Intersection Decision Guide

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Indiana Department of Transportation (INDOT)

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Contents

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I. Introduction and Purpose

The *Intersection Decision Guide* aids in choosing among alternatives. It serves as documentation of an assignment carried out by a seven-member Technical Working Group to produce a procedure to determine corrective measures for intersections. Specifically, this *Guide* prescribes a method or model to be used by INDOT in decision-making relative to choice of basic intersection form, including forms common and uncommon to Indiana. The latter types are typically referenced as “alternative” or “innovative” intersections, and for instance include median U-turn, roundabout, displaced left-turn and other designs.

It is INDOT’s policy and purpose to expand use of alternative intersections statewide, in a responsible manner, supporting the agency’s ongoing commitment to improve service delivery, to continually advance business practices through innovation and ever-more cost-effective capital investments.

This document acts as practical guidance to that end, defining the systematic process to effect a sound decision as a function of essential project need and purpose. Note that diagnosis of problems in intersection performance is an upstream process, albeit a critical one. In the sequence of systems assessment or “scoping” steps, that identification of the problem, or “need,” is a prerequisite to execution of the process outlined in this *Intersection Decision Guide* that yields the best solution to the defined need. And in that regard, the solution produced from this model should be the result of integrated assessment with environmental study, and considered pre-decisional until formal environmental requirements are satisfied.

While the model outlined here leads one through a decision process on fundamental intersection form, it’s merely a framework for that action. It neither excuses the user of responsibility to exercise sound professional judgment nor does it replace or diminish the significant level of care and analytics necessary to determine measures of operational performance, impacts, and costs. The techniques presented in this *Guide* have been developed for use by a person with at least a moderately advanced understanding of and experience with the various types and operational characteristics of alternative intersections, and of traffic engineering methods of analysis to assess performance.

The *Guide* has flexibility to address merits of countermeasures ranging from more minor-scale treatment (e.g., adding an auxiliary right-turn lane, or changing from two-way stop to signal control) up to wholesale reconstruction/modernization in kind or to a fundamentally different design type. It may be applied to all intersections — be they public road to public road, or public road to private commercial drive. Though the *Decision Guide* does not address interchanges per se, it certainly may be applied to at-grade intersection elements of a service interchange, for instance, to the ramp junctions with the crossroad at a diamond interchange.

Content of the *Intersection Decision Guide* is ordered as a series of nine chapters, I to IX, with sub-chapters, followed by four appendices, A-D.

II. Background and Formation

The Department's executive leadership ordered development of a statewide policy regarding the manner under-performing or entirely new intersections are evaluated to determine appropriate treatment — specifically relative to fundamental intersection form. By that is meant the essential type of intersection, be it common signalized or unsignalized ("conventional") or "alternative" design.

A Technical Working Group was established to execute that directive. Its membership: Alisa Bowen, central office Highway Design and Technical Support; Mike Eubank, Crawfordsville District Capital Program Management; Jason Kaiser, Fort Wayne District Technical Services; Dana Plattner, Fort Wayne District Technical Services; Greg Richards, Traffic Management and District Support; Bill Smith, Crawfordsville District Technical Services; and Brad Steckler, central office Traffic Engineering. Charge of the Group was to develop and effect implementation of a rational, organized method to guide identification, assessment/comparison, and selection of countermeasure treatment relative to essential intersection style, and do so in a manner balancing simplicity of use with necessary thoroughness to promote sound decision-making.

The Technical Working Group collaborated in a series of sessions in the first quarter of 2013 to shape the model, making every effort to assure it is understandable, usable, and concise; leads to good and consistent decisions; and assures a thoughtful process to reach that decision. In cases of uncertainty of the value of a more complex vs. less complex feature to the decision process, the Working Group adopted the latter, erring on the side of a product more straightforward to the intended user as opposed to one more rigorous but only marginally more exact.

Another important feature in development of this *Decision Guide* was formation of a Focus Group for the purpose of identifying faults and refining methodology. Its membership: Damon Brown, Vincennes District; Karl Leet, central office; Hillary Lowther, Seymour District; Michael Miltz, LaPorte District; Bob Montgomery, Crawfordsville District; Dirk Schmidt, Fort Wayne District; and Jeremy VanVleet, Greenfield District. Their contributions were registered principally by means of a one-day consultation held in early April 2013 with the Technical Working Group. Constructive feedback from that relationship shaped adjustments and improvements to the decision-making process.

The Technical Working Group sought assistance from FHWA, which led to an invitation to national authorities in this specialized field of alternative intersections, to enhance the members' expertise in their operational characteristics relative both to traffic safety and traffic mobility (congestion). The

Working Group members met with these FHWA resources for an extended period over two days in mid-April 2013. As part of that dialogue, the version of the *Decision Guide* at that point was presented, and expert opinions conveyed there were translated into the succeeding version.

Select executive staff were presented with the *Intersection Decision Guide* in late-May 2013. On that occasion the Technical Working Group introduced the model approach and elicited executives' views on its basic structure and particular facets. That overall positive interaction as well generated ideas to polish the product.

Additional steps include presentation of the *Guide* to the broad assembly of users through INDOT beginning December 2013. There is an expectation that each stage of exposure of the analytical tool is an occasion to discover ways to make it better, and those will serve as means to continually update the methodology through later versions. Finally, the Technical Working Group is committed to conduct an audit of the implementation of this *Decision Guide* after one year of practice, both to gauge level of compliance and to spot opportunities to improve the model.

Questions regarding this document, the model presented herein, may be directed to Brad Steckler or any member of the Technical Working Group.

III. <u>Intersection Types</u>

There are in one fashion or another, of varying degrees of reasonableness and tangible practice, dozens of traditional and novel intersection design layouts. The *Intersection Decision Guide* directly addresses nine (and within those basic nine are many variations), those viewed as having potential applications on the state highway system, listed in no particular order:

- *Conventional intersection*. The most common in Indiana. Includes signalized and unsignalized traffic control sub-types, and a host of treatment options of varying scale from wholesale reconstruction to addition of auxiliary lanes to change in manner of traffic control.

- *Median U-turn intersection (MUT)*. Direct movements from mainline or crossroad are replaced by indirect, downstream U-turn movements. MUT has three sub-types (each with variations): boulevard left (also referenced as Michigan left), in which left-turn movements from only mainline (partial) or both mainline and crossroad are shifted to the mainline, downstream of main intersection; and signalized RCUT (restricted crossing U-turn, also called Superstreet) and unsignalized J-turn, in which for both types, crossroad left-turn and through movements are shifted to the mainline, to the right and downstream of the main intersection. The MUT is occasionally referenced as a reduced conflict intersection (RCI), notably RCUT and J-turn sub-types.

- *Roundabout intersection*. Also referenced as modern roundabout, or traffic circle in some regions.

- *Displaced left-turn intersection (DLT)*. Also referenced as continuous flow intersection (CFI) and cross-over displaced left (XDL). Mainline and/or crossroad left-turn movements are shifted to a point upstream of the main intersection.

- *Jug-handle intersection*. Also referenced as New Jersey left. Includes these sub-types (each with its own variations): near-side or exit upstream of the main intersection, and far-side or exit downstream of the main intersection.

- *Offset "T" intersection*. Crossroad legs of an otherwise 4-legged intersection are separated to form two "T" junctions with the mainline.

- *Green "T" intersection*. Also referenced as Florida "T" or continuous green "T". The crossroad left-turn movement has a dedicated auxiliary acceleration lane on the mainline, separate from the mainline through movement.

- *Quadrant roadway intersection (QRI)*. All left-turn movements at a 4-legged intersection are shifted to a 2-way connector roadway in one quadrant.

- *Grade separation*. Also referenced as an overpass. Though not an intersection, it is an alternative to one.

The decision to include these nine and not others was the consensus judgment by the Technical Working Group, after considering the full array of possible design types and after discussion with other contacts throughout development of the *Guide*. While certain, innovative design types may not be explicitly addressed in the *Guide*, their exclusion doesn't imply they're precluded from consideration. The manner prescribed for processing the named nine intersection types is generally valid for other alternative forms one may wish to consider as an intersection countermeasure. Do not discount the no-build/no-action/do-nothing alternative during the decision-making process, as by default it should remain a feasible option throughout.

Intersection labels will differ depending on region of the country, literature source, and time period, and a slight variation of the original form is often renamed in a manner that may or may not include traces of the original. To the extent possible, consistent naming convention is used in this document, using the most common but not necessarily universal term.

IV. Process Overview

The process is step-wise, a sequence of questions and answers guiding the user through a series of smaller decisions that ultimately lead to selection of the best course of action. The user enters the model with the universe of alternatives — the nine core forms along with sub-types if need be, and the no-build option — takes them one at a time through decision trees, discards those outright failing in any one of the performance factors, then compares and contrasts those remaining in terms of the multiple factors. The methodology involves a mix of quantitative and qualitative performance metrics, and factors that are objective and subjective. Exercising good professional judgment is essential.

A pair of decision trees frames the manner one navigates through. The two trees are labeled "Initial, Feasibility Screening," followed by "Secondary, Expanded Performance Assessment." They are addressed sequentially. That is, each alternative first faces Stage 1 Feasibility Screening by means of four questions and answers, then only the select alternatives deemed feasible based on preliminary inspection advance to face Stage 2 Expanded Performance Assessment. That second stage serves to check/verify each element of performance in more detail, again, by means of four questions and answers. Then for the alternatives verified as satisfying all those individual factors in the second phase, overall merit is appraised for the purpose of revealing the best choice.

As one applies the decision methodology, records are kept in two forms, one corresponding to each of the decision trees. While these forms are meant as the primary method of documentation, certainly other, supplementary records (notes, analysis, data, correspondence, etc.) will be appropriate to further support decisions made along the way and in the final state.

