How Did the Bicyclist Cross the Road?
A Case Study of 2 Traffic Signals in Seattle

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ABSTRACT

The City of Seattle completed a Bicycle Master Plan in 2007 as part of a larger plan for sustainability. One of the plan's goals was to triple bicycle-based travel by 2017. Increasing the number of bike routes on residential streets was a key strategy to achieve this goal. The new bike routes largely use residential streets paralleling major arterial streets and are intended to attract new, less confident or family bicyclists. Because of the residential nature of these streets, intersections with major arterials pose a difficult challenge for novice riders, who tend to be intimidated by high traffic volumes and complex traffic maneuvers. Local neighborhood concerns have prevented the installation of traffic control signals at these locations in the past. Since traffic volumes on residential streets are intentionally low, traffic signals are not typically warranted per the MUTCD. Regardless, some jurisdictions including Seattle, have installed signals at these locations in an effort to increase bicycle use and safety.

This case study will examine two locations in Seattle where traffic signals have been installed along residential corridors to facilitate bicycle travel. The study will determine if (1) following the installation, traffic signal warrants were met due to changing traffic conditions, (2) collisions involving all types of vehicles changed, including severity, and (3) non-motorized volumes changed due to the installation of the signal.

BACKGROUND

In the past decade, a number of treatments have been developed to assist bicyclists cross arterial streets, including traffic signals specifically designed for use by bicyclists. While some jurisdictions have developed local warrants, there are no nationally recognized installation guidelines other than engineering judgment on when to construct such improvements. As such, these specialized traffic signals are often installed without meeting any of the warrants described in the Manual of Uniform Traffic Control Devices (MUTCD)[1]. Unwarranted traffic signals often have unintended consequences. These include an increase in crashes, increases in red-light running, increases in delay for all users, increases in air and noise pollution, increased maintenance costs, and, for signals at residential streets, a potential increase in cut-through traffic.

Warrants for the installation of traffic signals are included in the MUTCD and the satisfaction of one or more of these is justification for the installation of signals throughout the country. However, the warrants are heavily geared for motor vehicle traffic and leave little guidance for other modes such as bicycles and pedestrians. This is confirmed by recent research into the pedestrian crossing warrant which identified that the previous warrant did not meet the needs of pedestrians. As such, Warrant 4, Pedestrians has been modified in the 2009 edition of the MUTCD to address items such as motor vehicle speed and length of crossing. Within the MUTCD, bicyclists can be treated as either pedestrians or motor vehicles depending on whether they are in the roadway or on the sidewalk.

A 2011 case study[2] for a single intersection from Pinellas County, Florida indicated an increase of 273% in yearly collisions (from 4.0 crashes/year to 14.9 crashes/year) following the installation of an unwarranted signal. The increase was primarily due to rear-end collisions while right angle and left turn crashes remained constant. A 2008 review of 67 warranted and unwarranted signals in Kentucky[3] showed that warranted signals had a reduction in all crashes of 18.0% while unwarranted signals had a 28.3% increase of crashes. Further analysis showed that while both warranted and unwarranted signals had a decrease in angle collisions/year (66.9% and 40.2%, respectively), unwarranted signals had an increase in rear-end collisions of 221.7% compared to the warranted signal increase of 49.1%. Both warranted and unwarranted signals had a decrease in fatal/injury crashes per year of 43.8% and 32.0%, respectively.

Older studies also indicate a similar pattern of increasing collisions at unwarranted signals. A 1989 study in New York City[4] examined six unwarranted signals and compared them to six warranted signals. A 12-month post-installation collision review showed that collisions increased 65% at unwarranted signal sites and declined 49% at warranted signal locations. Additionally, the executive summary also stated that injuries increased at unwarranted signal sites and decreased at warranted signals sites. In 1979, Purdue University's School of Civil Engineering published "Some Effects of Unwarranted Traffic Signals"[5] by Chung-Cha Liu which documented additional impacts of unwarranted traffic signals through evaluating ten intersections in one community in Illinois. Among the conclusions were that total delay increased for all motorists regardless of whether a signal was unwarranted or warranted, however, unwarranted signals resulted in delays of 3,200 to 4,200 vehicle hours for the major street (based on three intersections). The study also concluded that due to the large amount of delay, a substantial amount of fuel is wasted due to unwarranted signals.

