Modeling and Finding Bicycle-Friendly Neighborhoods in America's Most Bicycle-Friendly City

Earl Bossard

San Jose State University, California, USA
bossard3@pacbell.net

Abstract

Description: Ways for evaluating the effectiveness of the bicycle infrastructure component of sustainable urban systems are lacking. This paper measures level of service (LOS) provided by bicycle paths/lanes in Davis, California as the weighted density of bicycle paths/lanes per square kilometer. Separate ratings are developed for "Shared Bike-Ped Path Riders" seeking safer but slower travel along paths and "Bike Lane Riders" seeking faster travel, but willing to face more encounters with automobiles. Rating bonuses (or penalties) are given for LOS factors: bridges, tunnels, traffic signals, stop signs, and street speed limits. A gravity model "Walkscore" type neighborhood access to services rating is developed.
Method and Data Sources: Davis city officials provided data. ArcGIS and Excel were used for calculations.
Implications: Measures developed can be used in allocating funds for bicycle facility improvements, as well as for public information to encourage bicycle usage appropriate to the nature of existing infrastructure.

1. Introduction

Bicycle infrastructure developments such as in-street bike lanes and off-street bike paths provide many quality of life benefits for urban residents such as making bike riding safer (fewer collusions with motor vehicles), making bike riding more pleasant (fewer stressful encounters with motor vehicles, and encouraging more bike riding and fewer motor vehicle trips. More bike riding and fewer motor vehicle trips provide benefits such as: reducing air pollution and greenhouse gases while lowering carbon usage and improving health and well-being by healthy exercise. Biking to work also reduces need for motor vehicle parking facilities and makes cities more walkable. Biking to school helps children develop better health and frees parents/caregivers to undertake more productive activities. Recreational bicycling promotes physical and mental health and encourages complementary supportive land use activities such as park usage, as well as development of eating, entertainment, and shopping services along bikeways.

Planning for bike paths and lanes should be a part of comprehensive cross-disciplinary cooperation to manage the landscape. However, ways for evaluating the effectiveness of the bicycle infrastructure component of sustainable urban systems are lacking. This paper measures a broad concept of level of service[1] (LOS) provided by bicycle paths/lanes in Davis, California as the weighted density of bicycle paths/lanes per square kilometer. Separate ratings are developed for "Shared Bike-Ped Path Easy Riders" seeking safer but slower travel along paths and "Bike Lane Speedy Riders" seeking faster travel, but willing to face more encounters with motor vehicles. Rating bonuses (or penalties) are given for LOS factors: bridges, tunnels, traffic signals, stop signs, and street speed limits. A gravity model "Walkscore" type neighborhood access to services rating is developed.

The quantified bike friendly neighborhood ratings developed in this paper provide a systematic, less subjective basis to judge the bike friendliness of neighborhoods then qualitative descriptions generally provided. These bike friendliness ratings can be used by planners to help determine

[1] Bicycle level of service (BLOS) is a developing concept reflecting the quality of facilities for bicycle travel. LOS concepts were originally designed to reflect the capacity of roadways to move motor vehicles. In the 1990's BLOS qualitative measures were designed to reflect the stress level experienced by bicyclists while riding on roadways with various conditions such as proximity to motor vehicles, lane widths, traffic speeds and mixes and context factors such as parking and land uses along the roadway. This paper introduces a broader concept of BLOS by considering stop signs and traffic lights at intersections and develops separate measures for two classes of users, calculated on the basis of neighborhood areas instead of the bikeway corridors. References 5, 7, 12, and 14 provide more details regarding traditional BLOS measures.

areas meriting bicycle infrastructure improvements. Bike friendliness ratings can facilitate decisions as to where to: live, open a business, shop, go for services, or go for an enjoyable ride.

