BICYCLING SPEEDS: A LITERATURE REVIEW

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INTRODUCTION

More than 3,300 bicyclists were killed in crashes (presumably involving vehicles) between 2008 and 2012.[1] 74% of all bicyclist deaths occurred as a result of crashes where the bicyclist (travelling in a straight manner) was struck by the front of a passenger vehicle.[2] In collisions such as these, it is quite common to have an investigation into the liability of the involved parties.

Bicycle speed is an important factor to consider in these investigations, however this is often difficult to assess. The speed of the bicycle is related to the time-to-impact. More specifically, the time from when the bicycle became an immediate hazard to a typical driver, to when the impact occurred. This can also be referred to the time available for a typical driver to avoid a collision. In vehicle and bicycle collisions, where the bicycle was travelling at a relatively constant speed immediately prior to and at impact, it is often difficult to assess the speed of the bicycle.

(New P) Given that the bicycle speed is often unknown, the alternative is to assume a reasonable range of bicycling speeds based on previous findings in the literature. In the field of accident reconstruction, use of available information related to the involved bicyclist (general age, riding experience, etc.) and the collision (path of the bicyclist, the bicyclist's manoeuvres, etc.), can aid in predicting a reasonable range of bicycling speeds for a given scenario based on pre-existing data found in the literature. The purpose of this article is to summarize bicycling speeds from several different papers, for ease of reference.

Given that most vehicle and bicycle collisions occur while the bicycle is travelling in a straight manner (i.e. not on a curve), we chose to focus only on the existing literature that examined the speed of bicycles travelling in a straight manner. Additionally, an effort was made to restrict the literature review to papers that discussed bicycling speed studies conducted primarily in North America, as typical bicyclist behaviour (including speed choice) may vary internationally.

The majority of the papers reviewed discussed research that was conducted for a purpose other than studying the speed choice of bicyclists. As such, there was limited information with regards to some of the studies on bicycling speeds summarized in this article (i.e. bicycle type, terrain, etc.).

LITERATURE REVIEW

Opiela, Khasnabis, and Datta[3] studied bicycle traffic at urban intersections in close proximity to college campuses in Michigan. The intersections were either priority (where one street was given priority over the other, presumably a through road with a stop controlled side road), four way stop, or controlled by traffic signals. 486 bicyclists travelling over a variety of bicycling facilities were videotaped at positions upstream of seven intersections. The overall average speed was 21 km/h [13 mph]. Bicyclists travelling in bicycle lanes (presumably on the road) had an average speed of 25 km/h [15.5 mph], with a range of 4 to 41 km/h [2.5-25.5 mph]. Those travelling on bicycle paths (i.e. presumably off-road trails) had an average speed of 20 km/h, with a range of 4 to 39 km/h [2.5-24 mph]. The average speed of bicyclists on sidewalks was 19 km/h [12 mph], with a range of 3 to 30 km/h [2-18.5 mph]. Bicyclists travelling on the road with no bicycle lanes (referred to as "no facilities" for the remainder of this article) had an average speed of 19 km/h [12 mph], with a range of 8 to 37 km/h [5-23 mph]. The authors of this paper stated that the majority of the studied bicyclists were most likely young adults, due to the locations of the intersections. The authors also provided the following plausible reasons as a possible explanation for the variation in speeds: bicycle lanes provided the greatest amount of manoeuvring space (resulting in higher speeds), pedestrians on sidewalks could cause bicyclists to be more cautious (resulting in lower speeds), and the difference in conditions at each location.

In his book on bicycle transportation, **Forester**[4] briefly described a study conducted in Mountain View, California of bicyclists travelling on a level street bicycle lane. This study was conducted in an area where recreational and commuter cycling was popular, during the morning commute, on a day with no wind. The average speed was 26 km/h [2.5-25.5 mph], with a range of 19 to 32 km/h [12-20 mph].

