two of the sources are academic, the other two are written by consultants
- The evidence is found in the academic papers, and in one consultant’s report
- Three studies are at the level of the country, six are at the level of an area (for example, town or city level), four are at the level of a route or network of routes, one is concerned with a bridge and another concerned with a bicycle hub.
- The evidence ranges in date from 1997 to 2013. The majority of evidence (eleven sources) have been published in 2008 or subsequently.
- All of the interventions discussed are currently still implemented

**Box 2:** characteristics of source material for this review

*20.3.2 Cycling and risk*

In a disaggregate study and an aggregate study respectively, Ekman (1996) and Jacobsen (2003) show that risk of collisions and injuries with other motor vehicles is reduced where there are greater numbers cycling. Bhatia and Wier (2011) note, however, that accident studies consistently suggest non-linear relationships between volumes of use and collision and injury frequency. The consequence is that great care is needed in when discussing policies in relation to cycling and safety. Promotion of a more benign mode such as cycling, which suffers more at the hands of other traffic, will still result in more collisions and injuries overall, all other things being equal, despite reductions in the rate of collisions relative to measures of use. Bhatia and Wier note that confounding in the evidence base may exist, with safer environments increasing both numbers cycling and safety. In order to understand a little more clearly the direction of causality, Luukkonen and Vaismaa (2015, forthcoming) systematically review evidence which considers cycling levels of use and cycling safety. They find that land use planning, traffic network planning and quality of the bicycle infrastructure are all highly significant positive influence in relation to both safety and level of use. Aldred and Crosweller (2015) confirm in a recent study much previous work which shows that fear of injury is a barrier to cycling, and experiencing non-injury incidents (near misses) may contribute to this fear. They note that UK cyclists experience very high rates of non-injury incidents, by comparison with any reported injury rates.
20.3.3 Aggregate data analysis and modelling

Yang et al. (2010) summarise the outcome from a controlled repeat cross-sectional study which examined the effect of improved network connectivity in an area of Delft, The Netherlands. In the control area the proportion of household trips made by bicycle rose from 38% to 39% over a three year period, however, in the intervention area the proportion rose from 40% to 43%.

Nelson and Allen (1997) investigated the relationship between bicycle use and available miles of bicycle pathway per 100,000 population in cities in the USA. They found positive correlation between commuting and the length of bicycle pathway. Other variables they included were as follows: weather, terrain and number of college students.

Dill and Carr (2003) investigated presence of facilities in relation to use of the bicycle in cities in the USA. They investigated commute cycling in relation to the presence of bike paths or shared use paths (so-called class I facilities) and on-carriageway bicycle lanes (class II facilities) compared with bicycle commuting rates. The extent of cycle lanes was the most significant variable in the model, showing positive correlation with commute cycling. Other variables included were as follows: state spending per capita on cycling and walking, vehicles per household, days of rain, percentage of workers in forestry and farming. They introduced a dichotomous variable to account for New York.

Merom et al. (2003) evaluated a promotional campaign based around a newly constructed Rail Trail in western Sydney, Australia. 450 adult randomly selected respondents completed a pre- and post-intervention telephone survey and were either within 1.5 km of the Trail or bike-owners only 1.5–5 km from the Trail. There was a significant increase in unprompted trail awareness in the after cohort (2.9%, McNemar $P < 0.05$) but post-campaign awareness remained low (34%). Trail usage was higher among bike-owners than pedestrians (8.9% vs 3.3%, $P = 0.014$) and was moderated by proximity to the Trail. Inner cyclists increased mean cycling time by 0.19 hours ($SD = 1.5$) while outer cyclists decreased cycling time (0.24 hours, $SD = 1.6$). Mean daily bike counts in the monitored areas increased significantly after the Trail launch ($OR = 1.35$, $P = 0.0001$, and $OR = 1.23$, $P = 0.0004$). Overall, the researchers considered that the campaign reached and influenced cyclists in the inner area.

