Method to Determine Level of Service for Bicycle Paths and Pedestrian-Bicycle Paths

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In the Highway Capacity Manual of 1985, no levels of service (LOSs) for cyclists on separate paths are given. In the framework of the Dutch manual on bicycle infrastructure, a measure of quality of operation was developed: the hindrance that users of the path experience due to their interactions or maneuvers. Simplifying this to the frequency of passing and meeting maneuvers, the well-known LOSs from A to F can be defined. A new point is that LOS F is not merely a congested state of traffic, but is defined as a very poor overall quality of traffic operation. This approach was then extended to traffic operation on separate narrow paths used by pedestrians and bicyclists. Using this method the LOS can be determined separately for pedestrians, bicyclists, and the average user of the path. LOSs are a function of the volume of both types of users. Results appeared consistent, but some key parameters used as an input of the procedure have to be estimated empirically in applying this method. That is, they should be based on investigations of rating of maneuvers in terms of hindrance. The results can be used to determine requirements for path width and criteria for separation of bicycles and pedestrians.

In quite a few countries a policy exists to promote use of the bicycle and walking for transportation. The motivations for this policy are the problems that accompany intense use of the car: congestion, required space, air pollution, and noise. Analyzing trips in urban areas, it is found that a large proportion consist of relatively short trips and part of these could be replaced by a trip on foot or on bicycle. Walking and bicycling are also attractive solutions as methods of gaining access to public transportation. What is possible in terms of changing mode choice from car to foot and bicycle will also depend on local conditions such as terrain and climate.

Promoting pedestrian and bicycle traffic has many aspects. One of these is the provision of well-designed and appropriate facilities or infrastructure. Although walking is as old as humanity, and mass use of the bicycle preceded car traffic in many countries, these modes of transportation have not had much attention compared to studies on the automobile system and public transportation. This might have been due to the idea that pedestrians and bicyclists are so flexible that they can manage without special attention. When authorities really want to promote bicycling and walking, it turns out in many cases that sound design principles and methods are lacking.

The Highway Capacity Manual (HCM) of 1985 (*1*) illustrates this point: the chapter about pedestrians does cover some topics, but the bicycle chapter is rather meager. In western Europe the state-of-the-art is not much better, but times are changing. In the new German highway capacity manual (*2*) attention is given to bicycles. In the Netherlands much knowledge has been collected and new studies have been carried out in the framework of the Bicycle Masterplan (*3*). Especially relevant in this context is the *Design Manual for a Cycle-Friendly Infrastructure* (*4*).

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In this study two subjects were treated. First the Dutch guideline for the required width of a separate bicycle path was analyzed and levels of service (LOSs) were determined. Next the same method was used to define LOSs for paths used by pedestrians and bicyclists.

To investigate this method and determine its practical value, field studies and behavioral investigations will certainly be needed. The procedure sketched out herein is intended to guide these studies and make them more specific and therefore more efficient. Consequently the main emphasis of this study is on methods and not on results. The results presented are based on first guesses of some parameters and should be seen as an illustration of how the method can be worked out.

Applications can be found in the design of separate bicycle paths and pedestrian-bicycle paths. For the latter, the method seems appropriate for paths that are not very heavily loaded. It is assumed that in the case of large volumes of either pedestrians or bicyclists a separation is needed. For in-between cases, the procedure proposed could be used to derive criteria for separation.

It can be added that this study does not deal with a mix of motorized vehicles and bicycles on one facility, a very common and sometimes problematical situation. In that case safety is a main concern, whereas in this study comfort and convenience are the points of interest.

CONCEPT OF LOS

The concept of LOS was introduced in the HCM of 1965 (*5*) and maintained in the HCM of 1985, only the view was changed. We quote from the latter: "The concept of LOS is defined as a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers. A LOS definition generally describes these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety." Although the definition does not explicitly cover pedestrians, it is assumed they are meant as well as bicyclists. Important in this definition is that the quality of the traffic stream has to be assessed as experienced by the user and not, for instance, from the point of view of the road authority. This choice is debatable, but it will not be discussed in this paper.