Taylor[5] studied safe clearance intervals for bicycles and automobiles at signalized intersections. In Austin, Texas, 28 subjects were asked to accelerate up to their normal cruising speed, and to continue at this speed for about 46 m, after which they were asked to accelerate or to decelerate. This testing was conducted on a level and somewhat busy street, where there were cars parked along the sides. The test subjects were held until the coast was clear. The author stated that some interference (presumably from vehicles and/or pedestrians) may have occurred, but was not considered to be a limitation. The average speed was 23 km/h [14 mph], with a range of 13 to 34 km/h [8-21 mph].

Wachtel, Forester, and Pelz[6] examined bicyclist clearing times at intersections. The authors referred to data collected by the Palo Alto Transportation Division of 139 bicyclists at six intersections in Palo Alto, California. At three of the intersections, the bicyclists were mostly high school and college students; at two of the intersections, bicyclists included elementary school students; and at one intersection, the bicyclists were primarily elementary school students. The average speeds from the six intersections ranged from 14 to 27 km/h. [8.5-17 mph] After excluding data from the one intersection with primarily elementary school student bicyclists, the average speeds ranged from 19 to 27 km/h [12-17 mph].

Pein[7] examined bicycle crossing performance at intersections. The average cruising speed of 65 bicyclists was determined at 16 trail-roadway intersections on the Pinellas Trail in Pinellas County, Florida (using video analysis). The time the bicyclists travelled over a distance of 5.5 m [19 ft] was determined. The average cruising speed was 15 km/h [9.5 mph], with a range of 8 to 28 km/h [5-17.5 mph]. Pein noted that the 65 bicyclists in his study also included elderly adults. Additionally, Pein stated that in general, bicyclists may ride faster on the roadway, compared to riding on a trail. As discussed later in our article, Pein's suggestion was consistent with the results of future studies.

Thompson *et al.*[8] conducted research to determine how well people estimated their own speeds while riding a bicycle, in Seattle, Washington. The speeds of 152 individuals (children and adults, 70% of which were children ages 13 years and younger) while they were riding their bicycles along a 4.8 km [3 mile] stretch of closed road at two weekend recreational events were measured using a radar gun mounted on a tripod. The closed road was level, and largely unobstructed. The average speed of all of the participants combined was 15 ± 4 km/h [9.5 ± 2.5 mph], with a range of 4 to 24 km/h [2.5-15 mph]. By group, the

average speed of children riding bicycles was approximately 14 ± 4 km/h [9 ± 2.5 mph], while the average speed of adults (persons aged 14 years or older) was slightly higher at 16 ± 5 km/h [10 ± 3 mph]. The average speeds of the bicyclists were also given by age and gender (along with the standard deviation), shown in Table 1. Note that some of the results may not be an accurate representation of the total population, due to the extremely limited sample size (for example, the 4 year old group).

Thompson *et al*. also referred to unpublished research by Neathery and Diolata, where speeds of 363 bicyclists (approximately 6% were estimated to be 13 years old or younger) travelling a path used by bicyclists, pedestrians, and roller bladers were studied. The average speed of the adult and child riders was approximately 21 km/h [13 mph] and 15 [9.5 mph] km/h, respectively. Thompson et al. noted that the results from their own closed road study may have been skewed for the adult riders, as many of the adult riders were accompanying a child rider, and as such, their speeds would likely have been lower than adults riding alone.

Virkler and Balusabramanian[9] examined the flow characteristics of two trails shared by hikers, bicyclists, and joggers. One of the trails was located in North America - in Columbia, Missouri. The other trail was located outside of North America, and as such, will not be discussed in this article. The Columbia trail was recreational, had a level crushed rock surface, and was 3 m [10 ft] wide. Data collection occurred on autumn weekends. Virkler and Balusabramanian collected data on bicycle speeds by recording the time the bicycles travelled over a short section (9 m, 30 ft) with a stopwatch. The average speed of 53 bicyclists travelling on the trail was 21 ± 8 km/h [13 ± 5 mph], with a range of 4 to 37 km/h [2.5-23 mph].

