Practitioner's Guide to Planning, Designing, and Implementing Bicycle Highways in North America

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ABSTRACT

North American cities need excellent bicycle infrastructure between regional destinations to allow residents to cycle long distances. Planners must make long distance bicycle travel feasible if they are serious about treating cycling as a form of mass transportation (Transport for London, 2014).

Bicycle highways are high quality bicycle routes that connect major destinations and are designed for safe and comfortable long-distance travel. They facilitate comfortable and safe long distance travel. Preliminary research has shown that they are effective in increasing ridership and attracting users from other modes such as cars or transit.

The purpose of this review is to offer guidance on how practitioners can plan, design, and implement bicycle highways as part of a bikeway network. The study draws upon literature and design guidance and seven case studies that are emerging in Europe and Asia. Through this review we propose a definition for bicycle highways, differentiate them from other bikeway facilities, present research on their effects, and characterize their planning, design, and implementation. We conclude this papers with seven policy takeaways for North American practitioners.

There are several key findings that are discussed in detail in this review:

- The planning, design, and implementation of bicycle highways will most likely occur at a regional level. This is because these routes often cross jurisdictions as they cover long distances (typically more than 5km).
- Route choice is integral to bicycle highway planning. Route planning must balance the need to minimizing stops with directly connecting regional destinations. There are several strategies to choose a route type.
- Bicycle highways are a route type and not a specific bikeway facility. A route type describes its function within a cycling network, whereas bikeway facilities describe its form. Facilities are typically differentiated by the separation and exclusivity of bikeways from other modes. There is comprehensive guidance in North America for facility design, while guidance on the function of bikeways within a network of routes is lacking.
- A single bicycle highway may have segments of different bikeway facility types such as cycle tracks or multi-use paths. Because these routes cover long distances, they respond to the local context while meeting minimum design and quality standards.
- Branding and route identity is an essential component of the design of bicycle highways
- Bicycle highways are the highest level route in a cycling route network hierarchy.
- North American practitioners and design guidance should strongly consider developing a cycling networks with a hierarchy of bicycle route types. Each route types would serve a different function within the network. This paper offers a similar taxonomy to a roadway hierarchy with arterial, collector and access routes (based on literature from Transport for London, the Netherlands, and Minneapolis).

INTRODUCTION

North American cities lack excellent bicycle infrastructure between regional destinations (Thomas et al., 2015). At the same time, new bicycle technology is enabling users to comfortably bike long distances and can reduce residents' dependency on transit and private motor vehicles. Electric bicycles, for example, are becoming commonplace and affordable. In Germany, over 700,000 e-bikes were sold in 2017, which represents 20% of total bicycle sales (Oortwijn, 2018). Long-distance cycling infrastructure is necessary to support this new mobility trend and reduce dependency on motor vehicle trips. Planners must make long distance bicycle travel feasible if they are serious about treating cycling as a form of mass transportation (Transport for London, 2014). Bicycle highways can serve comfortable and safe long distance travel.

Bicycle highways are a cycling infrastructure innovation that has emerged over the last decade (Thomas et al., 2015). They are purpose-built to facilitate long-distance trips between regional destinations with minimal stops.

Bicycle highways have been built in Denmark, the Netherlands, Belgium, Germany, China, and the United Kingdom, and more are on the way. New networks are being planned in countries such as Australia, France, and Norway. The Norwegian government unveiled a plan in 2016 to invest nearly $1 billion USD on a network of ten routes that will connect the country's cities (O'Sullivan, 2016).

Despite their expense, preliminary research has shown that they are effective investments that contribute towards improving population health and decreasing traffic congestion. Ridership has increased by an average of 77% on London's first four bicycle highways since inception, and 30% of those trips are new or have switched from a different transportation mode (Transport for London, 2016). On other routes, the introduction of bicycle highways in London led to an increase of cyclists as high as 1000% from 2003-2012 (Law, Sakr, & Martinez, 2014). The Capital Region of Denmark has estimated a 19% return on investment in bicycle highways in terms of reduced sick days, congestion, and health care costs (Cycle Superhighways Secretariat, 2016).

As a recent innovation, there is no guidance for how to plan, design, or implement bicycle highways in North America. Given that there are a number of robust case studies and international design guide documents to learn from, there is an opportunity to proactively develop guidance for North American practitioners.

Objective

The purpose of this review is to offer guidance on how practitioners can plan, design, and implement bicycle highways as part of a bikeway network. The study draws upon case studies and guidance that are emerging in Europe and Asia. Bicycle highways are defined here as high quality bicycle routes that connect major destinations and are designed for safe and comfortable long-distance travel (discussed in the definitions section).

Naming conventions
We use the term bicycle highway in this paper but recommend thorough consideration of the term before it is widely adopted in North America. National-level organizations such as the Transportation Association of Canada (TAC) or the American Association of State Highway and Transportation Officials (AASHTO) should weigh the benefits different names when incorporating this route type into network planning guidance.

These routes are called 'bicycle highways' in the Dutch CROW Manual, 'cycle highways' in German documentation, and 'cycle superhighways' by Transport for London (TfL) and in Danish documentation.

STUDY APPROACH

To complete this review, we drew from a broad range of academic and non-academic sources including case studies, peer reviewed articles, grey literature, design guides, and news articles. This was conducted through internet searches for relevant literature and citation mining. There is a reliance on non-academic literature in this review because bicycle highways are a new and relatively unstudied phenomenon. Seven international bicycle highway case studies informed this review, all of which are mostly or completely constructed. Only one of them (the regional trail system in Minneapolis) is not referred to by local planners as a bicycle highway (or similar term).

We developed criteria to compare and analyze the case studies and definitions based on commonalities that arose during preliminary analysis of the information reviewed. We synthesized this analysis to identify and describe considerations for bicycle highway planning, design and implementation for North American practitioners (Results of Review). From this research we developed policy implication 'takeways' on bicycle highways and bicycle network design for practitioners.

