Low-Cost Opportunities for Making Cities Bicycle-Friendly Based on a Case Study Analysis of Cyclist Behavior and Accidents

ROBERT G. THOM AND ALAN M. CLAYTON

Cycling as a means of transportation has increased substantially in cities throughout the developed world. This increase in bicycle use has taken place largely on urban transportation systems that were not specifically planned or designed to accommodate cyclists, particularly in North America. As a result, these cities are witnessing increases in bicycle accidents and growing problems in coping with bicycle traffic. Furthermore, the proportion of adult cyclists involved in accidents has increased, reflecting the bicycle's increased role in urban transportation. Field observations of cyclist behavior were carried out at key sites in the cities of Winnipeg and Vancouver, Canada, whose road networks were not specifically planned with the bicycle in mind. These observations reveal that only half of cyclists ride correctly. Practices such as riding on the sidewalk, going straight from right-turn-only lanes and bus bays, and overtaking between traffic and the curb were common. In addition, two-thirds of left turns were done incorrectly and cyclists tended to "switch roles" between pedestrian and vehicle operator. These behavior patterns are compared with Winnipeg's bicycle accident experience, on the basis of detailed consideration of some 2,300 police-reported, bicycle–motor vehicle collisions over 13 years. The comparison indicates that many of the observed patterns contribute to accidents. To counter the increase in bicycle accidents and to make current transportation systems bicycle-friendly, low-cost opportunities in the areas of roadway modifications, cyclist training, and public awareness are proposed.

The bicycle is increasingly used as a means of transportation in cities throughout the developed world. This increase in bicycle use has taken place on urban transportation systems that typically were not planned or designed to accommodate cyclists, particularly in North America. As a consequence, these cities are experiencing growing problems with bicycle accidents and coping with bicycle traffic. Furthermore, the proportion of adult cyclists involved in accidents has increased, reflecting the bicycle's growing role in servicing short-distance urban trips. Given the increased concern for the environment, cycling as a means of transportation is likely to continue to increase.

If bicycles are to play a greater role in urban transportation, it would be helpful to identify and implement low-cost methods to retrofit transportation systems in order to increase cyclist safety and to make urban areas more bicycle-friendly. To assist in this effort, it is useful to examine cyclist behavior in the current transportation setting and to identify cyclist actions that contribute to accidents. Currently, little research has been done to examine the influence of roadway and traffic characteristics on cyclist behavior and to link cyclist behavior to accidents.

The cities of Winnipeg and Vancouver, Canada, are used as case study situations. These are good examples of medium-sized North American cities (populations of 600,000 and 1,500,000, respectively) whose road networks were not planned or designed with the bicycle in mind.

R. G. Thom, University of Manitoba Transport Institute, Winnipeg, Manitoba, Canada R3T 2N2. A. M. Clayton, Department of Civil Engineering, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2N2.

PURPOSE AND SCOPE

The purpose of this research is to explore possible links between cyclist behavior and accidents with a view to developing countermeasures. Specifically, this paper

1. Examines the influence of urban roadway traffic characteristics on cyclist behavior through field observation at seven key locations in the cities of Winnipeg and Vancouver;
2. Correlates the behavioral characteristics observed in item 1 to the bicycle accident experience in Winnipeg, on the basis of some 2,300 police-reported bicycle–motor vehicle collisions over a 13-year period;
3. Suggests low-cost methods and countermeasures to make the transportation system more accommodating to cyclists and to improve overall safety, specifically in the areas of roadway modifications, cyclist training, and public awareness.

OBSERVATIONS OF CYCLIST BEHAVIOR

Why Observe Behavior?

It is hypothesized that cyclist behavior patterns are influenced by different roadway and traffic characteristics. It is also hypothesized that certain cyclist behavior patterns influence accidents. In order to link cyclist behavior to accidents, it is necessary to observe how cyclists ride under varying roadway and traffic characteristics in different urban settings.

Summer 1991 Field Study

Field observations were carried out at seven key locations to examine cyclist behavior under varying roadway and traffic characteristics in Winnipeg and Vancouver. Observations were done on 900 cyclists in June and July 1991. A total of 14 hr of data were collected, or 2 hr of data for each site. All observations were conducted on weekdays between 9:00 a.m. and 9:00 p.m. to include a variety of traffic and cyclist characteristics.

Observation Methodology

Data for individual sites were collected by a single observer. The observer was to select a vantage point with a clear view of the site while being as inconspicuous as possible to motorists and cyclists. Observations were made on all cyclists passing through the site during the 2 hr. Information was collected on the following parameters for each cyclist.

Cyclist Maneuver

One of three possible cyclist maneuvers was indicated: going straight, turning left, and turning right.

Correct Riding Style

A cyclist was considered to be riding correctly if the cyclist obeyed stop signs and red lights, yielded the necessary right-of-way to traffic and pedestrians, rode with traffic, positioned self correctly in the intersection for the maneuver, shoulder checked and signaled before changing lanes, and did not weave or overtake traffic on the right. If a cyclist maneuver was considered to be incorrect, the reason was indicated according to the parameters that follow (with the exception of "riding on shoulder" and "in bus bay," the parameters were considered to be actions that contributed to accidents, on the basis of the Winnipeg study):

- *Disobeyed stop sign or red light*. The cyclist failed to stop at a stop sign or red light or proceeded into an intersection on a red light.
- *Fail to yield right-of-way*. The cyclist failed to yield the necessary right of way to pedestrians or traffic during a maneuver.
- *On sidewalk or in crosswalk*. The cyclist was riding on a sidewalk or in a crosswalk for all or part of a maneuver.
- *Improper position for left turn*. The cyclist was in the incorrect position at an intersection when making a left turn. Examples of incorrect positions include turning left from the right curb, turning left from a sidewalk or crosswalk, turning left from the wrong side of the roadway, or turning left from the right side of a dual left/through lane.
- *Proceeding from exclusive right-turn lane*. A straight-through cyclist was proceeding from a right-turn-only lane.
- *Too close to parked cars*. The cyclist was riding less than a car door's width to the left of parked cars.
- *Overtaking between traffic and curb*. A cyclist was overtaking slower-moving or stopped traffic between the traffic and the curb.
- *Weaving*. The cyclist was weaving in traffic or in gaps between parked cars.
- *In bus bay*. The cyclist proceeded from a bus bay.
- *Wrong way*. The cyclist was riding on the roadway or road shoulder against traffic. This parameter did not include cyclists who were riding against traffic on the sidewalk or in a crosswalk.
- *Riding on shoulder*. The cyclist was riding on a shoulder.