A study compiled by **Landis *et al.***[10] involved measuring the speed, accelerations, etc. of several different types of pedestrian movements (i.e. on scooters, bicycles, etc.). Bicycles were observed on three different trails; the Pinellas Trail in St. Petersburg, Florida, the Paint Branch Trail in College Park, Maryland, and the San Lorenzo River Trail in Santa Cruz, California. Both active participants (bicyclists who were briefed on the purpose of the study and given an overview of the course) and in situ participants (bicyclists who were passing by at the time of the testing) were involved. A total number of 367 bicycles were videotaped over a specific section of the trail, where 114 of them were active participants (65 males, 49 females), with an average age of 39. The study found that the average speed of all the bicyclists was 17 ± 6 km/h [9.5 ± 3.5 mph], whereas the average speed of the active and in situ participants was 19 km/h [12 mph] and 16 km/h [10 mph], respectively. The difference in average speeds between the active and in situ participants could have been the result of the active participants riding at a higher speed than normal, possibly to demonstrate their cycling abilities. Or, the difference could have been the result of the in situ participants riding slower than normal, due to possibly being distracted by the unusual activity (i.e. people operating testing equipment, etc.)

Khan and Raksuntorn[11] analyzed the characteristics of passing and meeting manoeuvres of bicycles travelling an exclusive bicycle path section (i.e. bicycles only) of the Cherry Creek Bicycle Path in Denver, Colorado. A passing maneuver occurred when one bicyclist approached and overtook another bicyclist (both travelling in the same direction), and a meeting maneuver occurred when two bicyclists travelling in the opposite direction approached and passed each other. This 3 m wide path was typically travelled by students, recreational users, and commuters; and the section studied was located in downtown Denver. Two video cameras providing longitudinal views of a 91 m section of the bicycle path were set up on a bridge overlooking the bicycle path. Khan and Raksuntorn reported that the bicycle speeds ranged from 17 to 36 km/h [10.5-22.5 mph], with an average speed of 25 ± 4 km/h [9.5 ± 2.5 mph]. It is unclear whether these bicycles were involved in meeting manoeuvres, riding in pairs, or cruising alone; as such, we referred to these as "cruising bicyclists". Khan and Raksuntorn also reported on the speeds of passing and passed bicycles from 29 passing events. The average speed of passing bicycles was 27 ± 5 km/h [17 ± 3 mph], and ranged from 17 to 38 km/h [10.5-23.5 mph], during the passing event. The average speed of bicycles that were being passed was 18 ± 5 km/h [11 ± 3 mph], and ranged from 6 to 30 km/h [3.5-18.5 mph], during the passing event.

El-Geneidy *et al.*[12] developed a model to predict bicycle travel speeds in various facilities. The authors conducted a study in Minneapolis, where 8 bicyclists (4 male and 4 females aged 28 to 60) had a GPS unit attached to each of their bicycles which was checked at the end of each week, for three weeks. The bicyclists were told to use three different facilities: off-road bicycle paths, on-street (i.e. with traffic, also referred to as "no facilities"), and on-street designated bicycle lanes. The bicyclists were not told that their speeds would be recorded. Their cycling habits averaged from 0.5 to 6 times per week. The average bicycle speed for each of the three facilities was about 16 km/h. The bicyclists who reported that they were comfortable riding in heavy traffic rode at an average speed of 17 km/h [10.5 mph]. No statistical difference was found in the speed of bicycles travelling in bicycle lanes, compared to bicycles travelling on the street with no facilities. Further, it was found that the comfort level, age, and gender of the bicyclist affected bicycle speeds by about 1 to 2 km/h [0.6-1.2 mph], on average.