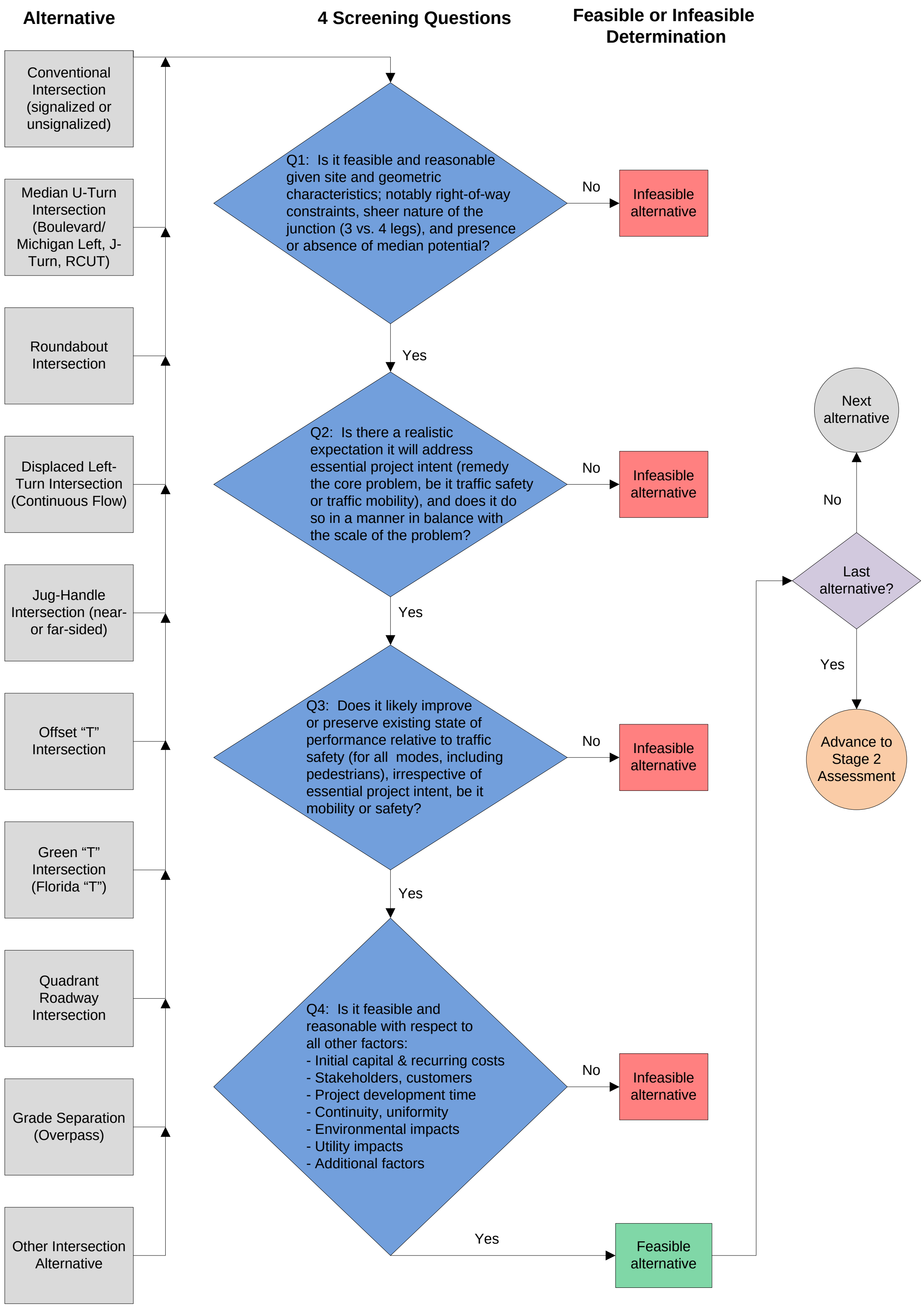
Do not overlook traffic safety and mobility service to pedestrians, notably persons with disabilities, including those blind or otherwise visually impaired. All else equal, an alternative may perform well or poorly depending on nature, extent, and intensity of users other than motor vehicles. References cited within this document under chapter IX Resources and in the Technical Briefs along with additionally available INDOT, AASHTO, and FHWA policy and procedural guidelines exist to assist in this task. Proper navigation through the decision model/trees requires an understanding of this special aspect of travel through intersections.

The relative merit of an intersection treatment may in certain cases be a function of its setting. While many intersections may be adequately judged in isolation, for some the appropriateness of a particular design may be subject to prevailing types aside the one in question along a corridor, and its dominant manner of access control. This concept of adjacent conditions affecting preferences for an individual site is that which is addressed as "continuity, uniformity" in the decision trees. Context does matter in regard to systems' effects in intersection decision-making.

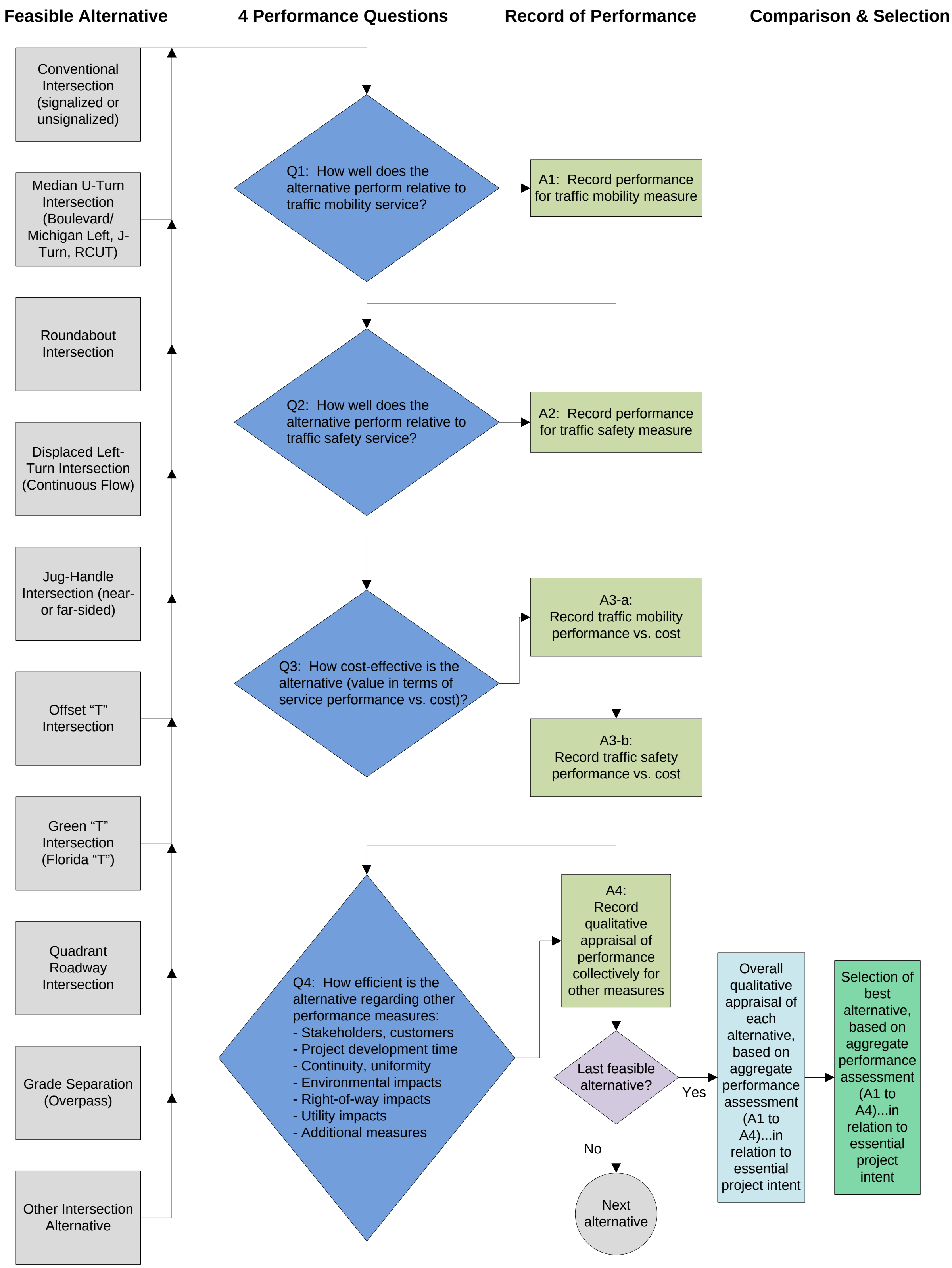
V. <u>Decision Trees</u>

Presented here are the two decision trees (absent specific reference to the no-build alternative):

Stage 1: Initial, Feasibility Screening



Stage 2: Secondary, Expanded Performance Assessment



VI. <u>Instructions</u>

Information presented in this chapter further explains the manner one navigates through each of the decision trees. Instructions are broken down by Stage (1 and 2) and by column heading — three for Stage 1, labeled Alternative, 4 Screening Questions, and Feasible or Infeasible Determination; and four for Stage 2, labeled Feasible Alternative, 4 Performance Questions, Record of Performance, and Comparison & Selection.

A. Decision Tree for Stage 1: Initial, Feasibility Screening

The purpose of this initial stage is to screen out early in the assessment process the treatments that are clearly unreasonable therefore infeasible based on simple inspection or cursory review of performance, to reduce the universe of candidate alternative intersection forms to those having clear potential merit. Alternative forms are not compared against one another in Stage 1 assessment, merely analyzed in isolation to determine if they work or don't work, satisfy or don't satisfy essential project need and purpose. Alternatives left standing (not screened out, not discarded) at the end of Stage 1 are those considered at least provisionally feasible as opposed to clearly infeasible, based strictly on preliminary review. (Those judged feasible in Stage 1 will be further assessed in Stage 2 to verify or prove false that initial judgment, and to determine the degree of value of each feasible alternative, comparing and contrasting the alternatives' performance relative to various factors.) Time and effort to process through the Stage 1 decision tree are minimal, given requisite information for the four principal screening questions has been collected before starting.

a) Alternative

All nine base intersection styles are listed on the left-hand side of the Stage 1 decision tree. The no-build alternative is understood to advance into Stage 2 as a feasible alternative. Some or many of the alternatives can be eliminated by initial assessment, without having to invest in more rigorous analysis (of Stage 2). Each alternative should be routed through the decision tree, one at a time. For instance, first process the conventional intersection option through each of the four questions to determine its feasibility status. Then return to the Alternatives column to select the next treatment in order, Median U-Turn (MUT), and repeat the process until all nine alternatives in the list have been exhausted.