In the event that the observer was unable to collect the required information for a particular cyclist (for example, if his or her view was blocked by a passing transit vehicle), all information on the cyclist was discarded.

Description of Observation Sites

The intent of the observations was to examine cyclist behavior on arterial roads in the vicinity of intersections, where more than half the bicycle–motor vehicle collisions occurred (*1*). Bicycle volumes for each of the sites had to be high enough to obtain an adequate number of observations within a short time frame. Therefore, cyclist behavior on resident streets, back lanes, parking lots, and driveways, where some 30 percent of the accidents took place, was not observed. The sites were selected in an attempt to incorporate a variety of roadway, cyclist, and traffic characteristics and to reflect the accident situation along arterial roads rather than represent all accidents.

Figure 1 represents the layout of the seven sites. The speed limit (in kilometers per hour) and approximate average daily traffic volumes are indicated for each site. All traffic lanes are 3.7 m (12 ft) wide, with the exception of one roadway at Site 6, which has curb lanes 4.9 m (16 ft) wide.

Site 1

Site 1 is situated just outside the downtown area. Observations were carried out during the afternoon rush hour. Traffic was generally heavy and slow-moving. Most of the cyclists observed were adults, many of whom appeared to be regular bicycle users, and many were traveling as fast as the traffic. Of special interest was the incidence of cyclists going straight from the right-turn-only lane and the bus bays.

Site 2

Site 2 is on a suburban university campus. Observations were performed during the morning rush hour. Traffic was operating under free-flow conditions. Most cyclists observed were regular adult commuters and were traveling at about half the speed of traffic. Close attention was paid to cyclists turning left from the right side of the dual destination lane.

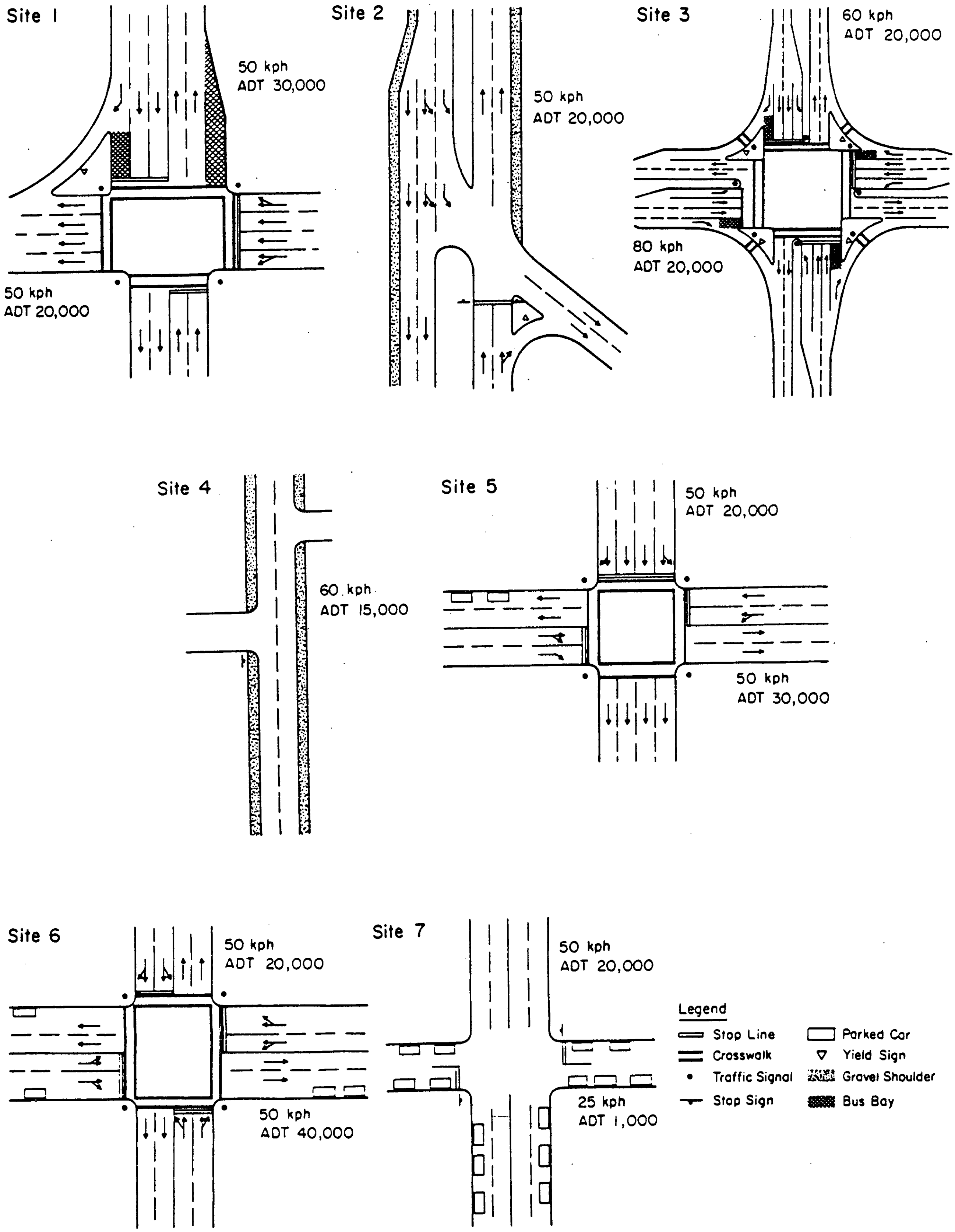


FIGURE 1 Site layouts.