The question is how can the operational quality of traffic operation for bicyclists and pedestrians be characterized when they use their own facility. For bicyclists no criterion is given in the HCM. Density is chosen for pedestrians, in the form of number of pedestrians per area. As the situation with a mix of pedestrians and bicyclists on a separate path is rather different from a sidewalk with pedestrians only, density might be less appropriate. However, first a discussion of the criterion suitable for bicyclists on a separate path will be given.

Potential measures of operational quality for bicycle traffic can be found in the HCM of 1985 and checked for suitability.

The first candidate is mean speed or mean travel time. However, in an earlier study it was found that mean speed was not influenced by volume over a large range (*6*). It seems that the behavior of traffic streams on freeways and bicycle paths are similar in this aspect.

The second candidate is density. This criterion is, for example, chosen in the German highway capacity manual (*2*). However, it seems difficult to decide which values are suitable boundaries between quality classes. Some interesting results are presented in a Canadian study (*7*), in which three zones around a cyclist are distinguished: a collision zone, a comfort zone, and a circulation zone. From this are derived LOSs that are much less generous than the ones resulting from the proposal in this paper.

A third candidate is the percentage of bicyclists being forced to follow the vehicle in front due to lack of passing possibilities. This criterion is used for two-lane rural roads in the HCM. However, bicyclists sometimes prefer to follow closely because it reduces air resistance considerably.

Going back to the basic concept of LOS, the terms "freedom to maneuver," "driving comfort," and "convenience" are found. These have been worked out as follows. On a bicycle path the following maneuvers can be distinguished: passing a user going in the same direction, meeting a user going in the opposite direction, and a combination of passing and meeting. Every maneuver brings with it some discomfort, inconvenience, and possible danger for those involved. In the sequel of this paper the term "hindrance" will be used for this concept. It is obvious that the amount of hindrance will depend on the type of maneuver, the parties involved, and the space available for the maneuver (path width).

With either an analytical model or a simulation model, the frequency of the maneuvers can be determined. Using weights called hindrance scores, the total hindrance can be obtained for each type of maneuver. This approach was followed in an earlier Dutch study (*8*), the outline of which is depicted in Figure 1. The upper part illustrates the model and the lower part the accompanying field survey. The goal of that survey was to determine the amount of hindrance perceived by users in real situations, because the users' perceptions should be the ultimate criteria for the quality of traffic operation.

Applying the model to the registered volume and composition of the field survey has yielded two outcomes: the hindrance calculated by the model (*H*) and the perceived hindrance (*P*). Using this relation, the quality of traffic flow can be determined for conditions that have not been investigated.

LEVELS OF SERVICE FOR BICYCLE PATHS

With the relationship established between volume, composition, path width, type of traffic (one-way or two-way), and perceived hindrance of the users, boundary values that define the quality classes or LOSs are still needed. In the Dutch design manual (*4*) only one limit value is given. When less than 10 percent of the path users are experiencing hindrance over 1 km, the quality is considered sufficient. The peak hour is chosen as the period for which this requirement should be fulfilled.

The choice of 10 percent is rather generous for the bicyclists and can be seen as a clear sign of the political tendency to promote the use of the bicycle. According to the author, it represents the approximate limit for LOS A. The other LOSs have been defined on the percent with hindrance scale in such a way that LOS E covers 70 to 100 percent. LOS F presents conditions that are worse than 100 percent of users experiencing hindrance, that is, with more hindrance per user than at LOS E.

The corresponding volumes are determined with a simulation model developed in another study (*8*). For one-way paths, the percentage with hindrance increases linearly with volume; for two-way paths, the increase is sharper than linear.

Consequently a point illustrated in Table 1 is that LOS F is not defined as congested traffic, but as a state in which 100 percent of the users experience hindrance over a distance of 1 km. This implies that on two-lane, one-way paths, LOS F starts at a volume that is only 20 percent of capacity. At this volume mean speed is probably hardly any less than at much lower volumes.