We examined four areas of bicycle highways:

1. Definitions:
The purpose of this section is to offer a definition of bicycle highways for North American practitioners based on bicycle highway definitions found in the literature, design guides, and case studies. We examined thirteen one-to-three sentence definitions of bicycle highways. The most common or salient characteristics in the definitions were compiled to create the definition recommended in this paper.

2. Difference between bicycle highways and other bikeway facilities
In this section we compare the definitions and characteristics of bicycle highways in an effort to charactertize them within the taxonomy of facility and route types that are discussed in the literature.

3. Effects of bicycle highways:

The purpose of this section was to compile the preliminary research on the effects that bicycle highways have had on ridership and return on investment. This was primarily informed by grey literature. Very little literature exists on the effects of bicycle highways.

4. Characteristics of bicycle highways planning, design, and implementation:
The purpose of characterizing bicycle highways was to inform considerations for North American practitioners to plan, design, and implement bicycle highways.
This was informed through comparing and contrasting the case studies.

We used the following criteria to compare and contrast the case studies on their planning, design, and implementation. These criteria were developed based on commonalities that arose during our initial analysis. They allowed us to develop general principles and considerations for how to plan, design, and implement bicycle highways.

Planning Criteria

- Purpose for implementing - *comparing reasons for building the routes*
- Route choice - *comparing strategies for siting bicycle highways and tradeoffs*
- Type of trip targeting - *comparing what kind of trips were targeted with these routes*
- Areas served - *comparing what these routes connect*
- Role within cycling network - *comparing their relationship to the broader cycling network*

Design Criteria

- Design speed - *comparing strategies around designing to a certain riding speed*
- Intersection treatments - *comparing how routes managed intersections*
- Width - *comparing route widths*
- Separation - *comparing route exclusivity*
- Branding - *comparing whether routes had branding*
- Consistent Wayfinding - *comparing whether routes included for wayfinding*
- Context specific design - *comparing if the routes allowed design variation in segments*
- Consistent lighting - *comparing if the routes required lighting*

Implementation Criteria

- Governance - *comparing strategies for governance and maintenance*
- Communication - *comparing strategies for communication*
- Capital funding - *comparing how routes were funded*

RESULTS OF REVIEW

The information from the methods above informed four areas of bicycle highways, covered below: Definitions; Differences between bicycle highways and other bikeway facilities; Effects of bicycle highways; and Characteristics of bicycle highways.

Bicycle highway definition

We propose that bicycle highways are defined as 'high quality bicycle routes that connect major destinations and are designed for safe and comfortable long-distance travel'.

This definition was informed by combining the salient and most universal elements from thirteen one-to-three sentence definitions of bicycle highways found in case studies, academic literature, and grey literature, and design guides. Two of the definitions were found from North American sources: Caltrans and a report by the Federal Highway Administration (FHWA). They recognize this route type and have made efforts to describe it. Despite this, bicycle highways are not found in FHWA, AASHTO, or National Association of City Transportation Officials (NACTO) design guidance.

There was broad agreement among the definitions that these are high quality routes (9 of 13) that facilitate long distance trips (8 of 13). Long distance is usually defined as 5km or greater in the details of the route characteristics. Minimizing stops or obstacles was emphasized in six definitions, as was safety. Six of the definitions included connecting major destinations and a further two included directness.

Only three of the thirteen explicitly described these as separated from other modes of transportation. Five of the thirteen emphasized that these facilitated quick travel. Directness was mentioned by two and commuters were mentioned by three. The definitions are listed below:

Case studies:

Danish Cycle Superhighways Secretariat

> "A Super bike path is a bike path where the quality has been lifted, so it's easy and comfortable to choose the bike as a means of transportation - also on long stretches. The super bike paths are designed with as few obstacles as possible, while great emphasis is placed on safety, safety and high comfort" (Sekretariatet for Supercykelstier)

Belgian Province of Flemish Brabant

> "A bicycle motorway is a bicycle connection between attraction poles, which is (more) friendly and high-quality about the entire process" (Provincie Vlaams-Brabant – Dienst Mobiliteit, 2014)

Academic literature:

Health impact model for modal shift from car use to cycling or walking in Flanders: application to two bicycle highways

> "The bicycle highways offer commuters a convenient, high quality and safe connection between cities... Generally separated from motorised traffic, only accessible by bike and with very few level crossings" (Buekers, Dons, Elen, & Panis, 2015)

Measuring the Changes in Aggregate Cycling Patterns between 2003 and 2012 from a Space Syntax Perspective

> "Cycle Superhighways (CS) are designed to be direct, continuous, comfortable, easy to find and safe" (Law et al., 2014)

The Project "ecycle Superhighway – Facilitating the Changeover" – New Ways to Promote Sustainable Means of Transportation

> "Its purpose is to facilitate quick and safe cycling, in order for people to get quickly from A to B by bike... [with] enough sectional width, a ground surface which is as flat as possible, and a ride which is as conflict-free as can be provided, with minimal waiting time for cyclists at junctions" (Piccinini, Dienberg, & Karnehm-Wolf, 2014)

Health in All Policies? The case of policies to promote bicycle use in the Netherlands

> "Long distance roads for bicycles only" (den Broeder, Scheepers, Wendel-Vos, & Schuit, 2015)

Industry/grey literature:

Cycle Highways Innovation for smarter People Transport and Spatial Planning (CHIPS)

> "A Cycle Highway is a mobility product that provides a high quality functional cycling connection. As backbone of a cycle network, it connects cities and or suburbs, residential areas and major (work)places and it satisfies its (potential) users" (Cycle Highways Innovation for smarter People Transport and Spatial planning)

