Developing and Using Tables Showing the Pedestrian Optimum and Bicyclist Optimum Feasible Intersection Designs

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Planners and designers have many intersection alternatives to choose from these days, and many considerations typically go into that choice. Pedestrians and bicyclists are high on list of considerations at many sites. Even in areas that are currently rural, there may be a need to consider those road users due to a chance that the area will develop, and demands will emerge. However, it is usually not clear which alternative intersection design would be best for pedestrians and bicyclists from among the concepts that would otherwise fit at a particular spot.

Much of the literature on pedestrians and bicyclists at intersections is focused on how to improve existing conventional intersections, and many agencies are making efforts to provide safe and convenient multimodal networks.[1, 2] Some researchers have focused on how to improve alternative designs for pedestrians and/or bicyclists.[3, 4] Each of the four Federal Highway Administration (FHWA) guidebooks on the most popular alternative intersection designs has a chapter on pedestrians and bicyclists, but again the focus is on making the experience the best possible for those road users once the design concept has been chosen.[5-8]

FHWA guidance on intersection control evaluation (ICE), a formal process for considering alternative concepts early in project development, implies a qualitative assessment of how well each concept treats pedestrians and bicyclists.[9] Indeed, there is little available guidance to planners and designers on which intersection concept to choose to best meet the needs of those road users.

Fortunately, there is a new method available in *NCHRP Research Report 948* that quantifies the quality of experience for a pedestrian or bicyclist at any intersection.[10] Based on focus groups, surveys, and expert opinions, the researchers developed a method that scores each crosswalk and bicyclist movement at an intersection on 20 different aspects. Each of the 20 aspects could be scored as "no flag" meaning no unusual concern about that aspect of the pedestrian or bicyclist movement; a "yellow flag" meaning concern that that aspect of the movement could be inconvenient or uncomfortable; or a "red flag" meaning concern that that aspect of the movement could lead to more crashes. *NCHRP Research Report 948* provided detailed descriptions of each of the 20 aspects and criteria for what earns a yellow or red flag.

The author made a recent attempt to help planners and designers choose the safest feasible intersection design (SAFID) from among the set of possibilities. The SAFID tables showed, for any combination of major street size and demand and minor street size and demand, the safest design based on published crash modification factors.[11] The idea was that planners and designers could start their search for the optimum intersection concept for any particular spot with the design from the SAFID tables.

The objective of this paper is to combine the ideas from *NCHRP Report 948* and the SAFID effort to produce tables that showed the pedestrian optimum feasible intersection design (POFID) and the bicyclist optimum feasible intersection design (BOFID). The aim is to provide, for any combination of major street size and demand and minor street size and demand, the feasible intersection concept that would minimize the number of flags for pedestrians and bicyclists. Like the SAFID tables, the POFID and BOFID tables could give planners and designers a default concept for a particular spot that could be the starting place for detailed analysis.

Method

The intersection designs considered included all of the four-legged concepts in the FHWA CAP-X tool except the partial median U-Turn (MUT) and the split intersection, which are very rare (I only know of one partial MUT in the United States, and no split intersections).[12] The only other common four-legged intersection types that I could think of are jug handle and offset intersections. While jug handles are common in a few states, in North Carolina, USA, they are not considered to be a competitive design as they require more right-of-way than a partial continuous flow intersection (CFI) while delivering only a fraction of the delay savings. Meanwhile, it seems that agencies are much more often considering removing offset intersections than installing them. With the possible exception of offset intersections, the POFID and BOFID tables considered all common and feasible four-legged intersections.

To construct the POFID and BOFID tables, consideration was given to the feasibility of the various designs with the following rules, which were the same as for the SAFID paper (11):

- All-way stop control (AWSC) is viable on two-lane roads with demands of less than 7,500 vehicles per day (VPD) on each road.
- Based on the latest national guide a single-lane roundabout can handle up to 25,000 VPD total and a two-lane roundabout can handle up to 45,000 VPD total.[13]
- Based on the FHWA guidebook a signalized reduced conflict intersection (RCI, a/k/a superstreet, J-Turn, or RCUT) can handle up to 25,000 vpd on the minor street.[7]
- Two-lane minor streets should be signalized in RCIs at demands ranging from 3,000 to 11,000 VPD based on North Carolina Department of Transportation (NCDOT) research.[14]
- Because RCIs have superior signal progression and are not as vulnerable to driver confusion, MUTs, CFIs, and quadrant roadway intersections only become feasible at minor street demands above 25,000 VPD.

