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An analysis of bicycle travel speed and disturbances on off-street and on-street facilities

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Abstract

For transport planners and land use practitioners, many are the qualitative guidelines provided regarding the location and quality of separated bicycle facilities. When separated bicycle facilities are poorly designed or placed in less than optimum locations, their intended use is less than anticipated. An interesting element in the evaluation of bicycle facilities that have received less attention revolve around the disturbance due to the presence of other users on cyclists way. Other users consists in cyclists and pedestrians for off-street bicycle facilities, and motorized vehicles on the roadway. This study focuses on quantifying the role of disturbances encountered on separated cycling facilities, compared to disturbances from cycling mixed with traffic, assuming cyclists speed as a performance measure and analysing the cyclist speed reductions from different types of disturbances. Collecting data on three segments of Bologna's cycling network (Italy), we measured the frequency, type, and speed reduction attributed to different types of disturbances. The data collected shows that pedestrian disturbances on the separated facility are highly frequent but associated with moderate speed reductions, while disturbances in the mixed traffic environment can be relatively fewer but have more severe speed reductions. Moreover, our results suggest that design elements of separated facilities can play a role in affecting the frequency, type, and severity of disturbances. This work helps lay the foundation for outlining the existing relationship between bicycle travel speeds and non stationary disturbances.

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Keywords: cycling; bicycle speed; separated bicycle facilities; pedestrians

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1. Overview

Depending on the context in which they operate, transport planners and land use practitioners can refer to various manuals and guidelines that classify and describe the geometric and functional features of separated bicycle facilities, and evaluate their applicability.(e.g., CROW 2007, NACTO 2012, AASHTO 2012).

In research, several efforts have focused on evaluating the effectiveness of such facilities in terms of cyclist safety and user satisfaction. Using stated preference surveys (Abraham et al. 2002, Sener et al. 2009, Stinson and Bhat 2005, Krizek and Roland 2005, Tilahun et al. 2007), revealed preference surveys (Broach et al. 2012, Menghini et Al. 2010, Hood et Al. 2011), and accident data (Lusk et al. 2011, 2013), the research base generally points at how separated facilities improve perceived safety, have some actual safety benefits, and provide a more pleasurable cycling experience.

Cyclists consider a variety of factors when choosing particular segments of routes. For many European cities, actually, the main cyclist's choice is between the use of an existing separated facility or the use of the roadway, mixing with vehicular traffic. Moreover, not every street can integrate an off-street exclusive bicycle facility, for reasons of space availability or for its use patterns. But even when a widespread cycling network is present, sometimes the design of separated bicycling facilities is poor and the impact and use of facilities is less than intended (Aultman-Hall et al. 1998, Sener et al. 2009, Tilahun et al. 2007).

There are several factors that possibly explain the decision of cycling on the roadway instead than on a bicycle facility. Socio-demographics and cyclist experience is important; more experienced cyclists often prefer to ride in the road. Knowing specific elements about the environment is also important; where facilities stop and start or where traffic volumes are low, it is often easier for cyclists to simply ride in the road (Sener et al. 2009). However key elements in designing separated bicycle facilities that have received less attention revolve around disturbances—specific obstacles in the facility that affect user satisfaction.

Disturbances may be stationary (e.g., intersections, utility poles, bollards) or non-stationary (e.g., other cyclists or pedestrians). For example, intersections that interrupt separated bicycle facilities have shown to be particularly vexing, both in terms of safety and in terms of speed. For non-stationary disturbances, little work has focused on the role of pedestrians mixing with cyclists on separated or dedicated facilities. Pedestrians slow cyclists travel speed, thereby influencing the overall utility of the choice for the cyclists who might use the facility.

The most relevant literature in this respect refers to "pedestrian hindrances." Knowing volumes and speeds of pedestrians and cyclists, Botma (1995) initially proposed a model to evaluate the number of events such as passing another cyclist or a pedestrian (or meeting, when opposite direction volumes are present) on a given section of an off-street bicycle facility. This method was later adopted and applied to different contexts (Allen et al 1998, Virkler et al. 1998, Kiyota et al 2000, Green et al. 2003, Highway Capacity Manual 2010) to demonstrate how hindrances affect functional characteristics of bicycle facilities. In these works, the frequency of passing and meeting events provide a measure of how much a cyclist is disturbed in its trip and is used to determine the level of service of a bicycle network's link.