Caltrans

> "A bicycle highway restricts use to bicyclists, has intermittent entrances and exits, serves longer distance trips (five miles or more), and supports higher-speed travel up to 20-25 miles per hour. As e-bikes extend the range of bicycle trips, bicycle highways may be needed to support longer trips. Primarily a system of separated facilities, connecting segments of separated bikeways or bicycle boulevards may be required. In suburban and rural contexts, these facilities could include low-speed on-street bikeways that also accommodate neighborhood electric vehicles and electric bikes" (Caltrans, 2017)

Danish Cycle Super Highways Documentation

> "A Cycle Super Highway is a cycle highway, where the commuters' needs have been given the highest priority. The project seeks to create routes that offer fast, comfortable and safe service. A Cycle Super Highway is defined both by its location, as well as its physical qualities. The highway should connect areas with many workers and students to their homes, and to public transportation possibilities as well." (Sekretariatet for Cykelsuperstier)

US Department of Transportation Federal Highway Administration

> "Bicycle superhighways (cykelsuperstier) are a recent innovation over the past decade and are designed to support longer trips at higher travel speeds, avoiding most stops and conflicts. Specifically, the purpose its to increase the number of persons bicycling for trips farther than 5 km (3 mi). Although routes may link several types of bicycle facilities together, including separate paths or separate bike lanes, most major barriers (major highways or water barriers) are crossed by bridges, underpasses, or tunnels." (Thomas et al., 2015)

Design guides:

Dutch CROW Manual

> "A bicycle highway is a regional main cycle route with a high-quality finished geared towards facilitating journeys by bicycle over longer distances (between 5 and around 30 kilometres." (CROW, 2017)

Transport for London: London Cycling Design Standards

> "Superhighways are cycle routes running from outer London into central London. They enable safer, faster and more direct cycle journeys into the city... The aim of Superhighways is to improve cycling conditions for people who already commute by cycle, and to encourage new cyclists" (Transport for London, 2014)

Copenhagen guidelines for the design of road projects

> "Cycle Super Highways are a collaborative regional project between the City of Copenhagen and the neighbouring municipalities. The focus is on long distance commuting; joint quality standards have been developed for the Cycle super highways." (City of Copenhagen, 2013)

Differences between bicycle highways and bicycle facilities

Bicycle highways are defined by their function, whereas bikeway facilities are defined by their form. Route function is the role of the route within the range of links provided in the network. Facility form is characterized by its degree of separation or exclusivity from other modes (AASHTO Task Force on Geometric Design, 2012; NACTO, 2013; Transportation Association of Canada, 2017).[1] An FHWA publication notes that bicycle highways "may link several types of bicycle facilities together, including separate paths or separate bike lanes" (Thomas et al., 2015). The F35 bicycle highway in the Netherlands, for example, employees different degrees of separation on different segments, but is a single coherent route (Regio Twente, 2009). We therefore describe bicycle highways are route types and not facility types.

Information on route function and network design is high-level, broad, or missing from North American national-level bikeway design guidance. We examined three prominent national-level bikeway guidance documents that are frequently referred to in regional or local design guidance: NACTO Urban Bikeway Design Guide (2014), AASHTO Bicycle Facilities Guide (2012), and the TAC Geometric Design Guide (2017). A supplementary paper from the FHWA is also relevant here.

The NACTO Urban Bikeway Design Guide (2014) offers no network guidance.

[1] The TAC Geometric Design Guide (GDG), for example, defines bikeway facilities "based on varying degrees of separation and/or exclusivity of use among cyclists, pedestrians, and motorists". The American Association of State Highway and Transportation Officials (AASHTO) Bikeway Facilities Guide differentiates bicycle facilities based on degree of separation from motor vehicles, exclusivity to other modes, and the characteristics of the vehicular traffic on the roadway. The NACTO Urban Bikeway Design Guide makes a similar distinction.

AASHTO (2012) gives a laundry list of things to consider, broadly wrapped under two strategies: “Deciding where improvements are needed” (user needs, traffic, barriers, connections to land uses, directness, logic, intersections, aesthetics, spacing, safety security, overall feasibility) or “Opportunistic”. Opportunistic planning is not appropriate as a complete strategy for roadway or transit network development - why should it be appropriate for cycling?

The TAC GDG (2017) offers little guidance beyond stating that “Bikeway facilities should combine to form a network on which bicycle trips can be made effectively and conveniently. In establishing bicycle networks, practitioners should provide intuitive connections between existing and future routes, with direct routes that minimize the diversion distance required”.

There is comprehensive guidance in North America around bikeway facility (form) selection, but little on bikeway network development. This is a gap in the literature.

Effects of bicycle highways

Preliminary research has shown that bicycle highways are effective in attracting cyclists and have a positive return on investment when considering sick days, traffic reduction, and health care costs. As these are new routes, the breadth of research is limited.

London has seen dramatic increases in cycling on their bicycle highways. Cycling increased by an average of 77% on the first four bicycle highway since their inception (from 2010 or 2011 to 2014), and 30% of those trips were new or had switched from other modes (Transport for London, 2016). There has been a 50% increase in the first five months of newest four routes as of 2014 (ibid). Other research has shown that cycling has increased 1000% on some bicycle highways in London (Law et al., 2014).

The Capital Region of Denmark has recorded increase of bicycle commuters along their routes. The Region’s goal was to increase the number of bicycle commuters by 30% (Sekretariatet for Cykelsuperstier). The Farum rote saw a 52% increase in bicycle commuters from 2013 to 2015. The Alberton route saw a 34% increase in bike commuters from 2012 to 2016. This has led the Region to estimate a 19% return on investment on route construction when accounting for sick days, congestion reduction, and health care costs (Cycle Superhighways Secretariat, 2016).