In intersection site assessments, multiple sub-types of one or more of the base alternative forms will need to be assessed as unique treatments (e.g., MUT is a base form, with three sub-types: boulevard left, RCUT, J-turn; and within those sub-types there may be significant variations). For instance, site conditions may compel consideration of variations in effecting enhancements to an existing conventional, unsignalized intersection: add active signal control with no other expansion, signalize and add select auxiliary lanes, or carry out wholesale intersection reconstruction in concert with adding signal control. Or circumstances may call for consideration of two MUT forms: an unsignalized J-turn or signalized RCUT layout. However, only break the base intersection designs into variant forms when under given site characteristics they differ markedly in traffic operational performance (safety and mobility), cost, or essential character.

b) 4 Screening Questions

The Stage 1 decision tree's principal, middle column asks four questions to enable a determination of feasible or infeasible status for the purpose of screening out (discarding) alternatives or advancing them to Stage 2. The four questions:

- Q1: Is it feasible and reasonable given site and geometric characteristics; notably right-of-way constraints, sheer nature of the junction (3 vs. 4 legs), and presence or absence of median potential?
- Q2: Is there a realistic expectation it will address essential project intent (remedy the core problem, be it traffic safety or traffic mobility), and does it do so in a manner in balance with the scale of the problem?
- Q3: Does it likely improve or preserve existing state of performance relative to traffic safety (for all modes, including pedestrians), irrespective of essential project intent, be it mobility or safety?
- Q4: Is it feasible and reasonable with respect to all other factors:
  - Initial capital & recurring costs
  - Stakeholders, customers
  - Project development time
  - Continuity, uniformity
  - Environmental impacts
  - Utility impacts
  - Additional factors

Steer one intersection alternative at a time through the four questions (Q1‐Q4). A "No" response to Q1 renders the alternative infeasible, and similarly for the other three questions. At any point through this series of questions if routing is to this determination (infeasible), then assessment may end for that alternative, effectively eliminated from further consideration. (Optionally, to determine and record whether there is more than one "fatal flaw" with that option, assessment of the alternative may continue through the remaining questions, though not to advance to Stage 2.) On the other hand, a "Yes" response leads to the 2nd question (Q2), and so forth.

Given that in Stage 1 the candidate intersection designs are evaluated individually, not compared or contrasted, different methods or performance measures may be used to judge their feasibility relative to traffic mobility, in the context of Q2. Among them are LOS, average vehicle delay, volume-to-capacity ratio (v/c), critical lane volume, speed, travel time, queuing, and stops. It could be the case that overall intersection LOS is used to screen one alternative, average delay or queuing on heaviest approach on another, total intersection influence area speed or travel time on another, and so on.

Continuing with this discussion of gauging in Stage 1 an alternative's feasibility relative to traffic mobility service, the advice is not to invest a great deal of time and effort in very detailed, complex analysis for this purpose, but rather to use wisely abbreviated methods. There are various techniques to accomplish this, to mention but a few: *CAP-X* application developed by FHWA specifically for alternative intersection sketch-plan analysis (listed in chapter IX, Resources); JTRP's *Safety and Operational Impacts of Alternative Intersections*, specifically the series of tables in Section 9.2 of the research report (as well referenced in chapter IX, Resources); and preliminary or "planning-level" analysis in the context of methodologies of the *Highway Capacity Manual* (HCM, and HCS software) or traffic simulation models.

With respect to Q4, it is in reality made up of seven sub-questions, and a "No" for any of those seven renders the intersection infeasible, rules it out from further consideration as a viable treatment. "Project development time" captures urgency of bringing on line the intersection improvement, should that be an issue. What is meant by "Additional factors" in the list in the 4th question is any noteworthy, extraordinary factor/question unique to the site not explicitly in the first six listed but that may cause the alternative to be infeasible or feasible based on the answer.

c. Feasible or Infeasible Determination

By default, the no-build alternative is feasible. Where each other alternative lands through the decision tree at this right-most column determines whether it's infeasible or (provisionally) feasible, in the former case stopping and not advancing to Stage 2 consideration and in the latter case advancing. Thus, if there is reasonable confidence an intersection alternative is infeasible in relation to any of the four questions (Q1 - Q4), it should be set aside, rejected from further consideration. On the other hand, if the view is held of anything less than reasonable confidence that it's infeasible with respect to any question, then one should give the response to the question as feasible, erring on the side of inclusion when in doubt (advancing it as opposed to discarding it), given that Stage 2 will revisit its performance in more detail and catch any "false positive" generated from Stage 1 assessment.

To illustrate this notion of siding with inclusion vs. exclusion in Stage 1, relative to the statement in Question #1 on "median potential," the mere absence of a wide median may not necessarily cause to be infeasible the median U-turn intersection designs, as addition of a "loon" or "bulb-out" may suffice. "Right-of-way constraints" mentioned as well in Question #1 does not imply an alternative that requires additional right-of-way should be labeled infeasible, only that there may exist an apparent right-of-way barrier making the alternative clearly non-viable by inspection.

Information is rarely perfect, nor is absolutely perfect information necessary to make rational decisions. This involves sound engineering judgment on the part of the user, balancing the desire to give a credible option due consideration but not operating in a manner overly inclusive where an alternative with little apparent merit unnecessarily consumes time and effort in carrying out more rigorous analysis.

B. Decision Tree for Stage 2: Secondary, Expanded Performance Assessment

The purpose of this second stage is to assess in relative depth the operational performance and related qualities of each alternative intersection type successfully passing all tests of feasibility in Stage 1. Stage 2 performs these two main functions: (a) confirms or disproves the initial feasibility finding, and (b) yields specific performance statistics, for the purpose of judging the best among the truly feasible options. As was the case in the initial stage, in the Stage 2 decision tree each alternative should be routed through one at a time. Time and effort to process through the Stage 2 decision tree is more than minimal but not onerous, assuming analysis relevant to the four principal performance questions has been completed ahead of time and results are present and well-organized.

a) Alternative

While the Stage 2 decision tree lists all intersection alternatives in the left-most column (the no-build alternative is understood as feasible through Stage 1), only the select alternative forms (and sub-types) that advanced out of Stage 1 — were judged feasible — actually progress into this more rigorous assessment phase. One at a time, each feasible alternative should be routed through Stage 2 decision tree's 4 Performance Questions. For instance, if conventional intersection and roundabout intersection are the first two in the list determined to be feasible through Stage 1 screening, first process the conventional intersection option through each of the four questions to determine its performance. Then return to the Alternatives column to select the next treatment in order, roundabout, and repeat the process, until all feasible alternatives in the list have been exhausted. Again, as was the case in Stage 1, unique sub-types within each base alternative intersection form — those that differ markedly in function, cost, impact — should be processed and judged separately in Stage 2.

b) 4 Performance Questions

The Stage 2 decision tree's 2nd column asks four questions:

- Q1: How well does the alternative perform relative to traffic mobility service?
- Q2: How well does the alternative perform relative to traffic safety service?
- Q3: How cost-effective is the alternative (value in terms of service performance vs. cost)?
- Q4: How efficient is the alternative regarding other performance measures:
  - Stakeholders, customers
  - Project development time
  - Continuity, uniformity
  - Environmental impacts
  - Right-of-way impacts
  - Utility impacts
  - Additional measures

Steer one intersection alternative at a time through the four questions. If at any point through this series of questions there is discovery that a particular alternative is indeed infeasible, has a "fatal flaw," (thus overturning the preliminary finding in Stage 1 assessment), then assessment may end for that alternative, effectively eliminated from further consideration from that point forward. (Optionally, that alternative may continue its routing through the tree to determine and record the remaining performance statistics.)

What follows is an expanded discussion of meaning, make-up, and quantitative and qualitative metrics related to each of the four core questions in Stage 2 assessment:

i. **Q1**: How well does the alternative perform relative to traffic mobility service?

"Mobility" means movement of traffic — motor vehicle and other modes — and accounts for not just pace of movement but also notions of accessibility and connectivity. In the context of an intersection, mobility is generally associated with congestion, or lack thereof. There is a number of ways to measure mobility/congestion, among them travel time, delay, volume-to-capacity ratio, queuing, emissions, and LOS. All listed there are quantitative measures, other than LOS, though even it is derived from a quantity measure, such as control delay.

Recall that Stage 1 merely screens intersection alternatives in isolation to determine feasibility, does not compare one against the other. But Stage 2 explicitly assesses their differences — how one compares better or worse to the other feasible options. And because of this, the *primary* performance measure of Stage 2 for traffic mobility must satisfy both of these conditions:

1. Be applied as a common measure across all feasible alternatives, and over identical intersection influence areas, the latter to normalize study area scale as not to distort performance statistics by sheer differences in extent of road network making up the modeling area.
2. Be one that fairly describes intersection performance in a comprehensive manner, rather than gauging some narrow component of overall performance (e.g. of the latter, looks only at number of average vehicle stops).

Therefore, the Technical Working Group suggests total or average travel time — within a common analysis zone — as the *primary* measure for Stage 2 analysis. Others are acceptable if they satisfy the two conditions. And certainly use of multiple *primary* measures is acceptable.

Supplementary traffic mobility performance measures may accompany the chosen *primary* one(s). The *supplementary* measure need not necessarily satisfy the two conditions outlined for the *primary*. Meaning, the *supplementary* measure need not be applied across all feasible alternatives but can be used for one or some, and it need not be comprehensive but can focus on a specific aspect of the design's function (e.g. of the latter, queuing behavior). One or multiple of the *supplementary* types may be used.

As is customary, evaluate mobility service levels of the alternatives in current/base and future/design years, in peak periods of the day, and appropriately, an additional period representative of off-peak travel. On that latter point, certainly the measure of peak-period mobility is critical, yet as 60-80 percent of an intersection's daily travel use occurs off-peak, an alternative's service level at those times of the day should be factored in. It may be the case that an alternative has superior mobility (travel time) performance under peak traffic load yet is inferior to other options during off-peak hours.

Mobility statistics may be presented in absolute form, or optionally in a manner relative to a base condition. That base would typically be the no-build (no-action, do-nothing) alternative. In either case — absolute or relative form — be consistent across all feasible alternatives in recording the performance statistics.

There are several applications available to generate intersection traffic mobility performance statistics. To a significant degree their accuracy is a function of the user's competence and familiarity with the particular application. They are often in computer platforms, though manual methods are not necessarily inferior. Some of these models for evaluating operational performance of non-traditional intersection design are "static," while some make use of traffic simulation. They include but are not limited to methodologies of the Highway Capacity Manual (HCM) and its companion software HCS, Synchro/SimTraffic, and VISSIM. Fully addressing the subject matter of intersection traffic operational analysis is beyond the scope of the *Decision Guide*. The Technical Working Group is not endorsing or prescribing a particular application, as a host of acceptable tools is available, capable of satisfying the need for advanced-stage mobility analysis called for in Stage 2. (Some applications are more tailored to sketch-planning analysis, more to test of feasibility or as an initial screening tool and so suitable for Stage 1 but not Stage 2.)

Irrespective of the choice one makes to explain traffic operational performance, in order to generate Stage 2 statistics reliably representing an alternative's traffic flow characteristics, it is crucial to understand the application's limitations. Results are sensitive to input data quality, the manner defaults are handled, and overall calibration. Selection of measures of effectiveness (MOEs) is significant. Finally, exercise caution in any attempt to compare MOE results from one application to another, even the "same" MOE by name, as the logic and equations they're built on may be quite different, are often not directly comparable.

ii. **Q2**: How well does the alternative perform relative to traffic safety service?

