INTERSECTION DESIGN TOOL TO AID ACCESS MANAGEMENT

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ABSTRACT
The goal of this project is to develop a structured and objective evaluation process to compare alternative design concepts and evaluate them based on access management, pedestrian/bicycle accommodations as well as safety operations. This will allow for a preliminary evaluation of a broader range of possible designs, screening out those that would be considered less desirable or appropriate based on operational performance. This approach permits a more objective comparison of all alternatives, since all options target the same operational service level. The use of the Critical Method Analysis (CMA) was considered an appropriate approach for developing such size estimates for intersections and it was expanded to address stop-controlled and yield control intersections. The Intersection Design Alternative Tool (IDAT) developed through this effort is capable of evaluating 13 different intersection alternatives and it would be invaluable in evaluating alternative designs that could enhance access management and implementing innovative intersection treatments such as alternative left-turn treatments.

INTRODUCTION
Intersections can act as choke points on the transportation system and improper designs have the potential to block access, increase the potential for crashes, and reduce the effectiveness of access management plans. Intersection design therefore becomes a balancing act of various elements and constraints aiming to produce a solution that addresses mobility, access, safety, environmental, and financial aspects of the project. To achieve this balance, alternative strategies and options must be identified, developed and evaluated in a systematic manner. Traffic control measures have been developed that can improve the operational efficiency and safety of intersections. The implications and effectiveness of such designs are not, however, well understood, nor have significant efforts been undertaken to provide an objective comparison between various types of intersection designs or traffic control measures. Moreover, high level evaluation of how such alternatives operate with regard to access control measures is limited. Such an effort will allow for establishing the proper design and traffic control for an intersection and thus enhance the ability for a proper access management and control. It is therefore important to develop an objective methodology for evaluating alternative intersection designs while meeting the project constraints and goals. Current practice, while achieving great strides in improving the efficiency, lacks a systematic, objective and well defined approach to evaluating individual design alternatives.

A review of current literature identified 13 alternative intersection designs. Of interest is the fact that no systematic process can be identified, which compares these alternative designs. Most guidelines identify the need for comparative studies but do not identify the factors or methods that one should apply in determining the most appropriate design for a specific situation. The lack of such specific guidance both at the national and state level is likely to discourage engineers from considering one or more of the alternatives, even though such design may be appropriate. It is reasonable then, to conclude that unwarranted operational or safety problems, or unwarranted costs may be incurred when such suboptimal designs are constructed.

The goal of this project is to develop a structured and objective evaluation process to compare alternative design concepts and evaluate them based on safety performance, access management enhancement, and pedestrian and bicycle accommodations. In order to facilitate this evaluation, the methodologies described in this report were developed into a software based tool identified as the "Intersection Design Alternative Tool (IDAT)." The tool developed provides designers with a list of potential solutions that are based on the minimum number of lanes required to achieve a targeted level of operation.

LITERATURE REVIEW

The Maryland State Highway Administration had identified a list of unconventional intersections and provided conceptual information and considerations for a wide range of alternative intersection designs (*1*). Most of the intersection designs also utilize innovative left turn treatments, provide or accommodate channelization and/or raised medians and accommodate u-turns: all access management components. A number of the alternatives included in the list have been used throughout the country. For example, the median u-turn design has been used in Michigan extensively for years, the jughandle design in New Jersey, and the continuous flow intersection used in New York and Maryland. The use of modern roundabouts is perhaps the most adopted alternative and its use is increasing rapidly throughout the United States.

There is limited guidance on the evaluation, design and implementation of these designs is available despite their long use. Even though the American Association of State Highway Transportation Officials (AASHTO) Policy on Geometric Design of Highways and Streets contains guidelines on the design of standard intersections along with some guidance on the median u-turn, jughandle, and roundabout alternatives, this guidance is very limited and does not adequately address evaluation issues (*2*). A recent report by the FHWA addressed the Restricted Crossing U-turn intersections (Superstreet) and Median U-turn at-grade intersections and has issued Technical Brief on their use (*3*). A review of states identified twelve states that have developed roundabout guides which address the planning, design and operations of roundabouts, primarily based on the FHWA Roundabout: An Informational Guide (*4*), though several have much more comprehensive guides.