Belgian researchers estimate that in the least favourable case, bicycle highways amount to societal savings that are twice the construction costs in a 20 year period. In the most favorable case, the savings are ten to fourteen times higher than construction costs. Societal savings from increased cycling include reduced health care spending due to increased physical activity, reduced air pollution, reduced congestion, and fewer traffic accidents. The costs included investments in the infrastructure, depreciation, harm from crashes, and air pollution - Flanders is a European hotspot for air pollution. The study concludes that “further investment in bicycle highways seems warranted” (Buekers et al., 2015).

Planning, design and implementation characteristics

Planning Characteristics

We analyzed the case studies across five planning criteria. Several key themes emerged that are important to consider when planning bicycle highways in North America:

- Route choice is integral to bicycle highway planning. It informs design characteristics, affects the number of stops, and determines the route's utility. Connecting regional destinations is key.
- Bicycle highways are purpose driven. Most were implemented to facilitate long distance cycling. Many organizations set specific targets for these routes, such as the number of trips they would like to increase cycling by, or how many vehicular trips they aim to replace.
- Bicycle highways are the highest level route type in an hierarchical cycling network. They form the backbone of a regional network.

Analysis in each of the five planning criteria follows.

Route Choice

Route choice is arguably the most important part of planning a bicycle highway and was an important consideration among the case studies. Route choice planning involved tradeoffs between what corridors are available, access to regional destinations, minimizing stops, minimizing pollution exposure, exclusivity, cost, traffic impacts, etc.

In the case studies, route choice was either opportunistic, based on directness, or determined through a network planning process. These strategies are not mutually exclusive. Many of the routes were opportunistic, whereby planners took advantage of existing conditions. The RS1 in German and the greenway system in Minneapolis were built on former rail corridors. The route in Xiamen was hung below a raised bus rapid transit network. The designers of Xiamen's route, the Danish architects Dissing+Weitling, note that the route was raised in part to attract cyclists with an exciting journey (DISSING+WEITLING architecture, 2017). In Belgium, 80% of the intercity routes are along existing corridors such as rail right-of-ways, canals, or other waterways (Provincie Vlaams-Brabant – Dienst Mobiliteit, 2014). Rail infrastructure operators are even part of the planning team for Belgian bicycle highways. The opportunistic strategy allows planners to minimize the number of stops along the route. This strategy may be especially relevant in North American cities with underutilized rail corridors.

Opportunistic route planning does not work everywhere. It is a 'low hanging fruit' strategy. In North America, many of the exclusive right-of-ways between regional destinations have be carved out for freeways. The Dutch CROW Manual recommends that bicycle highways should not be situated alongside main routes for motorized traffic, due to air pollution and noise pollution(CROW, 2017). Motor vehicle noise and pollution negatively impact cyclist comfort and health (Apparicio, Carrier, Gelb, Séguin, & Kingham, 2016; Bigazzi & Figliozzi, 2014; de Nazelle et al., 2011; Zuurbier et al., 2010). Other opportunistic corridors may not connect destinations, making the route useless for utilitarian trips. A bicycle highway route should serve as many

destinations as possible, “without losing its function as a long-distance connection” (CROW, 2017).

Direct route planning is an important consideration. It impacts route utility, especially for long distance trips. The CROW Manual recommends that the ‘detour factor’ for the trip should be less than 1.2. This means that the bicycle highway should not be 1.2 times longer than the euclidean distance between major destinations (CROW, 2017). Directness is a factor in network planning in most national-level North American design guidance documentation (AASHTO Task Force on Geometric Design, 2012; Transportation Association of Canada, 2017). Defining the major destinations will be a key part of direct route planning.

Network planning is the third strategy to determine bicycle highway routing. TfL employs a five-step model which includes reviewing existing conditions, a cycling level of service assessment, and a porosity analysis, which determines how easily cyclists can get on and off major cycling routes. This informs their cycling network hierarchy, of which bicycle highways are the highest level route type (Transport for London, 2014). TfL’s process may be a best practice for North American cities that are working to prioritize cycling investments or deciding how to plan cohesive bikeway networks.

Adjacent land use is another consideration when planning bicycle highway routes. Planners can maximize the utility of the route by having local destinations in close proximity. Higher density land uses are more likely to generate cycling trips, so locating a bicycle highway in proximity to those may make it more likely that the route is well used (Gerike & Jones, 2015). If designed for mass transportation, these routes may in turn impact land use and serve higher density development.

Purpose

Nearly all of the bicycle highway case studies were created with specific goals in mind. There were a variety of goals cited. Mostly, they were to facilitate long distance trips for commuters. Improving population health, sustainability, and decreasing congestion were other reasons. The Capital Region of Denmark’s bicycle highway network aims to increase bicycle commuting into the capital regional by 30% (Sekretariatet for Cykelsuperstier). According to Danish planners, bicycle highways help increase bicycle commuting by making cycling a competitive transportation alternative to cars and public transport.

The RS1 in Germany was primarily created to replace 52,000 daily car trips in the Ruhr Metropolis (Ruhr Regional Association (Regionalverband Ruhr), 2014). London’s bicycle highways aim to support TfL’s target to have 1.5 million daily bicycle trips by 2026 (Transport for London, 2014). They supported this moving high volumes of cyclists to and from the city centre. Planners of routes in Germany, the Netherlands, Belgium, and China also aimed to increase the use of e-bikes through bicycle highways.

Type of trip targeted

Most of the case studies targeted commuter or other long distance trips, with some exceptions. The Minneapolis greenway system was initially developed through a grassroots campaign and was not aimed a specific user or trip type (Midtown Greenway Coalition). These ‘Principal Arterial Bikeways’, which are the highest order facility in Minneapolis’ bikeway hierarchy, are for ‘any purpose’ and every type of rider (City of Minneapolis, 2010). There is insufficient

information on the Xiamen case study to determine the type of trip targeted. London's bicycle highways were originally created for commuters, but the purpose for these routes has broadened in recent policy statements to include "all Londoners, existing and new cyclists, and for all journey purposes" (Transport for London, 2016).

