An Integrated Program for Preliminary Evaluation of Unconventional Intersections

Xiaorong Lai <xrlai@wam.umd.edu>

Department of Civil and Environmental Engineering,
University of Maryland at College Park
College Park, MD, 20742, USA
Phone: (301) 405-2638

Jonathan D. Reid <Reid@pbworld.com>

Parsons Brinckerhoff Quade & Douglas, Inc.
401 South Tryon Street, Suite 2550
Charlotte, NC 28202
Phone: 704.342-5403
Fax: 704.342-8472

Saed Rahwanji <SRahwanji@sha.state.md.us>

Maryland State Highway Administration
7491 Connelley Drive, Hanover, MD 21076

Gang-Len Chang <gang@glue.umd.edu>

Department of Civil and Environmental Engineering
University of Maryland at College Park
College Park, MD, 20742, USA
Phone: (301) 405-1953

[Abstract]

This paper presents the framework and major functions of an integrated program for unconventional arterial intersection design. The proposed program features its integration of a build-in knowledge base and the interactive analysis tools, which aims to provide a better understanding and convenient evaluation of all unconventional intersection types. Various factors, related to traffic analysis, safety concerns, cost estimation, and pedestrian impacts can be included in the evaluation framework through user-friendly interfaces. A case study is presented to show the applicability of the proposed system with respect to the selection and design of unconventional intersections under user-specified scenarios.

1. Introduction

This paper presents an integrated program for Unconventional Arterial Intersection Design (UAID program). As a collaborative research effort among University of Maryland, Maryland State Highway Administration, and Parsons Brinckerhoff Inc., the proposed program aims to help traffic engineers and planning researchers to consider the unconventional designs as a feasible solution for relieving arterial congestion, and to select proper unconventional design schemes based on actual traffic patterns.

Being an effective alternative to improve arterial traffic conditions, unconventional intersection concept generally attempts to increase arterial intersection capacity by reducing the impacts of the turning movements at major intersections through various design, operation and management strategies [1]. In the literature, some specific unconventional design schemes have been analyzed and compared in carefully designed simulation experiments [2-9]. Yet most of these studies have focused on traffic operation performance, which may not be sufficient for practitioners who need to consider other issues, such as safety, driver's expectations, pedestrian's safety and mobility, right-of-way requirements, and construction costs.

To tackle this issue, the proposed UAID program has integrated two major functional modules together. The first is a build-in knowledge base with various design/ management principles, while the second contains interactive analysis tools to provide various evaluations related to traffic analysis, safety concerns, cost estimation and pedestrian impacts under user-specified scenarios. The current version of the system can analyze a total of 22 unconventional intersection types, including both at grade designs where all the movements are made at the same level and grade-separated designs where a vertical delimitation presents among the turning movements.

This paper is organized as follows. Section 2 describes the system framework of the UAID program. Each module of the UAID program is elaborated in Section 3. A case study for the applicability of the UAID program is illustrated in Section 4, followed by conclusions in Section 5.

2. System Framework

Figure 1 presents the framework of the proposed UAID program.