Agencies often make exceptions to these rules, but they should serve well to start.

Once the competitor intersection concepts in each cell of the Table 1 were listed, *the NCHRP Report 948* method was applied on each concept in each cell.[10] The 20 aspects evaluated were:

1. Motor vehicle right turns
2. Uncomfortable/tight walking environment
3. Nonintuitive motor vehicle movements
4. Crossing yield or uncontrolled vehicle paths
5. Indirect paths
6. Executing unusual movements
7. Multilane crossings
8. Long red times
9. Undefined crossing at intersections
10. Motor vehicle left turns
11. Intersecting driveways and side streets
12. Sight distance for gap acceptance movements
13. Grade change
14. Riding in mixed traffic
15. Bicycle clearance times
16. Bicyclist crossing motor vehicle travel lane(s)
17. Channelized lanes
18. Turning motorists crossing bicycle path
19. Riding between travel lanes, lane additions, or lane merges
20. Off-tracking trucks in multi-lane curves

Aspects 1-13 apply to pedestrians, and 4-20 apply to bicyclists. Assumptions included typical road geometry, one exclusive lane for each signalized left-turning movement, and one exclusive lane for each right-turning movement on multilane approaches. Typical turning percentages (10 percent lefts and rights from the main street), peak hour percentages (nine percent), and directional splits (60/40) also were assumed to translate daily volumes into hourly movement volumes as needed for *NCHRP Report 948*.

Table 1. Numbers of flags for intersection designs.

Design	Cell number in Tables 2 and 3	Number of pedestrian flags				Number of bicyclist flags			
		Yellow	Red	Total	Weighted total	Yellow	Red	Total	Weighted total
AWSC	1	12	0	12	12	6	6	12	18
	2	12	0	12	12	4	8	12	20
Two-way stop control (TWSC)	1	12	2	14	16	6	12	18	30
	2	12	2	14	16	4	14	18	32
	3	6	8	14	22	4	14	18	32
	7, 12, 17, 22	4	10	14	24	8	16	24	40
	28	4	10	14	24	4	20	24	44
Roundabout	1, 3	0	8	8	16	2	14	16	30
	2, 4-6	0	8	8	16	0	16	16	32
	8-10, 13-15, 18-20, 23-25	2	8	10	18	4	20	24	44
	11, 16, 21, 26	4	8	12	20	4	22	26	48
Signal	3-5	6	8	14	22	14	22	36	58
	6	4	10	14	24	12	24	36	60
	7-9, 12-14, 17-19, 22-24	4	10	14	24	14	28	42	70
	28-30	4	10	14	24	8	34	42	76
	10, 15, 20, 25	2	12	14	26	12	30	42	72
	31	2	12	14	26	6	36	42	78
	11, 16, 21, 26, 27	0	14	14	28	12	32	44	76
	32, 33	0	14	14	28	6	38	44	82
	34	0	14	14	28	4	40	44	84
MUT or bowtie	8-10, 13-15, 18-20, 23-25	2	6	8	14	38	0	38	38
	29-31	2	6	8	14	24	14	38	52
	11, 16, 21, 26, 27, 32-34	0	8	8	16	28	12	40	52
Unsignalized RCI	7-9, 12-13, 17, 22, 28*	6	12	18	30	4	18	22	40
Signalized RCI	10, 14, 15, 18-20, 23-25	8	10	18	28	10	18	28	46
	11, 16, 21, 26	4	14	18	32	14	16	30	46
	29*, 30*, 31*	6	12	18	30	8	20	28	48
	32	6	12	18	30	14	16	30	46
Partial CFI	25	10	12	22	34	18	30	48	78
	31	10	12	22	34	20	32	52	84
	26, 27, 32-34	8	14	22	36	18	34	52	86
Full CFI	27, 32-34	4	12	16	28	12	36	48	84
Quadrant	27	1	10	11	21	28	16	44	60
	32, 33	1	10	11	21	19	25	44	69
	34	1	10	11	21	13	31	44	75