A review of the design guides used by each state examined the factors considered in intersection design and how decisions regarding control type and size are reached. Of the 41 state transportation agencies reviewed only Florida, Missouri, New Jersey, New York, Texas, and Washington have developed their own intersection design guidelines contained within a separate Intersection Design Manual or included within their roadway design manuals. All states reviewed have intersection design guidance that adhere to or follow the AASHTO guidance and Manual of Uniform Traffic Control Devices (MUTCD) for determining traffic control (mainly for signalization). Of those states with independent guides, the most frequently considered design factors are operational analysis and construction cost (five of six states with specific guidance). These two factors are considered controlling for designing and evaluating intersection options, since they define the operational and construction efficiency of the intersection. No manual provides specific guidance for selecting appropriate intersection design or control types; most manuals simply note that comparisons among alternatives should be performed. It is apparent that there is a lack of any tools that provide designers or planners with an estimate of appropriateness for different intersection designs.

The review of state practices revealed that there is limited guidance on evaluating alternative intersection designs and no state has developed a systematic process that compares such alternative designs. Most manuals identify the need for comparative studies but none identify the factors that one should consider in weighing alternatives and determining the optimal design. Maryland is the only state that is in the process of developing such an approach but not much progress has been made since 2005 when the concept was initiated. The development of separate manuals for roundabouts by a few states is a step in the right direction for identifying and considering alternative intersection designs; however, these do not provide a means for comparison and may further segregate alternative designs from traditional or other alternative designs. The lack of any specific guidance on the national and state level regarding the specific use and implementation of alternative designs is likely to discourage engineers from considering one or more of the alternatives, even though they may be appropriate.

RESEARCH FINDINGS

Based on the literature review a total of 13 different intersection alternatives were identified for consideration in the research. These are.

- Signalized

- Roundabout
- All-way stop
- Two-way stop
- Unsignalized inside left turn
- Median U-turn signalized
- Median U-turn unsignalized
- Superstreet, unsignalized
- Superstreet, signalized
- Continuous flow
- Continuous green T
- Jughandle
- Bowtie

These intersections may be broadly grouped into two major categories of signalized or unsignalized control.

Intersection Design Procedures

A typical problem in comparative analysis of roadway designs is ensuring that all alternatives examined deliver a similar level of targeted operational performance. For instance, a signalized intersection with two approach lanes may service the same volume as a single lane roundabout for a given set of conditions. However, during the initial concept development both alternatives may be compared with two lane approaches leading to comparing alternatives with vastly different operational performance in addition to costs and right of way and environmental impacts. The approach taken here was to identify the minimum footprint for each intersection design for a given traffic demand, while meeting a volume to capacity ratio (v/c) of 0.90. If an alternative meets this threshold, it is considered to be feasible and no larger footprint alternatives for this design are considered. This approach allows for full comparison of other design factors such as access management enhancement, construction costs, right of way and environmental impacts.

The critical aspect of the analysis tool to be developed is to determine the optimum design scenario meeting the desired operational threshold with a minimum footprint which subsequently will have the smallest construction costs and impacts. To achieve this, various techniques such as capacity analysis software or simulations may be used for design and sizing intersections, however, this approach requires an iterative process for each alternative to achieve the desired level of capacity. This approach can be time consuming and limit the range of alternatives to be considered. Therefore, a methodology that directly links the traffic demand, i.e., design hour turning movement volumes, to the optimum lane configuration for each alternative was sought.

The Critical Lane Analysis (CLA) was considered as the most promising approach to be used here. This method allows for the automation of the design process of signalized intersections by systematically linking traffic demand, geometric design and operational level of service (*5*). CLA distributes the approach volumes to the available lanes and utilizes developed phasing plans to allow for the appropriate intersection movements. Critical volumes for each phase are determined based on certain rules and these volumes are summed to determine the total critical lane volume for the intersection. This sum can then be directly related to the level of service definition for signalized intersections. Similar techniques (i.e. estimates of capacity) have been developed for unsignalized intersection designs as well. The Special Report 209 Highway Capacity Manual (*6*) provided intersection capacity estimates based solely on conflicting movements and reserve capacity while considering intersection geometry. Finally, a recent report offered another consideration for estimating capacity for roundabouts (*7*).

Even though the methods discussed for estimating intersection could be considered not as refined as current micro simulation models and/or more complex macro models allow for direct linkage between intersection design and operation. The simplicity of the models allows for manipulation through computational models, which permit the automation of preliminary designs for establishing the basic geometry needed to achieve a desired intersection capacity. CLA and unsignalized intersection Level of Service methods have served as the foundation for the calculating procedures used in the current version of the Highway Capacity Manual. These approaches are viewed as a basic, fundamental process for evaluating intersection design alternatives. The focal point behind all these approaches is that they provide the potential for a common basis of comparison, i.e. volume to capacity ratios or unused capacity, which can be used in targeting design options and provide a common basis for comparisons.