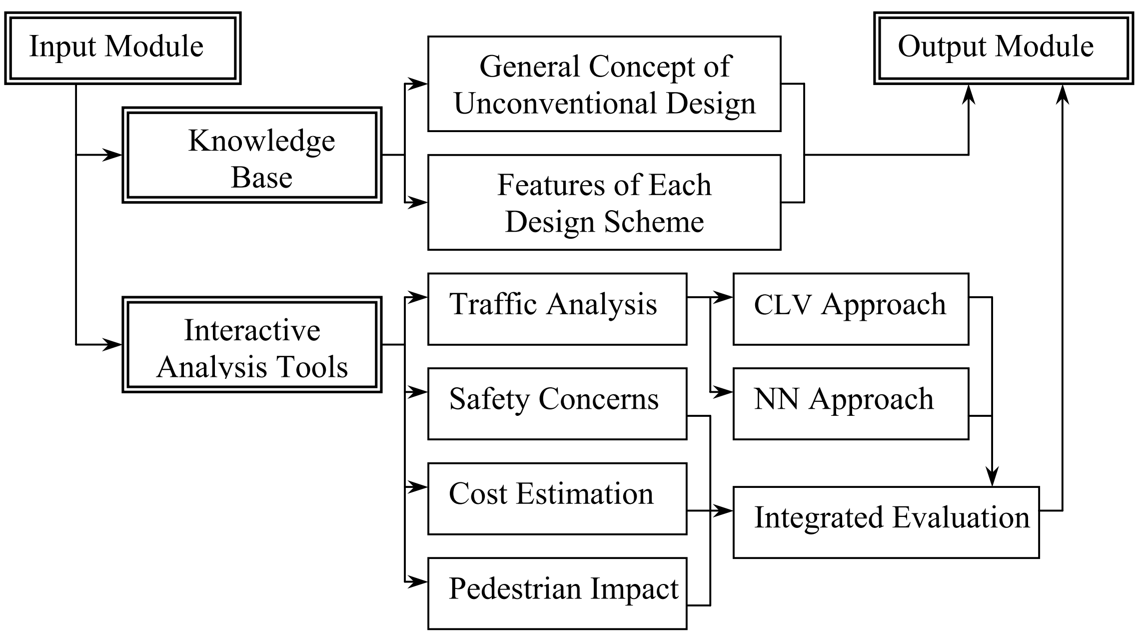


Figure 1. Framework of the UAID program

The current UAID system mainly includes the following four functional modules:

- Input module: This module obtains two types of input data from system users. The first type is the search criteria for withdrawing required information from the knowledge base, while the second type is to define a specific scenario such as volumes at each approach and turning proportions for later evaluation.
- Knowledge base: This database module stores extensive research results in the literature related to unconventional intersection design, including both general concept or design principles, and features of each intersection.
- Interactive analysis tools: This module functions to evaluate the selected unconventional intersection design schemes under given scenarios. Various design and management issues can be taken into consideration in the evaluation process, including traffic analysis, safety concerns, cost estimation and pedestrian impact.
- Output module: This module aims to provide the text or map based information in the knowledge base according to users' search criteria and to present detailed evaluation outcomes from the interactive analysis tools

Each of the above functional modules will be elaborated in the following section.

3. System Modules

Input Module

The input module of the UAID system accepts two types of input from system users. To directly acquire information from the knowledge base, users can select the following search criteria:

- Different topics of the general unconventional intersection design concept
- Different types of unconventional intersection designs
- Different resources for a selected unconventional intersection type.

The second type of inputs is required when using Interactive Analysis Tools to evaluate a selected unconventional intersection type under specified scenarios, which are defined by

- Type of evaluation, namely operations aimed evaluation, safety aimed evaluation or area context aimed evaluation;
- Unconventional Intersection types required to be analyzed;
- Intersection characteristics, including number of approaches, number of arterial / cross street through lanes, number of protective signal phases and cycle length;
- Volume information, namely through and turning volumes at each approach;
- Right Of Way information;
- Area Type.

A snapshot of the input module is given in Figure 2.

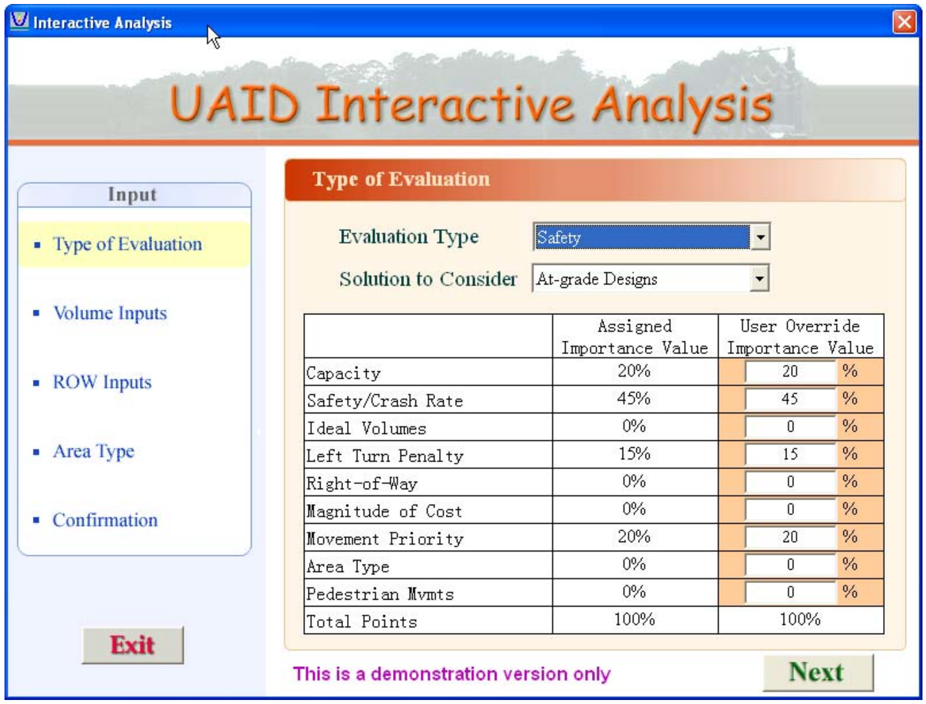


Figure 2. A snapshot of the input module

Knowledge base module

This database module contains both the overall concepts of unconventional intersection design and the available information for each specific design type. The purpose of the knowledge base module is to provide system users a better understanding of unconventional intersection concepts and principles, and to act as a manual for going through the features and existing knowledge of each UAID design.