It is unclear whether any of the signals studied were specifically installed for the benefit of bicycles and/or pedestrians and whether any of the signals were installed along a primarily residential street. Since the signal warrants contained within the MUTCD often cannot be met even when using both pedestrian and bicyclist volumes in addition to the side street motor vehicle volumes, many jurisdictions have either installed traffic signals specifically for bicycles and pedestrians or used conventional traffic signal designs and used signing and pavement markings to minimize impact on neighborhood traffic.

SEATTLE CASE STUDY

INTRODUCTION

In 2007 Seattle undertook an effort to create a Bicycle Master Plan[6]. As part of this process, the city identified various corridors to establish as bicycle boulevards. One such corridor, Fremont Avenue, connected downtown Seattle to the Interurban Trail, a separated multi-use path linking many smaller communities together. Within this project, there were three arterial streets which needed to have a signalized crossing prior to signing the bike route. These cross streets are N 80th Street, N 85th Street, and N 105th Street. Prior to the undertaking of the Bicycle Master Plan, a pedestrian half-signal was already in place at N 85th Street, therefore, it was not included in this case study.

N 80th Street is an east-west arterial street with one lane of traffic in each direction. On-street parking is provided on the north side of the street. The traffic signal was turned-on on November

16, 2007. Prior to the installation of the traffic signal, Fremont Avenue N was controlled by a stop sign while N 80th Street had no control. See Figure 1 for photographs of the intersection.

Figure 1. Photographs of Fremont Avenue N & N 80th Street

Looking Northbound on Fremont Ave N

Looking Eastbound on N 80th St

Looking Southbound on Fremont Ave N

Looking Westbound on N 80th St

N 105th Street is an east-west arterial street with two lanes of traffic in each direction. There is no parking on either side of the street. The traffic signal was turned-on on October 7, 2010. As was the case with the N 80th Street intersection, Fremont Avenue N was controlled by a stop sign while N 80th Street had no control before the signal was installed. See Figure 2 for photographs of the intersection. Minor differences between this signal and that at N 80th Street includes the use of video detection for the side street instead of loop detectors and using the standard "hot spot" marking as described in Section 9C.05 of the MUTCD for bicycle detection. The signal at N 80th Street used a white T marking which was standard practice in Seattle prior to the release of the 2009 MUTCD.

Figure 2. Photographs of Fremont Avenue N & N 105th Street

Looking Northbound on Fremont Ave N

Looking Eastbound on N 80th St

Looking Southbound on Fremont Ave N

Looking Westbound on N 80th St

The two traffic signals were designed as conventional four-way intersections. To prevent motor vehicles from using the route to bypass other arterial routes, motor vehicles were forced to turn either right or left at the intersection. These restrictions were conveyed to motorists using standard regulatory signs and pavement markings as shown in Figure 3.

Figure 3. Turn Restriction Sign and Pavement Markings

ANALYSIS METHODOLOGY

To determine what effects the signals at N 80th Street and N 105th Street had on traffic, the following analyses were performed:

- MUTCD signal warrant study, including pedestrian hybrid beacon (PHB) warrant studies for before and after traffic volumes and the Caltrans bicycle signal warrant
- Before and after traffic volume analysis
- Before and after crash analysis
- Bicycle and Pedestrian level of service analysis
- Field observation summary including turn restriction compliance

WARRANT ANALYSES

MUTCD traffic signal, pedestrian hybrid beacon (PHB), and Caltrans bicycle signal warrant analyses were conducted for the two intersections studied. Since these signals were in operation at the time of the study, two warrant analyses were done; one based on data collected prior to installation of the signal and one based on data collected after the installation of the signal. Table 1 summarizes whether the signal met at least one warrant.

Table 1. Summary of Warrant Analyses

Intersection	**Prior to Signal Installation**			**After Signal Installation**		
	Signal Warrants	*PHB Warrants*	*CalTrans Warrants*	*Signal Warrants*	*PHB Warrants*	*CalTrans Warrants*
Fremont Ave N & N 80th St	Not Met	Not Met	Not Met	Not Met	Met	Not Met
Fremont Ave N & N 105th St	Not Met	Met	Not Met	Not Met	Met	Met

The "before" traffic counts were conducted in April, however, April, 2011 was an abnormally rainy and cold month. Therefore, follow-up counts were conducted in September. In analyses conducted for both April and September counts, Warrants 1 (Eight-hour Vehicular Volume), 2 (Four-hour Vehicular Volume), 3 (Peak Hour Volume), 5 (Pedestrian Volume), and the Caltrans bicycle signal warrant were used to determine whether a signal was warranted or not. Right-turning vehicles off of the mainline and side streets were included in the count with no volume reduction.