2. Bicycle friendliness model: speedy bike lane and easy shared use bike-ped path rider bicycle friendliness ratings of Davis neighborhoods

The USA is experiencing a boom in bike usage, especially for adult journeys to work and recreation. "*The urban centers in the United States that have seen the highest levels of bicycle use are those that have built a network of bike lanes and shared use paths as the backbone of their system*." [2] Davis received the first USA city platinum level bicycle friendly rating, in part because of its extensive network of shared use bike paths and lanes with many grade separations from motor vehicle traffic. Davis has 86 kilometers of shared use bike paths and 71 kilometers of in-street bike lanes, along with 24 grade separations of bikeways from streets, express highways, or railroad tracks.

2.1. Components of first Davis Bike Friendly Infrastructure Measures

The fundamental characteristic of the infrastructure measures in Davis is the nature of separation of bike travel from motor vehicles on streets. Shared use bike-pedestrian paths are bikeways physically separated from streets and automobiles, while bike lanes are in-street facilities which expose bicyclists to motor vehicle traffic. The National Association of City Transportation Officials provides a detailed discussion of bike lanes:

> *A Bike Lane is defined as a portion of the roadway that has been designated by striping, signage, and pavement markings for the preferential or exclusive use of bicyclists. Bike lanes enable bicyclists to ride at their preferred speed without interference from prevailing traffic conditions and facilitate predictable behavior and movements between bicyclists and motorists. A bike lane is distinguished from a cycle track in that it has no*

[2] Source: National Association of City Transportation Officials (NACTO) (2012) Urban Design Guide, 2nd ed.

physical barrier (bollards, medians, raised curbs, etc.) that restricts the encroachment of motorized traffic.[3]

Davis does not have cycle tracks alongside the street physically separated from motor vehicle traffic, as is common in China and the Netherlands. Bike friendly rating of cycle tracks will be addressed later in this paper. Consideration for other places will be included in the conference presentation, but not in this paper because of space limitations. The simple first Davis Bicycle Friendly Infrastructure measure relied on separate measures of the lengths of bike lanes and paths, adjusted for the presence of street or path lighting on bikeway networks. This measure stressed the safety advantages of bike paths protecting bicyclists from potentially dangerous encounters with motor vehicles and therefore reduced the measured length of bike lanes by 50%, while maintaining the full length of bike paths in creating the artificial measure of bikeway kilometers shown in Equation 1.

$$\text{Bikeway kilometers} = \text{path kilometers} + 0.5 \times \text{lane kilometers} \quad \text{(Eq. 1)}$$

Equation 2 shows the calculation of the likelihood of reaching bicycle friendly infrastructure in each neighborhood (U.S. census tracts) as the weighted density of bikeways per unit of area in the neighborhood.

$$\text{Bikeway Densities} = \text{Bikeway kilometers} / \text{Neighborhood areas} \quad \text{(Eq. 2)}$$

Bikeway Lighting: The absence of bike network street or path lighting was considered an unfriendly aspect of some bikeways, so we determined the portion of bike lanes and bike paths in each census tract which were unlighted, using ESRI's Arc GIS program and the geographic location of each path and street light, along with their area of effectiveness depending on their height (Street lights lighted a circle with a radius of 45.72 meters (150 feet); Path lights lighted a circle with a radius of 22.86 meters (75 feet)). We drew buffers around each light and overlaid them upon the bike network downloaded from the City of Davis website.[4] Equation 3 shows the calculation of the estimated weighted density of bikeways in each census tract using the length of lighted and unlighted bike paths and lanes.

$$\text{Weighted Density Bikeways/Sq. Km} = (1.1 * \text{lighted path kms} + 1.0 * \text{unlighted path kms} + 0.55 * \text{lighted lane kms} + 0.5 * \text{unlighted lane kms}) / \text{area in sq. kms} \quad \text{(Eq. 3)}$$

