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What is at the end of the road? Understanding discontinuities of on-street bicycle lanes in urban settings

Kevin J. Krizek *, Rio W. Roland

Active Communities Transportation (ACT) Research Group, University of Minnesota, 301 19th Ave S., Minneapolis, MN 55455, United States

Abstract

Demarcating on-street bicycle facilities is often mentioned as an important strategy to encourage increased bicycle safety and bicycle travel. However, little if any literature has focused on instances where separate on-street bicycle facilities end. This paper better understands the severity of such instances and corresponding physical characteristics. We identify 30 discontinuities of on-street bicycle lanes in Minneapolis, Minnesota, and collect primary data measuring their physical attributes and cyclists' perceptions of the level of comfort while cycling through each. Using multi-variate analysis, the findings suggest that discontinuities ending on the left side of the street, with increased distance of crossing intersections, having parking after the discontinuities, and wider width of the curb lane are statistical elements that contribute to higher levels of discomfort. Such analysis is useful in determining bicyclists' comfort level where discontinuities exist and such methods can be an important part of an overall level of service toolkit for planning on-street bicycle lanes.
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1. Introduction

Published in 1994, the *National Bicycling and Walking Study* sets two primary goals: to double the number of trips made by bicycling and walking in the US, and to reduce the number of pedestrians and bicyclists killed or injured in traffic accidents by 10% (Federal Highway

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* Corresponding author.
E-mail address: kjkrizek@umn.edu (K.J. Krizek).

Administration, 1994). These goals are supported by specific policies such as encouraging on-street bicycle lanes. Also formerly referred to as type II facilities (American Association of State Highway and Transportation Officials, 1999), on-street bicycle lanes usually comprise a critical backbone of any city's bicycle plan, for either recreational or commuting use. The Federal Highway Administration (FHWA) recommends on-street bicycle lanes where the majority of cyclists are expected to be group 'B' bicyclists (Federal Highway Administration, 1999) defined as 'casual or new adult and teenage riders who are less able to operate in traffic without provisions for bicycles' (Minnesota Department of Transportation, 1996). Some cyclists require such provisions before they will make the decision to bicycle for a given trip; almost all cyclists at least appreciate such facilities (Antonakos, 1994).

But as the proverb goes, 'all good things must come to an end' and so too must on-street bicycle lanes. The location in which on-street bicycle lanes end, referred to in this paper as discontinuities, comprise the focus of this research. Most bicycle planners can easily recount anecdotes from citizens mentioning how ending bicycle lanes influence cyclist safety. If a system is only as good as its weakest link, then discontinuities often time comprise this weak link. Conditions where this merge takes place are sometimes benign; in other cases, however, they occur under unsafe conditions. In fact at least one Department of Transportation study suggests that bicycle lanes be used with caution on roads with high speeds since it may be difficult for average bicyclists to leave the lane because of the number of vehicles on the adjacent road (Minnesota Department of Transportation, 1996).

This study determines bicyclists' comfort levels when encountering different discontinuities and examines the strength of explanatory factors affecting their severity. The work focuses on 30 discontinuities in and around downtown Minneapolis by analyzing the results of a survey of cyclists. After briefly reviewing previous literature on this topic we describe our survey of Minneapolis cyclists and other data collection efforts. The analysis is described next, including a regression model predicting the severity of discontinuities and the results. The final section presents conclusions and policy significance.

Taken together—the focus on discontinuities, the methodology employed herein, and the results contribute to the literature related to on-street bikeway systems. Results from the model provide empirical evidence that help planners prioritize the relative importance of improving different facilities and specific characteristics of these facilities. Furthermore, this research builds on information useful for overall bicycle lane planning in concert with origin/destination studies, roadway segment models such as the Bicycle Compatibility Index, level of service applications (Landis et al., 1997) or intersection analysis (Landis et al., 2003).

2. Related literature

Given that on-street bicycle lane discontinuities are a relatively specific topic, we cast a reasonably wide net in reviewing past literature. Below we quickly review past studies analyzing cyclists perception of safety, focusing specifically on the degree to which it is influenced by physical characteristics. Cycling is widely considered to be among the riskiest modes of travel (Noland, 1995). Examining fatalities per kilometer traveled, it is second only to pedestrian travel (Pucher, 2000). Some contend there is no proof that separate facilities are less dangerous than cycling with auto traffic (Forester, 2001). However, there appears to be general consensus that demarcated on-street

bicycle lanes at least promulgate a perceived sense of safety and comfort (Lott et al., 1978; Antonakos, 1994; Harkey and Stewart, 1997; Moritz, 1997).