TRAFFIC VOLUME ANALYSIS

Table 2 shows the before and after peak hour volumes for bicycles, pedestrians, and motor vehicle traffic in the northbound and southbound directions approaching the intersections.

Table 2. Summary of Traffic Volume Changes

Intersection	**Bike Volume**		**Pedestrian Volume**		**Motor Vehicle Volume**	
	Before Peak Hour NB/SB	*After Peak Hour NB/SB*	*Before Peak Hour NB/SB*	*After Peak Hour NB/SB*	*Before Peak Hour NB/SB*	*After Peak Hour NB/SB*
Fremont Ave N & N 80th St	Not Available	14	2	17	72	69
Fremont Ave N & N 105th St	21	52	10	20	77	85

From the volume numbers, both pedestrian and bicycle volumes have increased while motor vehicle traffic has remained relatively constant. Although the total motor vehicle volume remained relatively unchanged, the distribution of traffic changed such that the left turning and through volumes increased while the right turning volumes decreased. This is likely the result of these movements being easier to complete with a signal in comparison to a stop-controlled intersection.

The two signals along Fremont Avenue N were located in close proximity to other signals either to the west or east. In the case of the N 105th Street signal, there was a previously unsigned bicycle route along Dayton Avenue N approximately 600 feet to the west which was being used by cyclists. The signal at N 80th Street was located near a signal to the east but that intersection was not on a route commonly used by bicyclists. Turning movement or vehicle classification counts were not done at nearby signals prior to the installation of the signals at either N 105th Street/Fremont Avenue N or N 80th Street/Fremont Avenue N intersections, so it cannot be determined whether the increase in bicycle traffic was due to bicyclists making a route change or if the growth was more organic.

CRASH ANALYSIS

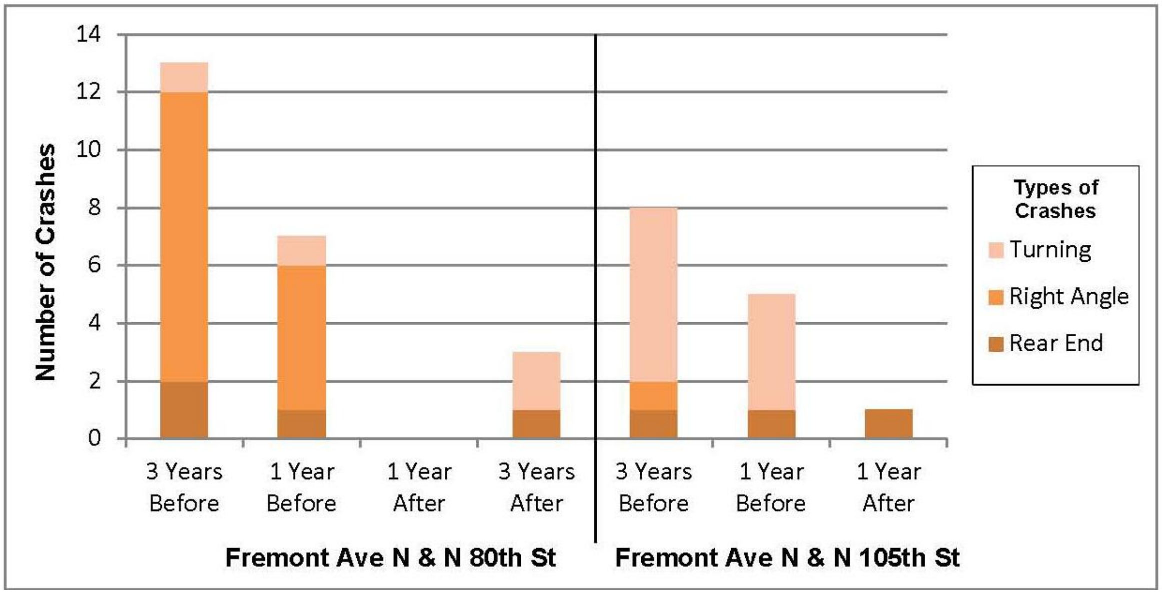
The results of the crash analysis show an overall reduction of crashes after the installation of the two signals. Table 3 below shows a summary of the crash analysis for the four intersections. Crash information was obtained from the Seattle Department of Transportation (SDOT) that included a 3-year crash history before installation and one to three year crash history after installation. To minimize the effect of construction activities on the analysis, a period of 6 months prior to signal turn-on date was excluded. Then, following the signal activation a 3-month period was excluded to allow roadway users to become accustomed to the signal. Table 3 summarizes the crash data obtained and classifies it based on whether the crash was correctable by a signal installation or non-correctable.