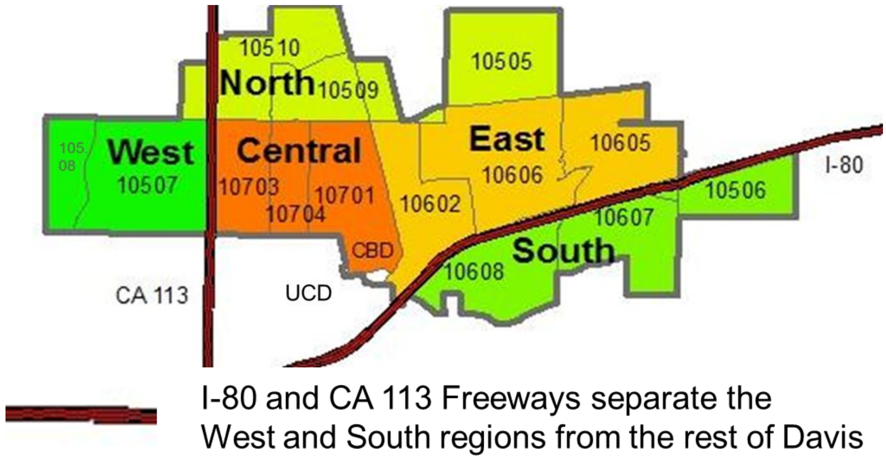
[3] Ibid.

[4] http://bicycles.cityofdavis.org/.

Figure 1 shows data for the simple first Davis Bike Friendly Infrastructure Measures.

		Weighted Densities Bikeways / Sq. Mile		Bikeway Lengths Feet		Lighted Shares		Tract Area	Grade Separated Bikeway
Community	Census Tract	Rank	Bkwy_PSM	Paths	Lanes	Paths	Lanes	Sq. Miles	Facilities
Mace Ranch	106.05	1	14.39	25,411	26,783	100.0%	100.0%	0.79	4.0
West Davis	105.07	2	12.71	47,500	34,306	90.3%	100.0%	1.05	3.5
South Davis	106.08	3	12.47	37,219	30,335	100.0%	96.7%	0.87	6.0
Covell Park	105.09	4	11.55	15,965	13,263	91.6%	95.5%	0.40	2.5
Northstar	105.10	5	10.25	25,996	16,174	99.7%	100.0%	0.69	1.5
Wild Horse*	105.05	6	7.59	30,449	20,592	98.0%	94.1%	1.12	0.5
South Davis	106.07	7	6.75	13,134	17,152	100.0%	91.3%	0.67	1.5
East Davis	106.02	8	5.60	7,086	24,413	100.0%	84.6%	0.71	0.5
East Davis	106.06	9	5.08	11,833	31,171	98.2%	100.0%	1.12	0.0
Central Davis	107.03	10	4.65	4,855	13,053	87.2%	100.0%	0.51	0.5
West Davis	105.08	11	4.41	3,895	6,978	100.0%	100.0%	0.35	0.0
Central Davis	107.04	12	4.34	405	13,354	100.0%	87.3%	0.33	0.0
East Davis	105.06	13	4.33	4,314	10,962	100.0%	100.0%	0.47	0.0
Downtown	107.01	14	4.23	4,183	24,949	100.0%	83.0%	0.80	2.5
		Davis	Feet:	232,244	283,484				23.0
		Totals	Miles:	44.0	53.7	96.8%	95.1%	9.88	

Fig. 1. First Bicycle Friendly Infrastructure Ratings for Davis Census Tracts



Map 1. Davis, California Census Tracts and City Regions with UCD and CBD

Map1 shows the location of the 14 census tract neighborhoods in Davis for which bicycle friendly measures were developed. Note that the central business district (CBD) is in the south central part of Davis, close to the University of California Davis campus (which is outside the city limits). Davis is divided by two major express highways, with Interstate Highway 80, the main road between San Francisco, Sacramento, Chicago, and New

York City cutting off South Davis from the rest of the city, while the California 113 freeway cuts off West Davis from the rest of the city. Davis officials have gone to great lengths to provide expensive grade separated bikeways to cross over or under these highways to tie the city together for bicyclists.