The second core performance measure is traffic safety. It is the level of risk road users — both motor vehicles and other modes, including pedestrians — encounter as they travel through the intersection. Develop that in terms of overall intersection safety, such that if for this purpose of analysis the intersection is divided up (its elements or movements), then in the final analysis, aggregate the separate pieces into a composite value.

Arriving at an estimate of traffic safety performance is relatively straightforward, a step-by-step method. It is important the assessment be done in the same manner for each alternative, to ensure even judgment. For that reason, the Technical Working Group has chosen to be prescriptive on the method to be used.

Appendix B explains the method in detail. A summary account is presented here. Prediction of traffic safety performance is in terms of a base case, typically existing conditions (e.g., crash history at the intersection over the past five years). That history of crashes of all severities is adjusted (weighted) to account for greater emphasis on more severe events, then converted to an annual frequency. The predicted effect on safety performance of an intersection countermeasure is through its assigned crash reduction factor (CRF). Some situations will involve calculating a composite CRF to collect multiple aspects of an alternative's changes at an intersection. This composite CRF is then multiplied by the adjusted, annualized crash frequency to estimate number of crashes reduced per year of service life of the alternative, called CR.

A special procedure is presented at the end of Appendix B for assessing an intersection's traffic safety performance on an entirely new facility, one not replacing the function of another, therefore a site lacking a crash history. Instead of the quantitative approach taken as the metric for improvements to existing intersections (calculating a CR value), the special method assigns one of four qualitative judgments on expected safety performance of the intersection design: outstanding, favorable, satisfactory, and unsatisfactory.

iii. **Q3**: How cost-effective is the alternative (value in terms of service performance vs. cost)?

Cost-effectiveness is performance of the intersection alternative in terms of the two core measures of traffic safety and mobility, as a function of project cost. In other words, it is its fundamental value or "bang for the buck." However, neither traffic safety nor mobility effectiveness is monetized. Rather they're in units of intersection influence area crashes reduced (or an alternate, qualitative safety measure in the special case of a totally new facility) and travel time or other mobility metric. Annualized project cost is the numerator, and traffic safety and mobility performance statistics recorded as answers to Q1 and Q2 of Stage 2 are denominators of the equations.

It is typically sufficient to calculate cost to be the sum of all project phase costs, such as engineering, right-of-way, and construction. However, if post-construction recurring operating and maintenance (O & M) costs are viewed as significant (e.g., lighting) — very different relatively so from one alternative to another — then the O & M costs may be captured as well, a simple addition as the methodology for cost-effectiveness converts all costs to a uniform annual value. Irrespective of whether initial construction or post-construction, sound estimate of costs is critical in gauging the value of an intersection investment, thus Stage 2 decision-making demands appropriate time and effort in this task.

While a true cost-effectiveness value in units of uniform annual dollars per annual property-damage-equivalent crashes reduced is calculated for traffic safety (or alternately, according to one of the four qualitative performance levels for the special case of an entirely new facility), traffic mobility cost-effectiveness performance is not presented in that way. Rather for traffic mobility it's left as a simple relationship between cost and performance (the latter whether in absolute form or optionally relative to a base case), such that there is no direct calculation between the two. The two parts are simply placed one over the other, to reinforce and convey the alternative's return on investment for mobility service.

Appendix C details the manner of calculating cost-effectiveness performance statistics for traffic mobility and safety.

iv. **Q4**: How efficient is the alternative regarding other performance measures:

Question 4 of Stage 2 is in reality made up of seven sub-questions. "Project development time" captures urgency of executing the intersection work, should that be an issue. While in some cases related to the concept of development time, "right-of-way impacts" is a relative measure, such that the mere point that an alternative has a right-of-way impact is not necessarily a critical negative feature. What is meant by "Additional measures" in the list in the 4th question is any noteworthy, extraordinary factor/question unique to the site not explicitly in the first six listed but that is considered critical in judging worthiness of the intersection alternative under the conditions present.

c) Record of Performance

The third column of Stage 2 decision tree is titled Record of Performance. It relies on previously determined answers to the 4 Performance Questions (Q1-Q4).

Answers to Question 1 on traffic mobility service and Question 2 on traffic safety service are just the recorded performance statistics generated for each alternative (e.g., hours of travel time and annual crashes reduced within the intersection influence area). The answer to Question 3 on cost-effectiveness — the relationship of an alternative's cost to the performance it generates — is presented as two separate measurements, one for mobility (A-3a) and one for safety (A-3b).

The answer to Question 4 is a collective appraisal of the relative efficiency of "other performance measures," presented in qualitative terms. Use this schedule, in order from better to worse:

- Highly efficient
- Moderately efficient
- Marginally efficient
- Not efficient

Assign one of these four appraisals to each of the six component questions for each alternative. For instance, if the alternative performs poorly in terms of development time (takes a relatively long time to design, clear right-of-way, construct), then it would receive a "not efficient" rating for that particular factor. Repeat this judgment for each of the six component factors on each alternative. Then establish the alternative's single, collective appraisal representing the prevailing opinion registered for the six (or more) factors in Question 4 — again, in one of the four qualitative terms.

d) Comparison & Selection

This is the concluding step in Stage 2. It is essentially the gathering of the four answers presented in the prior step — Record of Performance — to base selection of the best alternative. It mixes into the selection each alternative's two core performance statistics of traffic mobility (A1) and traffic safety (A2), two cost-effectiveness metrics (A3-a and A3-b), and qualitative judgments of efficiency for other decision factors (A4). Use those performance findings to assign to each alternative an overall appraisal. The following schedule of six levels is suggested for that:

- Excellent
- Very good
- Good
- Fair
- Poor
- Very Poor

An individual one out of this list may be applied to more than one alternative, such that, for instance, two intersection alternatives could be rated very good, one good, two fair, etc. In any event, the single alternative selected in the final analysis as the best choice is the one achieving the highest overall qualitative appraisal, or at least in the group of alternatives at that highest level. (Recognize that the no-build or no-action option is understood to remain viable throughout the assessment process, and in the end may end up as the selected alternative.)

VII. Record Sheets

Appendix A contains two *Record Sheets* corresponding to Stage 1 and Stage 2 decision trees. The *Sheets* serve as the central instrument for documentation as the user progresses through the model.

Each is condensed to one page, for convenience. However, in most cases, supplemental documentation in the form of working notes, data, analysis, correspondence, etc. must be registered to complement the limited extent of that that which can be entered on these two forms. The standard for adequate documentation in this decision process is such that a person not having conducted the intersection assessment is able to trace back from the final decision to the base alternatives, and clearly understand the rationale by which each optional treatment was advanced or not at any given step.

Notably in the Stage 1 *Record Sheet* it is important to register clearly and concisely under "Specific Notes" the key rationale for finding an alternative infeasible. As well, the "General Notes" area at the bottom of the *Record Sheets* is available to communicate crucial information supporting decisions made.

VIII. Technical Briefs

Appendix D is a series of what are described as *Technical Briefs*, each generally two pages in length. There are nine *Briefs* in all, one for each alternative explicitly addressed in this *Intersection Decision Guide*. The *Technical Briefs* represent neither comprehensive nor definitive content on the subject matter; their purpose is to assist the reader in understanding the intersection types' basic characteristics, as opposed to fine points. The *Briefs* do though list a handful of other sources containing fuller information.

IX. Resources

To support further understanding of the characteristics of the various forms of alternative intersections, presented here are select resources available today. They're principally synthesis and research reports, online web sites, and computer applications. Where the resource is posted to the internet, a link is provided, though recognize that an address presently active may not be at a later time, may have been reestablished elsewhere or fully severed. These are the more primary, comprehensive resources; those more or exclusively tailored to a particular design are offered in the Technical Briefs.

A. Documents

a. *Safety and Operational Impacts of Alternative Intersections*. By A. Tarko et al., JTRP/INDOT, SPR-3102, December 2008. Link: http://docs.lib.purdue.edu/jtrp/1171/ to the JTRP site from which the report may be downloaded.

b. *Alternative Intersections/Interchanges Technical Informational Report (AIIR)*. By FHWA, publication # FHWA-HRT-09-060, April 2010. Link: http://www.fhwa.dot.gov/publications/research/safety/09060/ to the site from which the report may be downloaded.

c. *Analysis and Methods of Improvement of Safety at High-Speed Rural Intersections*. By A. Tarko et al., JTRP/INDOT, SPR-3316, April 2012. Link: http://docs.lib.purdue.edu/jtrp/1495/ to the JTRP site from which the report may be downloaded.

d. *Median Intersection Design for Rural High-Speed Divided Highways*. By T.H. Maze et al., NCHRP, Report 650, 2010. Link: http://www.trb.org/main/blurbs/163452.aspx to the TRB site from which the report may be downloaded.

e. *Signalized Intersections: Informational Guide,* notably chapter 10 on "Alternative Intersection Treatments." By L. Rodegerdts et al., FHWA, publication # FHWA-HRT-04-091, August 2004. Link: http://www.fhwa.dot.gov/publications/research/safety/04091/10.cfm to site from which the report (ch. 10) may be downloaded.

f. *Roundabouts: An Informational Guide* (second edition). By L. Rodegerdts et al., NCHRP, Report 672, 2010. Link: http://www.trb.org/main/blurbs/164470.aspx to TRB site from which the report may be downloaded.

B. Web Sites

a. *Comprehensive Intersection Resource Library*. By FHWA. Link: http://safety.fhwa.dot.gov/intersection/resources/fhwasa09027/ to this efficient portal for searching by topic, keyword, title, or author an extensive library of publications by the FHWA and other parties on conventional and alternative intersections.

b. *Alternative Intersection Design*. By FHWA. Link: http://safety.fhwa.dot.gov/intersection/alter_design/ .

c. *Unconventional Arterial Intersection Design*. By University of Maryland Center for Traffic Safety and Operations and Maryland State Highway Administration. Link: http://attap.umd.edu/uaid.php to this handy web site on many forms of alternative intersections.

C. Software Applications

a. *CAP-X (Capacity Analysis for Planning of Junctions)*. By FHWA and Transportation Systems Institute (TSI) of Univ. of Central Florida, version 1.2 released November 2011. An Excel-based sketch-planning operational analysis application to assess traffic-carrying capability of eight types of innovative/alternative intersection forms. Link: http://tsi.cecs.ucf.edu/index.php/cap-x to the TSI site to register and downloaded the latest, free version.

b. *Synchro and SimTraffic* (part of *Synchro Studio* package). By Trafficware corp., version 8 the latest release. A traffic model with microsimulation and animation features, an application in widespread use at INDOT. Link: http://www.trafficware.com/products/simulationsoftware.asp .