Areas served

Similar to route choice, most of the bicycle highway networks studied connect significant regional destinations, such as education facilities, population centres, and downtowns, or connected central areas to the suburbs. Copenhagen's network, pictured in Figure 1 below, provides radial connections between local municipal centres and central Copenhagen.

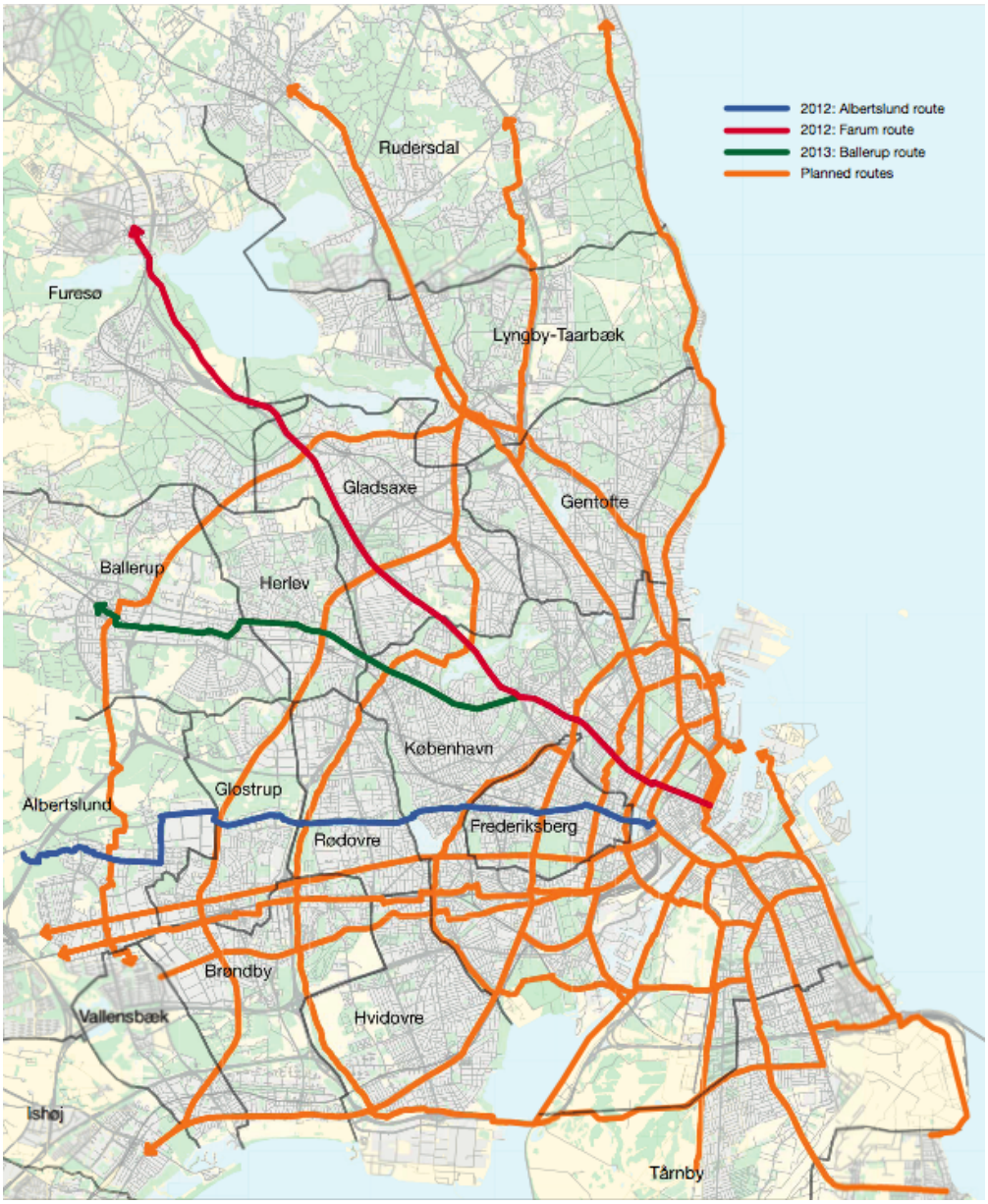

Figure 1. Copenhagen's planned and developed bicycle highway network (Sekretariatet for Cykelsuperstier)

Role within cycling network

In nearly every case study, bicycle highways are the top level of a connected hierarchy of route types. They "deliver logical connections between origins and destinations on a regional scale" (CROW, 2017). In London, bicycle highways are a 'prestige' route, which is the highest level in their hierarchy (Transport for London, 2014). It is critical that the bicycle highway "does not exist in a vacuum", but is part of the overall cycling network, where bicycle highways are the main arteries connecting broader destinations (CROW, 2017).

There is guidance on defining a bikeway route hierarchy from three of the case studies, in which bicycle highways are the highest level route type: The Minneapolis Bicycle Facility Manual's Bikeway Functional Classification (2010), TfL's bikeway hierarchy (2014), and the Dutch CROW Manual's (2017) pyramid of a functional, hierarchically structured bikeway network. The hierarchies in those routes can be categorized into three route types: arterial routes, collector routes, and access routes. Arterial routes are bicycle highways, which facilitate long distance travel. Collector routes facilitate inter-municipal travel and connect to bicycle highways, while access routes connect to local destinations. These routes are connected in a network to provide a seamless cycling experience from origins to destinations. A single long-distance trip may cross all three route types.

The CROW Manual (2017), for example, offers a pyramid of a functional, hierarchically structured bikeway network where "bicycle highways are the "highest order" artery in the network". Bicycle highways are "necessarily integrated with other bicycle connections of lower orders."