INTERSECTION DESIGN ALTERNATIVE TOOL (IDAT)

Each intersection design considered for evaluation could be manipulated through the use of a basic design (signalized, unsignalized or roundabout) and redirected or channelized turn movements. For example, the median U-turn operates as a signalized intersection at its center, paired with two adjacent intersections to accommodate left-turning movements. This approach allows for utilizing the basic methods identifying before to estimate the operational efficiency of each design and determine the minimum lane requirements to achieve the desired v/c ration 0.90. In addition, safety, right-of-way requirements, and access capabilities are considered to evaluate relative advantages and disadvantages and establish a composite score that could identify candidate designs for he given set of conditions. The following sections identify the components of the IDAT software.

For each intersection design a variety of lane configurations is evaluated. These include eight different left and right turn auxiliary configurations for each of one, two and three through lane combinations for a total of 24 combinations for each approach. All combinations of each approach are evaluated with each approach, except that a restriction is placed that both the major and minor street have the same number of through lanes. Figure 1 shows the eight different approach combinations for a single through lane alternative.

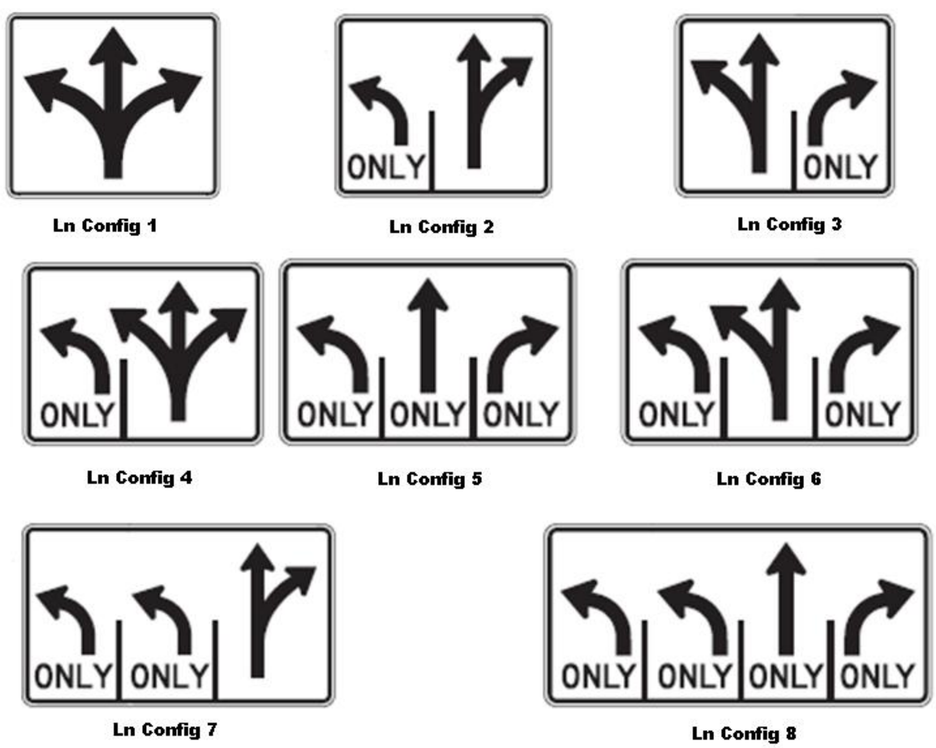

Figure 1: Approach Lane Configurations

These eight approach configurations developed for the signalized intersections served as the basis for the other intersection alternatives, which were modified to meet the unique demands of each of the differing designs. Each of the eight approach configurations were scored based on 1) the total number of lanes used in the design and 2) the desirability of the configurations from an operational, safety and driver expectancy (i.e. commonality of design used) standpoint. Lane configurations were rated as follows:

- 1: 8 (Highest Score)
- 2: 6.5
- 3: 6.5
- 4: 5
- 5: 4
- 6: 2
- 7: 3
- 8: 1 (Lowest Score)

A total intersection score is estimated for the designs with a v/c ratio of less than 0.90 (i.e. feasible combinations) as the sum of the individual approach scores. The combination with the highest score is then chosen as the preferred configuration for that alternative. For each alternative design, a preferred configuration is evaluated for single-lane, two-lane and three-lane approaches on the major street. If multiple approach lane configurations are feasible for a given alternative, those with a greater number of through lanes are identified as "Not Recommended" to identify that a configuration with a smaller footprint is feasible.