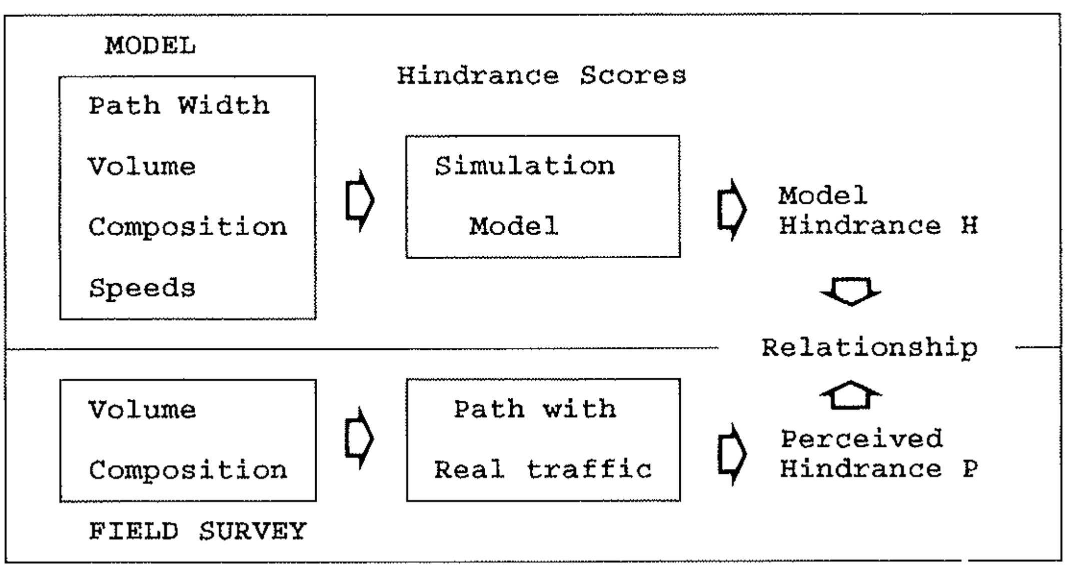

FIGURE 1 Setup of study to determine criteria for required width of bicycle paths.

TABLE 1 Service Volumes According to Hindrance Criterion

LOS	% with Hindrance over 1 km	Service Volume (bic/h) One-Way 2-lane	One-Way 3-lane	Two-Way 2-lane	Two-Way 3-lane
A	0-10	130	780	65	150
B	10-20	260	1560	105	230
C	20-40	520	3120	170	350
D	40-70	910	5460	250	500
E	70-100	1300	7800	325	630
F	100	----	----	---	---
Capacity		6400	9600	3200	4800
Volume Capacity Ratio at LOS E-F		0.20	0.81	0.10	0.13

For a three-lane path, LOS F is reached at 81 percent of capacity. A three-lane path is used much more efficiently than a two-lane path.

For two-way paths no data about capacity are available. The numbers in the table are based on the assumption that, due to the friction of opposing streams, the capacity is half that of a one-way path of the same width. For two-way paths the level of hindrance increases steeply with volume and LOS F is reached at volumes that are only 10 to 13 percent of the assumed capacity.

It is obvious that if density had been used as a criterion for the quality of the flow instead of hindrance, the results would have been quite different. In particular, the different functioning of a two-lane and three-lane path would not have been found.

New Criterion For Quality of Operation

The criterion "percentage of users experiencing hindrance over 1 km" will now be replaced by a simpler one, "the frequency of events with respect to time." It seems more appropriate to use frequency with respect to time than with respect to distance, especially when the concept is applied to users with substantially different speeds, as is the case for bicyclists and pedestrians.

Events are in fact maneuvers in this stage of the development, but they could encompass other phenomena. Events are defined for this study as either passings or meetings. The frequency will be used as a proxy for the hindrance a user experiences. When the frequency increases the quality of operation decreases. Because not all events bring about the same amount of hindrance, some form of weighting will be needed.