Smith[13] reported on the New York Statewide Traffic Accident Reconstruction (N.Y.S.T.A.R.) Society's bicycle test results, from their 2007 seminar. During this testing, male bicyclists rode a level asphalt course (30 feet long), on a road bicycle, in different gears. The speeds of the bicycle were obtained using a radar gun. There were 14 male bicyclists used in this study (4 advanced and 10 average). The average speed was 29 to 33 km/h [18-20.5 mph] among the advanced male riders, and 8 to 16 [5-10 mph] among the average male riders.

Langford, *et al.*[14,15] compared the naturalistic behaviours of electric bicycle riders with regular bicycle riders. This study was conducted in Knoxville, Tennessee from the summer of 2011 to the summer of 2013. Bicycles (both regular and electric) were instrumented with GPS, and were located at two bike-sharing stations on the University of Tennessee campus. In total, six regular bicycles were instrumented. About 100 users participated in this study (regular and electric bicycle riders), 82% of which were students, and 18% of which were faculty or staff (all were 18 years of age or older). Travel speed of the bicyclists were made across 23 greenway segments (the definition of greenway segments was unclear) in Knoxville, where the bicyclists travelled in mixed traffic conditions, and on shared use facilities. The average speed for regular bicyclists on the road was about 11 km/h [7 mph], and the average speed for regu-

TABLE 1 - Summary of Average Bicycling Speeds, from Thompson, *et al.*

	Average Bicycling Speeds (km/h)	Sample Size
Females (all ages)	14 ± 4	77
Males (all ages)	15 ± 5	75
4 year olds	14 ± 3	2
5 year olds	12 ± 3	9
6 year olds	15 ± 3	8
7 year olds	13 ± 4	13
8 year olds	13 ± 4	20
9 year olds	15 ± 5	24
10 year olds	15 ± 4	11
11 year olds	14 ± 4	12
12 year olds	20 ± 3	6
13 year olds	16 ± 0	2
Females (children)	14 ± 4	52
Males (children)	15 ± 5	55
Females (adults)	15 ± 5	25
Males (adults)	17 ± 5	20

lar bicycles on shared use facilities was about 13 km/h [8 mph]. The average top speed for regular bicyclists on shared use facilities was 26 km/h [16 mph]. Langford et al. noted that there was hilly terrain, which may explain the lower average speeds in this study, compared to the other studies discussed above.

Currently a naturalistic study on bicyclist behaviour is being conducted by Virginia Tech Transportation Institute and the Motorcycle Safety Foundation that will add to the existing database of typical bicycling speeds.[16,17]

ANALYSIS OF EXISTING LITERATURE

Combining the results from all of the above studies gave a bicycling speed range of 3 to 41 km/h [2-25.5 mph] (for at least 1,750 bicyclists - Forester and Langford et al. did not provide a specific sample size). The slowest speed corresponded to bicyclists travelling on a sidewalk in the Opiela, Khasnabis, and Datta study, and could be attributed to cautiousness on the bicyclists' part (due to pedestrians). The highest speed corresponded to bicyclists travelling in bicycle lanes in the same study. The range of average speeds from all of the above studies was 11 to 27 km/h [7-17 mph]. The overall average of all the average speeds was 19 km/h [12 mph], and the overall average of all the standard deviations was 5 km/h [3 mph]. The results from the above discussed studies (a total of 13) were summarized in Table 2.

To aid the accident reconstructionist, results from the above studies were organized into several different categories, and displayed in Table 3. The average bicycling speeds of children were not included in the live roadway or the shared trail categories.

The results from the studies that featured children gave consistent results (an average speed range of 14 to 15 km/h) [9-9.5 mph]. The average speed from one intersection in the Wachtel, Forester, and Pelz study was included in this range, as the bicyclists were primarily elementary school students.