The feasible alternatives are then further evaluated using a weighted scoring scheme to identify the most appropriate designs that merit additional detailed evaluation. The scoring system examines the right-of-way requirements (based on the number of lanes), safety performance considering vehicular, pedestrian and bicycle safety and access management capabilities. Each category is assigned a weight to indicate its level of importance in the project. In this version, IDAT uses an equal weight (0.33) for each criterion. Each alternative is scored against these criteria and a composite total score is developed.

An expert panel was employed to develop the alternative scoring. The panel consisted of traffic operations, highway safety, and design engineers who were asked to evaluate and score each intersection design based on a priori understanding of the level of safety, pedestrian and bicycle accommodation, and access management enhancement that it can provide. For example, roundabouts may be ranked higher for access management potential than a traditional signalized intersection as they can implicitly accommodate turning vehicles redirected by the circulatory roadway. Superstreet or Median u-turn alternatives may score higher still as they require restrictive medians and accommodate u-turns. The scoring method used a five-point scale where 1.0 represents the lowest score and 5.0 the highest. The safety level was scored individually for vehicular, pedestrian and bicycle traffic creating a unique score for each category, since there are different safety concerns for each travel mode.

For the right of way, the size of intersection was used to develop the scores. The size of the intersection becomes a critical determinant of suitability of each design, since all alternatives are developed to operate at the same level of efficiency. This is a relative comparison between alternatives, since precise estimates at the preliminary design stage are typically not available due to topographic or other constraints on the site. The scoring method provides 5 points for an approach with a single lane. Approaches with 5 or more lanes receive 0 points. Turn lanes, such as a left or right auxiliary lane are counted as ½ of a lane, since they will likely be required for only a short length. The average score of all approaches for the design is used in the final scoring. Jughandle and Bowtie designs were deducted 2 points overall due to the increased space requirements for this design. Even though intersection size may be disaggregated into components, including number of approach lanes, intersection number of lanes (including auxiliary lanes) and physical intersection area, such a detailed approach was not deemed appropriate for the level of anticipated use of the evaluation tool. An example of the IDAT output is shown in Figure 2.

INTERSECTION ALTERNATIVE	OPERATION EVALUATION	MINIMUM LANE CONFIGURATION						ROW	SAFETY			A.M.	SCORE
		L3	L1	L4	L2	L4 U	L2 U	0.3	Veh. 0.1	Ped. 0.1	Bike 0.1	0.3	
2-Way Stop Control*	Not Feasible							0	2.5	1.5	2.5	1.0	0
4-Way Stop Control	Not Feasible							0	4.0	4.0	5.0	1.5	0
Signalized Intersection (1 lanes)	Not Feasible							0	4.0	4.0	3.5	2.5	0
Signalized Intersection (2 lanes)	Feasible							3.75	3.0	3.0	3.0	3.0	3.2
Signalized Intersection (3 lanes)	Not Recommended							3.5	2.5	2.5	2.0	3.0	2.9
Jughandle A EB (1 Lanes)	Not Feasible							-2	3.0	2.5	3.0	3.5	0
Jughandle A EB (2 Lanes)	Feasible							1.375	2.5	1.5	2.5	4.0	2.5
Jughandle A EB (3 Lanes)	Feasible							1.25	2.0	1.5	1.5	4.0	2.3
Jughandle A WB (1 Lanes)	Not Feasible							-2	3.0	2.5	3.0	3.5	0
Jughandle A WB (2 Lanes)	Feasible							1.5	2.5	1.5	2.5	4.0	2.5
Jughandle A WB (3 Lanes)	Feasible							1.375	2.0	1.5	1.5	4.0	2.3
Jughandle A EB-WB (1 Lanes)	Not Feasible							-2	3.0	2.5	3.0	3.5	0
Jughandle A EB-WB (2 Lanes)	Feasible							1.875	2.5	1.5	2.5	4.0	2.7
Jughandle A EB-WB (3 Lanes)	Not Recommended							1.625	2.0	1.5	1.5	4.0	2.4
Roundabout	Not Feasible							0	5.0	4.0	4.0	5.0	0
Median U-Turn (Signalized) (1 Lanes)	Not Feasible							0	4.0	3.5	2.5	5.0	0
Median U-Turn (Signalized) (2 Lanes)	Feasible							1.75	3.0	2.0	2.0	5.0	3
Median U-Turn (Signalized) (3 Lanes)	Not Recommended							0.875	2.5	2.0	1.5	5.0	2.6
Median U-Turn (Unsignalized)*	Not Feasible							0	4.0	2.5	2.5	5.0	0
Superstreet (Signalized)	Feasible							1.75	3.5	2.5	1.5	4.0	2.7
Superstreet (Unsignalized)	Not Feasible							0	3.5	1.5	1.5	4.0	0
Inside Left Turn (Signalized) (NB 'T') (1 Lane)	Not Feasible							0	4.0	1.0	1.0	3.5	0
Inside Left Turn (Signalized) (NB 'T') (2 Lane)	Not Feasible							0	3.0	1.0	1.0	4.0	0
Inside Left Turn (Signalized) (NB 'T') (3 Lane)	Not Feasible							0	2.5	0.5	0.5	4.0	0
Inside Left Turn (Signalized) (SB 'T') (1 Lane)	Not Feasible							0	4.0	1.0	1.0	3.5	0
Inside Left Turn (Signalized) (SB 'T') (2 Lane)	Not Feasible							0	3.0	1.0	1.0	4.0	0
Inside Left Turn (Signalized) (SB 'T') (3 Lane)	Not Feasible							0	2.5	0.5	0.5	4.0	0
Inside Left Turn (Unsignalized) (NB 'T')*	Not Feasible							0	3.5	1.0	1.0	3.0	0
Inside Left Turn (Unsignalized) (SB 'T')*	Not Feasible							0	3.5	1.0	1.0	3.0	0
Bowtie (1 Lane)	Not Feasible							-2	3.5	3.5	2.5	5.0	0
Bowtie (2 Lane)	Not Feasible							-2	2.5	2.5	2.0	5.0	0
Bowtie (3 Lane)	Not Feasible							-2	2.0	2.0	1.5	5.0	0