Rietveld and Daniel (2004) modelled cycling levels between municipalities in The Netherlands. Factors included in the model were as follows: population, number of addresses per square kilometre, proportion of 15-19 year olds, presence of one or more schools for higher vocational education, share of non-native residents, share of liberal party voters, number of cars per capita, hilliness of the area. Factors specifically relating to policy that they found to be significant included the following: number of times per km a cyclist has to stop, car parking cost in eurocents per hour, number of hindrances (obstructions and narrowings) per kilometre, speed relative to the car. Policy factors not found to be significant were municipal budgets, the number of plans (e.g. policies and strategies) made in relation to cycling, measures for the bicycle network and bicycle parking, incentives given to municipal employees, measure for directness of trip, delay during the trip, average speed, and number of times that the cyclists need to slow down.

Parkin et al. (2008) investigated variability of cycle commuting in English and Welsh wards and found that the proportion of off-road route was relevant and has an elasticity of +0.049 (proportion cycle commuting relative to proportion of route that is off-road). A range of socio-economic and physical factors were also modelled. Hilliness is the most significant variable, with rainfall and temperature also playing a part. The state of repair of the road was also found to be significant.

Goodman et al. (2014) evaluated the effects of providing new high-quality, traffic-free routes for walking and cycling on overall levels of walking, cycling, and physical activity. Interventions were designed to complete missing links in networks and exposure was measured by distance from home to the infrastructure. A cohort of adult residents in three UK municipalities was followed from baseline in 2010 to 2011 (1796 respondents), and after two years (2012, 1465 respondents). After two-years it was found that those living nearer the intervention walked or cycled 15.3 additional minutes per week walking and undertook 12.5 additional minutes per week of total physical activity. The researcher found the effects were larger among participants with no car, and conclude that the findings support the potential for walking and cycling infrastructure to promote physical activity.

Panter et al. (2016) studied a cohort of 469 adult commuters as part of a quasi-experimental analysis of the Cambridge busway, which includes parallel cycling and walking routes. The analysis used an exposure measure based on the shortest distance from each participant's home to the busway. The measure of changed behaviour was the change in weekly time spent in active commuting between 2009 and 2012, measured by validated 7-day recall instrument. In addition, secondary outcomes measured were changes in total weekly time spent walking and cycling and in recreational and overall physical activity. The analysis adjusted for sociodemographic, geographic, health, and workplace confounders and also baseline active commuting; and home or work relocation within a multinomial regression model. It was found that exposure to the busway (and cycle and walking routes) were associated with a significantly greater likelihood of an increase in weekly cycle commuting time (relative ratio of 1.34, with a 95% confidence interval of 1.03 to 1.76) and also with an increase in overall time spent in active commuting among the least active commuters at baseline (relative ratio of 1.76, with a 95% confidence interval of 1.16 to 2.67). The research found no evidence of changes in recreational or overall physical activity.

*20.3.4 Analysis of components of networks*

The construction of Bryggebroen pedestrian and cycle bridge across the harbour in The construction of Bryggebroen pedestrian and cycle bridge across the harbour in Copenhagen reduced journey times because adjacent bridges are at a distance of 1km and 3 km respectively COWI (2008). The bridge cost DKK 77 Million and the net present value (NPV) and the internal rate of return (IRR) were DKK 36 million (2008 costs and prices) and IRR 7.7% respectively. Note that the network effects analysis was based on conjecture, not evidence. The re-construction of the Gyldenløvsgade-Nørre Søgade-Vester Søgade intersection to solve a conflict between right turning cars and cycles reduced injuries by three per year COWI (2008). The cost was DKK9 million, the NPV was DKK 59 million and the IRR was 33%.