2.2. Refined bicycle friendly measure refinements

While the First Davis Bike Friendly Infrastructure Measures were generally well received, objections were raised by some strong adult bicycle riders who said that they preferred bicycling in bike lanes in the street where they could ride at up to the legal speed limit for cars, while not having to slow down for pedestrians, as would be the case on the shared use bike-paths. In response the author decided to produce two refined bicycle friendly measures: the Shared Use Bike-Ped Easy Rider measure weighted as in the first measure, to favor shared use bike-ped paths over bike lanes, while the Bike Lane Speedy Rider measure favored speedy in-street bike lanes over the slower shared use bike ped paths.

Both refined infrastructure measures were adjusted for physical characteristics effecting bicycle friendliness including: bonuses for grade separations, penalties for excessive traffic speeds adjacent to bike lanes, penalties for trip continuity impediments (stop signs & traffic lights), and penalties for unlighted bikeways.

A second measure of bicycle friendliness was constructed, the relative accessibility of each neighborhood to likely land use destinations for bicyclists. This “Bicycle-Score” Gravity Model Estimating Accessibility to Diverse Destinations measure included access to: retail shopping and services; community facilities, schools, the University of California Davis campus; parks; and the Davis Amtrak Train Station, which provides 16 trips a day to the nearby Sacramento state capitol, as well as the San Francisco Bay area.

The final Bicycle Friendly Measures are averages of the Infrastructure and Bicycle-Score Gravity Model Ratings.

2.2.1. Separate measures for riders preferring bike lanes or shared use Bike-Ped paths

Bicyclists’ attitudes regarding how willing they are to deal with motor vehicle traffic differ. A few strong and fearless committed cyclists don’t mind interacting with motor vehicles and will bike on streets in traffic lanes, as permitted by law. Bike Friendly Measures are for the rest of the potential bicycling population. In-Street Speedy Bike Lane Riders prefer biking on streets with marked bike lanes, where they can ride at speeds of up to the legal limit. Many of these Bike Lane Riders are adult bicycle commuters. Off-Street Easy Bike-Ped Path Riders prefer biking on multi-user paths prohibiting motor vehicles (although shared with pedestrians). These Bike-Ped Path Riders include youths, the elderly, recreational riders, and adults preferring to ride in a safer, although perhaps slower manner.

Ninety per cent of potential bike riders prefer off-street bike paths which exclude motor vehicle traffic or in-street cycle tracks baring motor vehicles.[5]

There are separate measures for riders preferring bike lanes or paths. As Speedy Bike Lane Riders prefer in-street bike lanes over off-street multi-user bike paths, Off-street shared bike-ped path length values have been reduced by 50% in the Bike Lane Rider measure. As Easy Bike-Ped Path Riders prefer off-street shared bike-ped paths over in-street bike lanes, In-street bike lane length values have been reduced by 50% in the Bike Path Rider measure.

2.2.2.1 Negative effects of unlighted bikeways: The lengths of unlighted bike paths and bike lanes were reduced by 20% to reflect their unfriendliness for night bicycle riding.

2.2.2.2 Positive effects of grade separations: Grade separations are tunnels under or overpasses over streets, freeways, or railroad tracks. Davis has 24 grade separations enabling bicycle riders to avoid vehicle traffic. A bonus of 152.4 meters (500 feet) additional bikeway length is added in the infrastructure measure for each grade separation.

2.2.2.3. Negative effects of traffic lights and stop signs: "*Bikeways should be planned to allow for as few stops as practical, as bicycling efficiency is greatly reduced by stops and starts*."[6] The lengths of bike paths and bike lanes used for the weighted density calculations were reduced for each traffic light and stop sign which impeded free flowing bicycle travel along a bikeway. Recorded lengths of bikeways have been reduced by 76.2 meters (250 feet) for every stop sign effecting riders on a Bike Path or Bike Lane. Traffic lights have a lesser reduction of 38.1 meters (125 feet). Sometimes they are green, and even if red, they often have a

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[5] Source: Topeka, Kansas Bicycle Plan

[6] Footnote: AASHTO, 2-13.

control device enabling bicyclists to get a green light and safely cross a busy street.