What remains unexamined is how pedestrian presence influence cycling behaviour in different contexts. This research therefore aims to quantify the impact of disturbances along different types of cycling facilities, especially focusing on the role of pedestrians. Such impact is discussed both in terms of cyclists speed reduction and disturbance frequency. We systematically analyzed three transportation segments in Bologna (Italy) and examined cycling travel speeds along a separated bicycle facility and the adjacent roadway to specifically measure speed reductions and ascertain differences with and on-street alternative. Our results contribute to the literature by quantifying cyclist speed reductions due to pedestrians, bicycles (on separated facilities) and motorized traffic (in mixed traffic facilities). In Section 2 we describe the context of our research, the features of the three segments and the data collection process. The following Section 3 details our results, in terms of cyclists speed and disturbances effects. These results are discussed in Section 4, focusing on implications and future research needs.

2. Research approach

2.1. Separated cycling facilities in the Italian context

If we look at the current status of off-street facilities in Italian urban contexts, they frequently show discontinuities and for the most part are shared with pedestrians. In Italy, the structural and functional features of cycling facilities are regulated by the Codice della Strada, along with the Decreto Ministeriale number 557 of 1999. Such regulations set the guidelines for bike paths planning and design, stating as their main aim the achievement of a proper level of safety and functionality in order to promote bicycle use as an alternative to motor vehicles, thus reducing congestion and meeting the environmental sustainability goals. But, these guidelines are not always followed, leading to the design of some sub-standard facilities.

Unfortunately, many are the aspect in regards of which the Italian regulation proved to be lacking of clear and effective indications; moreover some of the indications provided are seen as limitations by local administrations, especially when dealing with restricted urban space available. For this reason, the provisions of Italian regulations in terms of cycling facilities standards are frequently waived. Many are the segments of the cycling network of insufficient width (the regulation indicates a minimum width of 1.50 meters for a single direction lane), or including physical obstacles reducing their effective width (Figure 1). Furthermore, the separation from pedestrians is frequently assessed merely by means of a painted stripe. Thus, when no sufficient space for both cyclists and pedestrians is provided, the separation gets eluded by users, leading to a decreased quality of the facilities.

Given the different bicycle facilities layouts existing in the Italian context, this study focuses on off-street paths, separated from motorized traffic but mixing with pedestrians, and shared travel lane, where cyclists mix with motorized traffic without any physical separation.

a

b

Fig. 1 – Examples of (a) insufficient width of the bike lane, or (b) presence of obstacles reducing its effective width.

2.2. Selection of segments studied and their characteristics

Our primary objective was to quantify how different types of disturbance affect the travel speeds of cyclists. The disturbances on which we focused are pedestrians and cyclists in separated bicycle facilities and motorized vehicles (cars, buses/trucks, motorcyclists) for mixed traffic.

Given these research goals, we chose segments of Bologna's (Italy) cycling network (Figure 2)[1]presenting a separated bicycle facility adjacent to the roadway, with different levels of pedestrian use of the facilities and different traffic volumes on the roadway, and away from key intersections. Each segment was defined to be 20 meters long and the location of each is in the proximity of the city center. Characteristics of each segment are described below with locations shown in Figure 2. Summary characteristics are presented in Table 1.

Regarding the off-street facilities it interesting to note that, following the order in which the three sections has been presented, the level of their sharing with pedestrians is decreasing.

Figure 2. Map of Bologna and locations of the three segments.

[1] We employ the following nomenclature throughout this manuscript to improve clarity. "Segments" are the three environments studied. These segments contain a "separated bicycle facility" (that is separated from traffic via a physical means—raised curb, parked cars or median) and an adjacent travel lane where the cyclists can mix with motorized traffic, referred to as " mixed traffic".

Table 1. Features of the three segments examined.

Segments	Type of separated bicycle facility	Width of the bicycle area (m)	Width of the pedestrian area (m)	Pedestrian volumes	Posted speed limit of adjacent roadway (km/h)	Peak bus volumes/hour
(1) Ercolani	Exclusive cycle track	1.80	-	Low	50	40
(2) Fioravanti	Track on pavement	2.10	1.90	Modest	50	5
(3) Matteotti	Track on pavement	1.90	1.50	High	50	55

Figure 3. The off-street facility and roadway layout in Segment 1 "Ercolani" (N.B.: the red circled sign with the pedestrian indicates pedestrians are technically prohibited from the facility).