The table below draws on a 'component based' review by Pucher et al. (2010) of the effect of different types of infrastructure for cycling.

| Infrastructure measure | Effect on use | Effect on safety | Effect on perceptions |
|---|---|---|---|
| Cycle lane on the carriageway | Mixed | No evidence | Little effect |
| Cycle tracks adjacent to the carriageway | Positive | Mixed | Rated better than lanes |
| Cycle tracks away from the carriageway | Positive | No evidence | Positive |
| Coloured cycle lanes | Mixed | Positive | No evidence |
| Markings to indicate a lane is shared by cycle traffic and motor traffic | No evidence | No evidence | No evidence |
| Two-way cycling on streets that are one way for motor traffic | No evidence | Positive | No evidence |
| Shared bus and bicycle lanes | No evidence | No evidence | No evidence |
| Signed bicycle routes | No evidence | No evidence | Positive |
| Streets primarily for bicycle traffic | No evidence | No evidence | Positive |
| Advanced stop lines at signal controlled junctions (creating a box for cycle traffic to wait in) | No evidence | Little effect | Positive |
| Separate stages for cycle traffic at signal controlled junctions | No evidence | Positive | No evidence |
| Parking | Positive | N/A | Positive |

**Table 1:** Effect of various infrastructure changes on cycling

hoods and full integration with public transport. There is an almost equally long list of measures that are not related to provision of infrastructure which are also

This rather barren set of evidence at the component level is in contrast to the analysis by Pucher and Buehler (2008) of The Netherlands, Denmark and Germany in which they note that the following all 'appear' (their word) to create higher aggregate levels of cycling: separate cycling facilities; extensive cycling rights of way; ample bicycle parking. These are explored in more detail in Box 3 below.

In addition (and considered in other evidence) they note the importance of traffic calming of most residential neighbourhoods and full integration with public transport. There is an almost equally long list of measures that are not related to provision of infrastructure which are also relevant, however, as follows: education and training; promotional events; making driving expensive and inconvenient; restricting car ownership; land-use policies.

20.3.5 Cost benefit appraisal of networks

Meletiou et al. (2005) investigated the return on investment of network wide measures in North Carolina (USA). In 10 years since 1993, $6.7 million was invested in 36.5 miles (58.74 km) of on-road facilities such as wide paved shoulders, wide curb lanes, marked bike lanes, and bridge improvements, 18.15 miles (29.21 km) of off-road facilities, such as greenway trails,

**Extensive systems of separate cycling facilities**

- Well-maintained, fully integrated cycle tracks, cycle lanes and streets primarily for cycle traffic in cities and surrounding regions
- Fully coordinated system of colour-coded directional signs for bicyclists
- Connections creating short-cuts for cycle traffic across what otherwise are dead-ends for motor traffic

**Intersection modifications and priority for cycle traffic at traffic signals**

- Changes to phasing and staging, separate green phases for cycle traffic and lay-out changes to allow cycle traffic to wait ahead of motor traffic, and which are fed by cycle lanes
- Cyclist short-cuts to make right-hand turns (for right hand rule of the road) before intersections and exemption from red traffic signals at T-intersections, thus increasing cyclist speed and safety
- Coloured surfacing across intersections
- Offset timings between sets of traffic signals set in such a way as to ensure a green wave for cycle traffic
- Flashing lights along routes to signal to cyclists the appropriate speed to cycle at to reach the next intersection at a green light

**Bike parking**

- Large supply of good bicycle parking throughout the city
- Improved lighting and security of bike parking facilities often featuring guards, video-surveillance and priority parking for women

**Box 3:** Infrastructure measures relevant to high levels of cycling

side paths, and other shared-use paths, to form an extensive bicycle transportation system linking towns and villages in the northern Outer Banks from Corolla south to Nags Head and west to Manteo. $60 million brought to the economy and 1407 jobs supported because of cycling. Return on investment about 9:1.

Wang et al. (2005) investigated the construction of five bike/pedestrian trails for leisure use in Lincoln Nebraska and their continued maintenance. The total cost of construction and maintenance for all five trails per annum (construction costs ammortised over 30 years) is $527,215 (1998 costs and prices). The benefit to cost ratio was found to be 2.94.

Börjesson and Eliasson (2012) considered facilities in Stockholm for cycling, and estimated values of time of cycle users. Bicycle paths are socially profitable at yearly average cycling volumes of a little less than 300 cyclists per day, which in urban contexts is very low.