It is easier to understand and appreciate the meaning of one event every 15 sec than a frequency of 4 times per minute. Therefore the frequency (F) will be expressed as number of events per second. For example, a frequency of 4 times per minute will be denoted as 1/15 event per second (e/sec).

Further discussion in this paper will be limited to two-lane paths, as a first step in the development. It is more difficult to make a first estimate for the weighting of the hindrance of the maneuvers for paths wider than two lanes without any field survey.

On a bicycle path no lanes are marked by lines, but a basic lane width has been established to be .75 m to 1 m. A narrow two-lane path has a width of 1.5 m, just allowing cyclists to ride two abreast. A more generous path has a width of 2 m, on which bicyclists are easily able to ride two abreast. It is this width that is implied by the phrase two-lane path. It is assumed that this width is really available to the users, that is, that sufficient lateral clearing is present.

Table 2 shows the values of the frequencies for the service volumes in Table 1 for one-way and two-way two-lane paths. For one-way paths the only events considered are passings. An individual bicyclist experiences a frequency that depends on the volume and the speed distribution. Assuming that bicyclists do not impede each other, and assuming a normal probability distribution for the speeds with a mean (U) set at 18 km/hr, standard deviation (σ) set at 3 km/hr, and a certain volume (Q), the frequency is given by the following equation (*9*):

$$F = 2Q\,\sigma/\{U\sqrt{\pi}\} \qquad (1)$$

For the chosen U and σ this works out as: $F = 0.188\,Q$

For LOS F the frequency is one passing per 15 sec or more. An average passing takes approximately 10 sec (*6*); therefore, at this LOS a bicyclist spends about two-thirds of the time carrying out a passing. (Probably the proportion two-thirds has a positive bias, because some passings overlap.) At LOS A there is less than one passing every 2.5 min.

LOS F represents conditions worse than 100 percent hindrance. This percentage cannot increase, by definition, but the hindrance per user does increase with increasing volume. This means that LOS F ranges from LOS E to capacity and over the congestion branch of the speed-flow relation (see Figure 2).

For two-way paths two types of events are of importance: passings and meetings. It is likely that a meeting causes less hindrance than a passing because both parties involved can anticipate the event. On the other hand, the relative speed of a meeting is much higher than that of a passing; consequently, the subjective fear of an accident might be higher.

At a preliminary estimate, a meeting gets half the weight of a passing. This approximation will influence the results, and should be investigated. The weighting can be accounted for by halving the

TABLE 2 Service Volumes and Frequency of Events for Two-Lane Bicycle Paths

LOS	% with Hindrance over 1 km	One-Way Service Volume (bic/h)	One-Way Frequency Passings (e/s)	Two-Way Service Volume[a] (bic/h)	Two-Way Freq. Meetings (e/s)	Two-Way Freq. Passings (e/s)	Two-Way Freq. Total (e/s)
A	0-10	130	< 1/150	65	< 1/55	< 1/589	< 1/95
B	10-20	260	< 1/75	105	< 1/34	< 1/365	< 1/60
C	20-40	520	< 1/35	170	< 1/21	< 1/225	< 1/35
D	40-70	910	< 1/20	250	< 1/14	< 1/153	< 1/25
E	70-100	1300	< 1/15	325	< 1/11	< 1/118	< 1/20
F	100		> 1/15		> 1/11	> 1/118	> 1/20

Mean Speed = 18 km/h, SD of Speeds = 3 km/h
[a]Two-way volume and 50:50 directional split