Attachments:

Appendix A — Record Sheets for Stage 1 and Stage 2 (attached as Adobe pdf fillable form files)

Appendix B — Traffic Safety Service Calculations (Stage 2, Question #2)

Appendix C — Traffic Safety and Mobility Cost-Effectiveness Calculations (Stage 2, Question #3)

Appendix D — Technical Briefs

Appendix A — Record Sheets (see 2 attached files of Adobe pdf fillable forms)

Appendix B — Traffic Safety Service Calculations (Question 2, Stage 2)

Appendix B

Traffic Safety Service Calculations

(Stage 2, Question #2)

This is an account of the technique for computing an intersection alternative's benefits in terms of expected crash reduction vs. taking no action at the site. It's a four-step process. Each alternative design advancing into Stage 2 (Secondary, Expanded Performance Assessment) requires separate calculation.

Steps 1 to 4 directly below apply to improvements to an existing facility. At the end of Appendix B is explanation of a special procedure for an entirely new facility, that not superseding the function of an existing one.

Step 1: Determine Historic Crash Frequency and Apply Severity Weighting

Count the number of fatal, incapacitating personal injury, non-incapacitating personal injury, and property-damage crashes at the site (read: influence area of the intersection), preferably over the past 5-year period though minimum of 3 years. This is the frequency count of crashes, not of number of vehicles damaged or persons injured or killed in those crash events.

While in many cases the final outcome of Step 1 (Annual $PD_{equivalent}$) will be the same for multiple alternatives at a given site, recognize that intersection influence area, thus historic crash count frequency to be matched against the treatment, may differ from one alternative to another, and so must be taken into account. An extreme illustration: Two alternatives, one simply to add a right-turn lane on a single approach of an existing conventional signalized intersection, the other to effect wholesale intersection reconstruction in the form of a MUT design reaching several hundred feet on each leg. The influence area of those two treatments differs greatly.

Indiana's traffic crash records — queried through the web-accessible database application named ARIES, populated with Indiana crashes back to 2003 — include the severity attribute "incapacitating" (a selection under "The Injury Status Description" filter) and implies that one or more persons were seriously injured in the crash. Fatal and incapacitating (serious) injury crashes are collectively referred to as "severe" crashes (wording commonly used in among other places outside and inside the state, Indiana's Strategic Highway Safety Plan, or SHSP). Reducing risk of severe crashes is the emphasis, the primary target group for INDOT traffic safety investments. INDOT's short- and long-run performance measures are established around that key crash subset — severe crashes.

Apply adjustments (weighting factors) to account for crash severity. A unique weight applies to each of these three levels: (1) Fatal & Incapacitating Injury (F & II), (2) Non-Incapacitating Injury (NII), and (3) Property Damage (PD). F & II and NII crashes are converted to PD-equivalent crashes by factoring (multiplying) each by 58 and 6, respectively. PD crashes are not adjusted; rather their weight or multiplying factor is 1.

The variables **h, y, and z** refer to the actual number (frequency) of crashes during the study period:

- **h** = number of F & II crashes
- **y** = number of NII crashes
- **z** = number of PD crashes

The crash numbers are multiplied by the weighting factors to obtain the equivalent number of PD crashes. So, the total number of PD-equivalent, weighted crashes for the analysis period is given by the following equation:

$$PD_{equivalent} = 58h + 6y + z$$

For example, if at a location there have been 1 fatal (F), 2 incapacitating injury (II), 11 non-incapacitating injury (NII), and 49 property damage (PD) crashes in the last 5 years, the crash history is converted into equivalent PDs in this manner:

$$PD_{equivalent} = 58(1+2) + 6(11) + 49 = 289$$

The total number of PD-equivalent crashes over the 5-year analysis period is converted to an annual average:

$$AnnualPD_{equivalent} = {PD_{equivalent}}/{5}$$

Note that if you choose to use a period other than 5 years to assess past crash frequency at the intersection, alter the prior equation to account for that. Therefore, if not 5 but 4 years of past crash records are collected, divide by 4, not by 5.

Applying the case outlined earlier, of 289 $PD_{equivalent}$ crashes over the 5-year period:

$$AnnualPD_{equivalent} = {289}/{5} = 58$$

<u>Step 2: Select Crash Reduction Factor(s)</u>

Consistent with the particular manner and scale of intersection improvement at a given site, select up to three individual Crash Reduction Factors (CRFs) as the basis for generating a representative single, composite CRF. CRF is simply the expected percent reduction in crash frequency produced by a countermeasure treatment. Example: A treatment CRF of 20% represents an expected reduction in frequency of crashes by one-fifth relative to that of no safety intervention, such that if the past performance of the site shows 25 crashes per year, the treatment would be expected statistically to reduce that frequency to 20 per year.

Use as the primarily source the *Crash Modification Factors (CMF) Clearinghouse*, an online application sponsored by FHWA, at this address: http://www.cmfclearinghouse.org/. As CRF is the mode adopted by INDOT, select the CRF value listed in the 2nd column of that source, not CMF in the first. (CMF is Crash Modification Factor. CMF = 1 – [CRF/100].)

If *CMF Clearinghouse* lacks sufficient CRF information, these two alternate sources are available: FHWA's September 2008 *Desktop Reference for Crash Reduction Factors* (available as a link from http://safety.fhwa.dot.gov/tools/crf/resources/fhwasa08011/ , or go directly to the 112-page document at http://safety.fhwa.dot.gov/tools/crf/resources/fhwasa08011/fhwasa08011.pdf), and AASHTO's *Highway Safety Manual* (HSM), specifically chapter 14 of volume 3. But again, CMF is the unit in that last source, thus a simple conversion is necessary to produce CRF.

Choose a countermeasure CRF that corresponds with the crash data. For example, only pick a countermeasure and CRF specifically to address rear-end crashes if the crash data set is composed only of rear-end crashes. As mentioned earlier, select up to three CRFs; although, in many cases selection of not three but one or two CRFs will suffice, depending on the nature of intersection improvement being evaluated.

Step 3: Determine Composite Crash Reduction Factor

Multiple CRFs selected in Step 2 require calculation of an "average" or composite CRF, by this formula:

$$CRF_{composite} = 100 \times \left\{ 1 - \left[\frac{100 - CRFa}{100} \times \frac{100 - CRFb}{100} \times \frac{100 - CRFc}{100} \right] \right\}$$

CRF_a is the 1st CRF, CRF_b the 2nd CRF, and CRF_c the 3rd CRF. Again, you may apply up to three CRFs, though two or even one will be adequate in some cases.

In this example, for what are two distinct safety countermeasures at an intersection, if CRF_a is 50% and CRF_b is 20%, then $CRF_{composite}$ is calculated in this way:

$$CRF_{composite} = 100 \times \left\{ 1 - \left[\frac{100 - 50}{100} \times \frac{100 - 20}{100} \right] \right\} = 100 \times 0.60 = 60\%$$

Step 4: Determine Annual Expected Crash Reduction

Lastly, the annual PD-equivalent crashes expected to be reduced (prevented) per year — labeled CR for Crash Reduction — by the intersection treatment is a direct multiplication of Step 1's and Step 2's results:

$$CR = AnnualPD_{equivalent} \times CRF_{composite}$$

And to illustrate, continuing with the example in which the *Annual* $PD_{equivalent}$ is 58 and $CRF_{composite}$ is 60%:

$$CR = 58 \times 0.60 = 35$$

Special Procedure for New Facilities

On rare occasions the analyst may be faced with assessing safety performance for an entirely new facility, one not replacing the function of another. As an example, this could be the case for a totally new-alignment, cross-country road with at-grade intersections planned for which decisions must be made on the basic design form of each intersection. This situation does not lend itself to the procedures outlined above in steps 1 to 4 that relies in large part on known crash history at the site. Instead, assessment of an intersection alternative's traffic safety performance on entirely new facilities will be qualitative (in lieu of a numeric CR calculation), a judgment based on the following schedule:

- Outstanding safety
- Favorable safety
- Satisfactory safety
- Unsatisfactory safety

Appendix C — Traffic Safety and Mobility Cost-Effectiveness Calculations (Question 3, Stage 2)

Appendix C

Traffic Safety and Mobility Cost-Effectiveness Calculations

(Stage 2, Question #3)

Cost-effectiveness is performance of the intersection alternative in terms of the two core measures of traffic safety and mobility, as a function of project cost. Separate cost-effectiveness values are calculated for each of the two.

Step 1: Translate Project Cost to Equivalent Annual Value

While in the end the answers will be identical assuming care is taken in adjusting between "real" and "nominal" interest or discount rates, rather than in current (nominal) dollars it is generally more straightforward to carry out engineering economic analysis in constant dollars, such that for example a future-year expense is presented in real terms (i.e., today's dollars rather than pre-inflated). In that case, use a real interest/discount rate of 5 percent.

Capture the full project cost, including all phases of development, such as preliminary engineering, right-of-way, utilities, and construction. In addition, if there are significant differences among feasible alternatives in post-construction recurring operating and maintenance (O & M), those may supplement front-end project cost. An example of O & M is ongoing lighting cost, relevant given that some of the alternative intersection forms with complex geometry or raised channelization require lighting.

Irrespective of whether initial construction or post-construction, it is important to note that sound estimate of costs is critical in gauging the value of an intersection investment. Stage 2 decision-making demands appropriate time and effort in identifying significant items contributing to cost, then calculating their costs well.

Whether in the form of a near-term single cost (e.g., capital construction), or a stream post-construction recurring future costs (e.g., O & M), convert all expenses to a uniform annual cost. That may involve a single step to translate a single expense already in present value to an equivalent annual value, or a sequence of steps that first converts a future-year value to present worth before annualizing it. For an expense recurring every year at the same value (real, inflation-removed dollars) over the design life, no adjustment is necessary. Unless special circumstances exist with the intersection alternative being evaluated, default to a 20-year design life for economic analysis purposes.