Subsequently, the provision of on-street bicycle lanes comprises a key ingredient in the literature appearing under several labels, including bicycle related stress factors (Sorton and Walsh, 1994; Lebsack, 1995), bicycle interaction hazard scores (Landis, 1994, 1996), compatibility indexes (Federal Highway Administration, 1998) or level of service models (Landis et al., 1997, 2003; Epperson, 2002). Early work of this sort (Landis, 1994; Epperson, 2002) aimed to forecast accidents between automobiles and bicycles as a function of pavement conditions, traffic speed, lane width, and traffic volume per lane. These applications, however, were deemed largely unsuccessful in meeting their goals of bicycle/automobile accident prediction because they did not take into account actual bicycle travel volumes along the route as a measure of exposure, were never correlated to actual accidents along a roadway, and subjectively measured many of the model variables. They did however, draw attention to the importance of measuring traffic speed, lane width, and traffic volume, thereby spurring the development of other similarly natured models.

Such models include the roadway condition index and the segment condition index (Landis, 1994), both of which teased out bicyclists' perception of hazard rather than actual hazard prediction. This application expanded the list of predictive variables including adjacent land use, number of driveways, and parking turnover. Again, however, this application suffered from a lack of statistical calibration and assigned relatively subjective values to a number of the variables. Others (Lebsack, 1995) suggest weighing cyclists' 'gut feelings' while riding roadway segments against the factors of traffic volume per lane, curb lane width, and vehicular speed in an attempt to calculate stress factors to create a bicycle/roadway compatibility map. Sorton and Walsh's (1994) major contribution was to consider the percentage of heavy vehicles along a roadway segment and to focus on peak hour traffic volumes as further refinements to modeling stress levels of bicyclists. They did so by relating traffic volume per lane, curb lane width, and traffic speed to surveyed stress levels of survey participants. Participants viewed video tape of bicyclists riding 23 segments in Madison, Wisconsin, roadways and were asked to rate their perceived stress level on a scale of 1 (very low) to 5 (very high). This appears to be the first attempt to statistically calibrate bicyclists' safety perceptions against explanatory variables (lane width, traffic speed, traffic volume, and the presence of on-street parking); it was later extended (Federal Highway Administration, 1998) to evaluate the capacity for cars and bicycles to share space along roadway segments. This research laid the foundation for further work (Landis et al., 1997) to statistically calibrate bicyclists' perception of roadway suitability with a bicycle level of service model. Participants cycled 30 roadway segments and the study measured dimensions such as included traffic volume per lane, posted speed limit weighted with the percentage of heavy vehicles, adjoining land use, width of outside through lane, and pavement conditions.

The literature to date, however, has focused primarily on through mid-block roadway segments. It rarely separates bicycle lanes from other shared use conditions (wide curb lanes or paved shoulders) and rarely considers the role of intersections. While stretches of roadways are important, often the most significant and complex design and safety challenges occur at street intersections (Chicago Bike Lane Design Guide, 2002). In response to this void, Landis et al.'s (2003) recent work derived a model to predict the perceived hazard of bicyclists riding through intersections as a function of motor vehicle volume, width of the outside lane, and the crossing distance of the intersection.

To further build on these active lines of inquiry, it is important to examine the perception of bicyclists as they encounter discontinuities and their perceptions of safety when merging with

traffic. This investigation responds to this call by uncovering factors that lead to perceptions of comfort or discomfort at on-street bicycle lane endings or gaps that are part of urban bikeway systems. It is specific to on-street bicycle facilities and to short segments (two blocks or less) where a bicycle lane ends and a bicyclist must merge with automobile traffic to continue in the primary direction. This study considers mostly intersections, but does so from the perspective that they are the transition from where there are on-street bicycle lanes to where there are none.