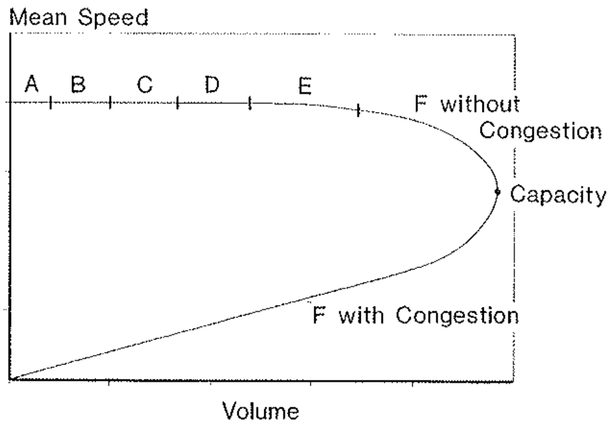

FIGURE 2 Sketch of the LOS in a speed-volume diagram.

frequency of the meetings before adding it to the frequency of passings. The results are presented in Table 2.

It can be seen that the total frequency for the two-way path is not very different from the frequency for the one-way path for the same service volumes. The values in the table are rounded to the nearest multiple of 5 sec and will be used as a first estimate when developing the method for a pedestrian-bicycle path.

LOS FOR PEDESTRIAN-BICYCLE PATH

As with the separate bicycle path the frequency of events or maneuvers will be used as a criterion for the quality of the flow. The treatment will be limited to two-lane facilities. As stated before, these have a width of 1.5 to 2.0 m, and it is assumed there is sufficient lateral clearance. One-way and two-way traffic can be distinguished. Because of space considerations only two-way traffic will be considered in this paper. One-way traffic is a simpler situation and can be derived in a straightforward manner from the two-way situation.

With two types of users on the path, the total hindrance can be divided into four components:

- Pedestrians (peds) experiencing hindrance from other peds. As the volumes of peds in the situations considered will be relatively low, this component will be neglected. Whether this is allowed can be verified by using the LOS for peds using the procedure of the HCM for peds on a sidewalk.
- Peds experiencing hindrance due to the presence of bicyclists (bics).
- Bics experiencing hindrance from peds.
- Bics experiencing hindrance from other bics.

The types of hindrances show that the LOS in a certain situation can be different for peds and bics. This is a consequence of the fact that quality is assessed by the users. The LOS for a group of users should be assessed in the framework of the network of facilities that is meant to provide service for this group. It is likely that the networks for peds and bics are not exactly the same.

Nevertheless it might be desirable to assign one LOS to the traffic situation on a facility with two types of user. This can be done by combining the LOS for both parties into one. The method is to average the frequency of events with weights proportional to the volumes, then derive from this the overall LOS.

Calculations

Consider a two-way path with peds and bics. It is assumed that the situation is symmetrical, with volumes and speeds the same in both directions. However, the procedure to handle unequal volumes in both directions is principally the same and requires no extra assumptions.

Suppose the one-way volume of peds is Q_p ped/hr, and of bics, Q_b bic/hr. Peds have, according to the HCM, a mean speed (U_p) of 4.5 km/hr. For bics on a flat path and without wind, studies in the Netherlands (*6*) indicate a mean speed (U_b) of 19 km/hr. In this study, the value of 18 km/hr is used because that is exactly 4 times the mean speed of pedestrians; using this value makes the numbers in the formulas easier to trace back. It is assumed that the speed distributions of peds and bics are such that they do not overlap, which is nearly always true.

Passings

The events considered are for a ped to be passed by a bic, and for a bic to pass a ped, to pass another bic, and to be passed by another bic.

The average frequency of a bic passing a ped (*9*) is as follows:

$$F\text{-pass}_{p\text{-}b} = Q_b\,(1 - U_p/U_b) \tag{2}$$

For the mean speeds chosen this works out as $F\text{-pass}_{p\text{-}b} = 0.75\ Q_b$

The frequency with which a bic passes a ped is calculated by the equation

$$F\text{-pass}_{p\text{-}b} = Q_p\,(U_b/U_p - 1) \tag{3}$$

And this works out as $F\text{-pass}_{b\text{-}p} = 3\ Q_p$

Consequently the frequency experienced by a bic is 4 times as high as that of a pedestrian, because a bic is 4 times as fast. The slower peds on the path cause relatively much hindrance for the faster bics. This can be compared to a situation with motorized traffic where a few slow-moving vehicles cause a disproportionate amount of hindrance for the faster vehicles.