** The numbers of flags shown in the table are for six through lanes in the major street. With eight through lanes the number of flags changed somewhat, but not enough to affect Tables 2 or 3.*

Each of four pedestrian crossing movements and a left, a through, and a right bicyclist movement from each approach were evaluated. For bicycle facilities, the assumption was a marked bicycle lane next to each curb and that bicyclists used the most convenient way to complete a left turn between using the motor vehicle lanes and using a green box on the far-right corner of the intersection.

Results

Table 1 shows which design was feasible in each of the 34 cells in the POFID and BOFID tables (Tables 2 and 3) and then shows the numbers of yellow and red flags for pedestrians and bicyclists for each design in each cell. In Table 1 the "weighted total" column weights red flags by a factor of two before adding that result to the number of yellow flags. The weight of two acknowledges that safety is more important than comfort, but that comfort still matters. Note that the results do not change much for various other weights and agencies, or project teams can apply their own weights and recreate the tables as they wish.

Tables 2 and 3 show the POFID and BOFID tables, e.g., the feasible intersection design in each cell that minimized the weighted total number of flags. Shaded cells in Table 2 and 3 represent cases when a particular design minimized the weighted total number of flags for both pedestrians and bicyclists. Red lettering indicates a design that was also the safest feasible intersection design as reported in Reference 11 based on total crashes.

For pedestrians in Table 2, the pattern was that AWSC was best at the smallest intersections; a roundabout was best at larger two-lane meets two-lane intersections; TWSC or conventional signal was best in the lower portion of the left column when a large main street meets a small minor street; a MUT was best at large intersections; and a MUT or its close variation bowtie were best in the middle of the table.[15]

For bicyclists in Table 3 the pattern was similar with AWSC best at the smallest intersections; a roundabout at larger two-lane meets two-lane intersections; a MUT at large intersections; and a MUT or bowtie in the middle of the table. The differences between the POFID and BOFID tables were along the lower left side where unsignalized RCIs or TWSC were generally best for bicyclists; along the bottom row where signalized RCIs were best for bicyclists; and along the right side for four-lane major streets meeting smaller four-lane minor streets where signalized RCIs were best for bicyclists. Some might be surprised that RCIs did so well for bicyclists, but they reduce conflicts with left-turn vehicles, shorten signal cycles, and break up long road crossings, and in the final tally those advantages outweighed their disadvantages.

The red lettering in Tables 2 and 3, showing designs that also were the safest in that cell (11), revealed that planners and designers often do not have to compromise motor vehicle safety to achieve optimum pedestrian and bicyclist experience. AWSC, roundabouts, and MUTs, in their niches, generally provide optimum safety, pedestrian experiences, and bicyclist experiences. Red lettering also shows up in Table 3 where sometimes RCIs are safest and best for bicyclists.

				Minor street						
			Number through lanes:	2				4		6 or 8
Major street			Low AADT:	0	5,000	7,500	10,000	10,000	25,000 and above	Any
Number through lanes	Low AADT	High AADT	High AADT:	5,000	7,500	10,000	15,000	25,000		
2	0	7,500		1) AWSC	2) AWSC	n/a	n/a	n/a	n/a	n/a
	7,500	15,000		3) Roundabout	4) Roundabout	5) Roundabout	6) Roundabout or signal	n/a	n/a	n/a
4	10,000	15,000		7) TWSC or signal	8) Bowtie or MUT	9) Bowtie or MUT	10) Bowtie or MUT	11) Bowtie or MUT	n/a	n/a
	15,000	20,000		12 TWSC or signal	13) Bowtie or MUT	14) Bowtie or MUT	15) Bowtie or MUT	16) Bowtie or MUT	n/a	n/a
	20,000	25,000		17) TWSC or signal	18) Bowtie or MUT	19) Bowtie or MUT	20) Bowtie or MUT	21) Bowtie or MUT	n/a	n/a
	25,000 and above			22) TWSC or signal	23) Bowtie or MUT	24) Bowtie or MUT	25) Bowtie or MUT	26) Bowtie or MUT	27) MUT	n/a
6 or 8	Any			28) TWSC or signal	29) Bowtie or MUT	30) Bowtie or MUT	31) Bowtie or MUT	32) Bowtie or MUT	33) MUT	34) MUT

Table 2. Pedestrian optimum feasible intersection design (POFID) table.