3. Methodology

The study focuses on bicycle lane discontinuities using Minneapolis, Minnesota, as a case study. Minneapolis is the largest city in the upper Midwest with a population of approximately 380,000. Minneapolis has the third highest percentage of cycling commuters in the country for large cities (Census, 2000 Supplemental Survey,). A total of 23 miles bicycle lanes are classified as Type II (Pflaum, 2003), the majority of which are in the downtown core and in areas central to the University of Minnesota. Because of the high level of bicycle commuters, existing Type II bicycle lanes, and the need to make scarce resource allocation decisions regarding bicycle facilities, Minneapolis affords a good opportunity to study this phenomenon.

Our first step was to identify specific locations in which bicycle lanes end. This was done by mapping all 26 Type II facilities in Minneapolis, noting their terminating points. We then retained all lanes that were: longer than a few blocks, fully maintained, marked, and clearly constituted a type II facility, and specific geographic points and could be readily identified by survey respondents. The final analysis paired down to 30 discontinuities that are mapped in Fig. 1. To better understand the characteristics of the discontinuities, we launched two data collection efforts. The first gathered relevant measures on the physical attributes of the discontinuities, including measures of the street width, number of lanes of traffic in adjacent lanes, traffic volumes, parking availability, the direction of adjacent traffic, side of the road of the bicycle lane, and other relevant physical characteristics.

The second data collection effort was a stated preference survey in which we asked cyclists to rate their level of comfort while cycling through each of the discontinuities. Given limited resources, our intent was to get as large and as interested population as possible using the most cost-effective approach. Respondents were recruited via a variety of means including direct emails to a dozen bicycle groups in the Twin Cities, flyers in bicycle shops, canvassing special events (e.g., the Minneapolis farmer's market), and posting the survey instrument on City of Minneapolis web page. A small incentive was offered—a $5 coupon at a local bicycle shop or a free water bottle that was mailed in the form of a voucher to each respondent who faxed, emailed or post mailed completed surveys.

The survey included a dozen or so questions about their socio-demographic characteristics and cycling experience such as preference for different types of cycling facilities, average number of days per week they cycle, and bicycle and auto ownership. The bulk of the survey, however, asked respondents to bicycle through at least 10 of the 30 discontinuities located on the map. After riding through the discontinuities, each respondent was asked to rate their perceived level of safety using the following scale:
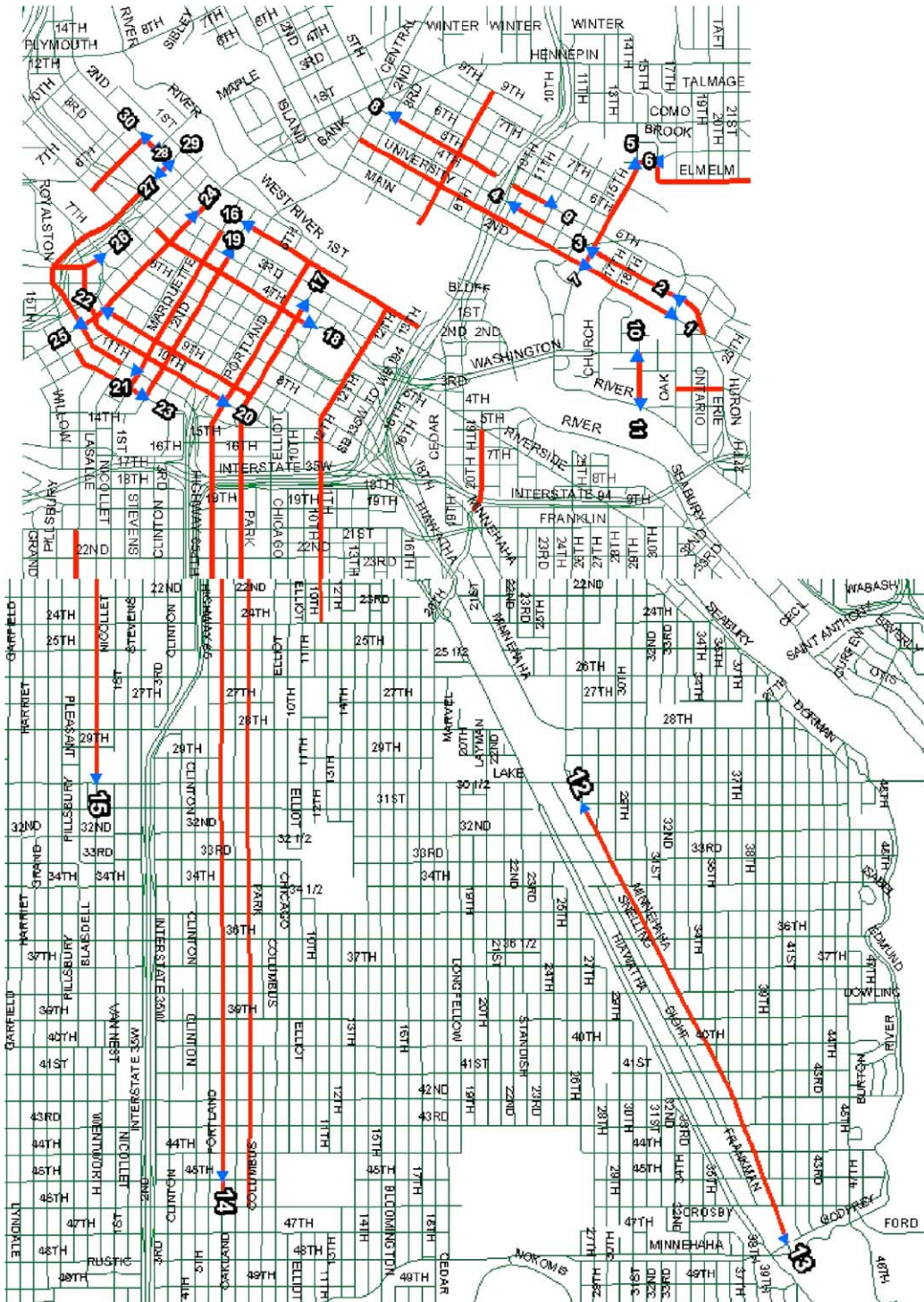
Fig. 1. Maps of the discontinuities in Minneapolis.