The frequency of a bic passing or being passed by another bic (Equation 1) is calculated as follows:

$$F\text{-pass}_{b\text{-}b} = 0.188\ Q_b \tag{4}$$

Meetings

A volume of users Q_1 with mean speed U_1 in Direction 1 meets users of an opposing flow having volume Q_2 and mean speed U_2. The number of meetings in a road time domain of size X (length of section) and time T (length of period considered) is calculated as follows (*9*):

$$N_{\text{meet}} = X\,T\,Q_1\,Q_2\,(1/U_1 + 1/U_2) \tag{5}$$

This is the basic formula from which all others can be derived.

A ped with a speed U_p walking in the opposite direction of a flow of bics with a volume Q_b and a mean speed U_b, meets bics with a frequency as follows:

$$F\text{-meet}_{p\text{-}b} = Q_b\,\{1 + U_p/U_b\} = Q_b\,\{1 + 4.5/18\} = 1.25\ Q_b \tag{6}$$

A bic meets peds with the following frequency:

$$F\text{-meet}_{b\text{-}p} = Q_p\,\{1 + U_b/U_p\} = Q_p\,\{1 + 18/4.5\} = 5\ Q_p \tag{7}$$

Comparing Equations 6 and 7, it can be seen that for the same opposing volumes the 4-times-as-fast bic experiences 4 times the frequency of meetings that the pedestrian experiences. For the same distance covered, both parties will experience the same number of meetings but the bic experiences them in a shorter time. Consequently the quality of service is lower for the faster user.

The frequency of a bic meeting other bics is calculated as follows:

$$F\text{-meet}_{b\text{-}b} = 2\ Q_b \tag{8}$$

Total frequency

The frequency of meetings and passings is added to find the overall frequency of events. As noted earlier, the frequency of meetings gets half the weight of the frequency of passings.

The overall frequency of events for a ped in a same-direction flow of bics of volume Q_b and an opposing flow of the same volume Q_b (combine Equations 2 and 6) is calculated as follows:

$$\text{F-total}_p = .75\ Q_b + 1/2\ 1.25\ Q_b = 1.375\ Q_b \tag{9}$$

A combination of Equations 3, 4, 7, and 8 gives the overall frequency for a bic.

$$\begin{aligned} F\text{-total}_b &= 3\ Q_p + 0.188\ Q_b + 1/2\ \{5\ Q_p + 2\ Q_b\} \\ &= 5.5\ Q_p + 1.188\ Q_b \end{aligned} \tag{10}$$

Equation 9 implies that the LOS for peds is a function of the volume of bics only. The service volumes can be calculated and are presented in Table 3. Equation 10 implies that the LOS for bics is a function of the volumes of both peds and bics. This result is presented in Figure 3.

To get the overall LOS for the users of the path, a sum weighed with the volumes of the frequencies of peds, Equation 9, and of bics, Equation 10, is calculated as follows:

$$\text{F-total}_u = \{6.875\ Q_pQ_b + 1.188\ Q_b^2\}/(Q_p + Q_b) \tag{11}$$

From the total frequency for a user, one can now determine the LOS for a given combination of volumes of peds and bics.

Examples

The following examples illustrate the results.