Figure 4. The off-street facility and roadway layout in Segment 2 "Fioravanti".

Figure 5. The off-street facility and roadway layout in Segment 3 “Matteotti”.

2.3. Data collection

For each of the three segments, we studied cyclist travel in the separated bicycle facility and in the adjacent mixed traffic (for a total of six different environments). We chose to collect the data on working days of April 2012, from 8:30 am until 10:30 am, to be best representative of general cycling conditions.

We collected data in two different phases. In first phase we counted the number of cyclists on each of the six different environments and timed how long each cyclist took to travel the 20 meter stretch. We tallied cyclists in all directions, and noted in which environment they were riding, either the separated facility or the roadway. This provided us with baseline information about actual cyclists’ speed distribution and also pointed to general patterns of use across the different facilities.

In the second phase we administered our own experiments to collect data relating disturbances and speeds. One researcher cycled each facility approximately 100 times. Employing the typology presented in Table 2, he used his own judgment to record all types of disturbance he encountered. For example, pedestrians encroaching onto the separated bicycle facility were a disturbance. In the mixed traffic, cars or buses that forced him to share a lane or otherwise affected his travel, were a disturbance. He was encouraged to apply consistency in how each type of disturbance was classified. This provided us with the number of tests in which the cyclist-researcher encountered each type of disturbance. Another researcher timed the cyclist-researcher on the 20 meter stretch, in order to obtain his speed.

Furthermore, the same data collection methodology was repeated on longer stretches of the separated facility for all the segments, with the help of a video camera fixed on the helmet of the researcher-cyclist.

Table 2. Classes of disturbances considered.

Separated Bicycle Facility	Mixed Traffic Facility
No pedestrians, bikes in same direction	No disturbances or two-wheeled vehicles
No pedestrians, bikes in opposite direction	1 car or more
1 – 3 pedestrians	1 bus or more
4 pedestrians or more	Heavy vehicles

3. Analysis and results

3.1. Speed and use attributes

The first data obtained from the first phase of data collection was volumes of cyclists on the three segments, shown in Table 3. These volumes are consistent with the intensity of land uses and activities around each segment. In fact Segment 3, where the highest cyclist volume was registered, is adjacent to the central station and along a primary corridor headed into town, while Segment 2, with the lowest cyclist volume, is located in a more peripheral location and on a minor road.

We calculated average cyclist speeds, by facility, using data collected from the first phase; the main statistics about calculated speeds are shown in Table 3. Average speeds varied between 14.6 and 22 km/h, which generally agree with the review provided by Allen et al. (1998). Overall, standard deviations are quite high, given that they reflect the different behaviour of the different cyclists constituting the sample, e.g. their "aggressiveness" in cycling, their expertise and confidence, etc.

A significance t-test was performed for the two speed samples, comparing off-street facility and mixed traffic data, and results revealed a statistically significant difference between the two samples for all the three segments. For all segments, average cyclist speed and standard deviation were higher in the mixed traffic than on the separated bicycle facility. Overall, cyclists' speeds were highest in Segment 1 (18.9 km/h on the separated bicycle facility and 22 km/h in mixed traffic), largely owing to pedestrians being technically forbidden in the separated facility and cyclists often using the dedicated bus lanes when in mixed traffic conditions.

Figure 6 shows the proportion of cyclists using the dedicated facilities. Segment 2 had the highest percentage of cyclists using the separated facility, 73%, followed by 58% in Segment 1. In contrast, less than half of the cyclists (47%) used the separated facility in Segment 3. Even in Segment 1, where the separated facility is exclusive, 42% of the cyclists chose to mix with traffic. Several factors, besides the quality of the separated facilities, can have contributed to these results and this research effort cannot fully explain such patterns. For example, they can be due to discontinuities of the separated facility further upstream, or downstream, the considered segments.

Table 3. Cyclists volumes and average speeds for the three segments.