Apply these equations to convert future-year investment (F) to present value (P), and present value (P) to equivalent uniform annual cost (A):

$$P = F(1+i)^{-n}$$

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

Where:
P = present cost
F = future cost
A = annual uniform cost
i = real interest rate (use 5%, or 0.05 in the formula)
n = design life in years (use 20 in most but not all cases)

Step 2: Relate Project Cost to Traffic Mobility Benefits (A-3a)

Stage 2 assesses the differences in function of traffic mobility or congestion relief among the feasible alternatives (as opposed to Stage 1, which merely screened to determine if each intersection alternative is feasible or infeasible, that is, if it works or doesn't work). Therefore, because of the nature of the competing design forms — in the various ways they redirect left-turn movements, for example — the *primary* effectiveness metric for traffic mobility in Stage 2 must be both (1) a common measure across all feasible alternatives over identical intersection influence areas, and (2) one that fairly describes comprehensive intersection performance (rather than a narrow aspect of that, or one relevant to certain design types but not to others).

In light of that, total or average travel time is the suggested *primary* measure to describe performance of feasible alternatives in Step 2; but others are acceptable, assuming they satisfy both conditions. In concert with the *primary* measure, a *supplementary* measure(s) may be used that doesn't necessarily satisfy both conditions (not common across all alternatives, or not comprehensive). And it may be fitting to assess performance through multiple *primary* and *supplementary* mobility measures, to examine function from various points of view. As well, whether *primary* or *supplementary*, it is fitting to assess performance for multiple periods, such as base year and construction year; and within that, peak and off-peak travel times of the day. Mobility statistics may be presented in absolute form, or optionally in a manner relative to a base condition. That base would typically be the no-build alternative. In either case — absolute or relative form — be consistent across all feasible alternatives in recording the performance stats.

The cost side of the cost-effectiveness equation for traffic mobility is "A", as calculated in Step 1. On the effectiveness side are the values for *primary* and *supplementary* mobility measure (e.g., 35 hours total travel time in design-year p.m. peak period for all vehicles entering the intersection study area). Again, multiple statistics on performance may populate this second part, the denominator, even multiple *primary* and multiple *supplementary* ones. The traffic mobility cost-effectiveness measure is more a relationship or ratio than a formula; that is, there is no direct calculation involved, such as dividing cost by travel time. Rather, the two parts are simply placed one over the other, to reinforce and convey information about the alternative's return on investment with respect to mobility service.

The general form of the relationship is this:

$$CE_{mobility} = \frac{A}{mobility\ statistics}$$

For instance, if the uniform annual project cost, or A, is \$100,000, and the multiple values calculated to demonstrate mobility performance are (*primary*) 35 hours total traffic stream travel time in the peak and 20 hours off-peak (*primary*), along with 2 average stops per vehicle and maximum 8-vehicle queue length in the peak (*supplementary*), the results would be presented in this or similar fashion:

$$CE_{mobility} = \frac{\text{\$100,000}}{\text{35 veh-hrs peak, 20 veh-hours off-peak; 2 stops/veh, 8 veh-queue}}$$

Step 3: Relate Project Cost to Traffic Safety Benefits (A-3b)

In the usual case, that of improvements to an existing intersection, calculate annual cost per annual property-damage equivalent crash reduced. The latter is CR, or Crash Reduction, as determined by the method outlined in Appendix B. The traffic safety cost-effectiveness (CE_{safety}) formula:

$$CE_{safety} = {}^{A}\!/_{CR}$$

For instance, for an alternative having an equivalent uniform annual cost (A) of \$100,000 and an expected annual reduction in property-damage equivalent crashes (CR = annual $PD_{equivalent}$ x $CRF_{composite}$) of 20:

$$CE_{safety} = (\$100{,}000 / 20\ crashes) = \$5{,}000 / crash$$

In the special case of an entirely new facility, simply substitute for CR in the CE_{safety} equation the selected qualitative safety performance measure of outstanding, favorable, satisfactory, or unsatisfactory. As an example, if an intersection alternative's expected traffic safety performance is judged to be outstanding, and its annualized cost is \$100,000, record the cost-effectiveness for safety in this manner:

$$CE_{safety} = \$100{,}000 / outstanding\ safety\ performance$$

Appendix D — Technical Briefs

Technical Brief: Conventional Intersection

Purpose – The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic – This tech brief will focus on a "conventional intersection" as an alternative intersection form to be considered when completing geometric improvements at an intersection. The term "conventional" is to refer to a form of intersection improvements that is typical or traditional for intersection treatment in Indiana. The picture below is an example of a conventional intersection.

Features – Conventional intersections have two essential forms – signalized and unsignalized. Unsignalized intersections have several variations in traffic control (e.g. two-way stop control and all-way stop control). This type of intersection improvement is primarily characterized by features such as left or right turn lane installation. Left turns are made directly, without displacement. Conventional treatment may also include realignment of the intersection approaches to address intersection skew or horizontal or vertical curvature modifications to address sight distance deficiencies. Access management concerns may be addressed with the installation of raised medians.

Operational Performance – Conventional intersection treatment has been shown to effectively address problems related to both intersection safety and mobility. The Highway Capacity Manual and the Highway Safety Manual both provide clear guidance indicating capacity and crash reduction benefits relating to intersection improvements with these treatments.

Application – Conventional intersection treatment may be suitable for high-speed, rural locations including large truck volumes as well as low-speed, urban locations with primarily passenger car traffic.

Consideration should be given to the conventional intersection treatment at locations that meet criteria such as:

- Intersection currently operates at or near capacity and relief is available with installation of additional turn lanes
- Crash history indicates a higher than expected crash rate involving rear ends or left turns that may be correctible by installation of turn lanes.
- Intersection sight distance is restricted due to the presence of horizontal or vertical curvature near the intersection that may be correctible by conventional intersection treatment including turn lanes or removal of sight obstruction.
- Intersection skew is deficient and a history of right angle crashes is present.
- A history of crashes at or near the intersection as a result of driveways too close to the intersection that may be correctible through access management methods.
- Intersections that may have right-of-way, utility or environmental constraints that would prohibit alternative treatments that involve large property acquisition on certain quadrants.

Resources – Numerous resources exist to assist in consideration of conventional intersection treatments. Several examples are below:

Manuals

- Highway Capacity Manual (HCM), *TRB*
- Highway Safety Manual (HSM), *AASHTO*
- Indiana Design Manual (IDM), *INDOT*

On-Line Publications

- "Signalized Intersections: Informational Guide," *FHWA*, http://www.fhwa.dot.gov/publications/research/safety/04092/index.cfm
- NCHRP Report 500 "Volume 5: A Guide for Addressing Unsignalized Intersection Collisions," *TRB,* http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_500v5.pdf
- NCHRP Report 457 "Evaluating Intersection Improvements: An Engineering Study Guide," *TRB,* http://onlinepubs.trb.org/onlinepubs/nchrp/esg/esg.pdf
- NCHRP Report 613 "Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections," *TRB,* http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_613.pdf

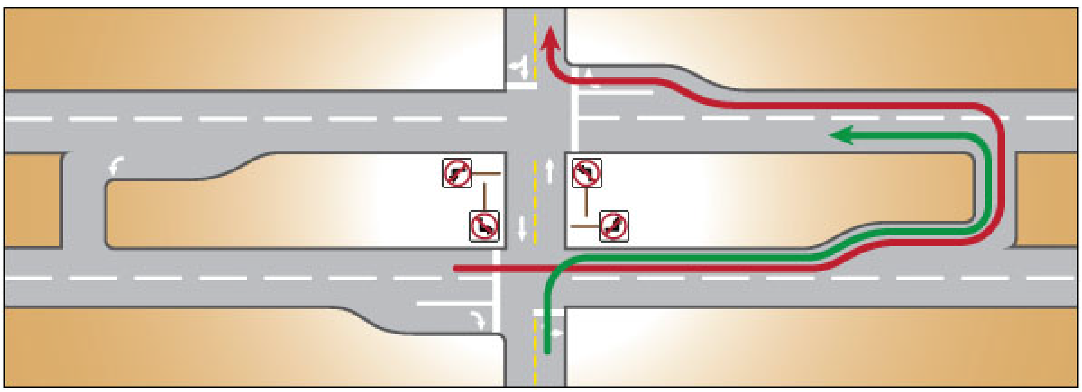
Software Tools

- Highway Capacity Software 2010 (HCS), *McTrans*
- Synchro/SimTraffic, *TrafficWare*
- Sidra Intersections, *Sidra Solutions*

Technical Brief: Median U-Turn Intersections

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on the Median U-Turn (MUT) intersection as an alternative form to consider when designing geometric improvements at an intersection. For purpose of consistent naming convention, the *Intersection Decision Guide* presents the MUT in three distinct sub-types. The first and most prevalent is the type commonly referred to as a Boulevard Left, also called Michigan Left due to the large number of this type of intersection used in that state. The RCUT (or Superstreet) and J-Turn intersections are further sub-types of the MUT family, the former generally signalized at the main intersection while that for a J-Turn is unsignalized. As well, variations exist within the sub-types, such as partial vs. full restriction of left turns at the center intersection in the case of Boulevard Left. The drawings below are of a Boulevard Left and RCUT.



Boulevard Left (Michigan Left)

RCUT

Features: Boulevard Left intersections are typically used where at least one road is a divided highway or boulevard and direct left turns from, and often on to, the divided highway are prohibited. In the variation where all left turning is restricted at the center intersection, left turning traffic from the cross street must turn right at the intersection then make a U-turn across the mainline median to complete their turn. Left turns from the mainline drive through the intersection, make a U-turn across the median, then make a right turn at the intersection to complete their turn. The Boulevard Left treatment can be implemented with or without signal control at the median U-turn openings. This type of intersection treatment favors through and right turning vehicles.

RCUT or J-Turn intersections differ from Boulevard Lefts in that mainline left turns are permitted at the intersection but all cross street traffic must make a right turn at the intersection. For the cross street, both through and left-turning traffic must make a U-turn across the mainline median. That through traffic must then make a right turn at the main intersection to complete its movement. Vehicles making left turns from the mainline make a conventional left-turn movement. In prevailing naming convention, the center intersection (where mainline lefts turn) at an RCUT is signalized, while at a J-Turn it's unsignalized. If signalized, the traffic signals at the main intersection operate as two independent two-phase signals. RCUT and J-Turn treatment favors vehicles on the major roadway relative to travel distance, but benefit traffic safety in all movements.

Operational Performance: For all three sub-types, MUT intersection forms have been shown to provide reduced delay and better progression for through traffic on the major arterial and increased capacity at the main intersection. Where the central intersection is signalized (Boulevard Left and RCUT), the signal operation is simplified, and there are fewer and more separated conflict points than at conventional intersections. The simplified traffic signal phasing allows shorter cycle lengths, thereby permitting more flexibility in traffic signal progression.

Replacement of a conventional intersection by a Boulevard Left can reduce total crash frequency by 25-50% and more. Reductions of 17%, 96%, and 61% of rear-end, angle, and side-swipe crashes have been observed. The increase in capacity typically ranges from 20-50%.