2.2.2.4. Negative effects of speed of traffic adjacent to bicycle lanes: The higher the speed of motor vehicles colliding with bicyclists, the more severe the collision for the bicyclists. Higher traffic speeds alongside in-street bike lanes lead to greater dangers for bicycle riders. A penalty reduction in bike lane length is applied for increases in speed limits over 40 kph (25 mph). This penalty reduces lengths of bike lanes measurements by 10 % for every 8 KPH over 40 KPH.

2.2.2.5 Summary of infrastructure length adjustments to reflect bicycle friendliness

1. Negative Effects of Unlighted Bikeways: Reduce lengths of Unlighted Bike Paths & Bike Lanes by 20%.
2. Positive Effects of Grade Separations: Increase lengths of Bike Paths by 152.4 meters (500 feet) for each bike path tunnel, underpass, or overpass.
3. Negative Effects of Traffic Lights and Stop Signs: Reduce lengths of bike paths and bike lanes 38.1 meters (125 feet) for each traffic light. Reduce lengths of bike paths and bike lanes 76.2 meters (250 feet) for each stop sign.
4. Negative Effects of Traffic Speeds > 40 kph on adjacent bike lanes: Reduce lengths of bike lanes measurements by 10 % for every 8 kph over 40 kph.

2.2.2.6 "Bicycle-score" gravity model estimating accessibility to diverse destinations in Davis census tracts

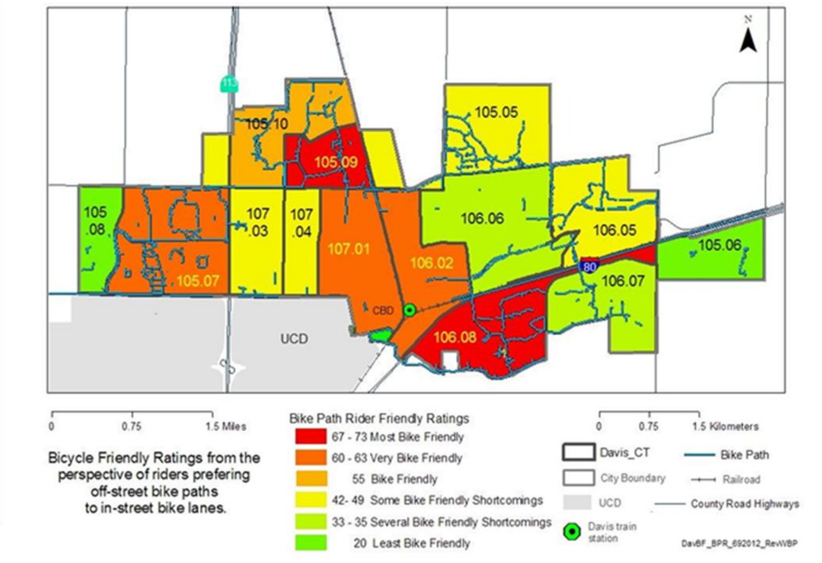
Convenient access to diverse destinations visited in the community on a regular basis is an important part of bicycle friendliness. A gravity model was used to estimate the accessibility of each census tract to a diverse set of land use destinations. The online database available for the Walkscore.com walkability ratings was used. Walkscore.com has recently released a "Bikescore.com" index for 100 of American cities. With half of Davis neighborhoods rated as "Biker's Paradise" and two having perfect scores of 100 .[7]

[7] www.Walkscore.com

3. The Bike Friendly Relative Ratings are the average of: the Infrastructure Relative Ratings and the Bicycle-Score Gravity Model Relative Ratings.

The Davis Bike Friendly Relative Ratings for Easy Rider Shared Use Bike-Ped Paths are shown in Map and Figure 2 below.