				Minor street						
			Number through lanes:	2				4		6 or 8
Major street			Low AADT:	0	5,000	7,500	10,000	10,000	25,000 and above	Any
Number through lanes	Low AADT	High AADT	High AADT:	5,000	7,500	10,000	15,000	25,000		
2	0	7,500		1) AWSC	2) AWSC	n/a	n/a	n/a	n/a	n/a
	7,500	15,000		3) Roundabout	4) Roundabout	5) Roundabout	6) Roundabout or signal	n/a	n/a	n/a
4	10,000	15,000		7) Unsignalized RCI or TWSC	8) Bowtie or MUT	9) Bowtie or MUT	10) Bowtie or MUT	11) Signalized RCI	n/a	n/a
	15,000	20,000		12) Unsignalized RCI or TWSC	13) Bowtie or MUT	14) Bowtie or MUT	15) Bowtie or MUT	16) Signalized RCI	n/a	n/a
	20,000	25,000		17) Unsignalized RCI or TWSC	18) Bowtie or MUT	19) Bowtie or MUT	20) Bowtie or MUT	21) Signalized RCI	n/a	n/a
	25,000 and above			22) Unsignalized RCI or TWSC	23) Bowtie or MUT	24) Bowtie or MUT	25) Bowtie or MUT	26) Signalized RCI	27) MUT	n/a
6 or 8	Any			28) Unsignalized RCI or TWSC	29) Signalized RCI	30) Signalized RCI	31) Signalized RCI	32) Signalized RCI	33) MUT	34) MUT

Table 3. Bicycle optimum feasible intersection design (BOFID) table.

As with the SAFID tables (11), TWSC and conventional signal almost never appear in the POFID and BOFID tables. There still may be reasons to stay with TWSC and conventional signal during any particular project, but optimizing the pedestrian and bicyclist experience might mean starting with a different concept.

As an example of the application of the tables, consider an intersection project I worked on recently where a six-lane arterial that will carry about 32,000 VPD in the design year meets a four-lane arterial that will carry about 27,000 VPD. Cell 33 of the POFID and BOFID tables show that a MUT is optimum for pedestrians and for bicyclists at this place (considerably better than a conventional signal as seen in Table 1) and show that a MUT is also the safest design. This information should be helpful to stakeholders as they consider the MUT, a new design in North Carolina.

Conclusions

Hopefully, the POFID and BOFID tables will help planners and designers when choosing intersection control concepts. At intersections with pedestrians and bicyclists, planners and designers can use the tables to find a default concept against which other concepts can be compared. The fact that in many cells an AWSC, a roundabout, or a MUT is simultaneously the generally safest, the best for pedestrians, and the best for bicyclists is a bonus and indicates strong default candidates. The 20-aspects tool from *NCHRP Report 948* is available to conduct detailed assessments (employing statistical techniques and sensitivity analyses as needed) and to help sharpen up a concept as it moves into later stages of design. Designing for pedestrians and bicyclists does not have to be a qualitative process in which the loudest voice wins, but can be a quantitative process of measurable improvements.

There are many avenues for productive future research and improvements along these lines. For example, the NCDOT has funded a research effort to validate the 20-aspects tool against crash data, and those results should be helpful and illuminating. Also, POFID and BOFID tables could be developed for three-legged intersections, grade-separated intersections, and interchanges. Finally, use of the SAFID, POFID, and BOFID tables could be formalized in agency project development procedures for early planning stages, funding and programming stages, and early design stages. Crucial project decisions like how to optimize pedestrian and bicyclist experiences should not be made in a haphazard manner. **itej**

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