RCUT and J-Turn intersections have been shown to provide reduced delay for left turn and through traffic on the major arterial. For an RCUT, progression on the arterial is improved by the independent operation of the two traffic signals at the main intersection, and for both types of intersections there are fewer and more separated conflict points than at conventional intersections. J-Turn design is often selected as a traffic safety counter-measure on high-speed divided facilities at unsignalized intersections with 2-way stop control.

Replacement of a conventional intersection by an RCUT or J-Turn intersection offers potential for substantial safety improvement; limited data suggests a total crash reduction of 17% and higher. In cases where cross street traffic was less than 20% of the total traffic, improvements of 30% and 40% in throughput and network intersection travel time have been generated.

Application:

Boulevard Left

- Suburban or rural arterial with high through volumes with low to moderate left turn cross street volumes
- Areas where median widths are greater than 30 ft. Narrow medians will require the construction of loons, also known as 'bump outs', at the median U-turns to accommodate trucks.

RCUT

- Suburban or rural arterials with low to medium side-street through volumes and heavy left turn volumes from the major road.
- The minor road total volume to total intersection volume ratio is typically less than or equal to 0.20.
- Areas where median widths are greater than 30 ft. Narrow medians will require the construction of loons, also known as 'bump outs', at the median U-turns to accommodate trucks.

J-Turn

- Rural divided arterials with low to medium side-street through volumes and heavy left turn volumes from the major road where traffic signals are not warranted for the mainline left turns.
- The minor road total volume to total intersection volume ratio is typically less than or equal to 0.20.
- Areas where median widths are greater than 40 ft. Narrow medians will require the construction of loons, also known as 'bump outs', at the median U-turns to accommodate trucks.

Resources:

- http://www.fhwa.dot.gov/publications/research/safety/07033/
  - Synthesis of the Median U-Turn Intersection Treatment, TechBrief, FHWA-HRT-07-033
- http://docs.lib.purdue.edu/do/search/?q=displaced%20left&fq=virtual_ancestor_link%3Ahttp%3A%2F%2Fdocs.lib.purdue.edu%2Fjtrp
  - Safety and Operational Impacts of Alternative Intersections, FHWA/IN/JTRP-2008/23 (2008)
- http://www.fhwa.dot.gov/publications/research/safety/09059/index.cfm
  - Restricted Crossing U-Turn Intersection, TechBrief, FHWA-HRT-09-059

Other Information: Issues that may cause these three MUT sub-types to be dismissed as viable alternatives are:

- Narrow or nonexistent median.
- Insufficient spacing between intersections to accommodate the median U-turns.
- Unfavorable mainline vs. crossroad distribution of traffic demand.

Technical Brief: Roundabout Intersection

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the Decision Guide. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on a roundabout as an alternative intersection treatment. A roundabout is a form of circular intersection in which traffic travels counterclockwise around a central island and in which the entering traffic must yield to circulating traffic. The picture below is an example of a multi-lane roundabout intersection with a right turn by-pass lane in the northeast quadrant.

Features: The key features of a roundabout are:

- Channelized approaches;
- Yield control on all entries;
- Counterclockwise circulation of all vehicles around the central island; and
- Appropriate geometric curvature to encourage slow travel speeds through the intersection.

There are three main categories of roundabouts.

- Mini roundabouts are small roundabouts with a fully traversable central island. Commonly used in low-speed urban environments.
- Single-lane roundabouts have a single-lane entry at all legs and one circulatory lane.
- Multilane roundabouts have at least one entry with two or more lanes.

Operational Performance: Vehicles travel in the same direction, eliminating the right-angle and left-turn conflicts associated with traditional intersections. The geometric features of a roundabout result in speed control, also contributing to increased safety and a reduced number of crashes.

Application: Consideration should be given to the roundabout treatment at intersections that meet criteria such as:

- A large number of crashes.
- A large number of U-turn movements.
- Balanced flow at all approaches.
- Limited right of way for lane widening between intersections.
- Desired speed reduction or traffic calming.
- Transition between two different land uses or speed zones.
- More than four approaches to the intersection.

Resources:

- *Roundabouts: An Informational Guide (Second Edition)*, NCHRP Report 672, 2010
- *Roundabouts Technical Summary*, FHWA-SA-10-006, 2010
- *Best Practices for Roundabouts on State Highways*, Pending Report from the Indiana JTRP Research Program, SPR-3530

Technical Brief: Displaced Left Turn Intersections

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the Decision Guide. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on the Displaced Left Turn (DLT) as an alternative intersection treatment. This type of intersection is also known as a Crossover Displaced Left Turn (XDL) and a Continuous Flow Intersection (CFI).

Features: DLT intersections have the left turning movement relocated to the far side of the opposing roadway upstream of the primary intersection. Left turning vehicles travel on a roadway parallel to opposing traffic and execute a left turn simultaneously with through traffic at the primary intersection, eliminating the left turn phase for the approach at the primary intersection. Signals are present at the primary intersection and at the left turn crossover locations. DLT intersections may be either partial or full. Partial DLT intersections have left turn crossovers on the major roadway; left turns on the minor roadway take place at the primary intersection. Full DLT intersections have left turn crossovers on all four approaches. A partial DLT has three junctions signalized; a full DLT has five junctions signalized.

Partial DLT Intersection, Fenton, Missouri

Operational Performance: The primary reason to consider a DLT is to improve traffic mobility, particularly at an intersection with high left turning and through volumes that are balanced through the day. Replacement of a conventional intersection with a full DLT can produce a 50-85% reduction in intersection delay and a 10-25% increase in intersection throughput. A partial DLT can produce a 30-40% reduction in intersection delay and a 10-20% increase in intersection throughput.
Safety data is limited; however a partial and full DLT intersection has 28 and 30 conflict points as opposed to the 32 with a conventional intersection. This reduction in conflict points may improve safety performance of the intersection.

Application:

- The cross product of left turning and through vehicles is greater than 150,000 on two opposing approaches
    - Heavy congestion with many signal phase failures
    - Urban or suburban arterial with balanced flow

- Left turning volume is greater than 250 vehicles per hour per lane and opposing through volume is greater than 500 vehicles per hour per lane
    - Left turn queues spill beyond the left turn storage bays

Resources:

- http://www.fhwa.dot.gov/publications/research/safety/09060/
    - Alternative Intersections/Interchanges Informational Report (AIIR), FHWA-HRT-09-060 (April 2010)
- http://docs.lib.purdue.edu/do/search/?q=displaced%20left&fq=virtual_ancestor_link%3Ahttp%3A%2F%2Fdocs.lib.purdue.edu%2Fjtrp
    - Safety and Operational Impacts of Alternative Intersections, FHWA/IN/JTRP-2008/23 (2008)
- http://www.fhwa.dot.gov/publications/research/safety/09055/index.cfm
    - Displaced Left Turn Intersection, TechBrief, FHWA-HRT-09-055 (2009)

Other Information: The DLT intersection has a larger footprint than a conventional intersection. Issues that may cause the DLT to be dismissed as a viable alternative are:

- Excessive right of way and utility relocation costs
- Impacts to protected environmental resources such as historic properties or wetlands
- Restricted access to parcels near the primary intersection
    - Frontage roads can be constructed, but add to the cost
- Heavy pedestrian volumes
    - If pedestrian crossing times cause long vehicular delays, multiple stage crossings may be needed by providing pedestrian refuges in a median between opposing through lanes
- Insufficient spacing between intersections to accommodate a DLT
- Heavy demand for U-turns at the primary intersection

Technical Brief: Jughandle Intersection

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on a jughandle intersection or New Jersey jughandle intersections (NJJIs) as an alternative intersection treatment. The NJDOT *Roadway Design Manual* defines a jughandle as "an at grade ramp provided at or between intersections to permit motorists to make indirect left turns and/or U-turns".

Features: A jughandle intersection typically removes the arterial lefts from a congested signalized intersection in order to reduce the number of signal phases. The arterial lefts are then made at stop-controlled intersections on the side street, while the cross-street lefts remain in the signalized intersection. The arterial lefts must exit the roadway from the right lane either upstream (near-side) or downstream (far-side) of the intersection. An example of both options is depicted to the right. Configurations of jughandle intersections vary as site conditions dictate which exit type can be accommodated.

Operational Performance: The primary reason to consider a jughandle is to improve traffic mobility. An FHWA study[2] modeled three different exit configuration cases with each having three different geometric scenarios. In general for near saturated traffic conditions, you can expect a 15-40% reduction in average intersection delay in comparison to conventional intersections and a 20-40% increase in intersection capacity. However in under saturated conditions, delays are comparable and travel time is slightly longer for jughandles. Pedestrian movements would be handled similarly to a conventional signalized intersection and pedestrian delay will decrease as the cycle length decreases. However, some pedestrian movements will be required to cross an additional roadway. Limited crash data is available, but one study showed 26% fewer fatal plus injury crashes per MEV. The main disadvantages include the potential driver expectancy violations for left turning drivers and the additional R/W and cost needed to build the jughandle.

Application: The following are various conditions that are a good fit for a jughandle intersection.

- Arterial with heavy through volumes and moderate left turn volumes with low to moderate cross street volumes when a conventional signalized intersection is at or near capacity
- An intersection with a right-angle crash problem associated with the left turn movements from the mainline.
- As a corridor treatment in order to keep R/W tight outside of intersection areas however R/W at the intersection it will be much greater.
- A single large congested intersection in the middle of coordinated signal system with good progression otherwise

Resources:

1. Section 6.8 of the New Jersey department of Transportation Roadway Design Manual http://www.state.nj.us/transportation/eng/documents/RDM/sec6.shtm
2. Traffic Performance of Three Typical Designs of New Jersey Jughandle Intersections, TechBrief, FHWA-HRT-07-032 (2007) http://www.fhwa.dot.gov/publications/research/safety/07032/index.cfm
3. http://attap.umd.edu/UAID.php?UAIDType=17&Submit=Submit&iFeature=1

Technical Brief: Offset T Intersection

Typical Offset T Intersection

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: An Offset T intersection converts a conventional intersection into two T intersections offset by some distance along the major street.

Features: The lateral separation between the two T intersections causes through movements from the minor streets to be converted to right turn movements followed by left turn movements at the other offset minor leg. Or through movements from the minor streets are converted to left turn movements followed by right turn movements at the other offset minor leg when the intersection skew is reversed. This design is effective for two lane and multi-lane major streets. It is most effective when the major street is multi-lane and the intersection is skewed.