Example 1

$Q_p = 20$ ped/hr and $Q_b = 100$ bic/hr (one-way volumes)

$F_p = 1.375 \cdot 100 = 137.5$ e/hr $= 1/26.2$ e/sec $=>$ LOS $=$ D

$F_b = 5.5 \cdot 20 + 1.188 \cdot 100 = 228.8$ e/hr $= 1/15.7$ e/sec $=>$ LOS $= F$

TABLE 3 Service Volumes for Two-Way Two-Lane Ped-Bic Path

LOS for Pedestrian	Frequency (e/s)	Service Volume One-Way (bic/h)
A	< 1/95	28
B	1/95-1/60	44
C	1/60-1/35	75
D	1/35-1/25	105
E	1/25-1/20	131
F	> 1/20	

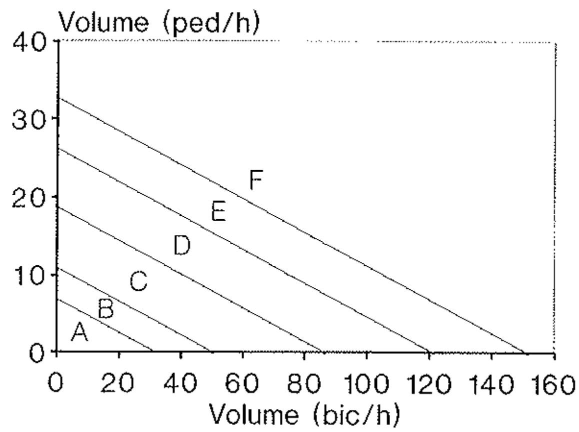

FIGURE 3 LOS for bicyclist using two-way ped-bic path; one-way volumes; directional split = 50:50.

Combination to get the frequency an average user experiences:

$F_u = \{20 \cdot 1/26.2 + 100 \cdot 1/15.7\}/(20 + 100) = 1/16.8$ e/sec
$=> \text{LOS} = F$

Without bics, peds would have a very favorable LOS A, but bics without peds would experience LOS D (see Table 2). Results are summarized in Table 4.

The LOS in this situation is rather bad for either type of user. The peds, whose LOS falls from A to D, are victims of the bics in this case. Bics alone would already have been at LOS D and would go down to LOS F.

Example 2

$Q_p = 100$ ped/hr and $Q_b = 20$ bic/hr (one-way volumes)

The same calculations as in Example 1 lead to results summarized in Table 4.

As in the previous example, both parties suffer from being mixed, with the bics perhaps suffering the most.

A general result is shown in Figure 4, in which the LOS for the users combined is given as a function of the volumes of peds and bics. This can be easily derived from Equation 11. It can be seen that at relatively high ped volumes, the effect of ped volume on the LOS is low and the effect of bic volume is high. At lower ped volumes, the volumes have a more equal influence on the LOS. It should be realized that the result for high ped flows can partly be explained by the fact that hindrance of peds from each other was neglected. However, for the ped volumes considered here that does not seem to be a critical assumption.

DISCUSSION OF RESULTS

It must be emphasized that this method of determining the LOS is a proposal and has a preliminary character. The method is considered more important than the results. A main point is that the assessment of the users is the ultimate criterion for the quality in accordance with the HCM's philosophy. Another important point is that the frequency of the maneuvers was chosen as a proxy for hindrance experienced by the users and this is a criterion for the quality of operation.

The criterion hindrance could be related to safety; this aspect certainly deserves special attention. Information knowledge about the frequency and severity of accidents between a pedestrian and a cyclist is probably scarce, as is information about a relation with geometrical factors such as width of the path.

It is sometimes argued that some cost criterion must be the ultimate yardstick for providing infrastructure. This is one of the reasons that travel time is used so frequently as a criterion for assessing quality. Costs are not an element directly included in this proposal. However, one should look at this aspect from a higher level. Every car trip that is replaced by the user with a foot or bicycle trip brings an economic benefit. For example, compare the required parking space at stations and shopping centers when people arrive as bicyclists or pedestrians rather than by car. Other benefits include improvements in noise, energy use, and air quality.

Some aspects of the development certainly need more studying.

- Is neglecting the hindrance caused by interaction of pedestrians justified at the volumes relevant here?
- Can second-order interactions be neglected? A second-order interaction occurs, for example, when a meeting and passing conflict with each other or when two passings conflict. At LOS A this assumption is certainly justified, but at lower LOSs it must be investigated.