Segments	Average # of cyclists measured in 2 hrs	Statistic	Separated Bicycle	Mixed Traffic
(1)Ercolani	480	Speed (mean)	18.90 km/h	22 km/h
		Standard deviation	3.16 km/h	5.08 km/h
		Coeff. of Variation	0.168	0.231
(2)Fioravanti	240	Speed	14.60 km/h	16.8 km/h
		Standard deviation	3.12 km/h	4.24 km/h
		Coeff. of Variation	0.213	0.252
(3)Matteotti	850	Speed	16.00 km/h	17.00 km/h
		Standard deviation	2.97 km/h	4,39 km/h
		Coeff. of Variation	0.186	0.259

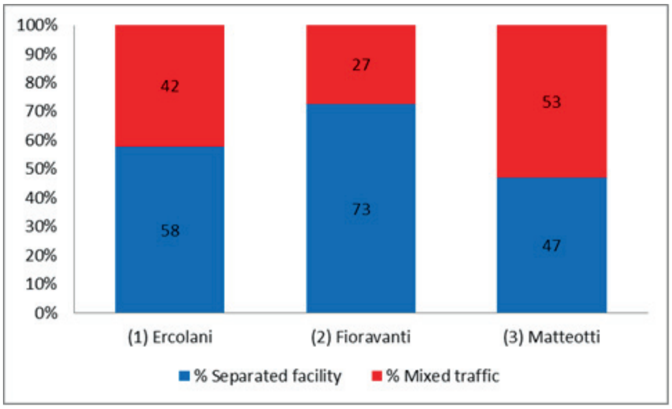

Figure 6. Cyclist use by facility.

3.2. Disturbance analysis

Our focus herein is on quantifying the role of non-stationary disturbances in affecting cyclist speed. In particular, we aim to quantify the impact of disturbances along each facility, using cyclist's speed as a performance measure. As previously explained, the data of this second stage of measurements refers to a single cyclist-researcher, thus the variables related to cyclist's behaviour do not play a role.

For each of the observations, we calculated average speeds and examined them with relation to the type of disturbance. For each disturbance type, we calculated the speed reduction relative to free flow (undisturbed) travel conditions. Results are shown in Tables 4 and 5, by segment and type of disturbance.

Regarding the speed in undisturbed conditions (free-flow speed), this resulted higher for Segment 1 compared to Segments 2 and 3, in line with the results of the measurements made on actual cyclists, previously described. On the bicycle facility, this could be explained by the exclusivity of the facility and the absence of potential pedestrian access along it, that can induce cyclists to slow down. In the mixed traffic, the higher value of free-flow speed registered could be explained by the presence of two lanes reserved for transit, on which cyclists often ride.

In each of the separated facilities, pedestrians had the largest impact on cyclists' travel speed, affecting a 10 to 27% reduction. Disturbances due to the presence of other cyclists were second, slowing speeds by 5%, on average. The speed reduction was felt most acutely in Segment 3: this may be owed to a variety of factors, but overall pedestrian volumes were clearly one of them.

In mixed traffic facilities, we noticed speed reductions from cars and trucks; disturbances from motorcycles were negligible. The largest impact was associated with heavy vehicles.

Table 4. Cycling Speeds by Type of Disturbance (Separated Bicycle Facilities).

	(1)Ercolani		(2)Fioravanti		(3)Matteotti	
Disturbance type	Average Travel Speed (km/h)	% Speed Reduction	Average Travel Speed (km/h)	% Speed Reduction	Average Travel Speed (km/h)	% Speed Reduction
No disturbance	16.7	-	15.2	-	15.6	-
Bikes same direction	16.0	4.2%	14.1	6.8%	15.5	0.14%
Bikes opp. direction	16.2	3.1%	14.4	5.0%	14.1	9.0%
1 – 3 pedestrians	14.5	13.1%	13.5	10.8%	12.3	20.9%
4 pedestrians or more	n.a.	n.a.	13.5	11.1%	11.3	27.2%

Table 5. Cycling Speeds by Type of Disturbance (Mixed Traffic).