1. Very comfortable. I did not notice that a bike lane was no longer available.
2. Comfortable. I noticed that a bike lane was no longer available but it did not matter that much.
3. Neutral.
4. Uncomfortable. This spot is a problem. It was confusing that the route ended and presented some safety issues.
5. Hazardous. This is a problem spot that the city should immediately target. Safety issues abound and there was no indication of where and how the cyclist was supposed to proceed.

Though many expressed initial interest, it was difficult to recruit participants due to the time commitment involved to complete the survey. Through two waves of recruitment—one in spring and fall of 2003—we received a total of 28 respondents. No single discontinuity was rated less than 10 times. Standard deviations of the scores were relatively high; all but two of the discontinuities received the maximum score (5) and 19 of the 30 discontinuities received a score of 1.

The average age of the respondents was 39 years and 80% were male. While 80% may seem high, it is not unusual when compared with other bicycle studies (Landis et al., 2003; Stinson and Bhat, 2003). Over 84% of the participants live in the city of Minneapolis or St. Paul and 16% live in suburban communities. The average household size in the survey is 2.4 (US average is 2.6). The average number of cars per household is 1.7 (US average is 1.63, Minneapolis average is 1.7) and, not surprisingly, the average number of bicycles is relatively high: 5.4 bicycles per household (each converts to 0.8 cars and 2.7 bicycles per person in the household, respectively). Almost all of the respondents (96%) stated that they bike to work at least once a week, with an average of 3.71 times per week, suggesting an extremely experienced sample in terms of cycling.

4. Description and analysis

Our analysis begins by adopting a taxonomy of discontinuity sites by grouping them into three categories: left-handed losers, intersection inconsistencies, and lapsing lanes. These groups were based principally on physical characteristics, traffic volume, and presence of a major intersection. While admittedly rough in nature, this classification brings together discontinuities similar in nature, describing general conditions leading to each.

Left side losers—This group (Fig. 2) represents discontinuities posing a relatively high risk to cyclists. They result from bicycle lanes being on the left side of the street, thereby forcing the cyclist to cross over lanes of traffic to continue moving in the forward direction (i.e., riding on the right side of the road in unmarked conditions). [1] A roadway (with left side bike lanes) intersecting with another roadway (with right side bike lanes) creates a confusing and potentially dangerous

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[1] Minneapolis is relatively unique in this respect having more than a dozen bicycle lanes on the left-hand side of the street. The primary reason for this in much of Minneapolis is to minimize bus/bike conflicts. The practice was prompted in part by a lawsuit the City was involved with in the mid 1990s after a bicyclist was killed by a bus on the Nicollet Mall. Subsequently, there was considerable discussion over what side of the road to put the bike lanes on throughout the downtown area. The arguments in favor of placing bike lanes on the left side of the road instead of the right side were no buses, fewer trucks, fewer opening car doors (more driver side doors open than passenger doors), and better vision for drivers (blind spots on the passenger side). In the downtown core, where a cyclist may be traversing the network of lanes, the left-hand lanes pose few movement conflicts where bike lanes intersect.