Site 3

Observations at Site 3, a suburban intersection, were made on a weekday evening under light, free-flow traffic conditions. The cyclists observed were a mixture of children and adults riding for recreation. There was a greater tendency here for cyclists to travel in groups than at the other sites. Of interest were cyclists riding on sidewalks or in crosswalks and cyclists riding in the bus bays. Most of the bicycle traffic was concentrated on the 60-km/hr roadway and was traveling slower than traffic.

Site 4

As with Site 3, observations on Site 4, a suburban arterial, were made on a weekday evening under light traffic conditions. Cyclists were primarily children and adult recreational riders, a number of whom were traveling in groups and were slower than traffic. Of interest were cyclists riding on the gravel shoulders and sidewalks because of the perceived danger of riding on the roadway.

Site 5

Observations at Site 5, a downtown intersection, were made during the afternoon rush hour with heavy, slow-moving traffic. Most cyclists were adult commuters or adult recreational riders who were traveling near the speed of traffic. Special notice was given to cyclists going straight through from the right-turn-only lane and cyclists riding the wrong way on the one-way street.

Site 6

Site 6 is in a well-developed urban setting outside of downtown. Observations were made during the mid-afternoon and early rush hour under moderate to heavy traffic flow with cyclists traveling near the same speed. Cyclists varied from school children to adult recreational riders to adult commuters.

Site 7

Site 7 is one block from Site 6. Observations were carried out during the afternoon rush hour with generally heavy, slow-moving traffic; recreational adult riders and community cyclists were most frequent. Of interest were cyclists that might disobey stop signs or fail to yield to traffic when crossing the arterial from the residential street. It was anticipated that a number of cyclists would use the residential street as an alternative to the arterial road at Site 6.

Observation Results and Comments

In total 900 cyclists were observed and recorded during the study. The results of the individual site observations are summarized in Table 1. The following comments can be made:

- *Incorrect riding style is very common.* One-half of cyclists were doing something wrong during a maneuver, as will be described in detail.
- *Sidewalk and crosswalk cycling is common.* Nearly one of four cyclists observed was riding on the sidewalk or in a crosswalk for all or part of a maneuver. This reflects cyclists' perceived danger of riding on the roadway in traffic and negotiating busy multilaned intersections. At Site 4, a two-lane, two-way arterial with gravel shoulders, sidewalk usage by cyclists was particularly high (about one-half of the cyclists observed). This may be motivated by fear of overtaking traffic on a narrow roadway.
- *Left turns are performed incorrectly.* Of the 160 cyclist left turns observed, less than one-third were done correctly. Many cyclists either lack the skills to safely get in the correct position for a left turn or perceive that changing lanes in traffic is extremely dangerous. Cyclists thus opt to ride through the crosswalk for all or part of the maneuver or turn left from the curb. At Site 2, 60 percent of the left turns were made from the wrong side of the dual left turn–through lane.
- *Right turns are more likely to be done correctly than other maneuvers.* Only 40 percent of the 114 right turns observed were considered to be done incorrectly, compared with more than 65 percent of left turns and 47 percent of straight-through maneuvers.
- *Cyclists proceed from exclusive right-turn lanes.* Approximately two-thirds of the cyclists going straight ahead at an intersection equipped with right-turn-only lanes (Sites 1 and 5) did so without changing to the adjacent through lane. Many cyclists either find changing lanes difficult or choose to ignore signage and pavement markings.
- *In heavy traffic, cyclists weave and overtake between traffic and the curb.* During periods of heavy traffic, there was a greater tendency for cyclists to overtake between traffic and the curb and to weave between lanes of slow-moving or stopped traffic when approaching an intersection. This phenomenon was evident at Sites 1 and 5. In free-flow traffic conditions, no cyclists were observed to be weaving in traffic. Cyclists were, however, more likely to disobey red lights and stop signs when traffic was light.
- *Cyclists travel in bus bays.* Approximately 80 percent of straight-through cyclists observed at sites with bus bays (Sites 1 and 3) were riding in the bus bays. It is probable that many cyclists do this believing that bikes belong near the curb.
- *Wrong-way riding on the roadway is uncommon.* The vast majority of cyclists riding on the roadway were observed to be riding with traffic. Wrong-way riding was more common at sites with one-way streets (Sites 1, 3, and 5). As many as half of the cyclists riding on the sidewalk or in crosswalks were riding against traffic.