Table 3. Summary of Crashes

Intersection	**Prior to Signal Installation**		**Following Signal Installation**			
	3-years		***1-year***		***3-years***	
	Correctable Crashes	*Non-correctable Crashes*	*Correctable Crashes*	*Non-correctable Crashes*	*Correctable Crashes*	*Non-correctable Crashes*
Fremont Ave N & N 80th St	11	2	0	0	0	3
Fremont Ave N & N 105th St	3	5	0	1	Not Available	

A further breakdown of collision types was also done. These results are shown in Figure 4.

Figure 4. Collisions at Fremont Avenue N Intersections



In addition to the numerical summary, the collision rate and severity index for these intersections were calculated. The collision rate is expressed as collisions per million entering vehicles. Both one- and three-year rates were derived for this project when data was available. Three-year rates tend to minimize the effect of abnormal conditions which can have an increased effect on the one-year rate. The collision rate was derived using the following formula:

$$R = \frac{A * 10^6}{365 * T * V}$$

Where: R: Collision Rate (collisions per million entering vehicles)
A: Number of collisions
T: Total Number of Years
V: Total Entering Traffic

The severity index (SI) used for this study was derived from a formula developed by the National Safety Council. Class 4 injury (incapacitating) collisions are combined with fatal collisions and have a higher severity value. Lower class injuries (i.e. non-incapacitating injuries and possible injury/no visible sign of injury but complaint of pain) are given a lower severity value. Since the collision data provided only indicated whether the collision involved fatalities, injuries, or property damage, the formula was modified as shown below:

$$SI = \frac{5.8 (N_k) + 2 (N_i) + N_{pd}}{T}$$

Where: SI: Severity index
N_k: Number of fatal crashes
N_i: Number of crashes which involved injury
N_{pd}: Number of property damage only crashes
T: Total number of crashes

Both collision rates and severity index values are provided in Table 4.

Table 4. Collision and Severity Rate Comparison

Intersection	Prior to Signal Installation		Following Signal Installation			
	3-Year Crash Rate	*3-Year Severity Index*	*1-Year Crash Rate*	*1-Year Severity Index*	*3-Year Crash Rate*	*3-Year Severity Index*
Fremont Ave N & N 80th St	0.751	1.77	0.000	N/A	0.200	1.00
Fremont Ave N & N 105th St	0.314	1.25	0.122	1.00	Not Available	

BICYCLE & PEDESTRIAN LEVEL OF SERVICE ANALYSIS

Although not required by the MUTCD, an analysis of the peak hour level of service (LOS) gives the traffic engineer another perspective of operations at an intersection. Typically, as the delay at an unsignalized crossing increases, the size of gap a bicyclist or pedestrian will accept a smaller than acceptable gap. This may lead to an increase in crashes at intersections operating with high delay values.

The peak hour LOS analysis was done based on the 2010 Highway Capacity Manual (HCM)[7] for unsignalized intersections and on the peak hour volumes prior to installation of a traffic signal. The level of service for crossing bicyclists required some modifications to the HCM procedure. This is due to the fact that the 2010 HCM does not have a method to calculate bicyclist delay at unsignalized intersections. First, the analysis was conducted for the motor vehicle traffic excluding bicycle traffic. Second, the analysis was conducted for bicycle traffic treating the bicyclist as a motor vehicle but excluding motor vehicle traffic. Finally, the analysis was conducted for bicycle traffic treating the bicyclists as pedestrians. The pedestrian LOS method was modified for bicyclists by revising the crossing speed to 14.7 feet per second (10 mph) and increasing the start-up time to 6 seconds. These values are in accordance with Caltrans Traffic Operations Policy Directive 09-06[8] regarding signal timing for bicyclists. The results of the LOS analysis are shown below in Table 5.