Fig. 2. Examples of left side losers (the bicycle lane ends in all shown examples).

situation for both motorists and bicyclists; especially when a bike or vehicle is aiming to turn direction. The situation is amplified in the case of discontinuities, forcing the cyclist into confusing or unsafe cycling conditions where they continue traveling forward. Rarely is there a safe or buffered transition to the new conditions.

Intersection inconsistencies—Intersection inconsistencies (Fig. 3) represents discontinuities in which the bicycle lane is disrupted or terminated due to a relatively prominent intersection. The bicycle lane prior to the discontinuity is usually on the right-hand side of the road but dissipates after the intersection because of a variety of reasons such as automobile parking, a markedly different street or urban form layout, or lack space on the right of way. In general, intersection inconsistencies are on streets carrying moderate volumes of traffic and they exist on the right side of the street

Lapsing lanes—The final group of discontinuities, lapsing lanes (Fig. 4) are those that typically end under relatively benign conditions and provide a well-buffered transition to riding among auto traffic (i.e., wide traffic lanes after the discontinuity). These discontinuities occur almost exclusively on streets with low traffic and in residential areas. They are generally well marked and striped to indicate the end of a given facility. They rarely end in a turn lane or intersection where a high volume of turns may interfere with the main direction of cyclists in the terminating bicycle lane.

Fig. 3. Examples of intersection inconsistency.

Fig. 4. Examples of lapsing lanes.

We now move to analyzing the elements of each in more detail in concert with perceptions of cyclists' safety. Our first look at the data shown in Fig. 5 reveals a histogram of the average scores for each of the discontinuities. [2] Six discontinuities stand out in the hazardous rating (# 28, 18, 4, 25, 24, and 23, in decreasing order of discomfort). All but one of these are classified as a left side loser, suggesting that this group of discontinuities are the most hazardous. To cut the data differently, we can learn how average scores ranked for each classification. Indeed, there were noticeable differences between each group with left side losers being judged the most hazardous (average score: 3.6, $n = 218$), lapsing lanes being the most comfortable (average score: 2.69, $n = 140$) and intersection inconsistencies falling between the two (average score: 3.15, $n = 95$).

The breakdown of scores is not terribly surprising considering each discontinuity was assigned to a group based on elements of its physical nature such as side of street and relation to an intersection. But in some respects, such elements are only loosely tied to many of the variables considered to be theoretically significant. To better understand the myriad factors contributing to varying levels of discomfort, we employed multi-variate modeling employing such measures. Using the rankings each cyclist assigned in the survey of each discontinuities as the dependent variable, we can employ ordinary least squares (OLS) regression techniques to test for and uncover more detailed explanatory factors, controlling for various socio-demographic characteristics. Our ultimate aim was to generate a model of the sort: [3]

$$\text{Discontinuity}_{\text{score}} = f(\text{Attributes}_{\text{discontinuity}}, \text{Preferences}_{\text{individual}}, \text{Characteristics}_{\text{individual}})$$

where $\text{Discontinuity}_{\text{score}}$ is the score each respondent assigned to each discontinuity; $\text{Attributes}_{\text{discontinuity}}$ is a vector representing physical characteristics of each of discontinuity; $\text{Preferences}_{\text{individual}}$ is a vector representing individual preferences (city/suburban residence, number of bicycles owned, number of cars owned, preferred cycling conditions, and average number of days they cycle); $\text{Characteristics}_{\text{individual}}$ is a vector of individual socio-demographic characteristics (e.g., sex, age, household size; gathered from the survey).

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[2] Each discontinuity was rated on average 13 times yielding a total of 453 observations.