Commentary

From the field observations, it is apparent that many cyclists do not ride according to the established rules and principles of traffic flow: only half of the cyclists were observed to be riding correctly. There is the tendency for cyclists to "switch roles" between being a vehicle operator and a pedestrian whenever they think it is safer or more convenient to do so. A significant number of cyclists lack an understanding of how

TABLE 1 Summary of Cyclist Observations in Winnipeg and Vancouver, June–July 1991

Observations	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Total (%)
Observations	265	113	75	47	150	150	100	900
Cyclist Maneuver:								
Straight	203	31	51	38	120	105	78	626 (69.6)
Turning Left	17	73	11	5	17	26	11	160 (17.8)
Turning Right	45	9	13	4	13	19	11	114 (12.7)
Cyclist Action:								
Disobeyed stop sign/red light	1	3	9	0	2	1	6	22 (2.4)
Fail to Yield Right of Way	0	0	0	0	1	0	1	2 (0.2)
On sidewalk/in crosswalk	75	10	27	24	16	46	16	214 (23.8)
Improper position for left turn	10	43	2	4	6	9	4	78 (8.9)
Proceeding from right turn only lane	43	n/a	n/a	n/a	30	n/a	n/a	73 (8.1)
Too close to parked cars	0	0	0	0	0	0	5	5 (0.6)
Overtaking between traffic and curb	13	0	0	0	13	2	1	29 (3.2)
Weaving	4	3	3	0	3	1	1	15 (1.7)
In bus bay	71	n/a	20	n/a	n/a	n/a	n/a	91 (10.1)
Riding wrong way	6	6	0	2	4	2	2	22 (2.4)
On shoulder	n/a	0	3	1	n/a	n/a	n/a	4 (0.4)
Correct riding style	96	56	24	19	95	96	71	457 (50.8)

n/a - not applicable

traffic operates, perceive cycling in traffic to be very dangerous, or believe that the rules of the road do not apply to them.

The high incidence of sidewalk riding may be motivated by the perceived dangers of overtaking traffic. In heavy traffic conditions, cyclists were observed trying to "get ahead" by overtaking between traffic and the curb, weaving, and taking to the sidewalk.

Left turns pose difficulties for many cyclists; only one-third of these were done correctly. Cyclists elect to use crosswalks or turn left from the curb in many cases. The use of exclusive right-turn lanes and bus bays by straight-through cyclists could be motivated in part by traffic laws requiring cyclists to ride next to the right curb.

WINNIPEG'S BICYCLE ACCIDENT EXPERIENCE

Data Base

This section presents the results of an analysis of nearly 2,300 police-reported bicycle–motor vehicle collisions in Winnipeg between 1976 and 1989. The purpose of the analysis was to determine the nature and extent of car-bike collisions with a view to identifying trends. The results of the analysis provide the basis for examining the bicycle accident problem as it relates to cyclist behavior.

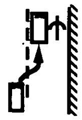
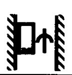
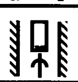
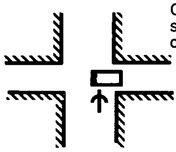
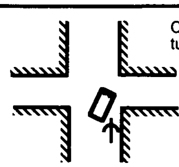
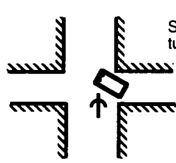
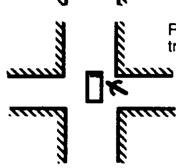
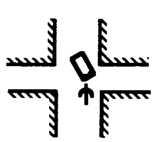
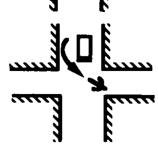
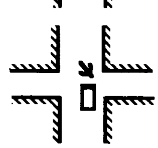
The analysis did not include accidents involving (a) a person walking a bicycle at the time of the collision, (b) unattended bicycles, and (c) falls or cyclist collisions with fixed objects, pedestrians, animals, or other cyclists.

Methodology

To develop an understanding of the nature of the accidents, it was necessary to reconstruct each collision on the basis of the data and witness narratives in the police reports. Currently, all accidents resulting in injury or a minimum of $500 property damage are required to be reported to the police. A total of 2,293 accidents were analyzed.

For each accident, cyclist, roadway, and weather characteristics were determined. Contributing factors were identi-

TABLE 2 Number of Bicycle–Motor Vehicle Accidents by Configuration: Winnipeg, 1976–1989

Group	Configuration	Diagram	Description	Occurrences	Principal Contributing Factors	Occurrences
A. Mid - block Collisions 528 (23.0%)	1. Rear End 156 (6.8%)		Cyclist strikes rear of stopped or parked motor vehicle.	[83]	• Cyclist inattentiveness • Cyclist loss of control	[78]
			Rear of cyclist struck by front of overtaking motor vehicle.	[73]	• Motorist improper overtaking • Cyclist swerves unexpectedly • Cyclist lack of reflector / taillight	[22] [35] [16]
	2. Opening Car Door 113 (4.9%)		Cyclist stricks driver side door.	[107]	• Motorist opening door into traffic • Cyclist too closed to parked car	[107] [107]
			Cyclist strikes passenger door	[6]	• Cyclist improper overtaking	[6]
	3. Sideswipe same Direction 222 (9.7%)		Cyclist sideswiped by overtaking motor vehicle	[162]	• Cyclist swerves unexpectedly • Motorist improper overtaking • Cyclist lack of reflector / taillight	[67] [82] [6]
			Motorist changes lane to right	[29]	• Motorist improper lane change	[26]
			Motorist entering/exiting parking spot	[31]	• Cyclist improper over taking • Motorist fails to yield right of way	[6] [25]
	4. Sideswipe - Opposite Direction 20 (0.9%)		Cyclist sideswiped by motor vehicle travelling in opposite direction	[20]	• Cyclist or Motorist travelling wrong way • Cyclist or Motorist loss of control	[10] [10]
	5. Head on 17 (0.7%)		Front of cyclist struck by front of motor vechicle travelling in opposite direction	[17]	• Cyclist or motorist travelling wrong way • Cyclist or motorist loss of controll	[15] [2]
B. Intersection Collision 1765 (77.0%)	6. Right Angle 983 (42.9%)		Cyclist proceeding straight intersection struck by straight through motor vehicle on perpendicular road way	[983]	• Cyclist or motorist disobeys traffic control device • Cyclist or motorist fails to yield right of way • Cyclist on sidewalk and / or wrong way • Cyclist lack of head light	[276] [486] [95] [23]
	7. Right turn 306 (13.3%)		Cyclist going straight struck by motorist turning right	[181]	• Motorist improper turning • Cyclist improper over taking • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of reflectors / taillight	[105] [54] [9] [8]
			Straight through cyclist struck by motorist turning right from perpendicular road way	[113]	• Motorist fails to yield right of way • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of head light	[28] [79] [2]
			Right turning cyclist struck by motorist travelling straight on perpendicular roadway	[12]	• Cyclist fails to yield right of way	[12]
	8. Left Turn 476 (20.8%)		Straight through cyclist struck by motorist turning left across his path	[312]	• Motorist fails to yield right of way • Cyclist riding on sidewalk and / or wrong way • Cyclist lack of head light	[212] [45] [49]
			Left turning cyclist struck by overtaking motorist	[117]	• Cyclist turning left from curb • Cyclist failure to shoulder check • Cyclist lack of reflector / taillight	[117] [117] [8]
			Cyclist turns left across motorist's path	[47]	• Cyclist fails to yield right of way	[47]