Gotschi (2011) modelled the benefits of the long term investment in cycling infrastructure by the City of Portland. Benefit-cost ratios based on health care and fuel savings are 3.8, 2.3, and 1.3 for the following scenarios: $100 million renewal ('basic'), $329 million to put 80% of population within quarter of a mile of a bikeway, and 'world class' plan of $773 million. Using a value of statistical lives saved, the benefit-cost ratios are 53, 33, and 20, respectively.

*20.3.6 Wider measures in relation to cycling*

Jones (2012) investigated the construction of an urban traffic-free cycle route. He found that the provision of a traffic free route is insufficient in encouraging a shift from car travel to cycling for everyday practical journeys. The odds of a respondent making a practical journey by bicycle increases if other family members cycle, and if there would be a feeling of regret if the journey was not made by cycle; and when, on balance, there is a belief in personal ability to make a practical journey by cycle (self-efficacy) and/or a perception that this journey is both possible and easy (controllability).

Yang et al. (2010) included in their review a study of the three year Danish National Cycle City project, which aimed to increase cycling in Odense and included promotional campaigns and infrastructural measures. After adjustment for trends in the region, a 3.4 percentage point increase in cycling was observed between 1996-7 and 2002 (increase in proportion of all trips from 22.5% to 24.6%).

Goodman et al. (2013) investigated the construction of a variety of cycling infrastructure and a variety of programmes to promote cycling in eighteen towns and cities in the UK. Investment of £14 to £17 per head of population per annum resulted in increases in the proportion that cycled to work from 5.8% to 6.8%. This represented a significant increase relative to three comparison groups with a percentage point increase for the intervention towns relative to the matched towns of +0.69% (95% CI 0.60% points, 0.77% points). Other data from a subset of six of the towns (reviewed by Yang et al., 2010) shows increased were found in the proportions of residents who reported cycling for at least 30 minutes once per month (+2.78% or +1.89%, depending on the choice of control areas) or 12 or more times per month (+0.97% or +1.65%).

Rodrigues and Joo (2004) found that the presence of walking and cycling paths and the population density measured at respondent's home location were not consistently related to mode choice. They conclude, however, that natural and built environments in mode choice studies for urban settings is relevant.

Carse et al. (2013) investigated the factors influencing the use of the bicycle in the bicycle-friendly city of Cambridge. They developed a multivariate logistic regression model to examine the socio-demographic, transport and health-related correlates of mode choice for work, shopping and leisure trips. Commuting distance and free workplace parking were strongly associated with use of the car for work trips, and car availability and lower levels of education were associated with car use for leisure, shopping and short-distance commuting trips. The case of Cambridge shows that more policies could be adopted, particularly a reduction in free car parking, to increase cycling and reduce the use of the car, especially over short distances.

Burke (2011) investigated a specific sort of infrastructure investment, a cycle centre. A cycle centre was constructed in Brisbane with a capacity for 420 members to park, shower and change and bicycle maintenance facilities are also offered. At this size, the hub is not viable, but would remove 120,000 motor vehicle kilometres per annum.

*20.3.7 Nature of methods employed*

The methods employed to analyse infrastructure typically comprise of aggregate multi-variable regression modelling, typically using a logistic regression model, and also cost benefit analysis.

The strength of regression modelling is the ability to understand the nature of the impact of one variable relative to other variables. It can be challenging, however, to collect in an appropriate and comprehensive format all of the data necessary to undertake such analysis. Another difficulty which can be revealed in the modelling is related to the fact that many variables are effectively averaged, because the modelling is using aggregate variables. This can mask relationships which exist at the level of the individual.

Cost benefit analysis is an established method for estimating the social benefits of public investment. There are deficiencies in this approach, however, linked with the difficulty of estimating appropriate values of variables such as time and a 'life saved'.

The studies presented here have been undertaken with high quality methodologies.

*20.3.8 Validity, reliability and significance*

The studies presented here are valid and reliable. Some of the studies have resulted in outcomes which demonstrate findings which are significant, as noted above.