[3] The model should be most robustly specified in a manner that accounts for the fact that measured attributes of each discontinuity and measured attributes of the individuals contain error terms that are correlated across each individual unit. Limited data and degrees of freedom in this application, however, precluded more theoretically unbiased specification.
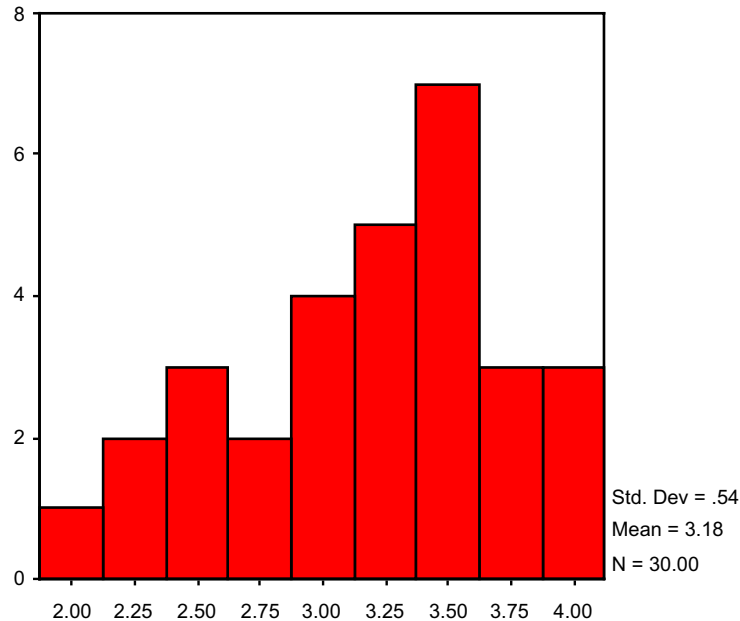
Fig. 5. Average scores for each discontinuity.

The physical characteristics for each discontinuity that were measured were based on a review of previous literature. Table 1 describes the theoretical significance of these variables, source of data, and hypothesized relationships. Results of the multi-variate analysis are presented in Table 2, complete with all theorized independent variables. Of the measured variables, eight were statistically significant in explaining 16% of the variation in the discomfort score: one individual characteristic variable, two individual preference variables, and five variables capturing characteristics of the discontinuities. [4] As expected, individuals who own more bicycles and who live in the city (as opposed to the suburbs) appear to be less affected by discontinuity severities. Because they exhibit higher levels of cycling experience (as exhibited by a greater number of bicycles) and they are more likely to be exposed to city street and city driving patterns, they appear, on average, to rate conditions as more comfortable. This is in slight contrast to findings of Landis et al. (1997), who discovered that inexperienced bicyclists perceived fewer hazards than more experienced bicyclists in level of service studies. Age is also inversely related to discontinuity score, which is mostly a reflection of the several senior/retired 'professional' cyclists who completed the survey.

In terms of physical attributes of the discontinuities, both the width of the crossing intersection and the presence of parking after the discontinuity increase the level of discomfort. As expected, a smaller curb width later leads to increasing levels of safety risk. Finally, after controlling for a variety of individual preferences *and* various physical characteristics of the discontinuities, the multi-variate analysis reveals that each of the previously described classifications are statistically

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[4] Few indications of multi-collinearity were detected. In a simple correlation analysis, the largest coefficient between independent variables was −0.49 (between low annual average daily traffic and posted speed limit). No measure of tolerance for any of the independent variables was less than 0.36.

Table 1
Description and source of measures of the discontinuity characteristics

Variable	Description and theoretical significance	Data source	Direction
Speed	The speed of adjacent traffic is often mentioned as an important factor affecting a cyclist's perceived level of safety	Speed limit signs	+
Traffic volume	Traffic volume is often mentioned in level-of-service studies and is generally reported in a per lane format (this measures if usually related to speed). Measure is adjusted to per lane calculations	Hennepin County engineer's office	+
Parking (1 = yes)	The presence of a parking lane after the discontinuity adds to a feeling of "squeeze" perceived by the cyclist. In addition, car parking and opening of doors potentially conflict with cyclist's level of comfort	Field measurement	+
Intersection width	The majority of the discontinuities were associated with a perpendicular street crossing. The width of the street was measured for this variable in meters	Field measurement	+
Warning sign (1 = yes)	The presence of some sort of warning sign is hypothesized to reduce the level of discomfort because of advance knowledge provided about the upcoming discontinuity	Field measurement	−