[ ] indicates number of occurrences

fied for both the motorist and the cyclist. For cyclists, typical accident causation factors included failing to yield right-of-way, disobeying stop signs and red lights, riding on the sidewalk, riding the wrong way, and lacking nighttime equipment. For motorists, common factors included failing to yield right-of-way and turning right improperly. An accident classification system was devised incorporating 16 configurations as illustrated in Table 2. The methodology and study results are reported in detail in Thom and Clayton (*1,2*).

Results

The following bicycle–motor vehicle accident characteristics were observed:

- Bicycle–motor vehicle collisions on Winnipeg's roadways increased by 50 percent between 1976 and 1989. In comparison, total accidents remained steady during the period.
- Cyclists are currently involved in 10 percent of all injury-producing accidents in the city during the peak cycling months (i.e., May to October).
- Not surprisingly, 9 of 10 accidents resulted in injury to the cyclist, 15 percent of which were serious enough to require medical attention.
- The proportion of adult cyclists involved in accidents increased from 20 percent in 1976 to greater than 49 percent in the late 1980s, reflecting the bicycle's increased role as an urban transportation mode.
- Nearly two-thirds of the accidents involved a major (arterial) roadway. This reflects cyclists' preference for these roadways because of their directness and fewer delays. In many situations, there are no alternative "quiet" roads paralleling arterial roads.

The distribution of accidents by configuration and contributing factor is shown in Table 2. From this table,

- Nearly one-quarter (528) of accidents occurred at mid-block locations, with rear-end, sideswipe, and cyclist striking opening car door being the most frequent configurations
- More than three-quarters (1,765) of the accidents were intersection-related, with right-angle collisions being the most common (983, or 43 percent) (Configuration 6).
- The rear-end collision (Configuration 1*b*) was very uncommon: only 1 percent of the accidents were the result of cyclists' being rear-ended by improperly overtaking motorists in daylight conditions. In fact, more than half of the overtaking collisions were the result of the cyclist's swerving unexpectedly into the motorist's path.
- One of 10 (230) accidents occurred in darkness. In nearly all of these, the cyclist lacked a headlight and adequate rear reflectors or taillight. One-quarter of the nighttime accidents involved a motorist turning left across the path of a straight-through cyclist (Configuration 8*a*).

The distribution of accidents by contributing factor for cyclists and motorists is shown in Table 3. From this table,

TABLE 3 Number of Bicycle Accidents by Principal Contributing Factor: Winnipeg, 1976–1989 (*2*)

(a) Cyclist	Number of Accidents	% Accidents
Fail to yield right of way	347	15
Sidewalk/wrong way riding	328	14
Disobey traffic control device	255	11
Improper left turn	117	5
Swerves unexpectedly	102	4
Lack of night-time equipment	230	10
Loss of control	84	4
Too close to parked car	107	5
Total cyclists	1570	69
(b) Motorist	**Number of Accidents**	**% Accidents**
Fail to yield right of way	447	19
Disobey traffic control device	31	1
Improper overtaking	104	4
Improper lane change	29	1
Improper right turn	113	5
Wrong way	3	< 1
Loss of control	6	< 1
Opening door into traffic	107	5
Unsafe backing	5	< 1
Total motorists	845	35

- The most frequent contributing factor on the part of the cyclist was failure to yield right of way (in 347, or 15 percent, of accidents), followed by sidewalk and/or wrong-way riding (in 328, or 14 percent, of accidents). Over 250 (or 11 percent) of the accidents were the result of cyclists' disobeying stop signs or red lights.
- The most frequent contributing factor on the part of the motorist was also failure to yield right of way (in 447, or 19 percent, of accidents), followed by improper right turn (in 113, or 5 percent, of accidents).

Cyclists were at fault in nearly 70 percent (1,570) of the accidents analyzed. Motorists contributed to 35 percent (845) of the accidents, 5 percent of which the motorist and cyclist were judged to be equally at fault. More than a quarter of accidents were the result of cyclists' either failing to yield the right of way or disobeying a traffic control device. Even in those accidents in which the cyclist legally had the right of way, the cyclist was often doing something unusual, such as riding on the sidewalk or riding against traffic (and in many cases, both). Virtually all of the nighttime accidents were the result of the motorist's not being able to see the cyclist until it was too late to avoid a collision because of the cyclist's lack of either a headlight or rear reflectors and taillight. More than 5 percent of accidents were the result of cyclists' making improper left turns.