Figure 2 IDAT Output

CONCLUSIONS

This paper documents the efforts and approach used to develop a systematic effort for developing and selecting proper intersection designs that could improve operations, safety, and access management. The prescribed tool and methods identified allow for an expanded evaluation of intersection functions beyond a basic comparison of operational performance. By designing an intersection to fit the operational parameters desired all intersection design may then begin on equal ground. The final determination of the preferred alternative can then be made, not on which alternative has 10 seconds less of delay, but rather which best accommodates an access management plan, provides desirable pedestrian or bicycle safety, or fits within the available right of way. As a result this tool will be invaluable in pursuing alternative treatment plans such as access management corridors and implementing innovative intersection treatments such as roundabouts and alternative left-turn treatments.

The ultimately applicability of this approach is to identify a wider range of feasible intersection design alternatives with significantly less effort, than is currently afforded through the independent evaluation of intersection designs through capacity software or micro-simulation programs. Notable is the approach taken to sizing intersection alternatives to deliver a targeted performance level so that comparative evaluations do not have to involve comparison of operations, but instead can focus on costs and impacts to the associated project area. The proposed approach provides a greater efficiency in the evaluation and conceptual design of intersection alternatives, with the intent to achieve greater operational efficiency and improved safety performance. This allows for a more appropriate and properly customized design for each intersection avoiding the use of "standard or typical" designs.

REFERENCES

1. Applied Technology and Traffic Analysis Program. *Unconventional Arterial Intersection Design. 2005. University of Maryland, College Park, MD.* http://attap.umd.edu/bbs/zboard.php?id=projects&select_arrange=headnum&desc=asc&page_num=5&selected=&exec=&sn=off&ss=on&sc=off&category=10&ss=on&ss=on&keyword=. Accessed June 22, 2010.
2. American Association of State Highway Transportation Officials. *A Policy in Geometric Design of Highways and Streets*. Washington, D.C., 2004.
3. Hughes, W. and Ram Jagannathan. *Alternative Intersections/Interchanges: Information Report (AIIR)* (FHWA-HRT-09-060). Federal Highway Administration. Washington, D.C., 2009.
4. Robinson, B., et al. *Roundabouts: An Informational Guide* (FHWA-RD-00-067). Federal Highway Administration. Washington, D.C., 2000.
5. Messer, C and Banial Fambro. Critical lane Analysis for Intersection Design. In *Transportation Research Record: Jounral of the Transportation Research Board,* No. 644, Transportation Research Board of the National Academies, Washington, D.C., pp. 26-35.
6. Highway Capacity Manual Special Report 209. Transportation Research Board of the National Academies. Washington, D.C., 1985.
7. Rodegerdts, L. M. Blogg, E. Wemple, E. Meyers et al. *NCHRP Report 572 Roundabouts in the United States*. Transportation Research Board, Washington, D.C., 2007.
8. Manual on Uniform Traffic Control Devices, 2009 Edition. FHWA, U.S. Department of Transportation, 2009.
9. DLZ Kentucky Inc., *Madison Pike (KY 17 Intersection Improvement Study.* Northern Kentucky Area Planning Commission and Kentucky Transportation Cabinet. Fort Wright, KY. 2006.