From Table 3, the range of average speeds of bicyclists on a live roadway was 11 to 26 km/h [7-16 mph]. The Thompson et al. and Smith studies were not included, as the studies were conducted on a closed road or course. It should be noted that the low end of this range corresponded to the Langford et al. study, where the terrain included some hills. It is also noteworthy that the Opiela, Khasnabis, and Datta and the El-Geneidy et al. studies did not discuss the terrain of the involved roadways. As the Opiela, Khasnabis, and Datta study was conducted at seven urban intersections in Michigan, it is likely that the terrain was mostly level (considering that most urban intersections are level in Michigan). However, the bicyclists in the El-Geneidy et al. study were given the freedom to ride where they chose; as such, the terrain was likely a combination of level and non-level areas. If the Langford et al. and the El-Geneidy et al. studies are excluded from the live roadway category, the range of average speeds is 19 to 26 km/h [12-16 mph] (for mostly level terrain).

Additionally, considering only those studies of bicyclists crossing an intersection (Wachtel, Forester, and Pelz; and Pein), the range of average speeds was 15 to 27 km/h [9-17 mph]. As such, without any formal analysis, it appears that bicyclists' speed choice is not significantly affected by crossing an intersection.

The range of average speeds of bicyclists travelling shared trails was 13 to 21 km/h [8-13 mph]. The Opiela, Khasnabis, and Datta and El-Geneidy et al. studies were not included, as the authors did not specify whether the paths/trails were shared or not; however, the average speed of the bicyclists on bicycle paths/trails in these studies were within the aforementioned range. The Khan and Raksuntorn study was not included, as the trail studied was exclusively for bicycles. The average speed of cruising bicyclists in this study was 25 km/h [15.5 mph], above the aforementioned range. This could be due to the possible lack of precautionary measures explored by bicyclists while riding on an exclusive bicycle trail (i.e. no pedestrians to watch out for, etc.). On an additional note, if the Langford et al. study is again excluded from the shared trail category, and assuming that the intersections observed in

TABLE 2 - Summary of Bicycling Speeds

Research Paper	Avg. Speeds (km/h)	Range (km/h)	Terrain/Location Details	Test Subjects
Opiela, Khasnabis, and Datta (1980)	Overall: 21 Bicycle lanes: 25 Bicycle paths: 21 Sidewalks: 19 No facility: 19	Bike lanes: 4-39 Bike paths: 4-41 Sidewalks: 3-30 No facility: 8-37	Upstream of 7 intersections in Michigan	486 bicyclists
Forester (1983)	26	19-32	Level bicycle lane in Mountain View, Cal.	---
Taylor (1993)	23	13-34	Level roadway in Austin, Texas	28 bicyclists
Wachtel, Forester, and Pelz (1995)	14-27	---	Six intersections in Palo Alto, Cal.	139 bicyclists, including elementary, high school, and college students
Pein (1997)	15	8-28	16 trail-roadway intersections in Pinellas Co., Fla.	65 bicyclists, including elderly adults
Thompson et al. (1997)	All: 15 ± 4 Children: 14 ± 4 Adults: 16 ± 5	4-24	Level, closed road in Seattle, Wash.	106 children 46 adults
Neathery & Diolata, ref. in Thompson et al. (1997)	Children: 15 Adults: 21	---	Shared trail	363 bicyclists
Virkler and Balusubramanian (1998)	21 ± 8	4-37	Level, shared trail in Columbia, Mo.	35 bicyclists
Khan and Raksuntorn (2001)	Cruising: 25 ± 4 Passing: 27 ± 5 Passed: 18 ± 5	Cruising: 17-36 Passing: 17-38 Passed: 6-30	Bicycle path in Denver, Col.	53 cruising bicycles, 29 passing events
Landis et al. (2004)	All: 17 ± 6 Active: 19 In situ: 16	---	Three shared trails in Florida, Maryland, and California	114 active bicyclists, 235 in situ bicyclists
El-Geneidy et al. (2007)	Bicycle paths: 16 Bicycle lanes: 16 No facility: 16	---	Bicycle paths, bicycle lanes, and on streets with no bicycle lane (no facility) in Minneapolis, Minn.	8 bicyclists
Smith (2008)	---	Advanced: 29-33 Average: 8-16	Level, 30 foot long closed course	4 advanced males 10 average males
Langford et al. (2015)	On road: 11 Shared use: 13	---	23 greenway segments w/some hills in Knoxville, Tenn.	100 total (including e-bicycle riders

the Pein study were mostly level, the range of average speeds is 15 to 21 km/h [9.5-13 mph] (for mostly level terrain).