CYCLIST BEHAVIOR AND ACCIDENT EXPERIENCE

This section relates the findings of the behavioral observations with the bicycle accident experience. The observed cyclist actions described earlier are compared to cyclist contributing factors in bicycle–motor vehicle collisions just summarized. The comparison of cyclist behavior and accident causation is shown in Table 4 as percentages of observed cyclists and accidents, respectively. In making the comparison, it is to be realized that no direct cause-effect relationship was expected (i.e., because X percent of cyclists are seen to be riding the wrong way does not necessarily mean that X percent of the accidents should be caused by wrong-way riding). The relatively high or low incidences of certain cyclist behavior patterns may reflect the nature of the sites from which the observations were made. Nonetheless, the comparison is considered useful in helping to establish cyclist actions that may contribute to accidents, particularly on arterial roads. The following observations respecting cyclist behavior and the contribution of that behavior to accidents are drawn from this table.

Disobeying Stop Sign or Red Light

Less than 3 percent of the cyclists were observed to disobey stop signs or traffic signals. This action contributed to more than 11 percent of bicycle–motor vehicle collisions. This suggests that when a cyclist does disobey a traffic control device, the probability of a collision is high. As well, this action is probably more common in residential areas where traffic volumes are low and the perceived danger of a collision is also low. At the observation sites, most cyclists were forced to comply with stop signs and red lights because of high traffic volumes.

TABLE 4 Cyclist Behavior and Accident Contribution (2)

Cyclist Action	% of Observations	% of Accidents
Disobeyed stop sign/red light	2.4	11.1
Failed to yield right of way	0.2	15.1
On sidewalk/in crosswalk	23.8	14.3
Improper left turn	8.9	5.1
Proceeding from right turn only lane	8.1	0.3
Too close to parked cars	0.6*	4.7
Overtaking between traffic and curb	3.2	2.9
Weaving	1.7	4.4
In bus bay	10.1	0.0
Riding wrong way	2.4	7.6**
Lack of night-time equipment	no night-time observations made	10.0
Sample size	900	2293

* Only a limited number of observations were made of cyclists passing parked cars. Five cyclists were considered to be riding too close to parked cars out of a sample of 10 cyclists.
** Includes accidents where cyclists were riding wrong way on a sidewalk or in a crosswalk

Fail To Yield Right-of-Way

More than 15 percent of bicycle–motor vehicle collisions were the result of cyclists' failing to yield the right-of-way. In the field study, only 2 of the 900 cyclists did not yield to traffic when they were required to do so. As with disobeying stop signs or red lights, failing to yield incurs a great risk of collision. The low incidence of failing to yield the right-of-way is a reflection of the observations sites selected. In most cases, cyclists were forced to yield because of the traffic characteristics.

Riding on Sidewalk or in Crosswalk

Nearly a quarter of the cyclists were observed to be riding on the sidewalk or in a crosswalk for all or part of a maneuver. This action places cyclists in significant danger of collision at intersections, where 14 percent of the accidents were attributable to sidewalk or crosswalk riding. When motorists are crossing or turning at intersection, they are scanning for traffic on the roadway and simply do not expect to see cyclists coming off of the sidewalk. This action contributed significantly to the incidence of the right-angle, motorist-left-turn, and motorist-right-turn configurations (Configurations 6, 8*a*, 7*a*, and 7*b*, respectively, from Table 2).

Sidewalk riding also poses a danger to pedestrians. This danger, however, is difficult to quantify, since very few bicycle-pedestrian collisions are reported to the police.

Improper Position for Left Turn

Cyclists were incorrectly positioned for left turns in 9 percent of the observations, or in approximately half of the left turns observed. Many of these cyclists failed to shoulder check before moving left. Five percent of the accidents were due to cyclists making improper left turns.

Proceeding from Right-Turn-Only Lanes

In 8 percent of the observations, cyclists were going straight from exclusive right-turn lanes. Only six accidents were attributable to this action (Configuration 7*a*). This difference between observed behavior and accident experience reflects the fact that the vast majority of collisions involving right-turning motorists occurred at intersections that were not equipped with right-turn-only lanes. In addition, two of the seven sites selected for observation had these lanes, therefore the number of cyclists observed going through exclusive right-turn lanes could be expected to be high.

Cyclists who attempt to go straight from a right-turn-only lane are likely to conflict with right-turning traffic. In fact, several near-collisions were observed at Sites 1 and 5 as a result of this action.

Too Close to Parked Cars

More than 100, or 5 percent, of the accidents were the result of cyclists' striking opening car doors (Configuration *2a*). In all of these, the cyclist was riding too close to the parked car. In this study, the number of cyclists observed passing parked cars was too small to be able to conclude whether cyclists generally allow enough room between themselves and parked cars. Of 10 cyclists observed passing a row of parked cars, 5 were considered to be traveling too far to the right.

Overtaking Between Traffic and Curb

More than 3 percent of the cyclists were observed to be passing between stopped traffic and the curb. A similar percentage of the accidents were attributed to this, particularly collisions involving right-turning motorists (Configuration *7a*). Motorists turning right onto a perpendicular roadway, or into a driveway parking lot, do not expect to be overtaken on the inside. In addition, cyclists overtaking on the right are often caught in the motorist's blind spot. This practice also frequently annoys motorists.

Weaving in Traffic

Less than 2 percent of the cyclists were observed to be weaving or "lane jumping" in traffic. This action was most frequent during periods of heavy traffic. Weaving or swerving contributed to more than 4 percent of the accidents, particularly those configurations involving overtaking motorists (Configurations *1b* and *3a*). In addition, this practice can be annoying to motorists stopped in traffic.

In Bus Bay

Ten percent of observed cyclists were proceeding from bus bays. In none of the accidents was it noted that a cyclist was in a bus bay before or at the time of the collision. However, this action is potentially dangerous in that (a) the cyclist is forced to reenter the traffic stream more often than is necessary, and (b) by being well to the right of the traffic stream, the cyclist is less visible to left-turning motorists (Configuration *8a*) than by staying out of the bus bay. In addition, cyclists stopped in bus bays may interfere with transit operations.