FHWA research on international best practices notes that the following cycling network route hierarchy with corresponding facility types (based on the auto network) is applicable to North American network planning (Thomas et al., 2015). In this hierarchy, show in Figure 2 below, a primary route such as a bicycle highway should always be separated on arterial streets but on lower level streets may only require bicycle priority over vehicles.

Bicycle Network Level	Auto Network Level		
	Arterial	Collector	Other
Primary	Always grade-separated	Preferably grade-separated, otherwise roundabout or traffic signal	Bicycle network always has priority (right-of-way)
Other main route	Preferably grade-separated, otherwise roundabout or traffic signal	Roundabout or traffic signal	In principal, priority to the bicycle network
Other route	Roundabout or traffic signal	Priority to collector street or roundabout or traffic signal	Either can have priority

Figure 2. Cycling network and facility hierarchy table (Thomas et al., 2015)

Design Considerations

We analyzed eight design characteristics. Several key design lessons emerged that will be important to consider when designing bicycle highways in North America:

- Route branding or identity arose as the most salient design element. It is an essential component of bicycle highway design. All of the case studies have an identity that communicates to cyclists that they are on a major cycling routes connecting regional destinations. Coherent branding often extended between jurisdictions. A coherent identity is important as these routes have a wide breadth of physical forms. Clear branding also makes these routes intuitive to navigate.
- These routes have minimal stops in order to facilitate comfortable and quick long-distance travel. Route choice is critical but stops can be minimized through grade separation or intersection treatments that prioritize cyclists. A range of options are available to mitigate challenges.
- Bicycle highways are bicycle priority routes, and cyclists are generally prioritized by design in the right-of-way and at intersections.
- Route design can vary in response to the local context. This includes mode separation, lighting, and track width. Certain qualities such as the branding and wayfind should remain consistent throughout.
- There are minimum standards of quality that should be adhered to for most of the route. Some cases define this minimum through design speeds, whereby designers ensure the route is comfortable at that speed.
- Many case studies included cycling amenities as a packaged portion of the bicycle highway. These amenities included electric bicycle charging stations, tire pumps, and rest areas.

Below, we present the results of the case study comparison for each of the eight design characteristic studied.

Design speed

Five of the seven case studies listed a specific design speed, ranging from 20km/h to 30km/h. This means that these facilities are to be travelled on at speed, with appropriate sight lines, corner radii, and design width. The Belgian case study notes that straight sections should have sight lines that leave appropriate reaction times at 30km/h but that corners should be comfortable at 20km/h (Regio Twente, 2009).

The Dutch CROW Manual notes that the ideal design speed is 30km/h but that the ‘gateway to gateway’ average speed should be 25km/h (CROW, 2017).

The Danish example goes against the grain to discourage high speed travel. “At the Super bike paths we focus on flow rather than high speed” where cyclists do not need to stop and can maintain a consistent speed (Sekretariatet for Supercykelstier, 2015). TfL does not suggest a design speed for bicycle highways but rather emphasize designing routes that can move high volumes of cyclists.

Intersection treatments

In order to reduce effort needed to travel long distances, cyclists need to be able to maintain their speed. This means that stops are minimized, which requires design treatments to prioritize cyclists at intersections. This is a critical component to bicycle highway design and is one of their defining design features. It has broad implications for how these routes are planned and prioritized in the transportation network. The CROW Manual states the maximum number of stops on a bicycle highway is 0.4 stops/km (CROW, 2017). Minneapolis bicycle highways must have less than three stops per mile (City of Minneapolis, 2010).

Minimizing stops is especially challenging in urban areas with fine grained street patterns. Large barriers such as freeways or waterways also pose challenges. Intersecting these large barriers may be inevitable on longer, regional routes. Stops can be minimized and conflicts can be reduced by taking advantage of exclusive right-of-ways, grade separation, or intersection priority treatments.

Most of the Belgian bicycle highways (80%) run alongside exclusive right-of-ways, such as rail corridors, canals, or freeways. This allows stop-free travel on long stretches of interurban bicycle highways. Belgian planners have invested into grade separated crossings where these routes intersected freeways, for example (Provincie Vlaams-Brabant – Dienst Mobiliteit, 2014).

Three of the seven cases were mostly or entirely grade separated. The bicycle highway in Xiamen, China was hung below an elevated bus rapid transit network. The regional trail system in Minneapolis runs mostly along converted rail corridors, as does the RS1 in Germany.

Denmark plans to implement ‘green waves’, a Swedish cycling innovation (Sekretariatet for Supercykelstier, 2015). Stockholm’s Götgatan cycling project coordinates green lights on a 9-km stretch of road, “which allows bicyclists in one direction to travel this distance (if they ride at 18 km/hr) without putting their foot down for a stop light” (Thomas et al., 2015).

Width

Minimum widths range from 1.5m to 2.5m on one-way segments and 3.5m to 4.5m on two-way segments. The CROW Manual wraps this topic within ‘comfort’. Faster cyclists should have enough space to comfortably pass those riding at a leisurely pace, and cyclists should be able to comfortably ride two abreast and socialize (CROW, 2017). TfL states that “in an era of mass cycling, facilities designed for minimal cycling will not work” and recommends a minimum facility widths of at least 2m in either direction (Transport for London, 2014). TfL goes further, and recommends having extra width where cyclists will be slowing to or speeding from a stop in order to leave sufficient space for cyclist to safely ‘wobble’ at slow speeds (ibid).

Mode Separation

Most case studies used exclusive, mode separated facilities such as cycle tracks. Mode separation is a priority but not a requirement for bicycle highways. Regardless of separation, cyclists should have priority along the entire route and especially in mixed traffic segments. The F35 route in the Netherlands has sections that mix with pedestrian traffic or low-volume and low-speed vehicular traffic. The CROW Manual takes a practical approach: there may be advantages for bicycle highways to use local streets in segments: piggybacking on well-lit roads or minimizing a route detour between destinations. There is comprehensive guidance in North America to draw on for bikeway facility choice under various circumstances.