The range of average bicycling speeds on live roadways (19 to 26 km/h) [12-16 mph] was slightly higher than the range of average bicycling speeds on shared trails (15 to 21 km/h) [9.5-13 mph] for mostly level terrain, supporting Pein's suggestion. This is likely due to bicyclists being less cautious given the lack of pedestrians, etc. on the roadway.

It should be noted that the low end of both of the aforementioned ranges (the range of average bicycling speeds on live roadways and shared trails) are higher than the low end of the speed ranges quoted in Allen et al. More specifically, **Allen *et al.*[18]** stated that the free-flow speed of bicycles appeared to be somewhere between 10 and 28 km/h [6-17.5 mph], with the majority of speeds between 12 and 20 km/h [7.5-12.5 mph]. These speed ranges have been used by accident reconstructionists in the past, however, it is important to note that these speeds came from studies conducted all over the world, including China, Sweden, Netherlands, as well as North America. The low end of the ranges (10 and 12 km/h [6-7.5 mph]) were from studies conducted in China, where the typical bicycling environment is likely different from typical bicycling environments in North America. As such, when analyzing a vehicle and bicycle collision where details of the adult bicyclist (such as riding experience, speed, etc.) are unknown, it is more reasonable to assume a speed of either 19 to 26 km/h, [12-16 mph] or 15 to 21 km/h [9.5-13 mph] (depending on the riding environment) for collision reconstructions in North America.

Based on the literature reviewed above, there are several ranges of average speeds that can be used by an accident reconstructionist, for collisions where the speed of the bicycle is unknown. For example, if the involved bicyclist was a child, an assumed range of average speeds of 14 to 15 km/h would be reasonable. Likewise, if the bicyclist was an adult, and was riding on a level roadway, a range of 19 to 26 km/h [12-16 mph] would be reasonable.

It appears that most of the studies observed on live roadways were conducted in primarily urban areas. As such, bicycling speeds in rural areas have not been well studied. Most of the studies discussed in this article were somewhat naturalistic (i.e. analysis was done using videos) and as such, details of the bicyclists (i.e. exact age, riding experience, etc.) were not reported. Therefore, the correlation between bicyclist age, riding experience, etc. and their average speeds have not been well studied. The results from the naturalistic study on bicyclist behaviour being conducted by Virginia Tech Transportation Institute and the Motorcycle Safety Foundation may provide further insight into these areas.

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TABLE 3 - Range of Average Bicycling Speeds

Category	Research Papers	Avg. Speeds (km/h)	Range of Avg. Speeds (km/h)
Children (approximately 13 years old and younger)	Wachtel, Forester, and Pelz (1995)	14	14-15
	Tompson et al. (1997)	14	
	Neathery and Diolata, referred to in Thompson et al. (1997)	15	
Live roadway	Opiela, Khasnabis, and Datta (1980)	19	11-26 (19-26 for mostly level terrain)
	Forester (1983)	26	
	Taylor (1993)	23	
	El-Geneidy et al. (2007)	16	
	Langford et al. (2015)	11	
Shared trail	Pein (1997)	15	11-26 (19-26 for mostly level terrain)
	Neathery and Diolata, referred to in Thompson et al. (1997)	21	
	Virkler and Balusabramanian (1998)	21	
	Landis et al. (2004)	17	
	Langford et al. (2015)	13	