Difference in # of traffic lanes	This was hypothesized to be important because it means traffic is being funneled to a smaller number of lanes. Measured as the number of lanes after the discontinuity minus the number of lanes before	Field measurement	–
Direction of adjacent traffic (1 = same direction)	Traveling in the opposite direction of adjacent traffic is uncomfortable to many. It is reality, however, of part of the system in the downtown core of Minneapolis	Map	–
Curb lane width	Important because it indicates space devoted to the cyclist. Measured from the edge of the gutter pan to the middle of the striping delineating the lane closest to the curb (where parking was present, three meters was subtracted)	Field measurement	–
Downtown	Indicates presence in the downtown core. Important because it indicates the bicycle lane is part of a network of lanes, intended to complement one another	Map	–
Left side loser (1 = yes)	Described above (used as the reference group in the regression model)	Field measurement	na
Intersection inconsistency (1 = yes)	Described above	Field measurement	na
Lapsing lane (1 = yes)	Described above	Field measurement	na

Table 2
Regression output modeling the discontinuity ratings

Vector	Variable	Unstandardized coefficients	t-Stat.	Significance
Attributes$_{discontinuity}$	Posted speed > 45 kph	0.0055	.036	.972
	High average annual daily traffic	−0.0818	−0.531	0.596
	Low average annual daily traffic	−0.0633	−0.408	0.684
	Intersection width	0.0114	2.352	**0.019**
	Parking	0.219	1.819	**0.070**
	Warning signs	−0.0396	−.304	0.761
	Different direction adjacent traffic	0.169	.817	0.414
	Curb Width After	−0.0339	−1.776	**0.076**
	In downtown core	−0.0248	−0.719	0.473
Classification$_{discontinuity}$	Sudden Stoppage	−0.409	−2.528	**0.012**
	Fizzlers	−0.889	−4.772	**0.000**
Preferences$_{individual}$	Prefers on and off-street paths	0.0518	0.417	0.677
	Resides in city	−0.755	−4.207	**0.000**
	# bicycles per person	−0.0403	−1.843	**0.066**
Characteristics$_{individual}$	Age	−0.00748	−1.869	**0.062**
	Sex (1 = male)	−0.0750	−0.481	0.631
	(Constant)	4.53	7.919	0.000

Adj. $R^2 = 0.16$
$F = 6.4$, $P < 0.000$
$n = 453$

significant and in the expected direction. The negative coefficients for both intersection inconsistency and lapsing lanes indicate they are significantly different from and scored lower on the discontinuity rating (i.e., more comfortable) than left side losers (the reference group). Being classified as an intersection inconsistency or a lapsing lane means that, compared to left side losers, the discontinuity score decreases by 0.41 and 0.89 units, respectively.

5. Conclusions and policy significance

On one hand, on-street bicycle lanes comprise an important part of an urban bikeway system. They help type 'B' bicyclists feel more comfortable cycling and thereby increase the possibility such individuals use bicycle travel for maintenance or discretionary travel. On the other hand, instances where on-street bicycle lanes end pose considerable risk to many cyclists. These instances force the cyclist to merge with auto traffic, creating weak links in the bicycle system that ultimately affects many people's decision to cycle. The aim of this research is to better understand the severity of these weak links and their corresponding physical characteristics. Using multi-variate analysis, we analyzed 30 discontinuities in Minneapolis. We conclude that having discontinuities end on the left side of the street, increased distance of crossing intersections, the presence of parking after the discontinuity, and increased width of the curb lane all contribute to a heightened level of discomfort for the cyclist.

At the most basic level, this research draws attention to discontinuities by focusing specifically on which ones are worst. The study directs the spotlight on an important, but often glossed over dimension in the literature related to bicycle travel. Second, this research offers a taxonomy that is a statistically significant to group different types of discontinuities—a taxonomy that can provide planners with a reliable 'back of the envelope' way to better understand bicycle facilities for the system they manage. [5]

Third, this research employs a methodology that could be easily applied to settings in other metropolitan areas. Doing so would serve two purposes. The first purpose is to prioritize which discontinuities are most hazardous and need to be more fully considered in capital improvement plans to lessen the deleterious effects of such endings. The second purpose is to provide a template to validate or improve on what was learned about each of the independent variables. How strong (and stable) are the measures when applied to other settings? Future research with larger sample sizes could strengthen the manner in which many of the dimensions are conceptualized or measured specific to discontinuities. This inquiry could even be supplemented with additional information and/or policy strategies. For example, it is important to learn the role of other unique treatments aimed to increase cyclists level of comfort through treatments, such as prioritized signals for bicycles, different locations for bicycle lanes, or other innovative treatments (Nabti and Ridgway, 2002).