Operational Performance:

Safety: This design has a total of 22 conflict points compared to 32 at a conventional intersection. It reduces traffic congestion in the median area, improving visibility. It reduces opportunity for angle collisions, but increases opportunity for a less severe type of collision associated with merging and weaving.

Mobility: This design could introduce a slight delay to the minor through movement relative to the offset distance; however, for safety purposes the offset distance should be maximized.

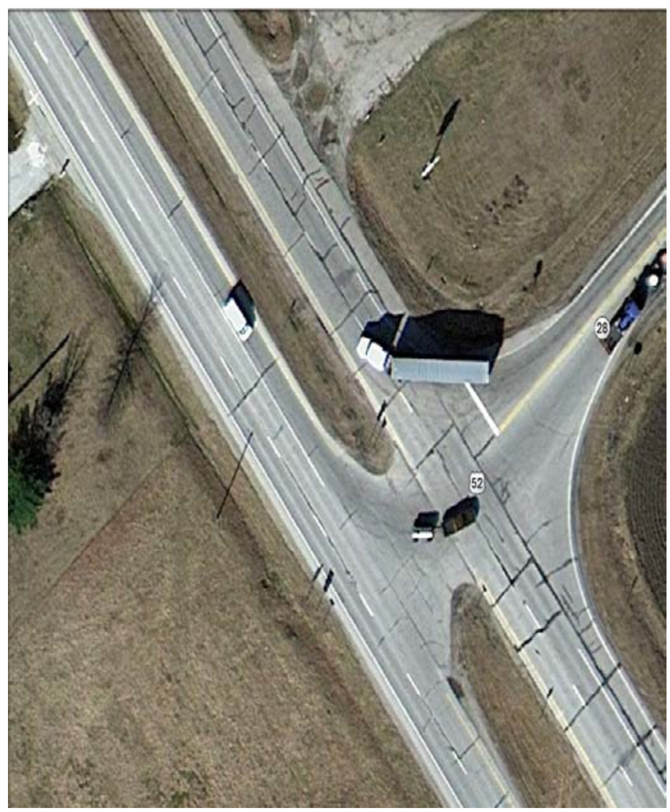
Application: This design is effective when both the major and minor street through volumes are low. It can be effective when a skewed intersection has a high volume of turning traffic with low through volumes.

Resources:

1. Chapter 6.3.4 Alternative Intersections/Interchanges Informational Report (AIIR), FHWA-HRT-09-060 (April 2010) http://www.fhwa.dot.gov/publications/research/safety/09060/
2. http://safety.fhwa.dot.gov/intersection/resources/intsafestratbro/ub14_4leg_intersections.pdf

Other Information: The lateral offset distance between the two T intersections is dictated by the through and left turn volumes present at the intersections and sight distance considerations. Speed limit is another contributing factor.

Typical legs of the offset T intersection at US52 and SR28, shown above.



Technical Brief: Continuous Green T Intersection

Also known as a Florida T intersection.

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: A Continuous Green T Intersection is a signalized T intersection with a major street free flow through movement (the free flow movement has a continuous green indication if heads are used).

Features: The intersection is always a signalized T (three legged intersection). This design is effective for two lane and multi-lane major streets. The major street left turn movement and the minor street left turn movement must be separated from the major street free flow through movement. Splitter islands are one technique that effectively provides the needed separation. The free flow major street movement may or may not have signal heads, depending on the presence of pedestrian signal features. Pedestrians crossing the major street could require pedestrian signals and will cause the free flow movement to be temporarily interrupted.

Operational Performance:

Safety: This design reduces certain types of collisions associated with traffic signals (i.e. collisions associated with red light running and rear end collisions), but increases opportunity for a less severe type of collision associated with merging.

Mobility: This design introduces a free flow major street through movement which could have a significant impact on intersection delay during those periods when this leg has the highest volume of traffic at the intersection. By eliminating a major street phase from the signal operation, the minor street should benefit from a decrease in delay.

Application: This design only works for a signalized T intersection (three legged). It is most effective when the free flow major street movement is the highest volume traffic movement in the intersection and when the minor street has a high volume left turn movement.

Resources:

1. Chapter 6.3.5 Alternative Intersections/Interchanges Informational Report (AIIR), FHWA-HRT-09-060 (April 2010) http://www.fhwa.dot.gov/publications/research/safety/09060/
2. http://attap.umd.edu/UAID.php?UAIDType=17&Submit=Submit&iFeature=1
3. http://safety.fhwa.dot.gov/intersection/resources/casestudies/fhwasa09016/fhwasa09016.pdf

Other Information: This design converts a traffic signal from a four phase operation to a three phase operation. When pedestrians are present, the intersection can be designed to operate as a typical four phase with the leg that normally free flows being stopped for the pedestrian movement.

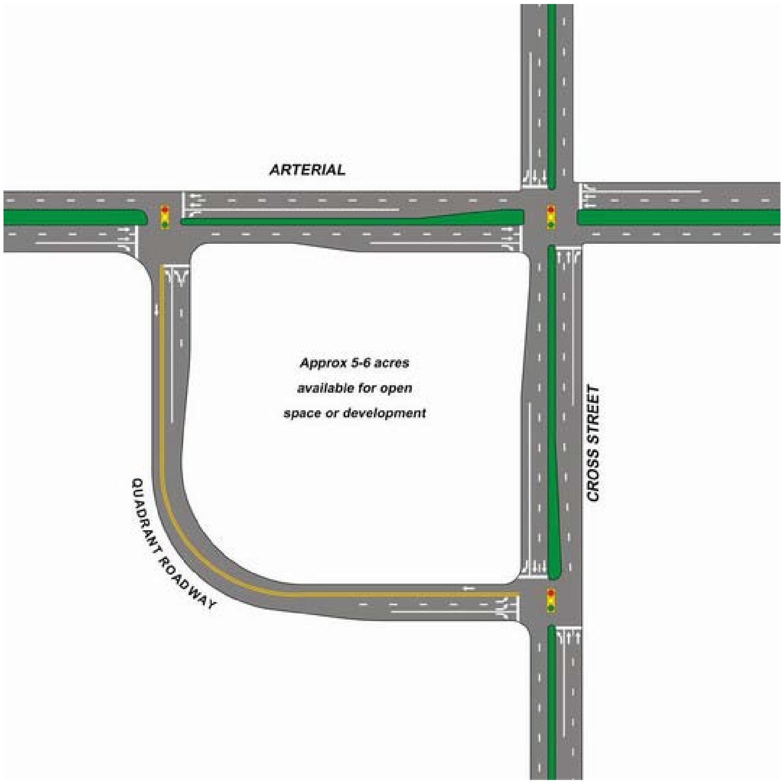
This view displays additional details for typical auxiliary lanes and merge tapers associated with a Continuous Green T Intersection.

<u>Technical Brief: Quadrant Roadway Intersection</u>

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on a quadrant roadway intersection (QRI) as an alternative intersection treatment.

Features: Jonathon Reid was the first to publish an analysis of a QRI in 2000. Reid's design, depicted to the right, removes all left turn movements from the main intersection via a connecting roadway in one quadrant of the intersection. This results in a two-phase main intersection while the secondary intersections require three phases. All three are fully coordinated. At least one QRI has been constructed in Fairfield OH and is pictured on the next page. Variations to Reid's idea can also be found[3] and include intersections utilizing quadrant roadways with or without signals, and varying left turn restrictions.



Operational Performance: The primary reason to consider a QRI is to improve traffic mobility. Several studies have simulated the design with varying geometry and traffic conditions. In general you can expect a 15-200% reduction in overall travel time and an increased throughput of 5-20% when compared to a conventional intersection. It produces the greatest benefit at routinely congested intersections where the benefited through movements can offset the slightly longer travel time for left turns. Pedestrian movements would be handled similarly to a conventional signalized intersection and pedestrian delay will decrease as the cycle length decreases. However, some pedestrian movements will be required to cross an additional roadway. No substantive crash data is available for this design, but the reduction in total vehicle-vehicle conflict points from 32 to 28 may serve as an indicator of improved safety. The main disadvantages include the potential driver expectancy violations for left turning drivers and the additional R/W and cost needed to build the quadrant roadway.

Application: The following are various conditions that are a good fit for a QRI

- Arterial with heavy through volumes and moderate left turn volumes when a conventional signalized intersection is at or near capacity
- R/W is available in a developing area or an existing street system could serve as the quadrant roadway
- A single large congested intersection in the middle of coordinated signal system with good progression otherwise
- At skewed intersections as the connecting roadway becomes shorter and it can eliminate the turns greater than 90 degrees.
- As a temporary measure when there are plans for a grade separated interchange.

Resources:

1. Alternative Intersections/Interchanges Informational Report (AIIR), FHWA-HRT-09-060 (April 2010) http://www.fhwa.dot.gov/publications/research/safety/09060/
2. Quadrant Roadway Intersection, TechBrief, FHWA-HRT-09-058 (October 2009) http://www.fhwa.dot.gov/publications/research/safety/09058/09058.pdf
3. http://www.quadrantintersections.org/
4. http://attap.umd.edu/UAID.php?UAIDType=17&Submit=Submit&iFeature=1

A QRI in Fairfield, OH

Technical Brief: Grade Separation

Purpose: The Technical Working Group has prepared a summary account tailored to each of the nine alternative intersection forms identified in the *Decision Guide*. The purpose of this Technical Brief is to serve as a quick, condensed reference, to describe basic geometric and operational characteristics of the design and to direct the reader to other resources that expand on the subject matter.

Topic: This technical brief will focus on grade separating an existing intersection without including interchange characteristics.

Features: A grade separation basically eliminates the at-grade intersection of two existing roadways. This is accommodated by elevating or lowering the profile of one of the roadways therefore eliminating the interaction of traffic between the roadways. Typically the profile of the roadway with the lowest functional classification would be adjusted as the design criteria would be less restrictive. Turning movements would be relocated to the adjacent roadway network.

Operational Performance: A grade separation can be utilized to improve both the traffic mobility and safety operation of an intersection. It would improve the through mobility on both roadways to a free flow condition. However, it would also negatively impact the accessibility of the area. Safety would also be addressed as all intersection related crashes would be eliminated. However, the R/W and construction costs associated with constructing a grade separation could be exorbitant.

Application: The following are various conditions that are a good fit for a grade separation

- An intersection with an unusually high crash rate where other safety countermeasures have been unsuccessful and there is an adjacent roadway network that can accommodate the relocated turning movements
- A rural intersection with low turning movements
- When converting an existing highway from a limited access facility to freeway facility
- A badly skewed at grade intersection where horizontal realignment is not viable.