Consistent branding

Every case study had specific bicycle highway branding. Identity is an essential component of bicycle highway design. The European project tilted Cycle Highways Innovation for smarter People Transport and Spatial Planning (CHIPS) notes that branding is necessary so that the route is recognizable at every junction (Cycle Highways Innovation for smarter People Transport and Spatial planning). Users should be able to intuitive recognize and use the route. Five Belgian provinces coordinated to develop a symbol and route nomenclature to make bicycle highways instantly recognizable as a bicycle highway. A 2,400km network of bicycle highways are planned in Belgium with consistent branding, shown in Figure 3 below (Vlaamse Provinciebesturen). The Dutch name their bicycle highways in the style of their freeway system, as did the Germans with the 'RS1'.

Some of the cycle superhighways in London were surfaced in 'Barclays blue' because the first routes were sponsored by Barclays bank. This made them instantly recognizable. Bicycle highway recognizability was the top priority in London- the first bicycle highways were often just blue-painted on-street bicycle lanes (Buczyński, 2018). Newer routes have blue thermoplastic paint patches to indicate to riders that they are on a bicycle highway, and offer higher degrees of mode separation.

The planners of the F35 bicycle highway in the Netherlands rolled out the "red carpet" on this route by paving it in a red colour (Regio Twente, 2009).

Figure 3. Belgian bicycle highway branding, identity, and wayfinding

Consistent wayfinding

Almost every bicycle highway incorporated wayfinding as an essential design element. The lone exception, Minneapolis, incorporated some wayfinding but it is not found consistently throughout the network (City of Minneapolis, 2010). Wayfinding is a core principle of the CROW Manual (CROW, 2017). Routes in London have distinct and highly visible design rules for general wayfinding signage in the city, where major destinations should have the time to destination in

minutes. The TfL Cycling Design Standards (2014) note that TfL has commissioned a new wayfinding system for cycling in London: A Tube Network for the Bike. Wayfinding would have to be regionally coordinated for routes that span multiple jurisdictions.

Context specific design

As bicycle highways may require regional planning efforts, local planners are often given leeway to respond to local design challenges. Some cases note a minimum base for bicycle highway design, such as the CROW Manual (2017), but note that local designers may tweak designs to accommodate local circumstances. Copenhagen's network was planned regionally and has minimum design requirements, but local municipalities are free to respond to local design challenges as they see fit (Sekretariatet for Supercykelstier, 2015).

Consistent lighting

Some case studies required lighting at night, while for others it depended on the local context. The planners of one segment of the Copenhagen's network installed a lighting feature to allow night-time riding, though this was not a minimum design requirement to be considered part of the bicycle highway network. (Sekretariatet for Cykelsuperstier).

Implementation Characteristics

Three characteristics for bicycle highway implementation stood out: governance, communication, and funding. Governance and funding were typically a regional affair in the case studies as bicycle highways were expensive and crossed boundaries. Some of the case study organizations prioritized communication strategies to ensure residents understood the projects.

Governance

Governance for these cases was mostly regional. Copenhagen and the 23 municipalities in the Capital Region of Denmark recognized that traffic doesn't stop at municipal borders, so alternative modes of transportation must be viable across borders as well. Bicycle highway planning was therefore established at a regional level. An independent secretariat evaluates project performance and identifies bottlenecks and improvements that can be addressed in future expansions. This secretariat is responsible for communication, funding applications and overall management. It coordinates between 23 local municipalities. Municipalities may opt out of the network, which may leave gaps (Sekretariatet for Cykelsuperstier).

The responsibility for London's bicycle highways lies between TfL and the London boroughs (Transport for London, 2014). Where the highways travel along borough-owned roads, TfL works with the boroughs to obtain buy-in and approvals. Where TfL has authority over the road, boroughs are closely involved in the process. It is the responsibility of TfL to engage with broader stakeholders about the route design. They may include ward councillors and the highway authority, local employers, cycling organizations, freight industry representatives, or others.

Another aspect of providing a high quality route is maintenance. A region may need to set standards for snow or leaf clearance and surface maintenance. There is an agreement in

place between the partner governments to provide a high priority for maintenance and snow-clearance for bicycle highways in the Capital Region of Denmark (Zinck, 2014).

Communication
Communication was a core part of the strategy in some of the case studies. Communication generated buy in for the planning process and ensured that residents knew about the routes after they were implemented (Ruhr Regional Association (Regionalverband Ruhr), 2014).

Capital Funding
Bicycle highways can be large infrastructure projects and so may be beyond the means of local governments to independently fund. Much like vehicular highways, different levels of government contributed to the funding of these case studies. Up to half of funding for Dutch bicycle highways is provided by the state government (Zinck, 2014). Minneapolis won federal funding to develop parts of its network (City of Minneapolis, 2010). North American planners could consider sponsorship, as Barclays bank sponsored the initial development of London's network.

POLICY TAKEWAYS

Through this research we identified seven policy takeaways to aid North American practitioners in planning, designing, and implementing bicycle highways as part of a comprehensive bikeway network.

Takeaway 1: The cycling network must serve all trip types and safely move high volumes of cyclists in order to be a form of mass transportation. This requires routes that can move high volumes of cyclists across long distances. Bicycle highways are effective in doing so. Regions need long distance routes with high volume capacity in order to move high volumes of cyclists (Transport for London, 2014). Planners should upgrade key routes in the city to bicycle highway standards in order to facilitate cycling as mass transportation.

Takeaway 2: Bicycle highways need to be distinguishable through branding and consistently high quality. Clear route identity builds clarity around the logic of the network, which makes it easy for residents to navigate. It also communicates that along these routes cyclists can expect to receive priority treatment. The planners of the F35 Route in the Netherlands, for example, created a unique route identity by paving it red (Regio Twente, 2009).