*20.3.9 Remaining evidence gaps*

Handy et al. (2014) provides a useful summary of a current research needs and challenges in relation to cycling promotion. Inter alia, they note the lack of knowledge about the relative importance of such support structures as shops and repair facilities. They point out that, despite a significant increase in cycle related research, we still know little about individual factors such as attitudes and preferences in relation to cycling, or factors relating to the households or larger aggregations such as community or city. The most significant point made is that there remains a dearth of studies directly evaluating the effectiveness of strategies to change travel behaviour.

## 20.4 Lessons for Successful Deployment of this measure

*20.4.1 Transferability*

Clearly, every geographical location has unique characteristics, as does the population which lives there. However, the studies included in this review are drawn from a range of countries and localities which allows for a higher level of confidence that the findings are transferable.

*20.4.2 Drivers and barriers from a PESTLE analysis*

Very few of the studies reference political, economic, social, technological, legal or environmental factors which could create barriers to, or be facilitators of, a wider deployment of suitable infrastructure for cycling. Five of the studies have considered the economic benefits relative to the costs of infrastructure investment, and these all find that the investment is very beneficial. There are likely to be political and social barriers which prevent wider construction of infrastructure for cycle traffic, but these have not been revealed in this review process.

*20.4.3 Complementarity*

Some of the evidence (for example Nelson and Allen, 1997) appears to suggest that a network of infrastructure for cycle traffic is sufficient. Jones (2012), however, points towards a much wider range of relevant social factors. Pucher and Buehler (2008), while not having specifically modelled the relationship between cycling and specific infrastructure provision, clearly suggest that there is likely to be a range of intervention, including infrastructure, needed to support greater volumes of people cycling. The aggregate models reported here identify the relevance of different specific infrastructure and other interventions. The models are not, however, constructed in such a way as to elicit understanding about what variables are required at certain levels as being necessary but insufficient conditions in relation to other factors.

It is logical that there has to be a sufficient basis in physical reality to allow for the growth in cycling. On this basis, it is clear that infrastructure for cycling in a key component for a successful SUMP.

*20.4.4 Resilience and durability*

There is no evidence concerning the conditions necessary for on-going success.

## 20.5 Additional benefits

As well as the evidence of economic and financial benefits of interventions discussed above, there are a number of additional benefits that are claimed for these policies:

- *Health Benefits:* Evidence of the health benefits of cycling is well documented, through both improved fitness of those who cycle, and reduction in atmospheric pollutants which affect the health of wider population (when cycle journeys substitute for journeys made by motorised transport).
- *Pedestrian environments (& Walking):* Cycling infrastructure can also improve the environment for pedestrians, thus encouraging walking as a transport mode.
- *Community benefits:* In turn, more cycling and walking as an alternative to car-use offers wider community benefit, improving the 'liveability' of streets and communities, and potentially facilitating greater community cohesion through increased levels of contact between people living there.

## 20.6 Summary

We can be very confident that appropriate infrastructure provision for cycle traffic is a necessary condition to help promote more cycling. The evidence suggests that comprehensive networks of routes for cycle traffic are required. These need to be built up from components such as safe junctions and bridges which create suitably direct routes for cycle traffic. What is less clear is the precise nature of the links in a network, or the types of provision at junctions, that might be deemed suitable by users and potential users. It is clear also, however, that there is a preference in terms of perception that cycle traffic is separated from motor traffic, i.e. separated routes are required.

It would be helpful if future research began to understand in a more detailed way a more precise description of a necessary condition in terms of infrastructure provision. Drawing on Handy et al. (2014) they make the point that we need to know more about attitudes and preferences in relation to cycling.

Success may be defined in terms of the overall proportion of journeys in an area that are undertaken by bicycle. Secondary to that might be the proportion of journeys made for a specific purpose such as commuting. It would be significant for an area to shift cycle use by as much as 10 percentage points in mode share, and this could be achievable over the medium to long term.

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