Riding Wrong Way

Only 2 percent of cyclists were seen to be riding against traffic on the roadway. This practice was more common on one-way streets. In the Winnipeg accident study, approximately 70 percent of the cyclists who were riding against traffic at the time of the collision were doing so from a sidewalk. Cross and Fisher demonstrated that as many as 17 percent of car-bicycle collisions are attributable to wrong-way riding (*3*).

Lack of Nighttime Equipment

Although no observations were made at night, a casual survey indicates that the vast majority of bicycles operated at night lack a headlight and have the bare minimum in rear reflectors (including pedal reflectors). Many cyclists are also seen wearing dark-colored clothing. More than 90 percent of cyclists involved in nighttime collisions lacked the necessary equipment.

LOW-COST OPPORTUNITIES FOR MAKING ROADWAYS BICYCLE-FRIENDLY

On the basis of bicycle accident experience and observations of cyclist behavior, this section identifies low-cost countermeasures in the areas of roadway improvements, cyclist training, and public awareness to assist in making the current transportation system more accommodating to cyclists.

Roadway Improvements

From the findings in earlier sections, the following roadway modifications are suggested. Some of these suggestions may not be feasible on all roadways.

Wide Curb Lanes

On some roadways, it may be possible to widen curb lanes from the current width of 10 to 12 ft to 12 to 14 ft. This may be accomplished by restriping lanes or paving gravel shoulders. The provision of wider lanes may help to reduce the incident of sidewalk riding by increasing the level of comfort between cyclists and overtaking motorists, particularly at Site 4. This modification has the potential of reducing overtaking-type accidents (Configurations *1b*, *3a*) and opening-car-door collisions (Configuration *2a*) by enabling cyclists to ride far enough to the left of parked cars without having to travel in the adjacent traffic lane.

More Clearly Defined Lane Destinations

On multilane roadways, the destination of each lane (i.e., left, straight through, or right) should be made clear through overhead signs or pavement markings such as at Site 2. This would help left-turning cyclists select the proper lane. In addition, dual-destination lanes, such as left and straight-through, should be avoided so that a cyclist only has to ride on the right side of the lane that serves his or her destination.

Modifications to Right-Turn-Only Lanes

Exclusive right-turn lanes can benefit cyclists because they can reduce the frequency of collisions between straight-through cyclists and right-turning motorists (Configuration 7*a*). Straight-through cyclists might be more likely to stay out of right-turn-only lanes if these lanes were designed in such a way that it was not necessary to make a lane change in moving traffic to proceed straight (i.e., requiring right-turning traffic to lane change to the right), particularly at Sites 1 and 5. Right-turn-only lanes can also be created by restricting parking on the near side of an intersection and allowing parking on the far side of the same intersection. This modification may be applied to Sites 6 and 7. A cyclist could thus avoid conflicting with right-turning motorists by remaining on the extreme left side of the lane.

Other Measures

A number of other modifications that do not relate specifically to cyclist behavior and accident experience may be considered to make roadways more amenable to cycling and to improve overall cycling safety. These include the following.

Bicycle-Sensitive Traffic Signals Many traffic-actuated signals do not respond to bicycles, resulting in delays to cyclists during low traffic periods; occasionally cyclists proceed on a red light. Vehicle detectors should be set up so that they can detect a bicycle.

Extended Amber or All-Red Phases at Signalized Intersections Because cyclists generally move slower than most traffic, cyclists require additional time to clear an intersection when the light changes to amber. Consideration might be given to extending the amber phase by several seconds or following a standard-length amber phase with an all-red interval.

Left-Turn Phases at Signalized Intersections To reduce the frequency of collisions involving left-turn motorists (Configuration 8*a*), an exclusive left-turn phase could be incorporated in the signal sequence at most intersections on arterial roads.

Right-Turn-on-Red Restrictions Restricting right turns on red at signalized intersections has the potential of reducing the frequency of collisions involving motorists turning right from a perpendicular roadway (Configuration 7*b*) and, to a lesser extent, the frequency of cyclists being cut off by right-turning motorists (Configuration 7*a*).

Improved Roadway Maintenance and Hazard Removal In addition to roadway modifications, attention should be paid to maintaining road surfaces and removing road surface hazards. Debris such as sand, glass, and gravel must be swept on a regular basis. Programs must be in place to remove wheel-trapping catch basins and to replace them with a safer design. Hazards such as potholes and longitudinal cracks must be kept in check. When resurfacing takes place, attention must be paid to parallel-to-traffic pavement joints and making the pavement flush with manhole covers. Railway crossings and bridge expansion joints should also be designed to minimize the hazard to cyclists.

Cyclist Training

Increasing the level of traffic cycling skills can help to make cyclists more comfortable when riding in traffic, improve relations between cyclists and motorists, and facilitate the smooth and orderly flow of traffic.

The objectives of any cyclist training program are to improve traffic cycling skills, to increase knowledge and awareness of accidents, and to present methods to avoid accidents. To have a significant impact, such courses must be readily available, and the cycling population, particularly adults, must be convinced of their value. From these findings, cyclist training programs should include the following.

Knowledge of Accident Types

Cyclists need to realize that most collisions involving motor vehicles are intersection-related and that very few accidents are caused by improperly overtaking motorists.

Awareness of Cyclist Behavior That Contributes to Accidents

Cyclists must know how practices such as riding the wrong way, riding on the sidewalk, weaving in traffic, and overtaking between traffic and the curb result in accidents. Cyclists should be predictable and ride where motorists expect to see them.

Destination Positioning at Intersections

Cyclists need to know how to position themselves at intersections according to their destination, particularly for making left turns. To minimize conflicts, it is essential that a cyclist be in the lane that serves his or her destination rather than always riding next to the curb.