Takeaway 3: Bicycle highway planning is a regional activity. As bicycle highways serve long distances trips, they may cross jurisdictions, which requires regional coordination to provide a consistently high quality cycling experience. This means that regions need to coordinate branding, wayfinding, and minimum quality standards. North American jurisdictions could learn from examples studied here such as the Capital Region of Denmark, which established regional branding, wayfinding, and minimum quality standards while allowing leeway for designers to respond to local characteristics. Defining regional origins and destinations is an integral part of

planning bicycle highways, so land use must directly feed into the planning of networks (Gerike & Jones, 2015).

Takeaway 4: Bicycle highways are a unique route type, not a unique facility type. They are high quality bicycle priority routes that connect people over long distances to important regional destinations like population centres, education facilities, urban cores, transit nodes, or health centres. They are not specific to a level of separation. A single bicycle highway may combine several facility types over its length.

Takeaway 5: Bicycle highways are the highest level of route type in a hierarchical cycling network. They do not exist in a vacuum (CROW, 2017). Within this cycling hierarchy, bicycle highways may be one of several route type that a cyclists takes from origin to destination. Their role is not to take cyclists from door to door. In a study in Minneapolis, people were willing to travel up to an additional 2.5km to access the regional trail system for long distance trips. Good bicycle highway planning requires good transportation network planning.

Takeaway 6: North American practitioners should develop a hierarchy of bikeway route types, and national-level bikeway design guides should include substantial guidance on bikeway network development. Both should put focus on the function of routes in a network hierarchy and the spatial scale on which they operate. Presently, North American national-level bikeway design guidance offers little help on network planning. This is a potential topic for further research but it is worth discussing here because bicycle highway planning is inalienable from cycling network planning.

Mass transportation networks use hierarchies, and planning in hierarchies can help clarify the logic of the system. The Minneapolis Bicycle Facility Manual's Bikeway Functional Classification (2010) suggests that planners should organize cycling networks as "a hierarchy of bicycle routes similar to that of a roadway system". The roadway system is organized through levels in a hierarchy. At the most basic level, the roadway hierarchy is comprised of highways that make long range connections between major destinations, arterials that move traffic within destinations, and local streets that connect to trip origin and destination points (US Department of Transportation Federal Highway Administration, 2013). This strategy moves high volumes of people across spatial scales and is intuitive for users to grasp.

Planning bikeway networks that are hierarchical helps to efficiently use funding and develops the rationale for gaining additional resources. This is because "well-justified schemes which form part of a network are likely to be easier to justify than discrete measures without a clear strategy behind them" (Gerike & Jones, 2015). Planning hierarchical networks would help North American practitioners to rationalize, coordinate, and communicate cycling, and ultimately work to make cycling a viable mass transportation option. The City of Minneapolis notes that their 'Bikeway Functional Classification' "allows for a systematic approach to prioritizing bikeways and creates a mechanism for designing appropriate bicycle facilities based on significance, use, maintenance needs, and funding opportunities while maintaining a clear and uniform public expectation" (City of Minneapolis, 2010).

Takeaway 7: Bicycle highways might influence land use since they have the potential to serve as mass transportation, yet can be sited in close proximity to higher density development with relatively less cost and negative impacts vehicular traffic serving the same right-of-way.

CONCLUSION

The purpose of this review is to offer guidance on how North American practitioners can plan, design, and implement bicycle highways as part of a bikeway network. As part of this objective we defined bicycle highways, compiled preliminary research on their effectiveness, and offered guidance from international case studies on how to plan, design, and implement bicycle highways. This report also offered seven takeaways for North American bicycle highway and bikeway network planning.

The following is a summary of the key learnings and provides direction for further study: Bicycle highways are high quality bicycle routes designed for safe travel that facilitate long-distance travel and connect major destinations. They can safely and comfortably move high volumes of cyclists over long distances. They are built to enable widespread use of e-bikes, reduce dependency on private motor vehicles, connect destinations, and facilitate cycling as mass transportation. Cyclists have priority in bicycle highway corridors. Preliminary research has shown that bicycle highways are effective in increasing ridership and attracting users from other modes of transportation. They have shown to have positive return on investments when accounting for health care costs reduction, traffic reduction, and reduced sick days. These routes are also proving to be popular. The results from public consultation to plan London's newest bicycle highway showed that 83% of more than 3000 responses were in favour of the new route (London Post, 2018). Planning these routes requires careful consideration of the optimal route and their role as the highest level route-type in a regional bikeway network. Well-designed bicycle highways will have an easily recognizable identity, minimal stops, and meet minimum quality standards. Implementing these routes may require regional governance and funding.

Because bicycle highways exist as part of a broader cycling network, this research touched upon how cycling networks are planned and delivered in North America. The current focus in much of the US is creating "low stress" routes (Gerike & Jones, 2015). Bicycle highways deliver a low stress connection, but make cycling a viable option for longer trips that are often underserved (ibid). They connect regional destinations and form the backbone of a network that may include collector and local routes to connect to local destinations and neighbourhoods.

Additional study is warranted on the potential impact if this route type, such as on land use, ridership, trip characteristics, population health, and vehicular congestion. More research is needed on bicycle network planning guidance in North America. Network planning guidance in North American national-level bikeway design guidance is perfunctory. Further research is needed on whether the increased cycling is attributable to higher quality conditions on the routes, whether it is because of improved cycling networks in general, or both. Research should build on initial studies to assess whether these facilities are generally successful in drawing users to make long distance trips over other modes, especially private vehicle trips.

Policy-makers believe that bicycle highways are necessary to accommodate future trends such as e-bikes that better facilitate long distance trips. Planners must make long distance bicycle travel feasible if they are serious about treating cycling as a form of mass transportation. Bicycle highways are a solution to enable safe and comfortable long distance cycling trips.

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