	(1)Ercolani		(2)Fioravanti		(3)Matteotti	
Disturbance type	Average Travel Speed (km/h)	% Speed Reduction	Average Travel Speed (km/h)	% Speed Reduction	Average Travel Speed (km/h)	% Speed Reduction
No disturbance	18.6	-	17.0	-	17.7	-
Two-wheeled vehicles	18.4	1.1%	17.0	0.26%	17.3	2.2%
1 car or more	17.0	9.0%	16.8	1.15%	12.0	31.7%
1 bus or more	13.8	25.8%	n.a	n.a	11.1	37.2%
Heavy vehicles	n.a	n.a	14.9	12.3%	6.6	62.9%

The frequency of the different types of disturbances was also tallied, reflected by the proportion of measurements where a disturbance was recorded. Results are shown in Tables 6 and 7, by segment and type of disturbance. The bottom row in the tables shows the frequency of measurements where at least one disturbance was registered—as a complement to the percentage of measurements where no disturbances were registered [2].

For Segments 1 and – even more – for Segment 3, disturbances were more frequent on the separated bicycle facilities than in mixed traffic. In Segment 2, the frequency of disturbances was more even.

Pedestrians constitute the most common disturbance for the separated facilities in Segments 2 and 3; for Segment 3, the cyclist-researcher encountered a pedestrian in 90% of the observances. For Segment 2, where pedestrian volumes are lower and more space is provided for the two categories of users, frequency of disturbance is less

[2] Percentages of observations with no disturbance and at least one disturbance (last row) sum to 100. Some of the observations, however, had more than one disturbance; therefore, the sum of the percentages of events for single classes of disturbance exceeds 100.

severe. In Segment 1, the situation is clearly different: cyclists moving in the opposite direction were most common than pedestrians; in fact, the separated facility in this segment is exclusive and pedestrians are technically prohibited (even though, as results show, the prohibition is sometimes eluded).

For the mixed traffic environment – predictably – cars were clearly the most common disturbance. The frequency of car disturbance on Segment 1 is half than the one on Segments 2 and 3 due to the presence, as previously mentioned, of two lanes reserved for transit.

Table 6. Frequency by Type of Disturbance (Separated Bicycle Facilities).

	Percentage of occurrence		
Disturbance type	(1)Ercolani	(2)Fioravanti	(3)Matteotti
No disturbance	45.9%	41.9%	9.6%
Bikes same direction	6.6%	13.3%	4.8%
Bikes opp. direction	29.5%	10.7%	1.2%
1 – 3 pedestrians	13.1%	33.3%	84.3%
4 pedestrians or more	0.0%	1.3%	18.1%
At least one disturbance	54.1%	58.1%	90.4%

Table 7. Frequency by Type of Disturbance (Mixed Traffic).

	Percentage of occurrence		
Disturbance type	(1)Ercolani	(2)Fioravanti	(3)Matteotti
No disturbance	55.2%	37.5%	42.1%
Two-wheeled vehicles	10.3%	3.1%	5.3%
1 car or more	24.1%	56.3%	47.4%
1 bus or more	10.3%	0.0%	21.1%
Heavy vehicles	0.0%	3.1%	2.6%
At least one disturbance	44.8%	62.5%	57.9%

Linear regressions have been built assuming as the dependent variable average cyclists speed, and assuming as independent variables the number of pedestrians encountered and the number of bicycles encountered. Statistical significance of the measurements has been analysed performing a t-test, results are summarized in Table 8. The values of R^2 for the regressions are modest suggesting that other factors, even if not considered as object of the present study, can play a role in affecting cyclists speed.

Nonetheless, for Segment 1 the number of bicycles encountered and for Segment 3 the number of pedestrians proved statistically significant. Thus new linear regressions – only accounting for the statistically significant variables – have been built (Figures 7 and 8).

Table 8. Results of the linear regressions.

Segments	Independent variable	R^2 of the regression	Coefficient of the regression	t-stat	t crit
(1)Ercolani	Number of pedestrians	0.49	- 0.014	-0.331	2.052
	Number of bicycles		-0.170	-4.968	
(3)Matteotti	Number of pedestrians	0.46	-0.068	-8.114	1.990
	Number of bicycles		0.008	0.269	