Some reasons for relative bicycle friendly census tract ratings of Davis, California census tracts are that generally the closer the tract is to downtown Davis, the better is its bicycle accessibility score. Generally the longer ago the tract was developed, the higher its Bike Lane Rider score is likely to be relative to its Bike Path Rider score because bike paths were not built until the 1960's.



Map 2. Bicycle friendly ratings

Census tract 106.08, with the best Infrastructure scores for both Bike Path Riders and Bike Lane Riders and a Gravity Model Accessibility score about half as good as the Downtown best, has the best of both Bicycle Friendly Rider ratings.

Some implications of relative bicycle friendly census tract ratings are that any census tract with much higher Bike Lane Rider than Bike Path Rider Bicycle Friendly ratings is less suitable for children and the elderly than for other adults.

	Ranked by Bike Path Friendly Ratings				Category Class	
	Location or Neighborhood Name	Census Tracts	Bike Path Rider	Bike Lane Rider	Bike Path Rider	Bike Lane Rider
1	South Davis: SE of Downtown	106.08	73	73	1	1
2	North Davis: Covell Park	105.09	67	66	2	2
3	Central Davis: Downtown	107.01	63	71	2	1
4	West Davis: Lake to CA 113	105.07	62	60	2	2
5	East Davis: East of RR to Poleline	106.02	60	69	2	1
6	North Davis: Northstar & Senda Neuva	105.10	55	53	3	3
7	East Davis: Mace Ranch	106.05	49	51	4	3
8	Central Davis: Anderson to Oak	107.04	46	64	4	2
9	Northeast Davis: Wild Horse (with golf course)	105.05	44	43	4	4
10	Central Davis: CA 113 to Anderson	107.03	42	49	4	3
11	East Davis: Poleline to Monarch	106.06	35	45	5	4
12	South Davis: Drummond to Mace	106.07	33	36	5	5
13	West Davis: Stonegate	105.08	20	22	6	6
14	East Davis: East of Mace	105.06	20	26	6	6

The relative bike friendly ratings are the average of the Infrastructure and Accessability GM relative ratings.
The highest Infrastructure and Accessability Gravity Model census tract relaitve ratings were set equal to 100
i.e. Infrastructure CT 106.08 = 100 and Accessabilty GM CT 107.01=100.

Fig. 2. Relative Bike PATH friendly ratings, Davis, California Census Tracts

3.1 Recommendations for refinements to Bicycle Friendly Infrastructure Measures

Possible Refinements to the Bicycle Friendly Supply Measures to Recognize Infrastructure Components Other than Bikeway Densities:

Give reduced weights to:

- Bike lanes with high motor vehicle traffic volumes
  (a work in progress)
- Bike lanes alongside curbside parking areas
- Bikeways with continuity gaps[8]
- Bikeway sections not wide enough for two bicyclists to safely ride abreast (less than 1.5 m. (5 ft.) one way) or (2.4 m. (8 ft.) two ways)
- Bikeway sections not in good physical condition
- Bike Paths lacking center lines and edge markings

[8] Mekuria et all 2012.

Give added weight to:

- Bike paths which exclude pedestrians or cycle tracks which exclude pedestrians, cars, trucks and buses
- Colored bike paths, lanes, or cycle tracks
- Bikeway sections which include well designed and placed bikeway signage.

Consider rating the bicycle friendliness hierarchy of various bike path bicycle infrastructure types. The best bike path infrastructure is physically protected-off roadway, separated from motor vehicle traffic, with pedestrians prohibited and with physical barriers to discourage pedestrians from walking in the bike path. Nearly as good are bike paths which are off roadways, but while prohibited to pedestrians, have no physical barriers to keep pedestrians off the bike path.

Bike paths which are alongside sidewalks are less bicycle friendly then similar paths prohibiting pedestrians not near roadways. Any bike paths which are shared with pedestrians are less bicycle friendly then those that forbid pedestrians. The lowest quality bike infrastructure is sidewalks jointly used by bikes and pedestrians, although these may be preferred by easy bike path riders to having to ride in the street with motor vehicles.