Skills in Shoulder Checking and Lane Changing

In order to make safe left turns in traffic, cyclists need to either develop skills in shoulder checking and lane changing or dismount and walk through the intersection.

Public Awareness

Awareness campaigns aimed at both motorists and cyclists are necessary to ensure a safe coexistence between the two groups. For motorists, awareness campaigns should emphasize the following:

- Exercise care in overtaking cyclists;
- Expect to encounter cyclists anywhere on the road system at any time;
- Remain behind a cyclist when turning right;
- Always scan for cyclists when crossing or turning at intersections; and
- Expect cyclists to stay out of exclusive right-turn lanes, bus bays, and parking lanes.

Motorists should also expect cyclists to move to the left at intersections to make left turns. For cyclists, emphasis should be placed on the following:

- The safest place to ride is on the roadway with traffic, not on the sidewalk or against traffic;
- Obey stop signs and red lights, and yield to pedestrians and traffic when it is required by law;
- Ride in the lane that serves the destination; and
- When approaching intersections, be alert for crossing and turning motorists.

CONCLUDING REMARKS

The principal findings of this work follow:

- Only one in two cyclists rides correctly, on the basis of the field observations of cyclist behavior.
- Many cyclist behavior patterns—such as riding on the sidewalk, riding against traffic, and weaving in traffic—contribute to collisions with motor vehicles.
- Accidents involving cyclists and motorists have increased over the past decade. As many as 10 percent of all injury-producing road accidents in Winnipeg during the summer months involve a cyclist. Furthermore, these accidents are increasingly involving adult cyclists, reflecting the bicycle's increased popularity as an urban transportation mode.
- Low-cost countermeasures in the areas of roadway modifications, cyclist training, and public awareness are available to address the increase in cycling accidents and to make the transportation system more accommodating to cyclists.

Cycling as a means of transportation in North America and throughout the world is likely to continue to increase, given the growing concern for the environment. This will call for a greater effort in retrofitting transportation systems to make cities bicycle-friendly.

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DISCUSSION

ANDY CLARKE
Bicycle Federation of America, 1818 R Street, N.W., Washington, D.C. 20009.

Thom and Clayton's paper provides a valuable insight into the realm of bicycle crash statistics and bicyclist behavior on the basis of observations and statistics from Winnipeg, Manitoba. The paper confirms the hypothesis that cyclist behavior patterns are influenced by different roadway and traffic characteristics.

The authors are clearly experienced cyclists who have developed and adhere to the principles of "effective cycling," or the vehicular style of cycling. This is reflected in the commentaries given on different patterns of behavior. For example, at the busiest observation sites a substantial number of bicyclists were observed riding on the sidewalk or shoulder, riding in bus bays, or proceeding straight ahead from a right-turn lane. The authors ascribe that "wrong" behavior to a fear of traffic and cyclists' belief that they belong as far to the right of the road as possible. It is also an indication that bicyclists enjoy the channelization offered by painted lines and car-free lanes.

In the suggested "low-cost opportunities for making roadways bicycle-friendly," the authors do not mention bike lanes, preferring to recommend wide-curb lanes. Wide-curb lanes are adequate for cyclists with confidence and experience, but for the type of cyclist observed riding on the sidewalk or in the bus bays, these widened curb lanes would do little to alter this behavior—and thus little to reduce the dangers caused by this behavior.

Other recommendations, such as more clearly defining lane destination markings, restricting right turns on red, and avoiding the use of dual-destination lanes, are helpful and practical suggestions that will benefit all road users.

The authors make the interesting observation that cyclists tend to switch roles between vehicle operator and pedestrian whenever they think it is safer or more convenient to do so. This is crucial, and very true. The existing roadway system simply does not work for many existing bicyclists, and it deters many more potential bicyclists from ever getting started.

AUTHORS' CLOSURE

Clarke's discussion provides several useful and valid comments. We take this opportunity to clarify and discuss several issues.

First, bike lanes can be effective in improving the cycling environment on roadways with few intersections, such as rural highways. However, in urban areas with a multitude of intersections, special lanes can promote dangerous behavior by both motorists and cyclists. The principal danger of bike lanes is that they attempt to separate traffic flow by vehicle type rather than by direction of travel. Bike lanes prevent motorists from making right turns from the extreme right side of the roadway, as is required by law, and encourage cyclists to overtake right-turning motorists on their right side. Cyclists wishing to turn left tend to avail themselves to the bike lane until they arrive at the intersection, then proceed to turn left in front of overtaking traffic rather than merging left well in advance of the intersection. Bike lanes also prevent motorists from using the full width of the roadway in the absence of cyclists. This usually results in the accumulation of debris in the bike lane, unless vigorous maintenance programs are in place.

Second, the roadway modifications suggested in the paper are not all-inclusive. For example, to make roadways more bicycle-friendly, we could have suggested additional measures, such as reducing speed limits, synchronizing closely spaced traffic signals to match cyclist speeds, and adding special pavement markings to guide cyclists through multilane intersections. We limited ourselves to suggesting low-cost measures that related specifically to observed cyclist behavior and accident experience. Further suggestions are welcome.

Third, roadway modifications alone will do little to change cyclists' behavior. None of the suggested improvements are substitutes for traffic cycling skills. In this regard, cyclist training programs can play a substantial role by increasing cyclists' confidence and enabling cyclists to make the existing roadway system work for them. The principles of traffic cycling are within easy grasp of virtually anyone, particularly if these are first practiced on residential streets and then applied to progressively busier roadways and more difficult traffic situations.

Finally, although we don't have all the answers to the problems that face cyclists, it is clear that efforts to make cities more bicycle-friendly must be taken from several fronts. These include modifying the existing roadway system, improving the skill levels of cyclists, making motorists more bicycle-friendly, and creating bicycle-friendly traffic laws.

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