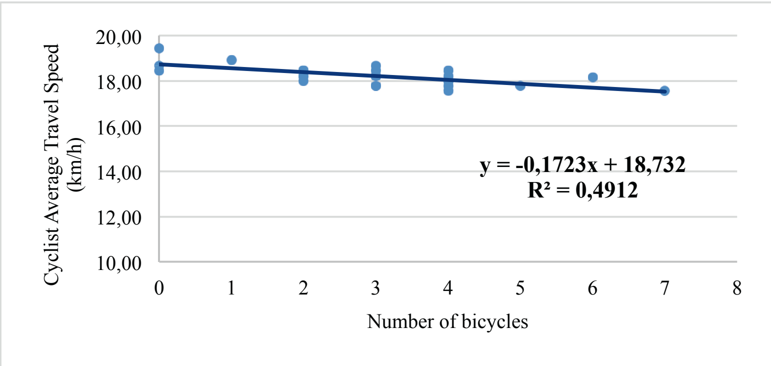

Figure 7. Relationship between number of bicycles encountered and average cyclist travel speed on Segment 1 (separated facility).

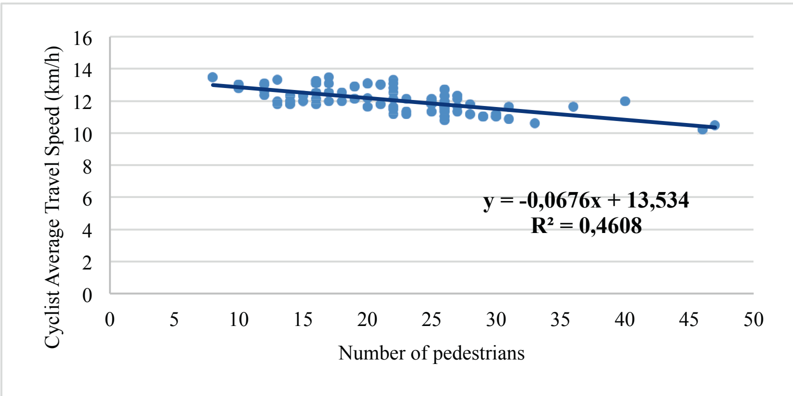

Figure 8. Relationship between number of pedestrians encountered and average cyclist travel speed on Segment 3 (separated facility).

4. Conclusions

The main goal of this work was to better understand the role of non-stationary disturbances along cyclists' trips, either travelling on separated bicycle facilities or in mixed traffic. In particular, we were interested in quantifying frequency of such disturbances and their impact, using speed as a performance measure. The data collected from the tests show that motorized disturbances (particularly heavy vehicles) have the strongest impact on lowering cyclist's travel speed, but resulted rather infrequent. For bicycle facilities shared with pedestrians, we learned that the presence of pedestrians can reduce cyclists speed by up to 30 percent. Our analysis points to a possible trade-off in evaluating the impact of disturbances on separated bicycle facilities, because two parallel factors are at play: (1) highly frequent pedestrian disturbances on the separated facility are associated with moderate speed reductions, (2) relatively fewer disturbances in the mixed traffic environment have more severe speed reductions. This suggest that those bicycle facilities that entail mixing with pedestrians can see their effectiveness – from a cyclist's point of view – reduced, especially if not enough space is provided for the two typologies of users. If the separation between cyclists and pedestrians merely consists in a painted stripe, and space is constrained, it is frequent that pedestrians invade the cycle lane, resulting in a deterioration of the facility's quality. Various factors inform a cyclist's link choice, particularly the decision to use a separated bicycle facility or ride in traffic. The probability of disturbances and their impact on travel speed are just two of them. Our results suggest that design elements of these facilities can play a role in affecting the frequency, type, and severity of disturbances.

Our data collection effort represents an univariate population, and this is by all means an oversimplification. Different types of cyclists prefer different facilities (Sener et al. 2009, Wilkinson et al. 1994). This type of investigation could benefit from more robustly accounting for demographic, attitudinal or other behavioral data which was unfortunately unavailable for this effort. For example, the type of detailed GPS data that is now being employed in other bicycle research applications (Broach et al. 2012, Hood et al. 2011, Menghini et al. 2011), could be adapted and used to investigate the role of disturbances in link choice patterns, providing trip data from a wider sample of cyclists.

This work therefore helps lay the foundation for a decay curve, which could be used to predict travel speed once pedestrian and bicycle volumes are known: planners would then be able to more robustly estimate cyclist speeds for different pedestrian and bicycle volumes. Furthermore, in analogy with what has been done for speed decay curves for motorized vehicle flow, thresholds of pedestrian volume could be used to predict the level of service of a separated facility.

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