The best bicycle infrastructure, the off roadway, bike paths, with physical barriers to pedestrians deserve the highest weights, while very low weights should be given to the sidewalks shared by bikes and pedestrians.

Possible Refined Bike Friendly Infrastructure Measure Adjustments: Bike Paths with physical barriers to pedestrians could be given a 15% length bonus. Bike Paths with only signage prohibiting pedestrians could be given a 10% length bonus. Bike Paths shared with pedestrians could be given a 10% length penalty, while sidewalks shared by bikes and pedestrians could be given a 50% length penalty unless they are very wide.

Cycle Tracks, are bikeways in the traffic right of way (ROW) but physically protected, i.e. separated from motor vehicle traffic by fences, bollards, curbs, raised pavement, and/or parked cars. Cycle tracks may also employ painted lines, buffer zones, and colored pavement treatments. Cycle Tracks are more bicycle friendly than Bike Lanes, but less bicycle friendly than Bike Paths which exclude pedestrians, and could be rated accordingly. The NACTO Urban Bikeway Design Guidelines[9] provides 47 pages of examples and discussion regarding cycle tracks. As Bike Lanes have visual markings and signs as the only infrastructure protection for bicyclists in the motor vehicle right-of-way, they are less bicycle friendly then cycle tracks because they have no physical barriers to keep motor ve-

[9] National Association of City Transportation Officials (2013)

hicles out. Enhancements to simple painted line bikeways include visual protection provided by painted buffer zones, and/or different colored pavement surfaces. Enhanced bike lanes could be given a length bonus of perhaps 5 or 10%.

Bicycle boulevards[10] are another infrastructure option which can provide bicycle friendliness. Features of bicycle boulevards can include prominent roadway markings and signs, round-abouts and speed bumps to slow automotive traffic, and barriers to block automobiles, but NOT bicycles for continuing on the route.

As convenient, inexpensive, dry and safe **bicycle parking** helps encourage bicycle use in urban areas, it is another possible infrastructure improvement to increase bicycle friendliness.

Local neighborhood streets not explicitly identified as bikeways can play a major role in bicycle friendliness. If motor vehicle traffic speeds and volumes are low, streets can be excellent routes for bicyclists of most ages. Some cities and villages in Germany, the Netherlands, and the United Kingdom have speed limits of 30 kph (20 mph) on many local streets to make them safer for both bicyclists and pedestrians. *Woonerfs*[11], in the Netherlands have very low speed limits to encourage use by children and others for play, and for bicyclists, as well as to provide access by motor vehicles to adjoining real estate.

4. Closing thoughts: a more ideal neighborhood bicycle friendly index

Ideal quality of life social indicator measures should reflect actual existing output conditions and not input related measures such as those discussed so far.

Actual existing output conditions of bicycle friendliness could include:

Surveys or counts of the modal shares of trips undertaken by bicycle

Surveys of persons' satisfaction with bicycling conditions and opportunities in the area.

Accident statistics reflecting the safety of bicycling in the area – ideally expressed in terms of accidents per kilometer of personal travel.

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[10] www.cityofberkeley.info/bicycleboulevards/

[11] Woonerfs are a concept developed in the Netherlands for quiet shared use transportation facilities shared by pedestrians, motor vehicles, and bicycles with design features intended to slow motor vehicles to about walking speeds.

Health statistics regarding residents of the area, such as life expectancy, weight, diabetes, and general physical condition.

Bicycle friendly environments can support sustainable urban development by:

(1) a continuous network of well-designed bicycle paths and lanes,
(2) serving compactly developed pedestrian-oriented neighbor hoods, and being
(3) linked to a diverse mix of neighborhood-serving land uses
(4) with conditions of mutual respect between motorists and bi cycle riders.

Effective bicycle friendly neighborhood ratings can help achieve more bicycle friendly environments and better quality of life.

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