By implementing planning strategies such as those outlined above, bicycle lane planning can take the leap from methods considered in most cities to be unscientific or ad hoc to one with more analytical underpinnings. Ultimately, any sort of prescriptive set of recommendations would be needed to be administered by planners familiar with local, state, and federal regulations regarding different types of roadways and financing. But doing so will likely have important implications to encourage increased levels of cycling, particularly for Type B cyclists. This would help address closely aligned objectives such as increased livability, heightened physical activity and decreased levels of mobile source pollution.

Acknowledgement

References

American Association of State Highway and Transportation Officials, 1999. Guide for the Development of Bicycle Facilities, American Association of State Highway and Transportation Officials.
Antonakos, C.L., 1994. Environmental and travel preferences of cyclists. Transportation Research Record 1438, 25–33.

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[5] One notable drawback to the system, however, is that the most severe and populated category (left side losers) may be endemic to Minneapolis, Minnesota.

Census 2000 Supplemental Survey, 2000. Means of Transportation to work for Workers 16 Years and Older, Summary Table P047. Washington, DC, US Census.

Chicago Bike Lane Design Guide, 2002. Chicago Bike Lane Design Guide. Available from <www.bicyclinginfo.org> Accessed July 21, 2004.

Epperson, B., 2002. Evaluating suitability of roadways for bicycle use: towards a cycling level-of-service standard. Transportation Research Record 1438, 9–16.

Federal Highway Administration, 1994. The National Bicycling and Walking Study. Federal Highway Administration, Washington, DC.

Federal Highway Administration, 1998. The Bicycle Compatibility Index: A Level of Service Concept, Implementation Manual. Federal Highway Administration, Washington, DC.

Federal Highway Administration, 1999. A Comparative Analysis of Bicycle Lanes Versus Wide Curb Lanes: Final Report. Federal Highway Administration, Washington, DC.

Forester, J., 2001. The bikeway controversy. Transportation Quarterly 55, 7–17.

Harkey, D.L., Stewart, J.R., 1997. Evaluation of shared-use facilities for bicycles and motor vehicles. Transportation Research Record 1578, 111–118.

Landis, B.W., 1994. Bicycle interaction hazard score: a theoretical model. Transportation Research Record 1438, 3–8.

Landis, B.W., 1996. Bicycle system performance measures. ITE Journal (February), 18–26.

Landis, B.W., Battikuti, V.R., Ottenberg, R.M., Petrisch, T.A., 2003. Intersection level of service: the bicycle through movement. Transportation Research Record 1828, 101–106.

Landis, B.W., Vatikuti, V.R., Brannick, M.T., 1997. Real-time human perceptions: toward a bicycle level of service. Transportation Research Record 1578, 119–126.

Lebsack, J.W., 1995. Calculating bicycle stress factors for a bicycle map. In: ITE 65th Annual Meeting.

Lott, D.F., Tardiff, T., Lott, D.Y., 1978. Evaluation by experienced riders of a new bicycle lane in an established bikeway system. Transportation Research Record 683, 40–46.

Minnesota Department of Transportation, 1996. Minnesota Bicycle Transportation Planning and Design Guidelines. Minnesota Department of Transportation, St. Paul, MN.

Moritz, W.E., 1997. Survey of North American bicycle commuters: design and aggregate results. Transportation Research Record 1578, 91–101.

Nabti, J., Ridgway, M., 2002. Innovative Bicycle Treatments: An Informational Report. Institute of Transportation Engineers, Washington, DC.

Noland, R.B., 1995. Perceived risk and modal choice: risk compensation in transportation systems. Accident Analysis and Prevention 27, 503–521.

Pflaum, D.C., 2003. Personal communication.

Pucher, J.A.L.D., 2000. Making walking and cycling safer: lessons from Europe. Transportation Quarterly 54, 25–50.

Sorton, A., Walsh, T.W., 1994. Bicycle stress level as a tool to evaluate urban and suburban bicycle compatibility. Transportation Research Record 1438, 17–24.

Stinson, M., Bhat, C., 2003. Commuter bicyclist route choice. Transportation Research Record 1828, 107–115.