Table 5. Bicycle & Pedestrian Control Delay Summary (Two-Way Stop Control)

Intersection	Pedestrian Delay *(sec)*	Motor Vehicle Side Street Delay *(sec)*		Bike as Motor Vehicle Side Street Delay *(sec)*		Bike as Pedestrian Side Street Delay *(sec)*
		NB	SB	NB	SB	
Fremont Ave N & N 80th St	237.2	32.5	27.2	Not Available		52.2
Fremont Ave N & N 105th St	5,297.9	44.8	53.4	124.5	109.4	247.0

Even though, motor vehicle side street delay is relatively acceptable for a two-way stop controlled intersection, it should be noted that the control delay is a weighted average of the movements, including right turns which frequently have a lower delay. Since bicyclists would be traveling through the intersection and require a larger gap than a motorist, the delay would be higher and be closer to the pedestrian delay value. Pedestrian delays in excess of 45 seconds often "exceed tolerance level" and result in a "high likelihood of pedestrian risk taking" (2010 HCM). As shown in the results for both intersections, the bicycle operating as a motor vehicle and as a pedestrian mode, the delay is in excess of 45 seconds.

A special note needs to be made regarding the pedestrian delay at N 105th Street. The delay calculation per the 2010 HCM indicates that the pedestrian would face a delay of 5,297.9 seconds (1 hour, 28 minutes). In reality, most pedestrians would avoid using this intersection and use nearby signalized intersections. This is validated by the low amount of pedestrian crossing before the signal installation.

Both pedestrian and bicycle delay values show that these modes would benefit from some sort of active device to reduce delay.

FIELD OBSERVATION SUMMARY

As shown in the turning movement counts for both intersections, a substantial portion of motorists are violating the turn restriction sign and continuing straight through the intersection. Table 6 shows the number of side street motor vehicle through traffic versus the total motor vehicle approach traffic based on the 8 hour counts obtained following the signal installation at both intersections. While there were no apparent conflicts with bicyclists or pedestrians traveling through, these violations increase the cut-through traffic in the neighborhood.

Table 6. Motor Vehicle Violations of Crossing Prohibitions Summary*

Intersection	**Northbound**			**Southbound**		
	Thru	*Total*	*Thru %*	*Thru*	*Total*	*Thru %*
Fremont Ave N & N 80th St	23	179	12.8	22	156	14.1
Fremont Ave N & N 105th St	38	281	13.5	30	233	12.9

*Based on 8-hour "after" turning movement count

A number of bicyclists using the signal pulled off the roadway to activate the signal by pressing the pedestrian push buttons. At N 105th Street, there are the hot spot markings as denoted in the 2009 MUTCD to show where the detection would be most receptive to bicyclists. Of the 232 bicyclists crossing in both directions during the 8-hour count, 27 or 11.6% went directly for the push button and one went for the push button after waiting for some time.

CONCLUSIONS

1. Both signals did not meet any of the eight MUTCD signal warrants in the before or after period. The signal at N 105th Street met the PHB warrant in the before and after period using bicyclists as pedestrians and the signal at N 80th Street met the PHB warrant in the after period. Even though the signals did not meet any traffic signal warrants, the signalized intersections did not experience an increase in the number of collisions as indicated by previous research.

2. The overall severity of collisions at the signalized intersection was less than that before the intersection was signalized. The reduction in severity is consistent with research on signal installations whether warranted or not.

3. The delay at both intersections for bicyclists and pedestrians prior to traffic signal installation was in excess of 45 seconds. Per the 2010 HCM, this level of delay has a "high likelihood of pedestrian risk taking." Following the installation of the traffic signal, both bicycle and pedestrian volumes saw increases of varying amounts. This is likely due to the decrease in delay from the previous unsignalized condition.

4. Observations shows 12 to 14% of motor vehicles violate the crossing restrictions at both intersections. This is the only negative finding of this case study. A review of the collision records did not indicate any safety concern involving this, however, the violations may increase neighborhood traffic and complaints.

5. It appears that there may be a misunderstanding of signal detection at these locations. 11.6% of bicyclists counted at N 105th Street went directly for the pedestrian push button instead of using the "hot spot" markings. Use of the R10-22 sign which tells a bicyclist to wait on the bicycle pavement marking symbol on the approach may minimize bicyclists traveling on the sidewalk to activate the pedestrian push button. Alternatively, push buttons placed such that bicyclists on the roadway can activate them may also be beneficial.

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