TABLE 4 Two-Way Path with Majority of Either Bics or Peds

	2-way volume user/h	LOS if alone	LOS for user	Combined
Majority of Bics				
Peds	40	superb A	A	240 users with LOS F
Bics	200	D	F	
Majority of Peds				
Peds	200	A	A	240 users with LOS D
Bics	40	A	F	

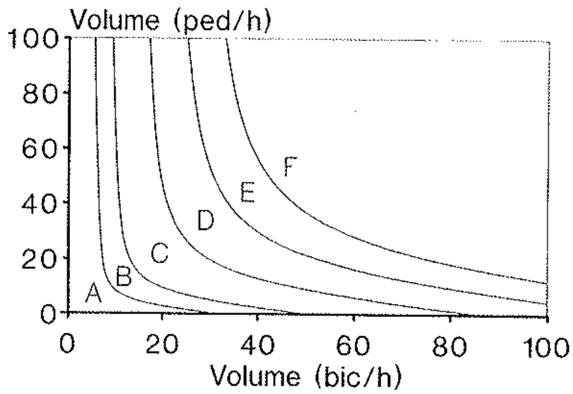

FIGURE 4 LOS of user on two-way ped-bic path; one-way volumes; directional split = 50:50.

- In the proposal some estimates have been made, the most important of which is probably the rating of a meeting at half the hindrance of a passing. Several methods are possible to determine how users rate these two maneuvers with respect to each other. One method would be to stop users of a path and interview them in a structured way. A second method would be to make photographs or, preferably, short videos of maneuvers for traffic experts and a sample of users to rate and discuss. It should be noted that the position of the camera could have an influence on the assessment of the hindrance.
- The speed distributions have an influence on the frequency of events and more field data are required. It is possible that one needs to distinguish between two groups of bicyclists: fast and possibly aggressive ones, and more relaxed ones.
- More information is needed about maneuvers on a pedestrian-bicycle path and on two-way bicycle paths. What is the area and time needed to carry out the maneuvers safely and comfortably?
- Would the passenger car unit (PCU) concept in a modified form be useful? That is, is it advantageous to express pedestrians as bicyclists and vice versa?

A special property of the proposal is the distinct meaning of LOS F, which refers not only to congested conditions, but to an unacceptable quality. This implies that the value of capacity is not that important for determining the LOS and that it need not be known precisely.

Possible applications of these concepts include the following:

- Development of criteria for separating pedestrians and bicyclists;
- Determination of requirements for the width of bicycle paths, pedestrian paths, and pedestrian-bicycle paths; and
- Extension of the concept to other mixed flows, for instance of cars and bicyclists.

REFERENCES

1. *Special Report 209: Highway Capacity Manual 1985.* TRB, National Research Council, Washington D.C., 1985.
2. Brilon, W. A New German Highway Capacity Manual. In *Proc. II Int. Symp. on Highway Capacity.* ARRB 1994.
3. Welleman, A. G. Why a Bicycle Policy in the Netherlands? In *Cycling in the City, Pedalling in the Polder. CROW Record 9,* Ede(NL), 1993.
4. CROW. *Sign up for the bike; Design manual for a cycle-friendly infrastructure.* CROW Record 10, Ede(NL), 1993.
5. *Special Report 87: Highway Capacity Manual 1965.* HRB, National Research Council, Washington D.C., 1965.
6. Botma, H. and J. H. Papendrecht. Traffic Operation of Bicycle Traffic. In *Transportation Research Record 1320,* TRB, National Research Council, Washington, D.C., 1991, pp. 65–72.
7. Navin, F. P. D. Bicycle Traffic Flow: Experimental Results and Comparisons. *ITE Journal,* Vol. 64, No. 3, March 1994, pp. 31–36.
8. Botma, H., and J. H. Papendrecht. Operational Quality of Traffic on a Bicycle Path. In *ITE Compendium of Technical Papers, 63rd Annual Meeting,* 1993.
9. Leutzbach, W. *Introduction to the Theory of Traffic Flow.* Springer, New York, 1988.

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