The general concepts of unconventional intersection designs in the knowledge base include the following subjects:

- Importance of arterials and intersection innovation
- Comparison of unconventional and conventional design
- Unconventional design principles

- Implementation issues
- Comparison of at-grade and grade separated designs

A snapshot of the overall concepts of UAID design in the knowledge base is given in Figure 3.

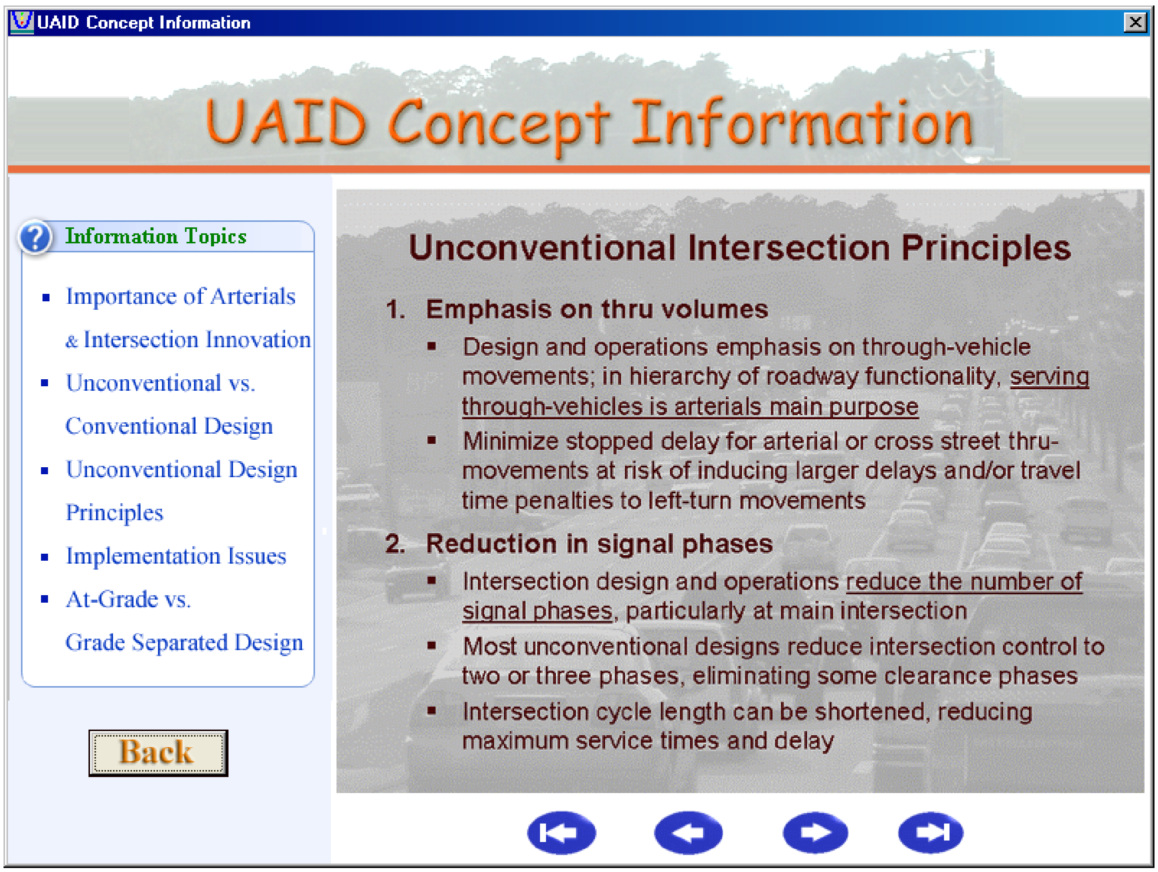


Figure 3. A snapshot of general concepts of UAID designs

The knowledge base also covers information for all the 22 types of unconventional intersection designs currently in use, which is listed in Table 1. Among that, there are a total of 11 types of at-grade designs and 11 types of grade-separated designs.

Table 1. Types of Unconventional Intersections Covered in the Knowledge Base

At-grade designs	Grade-separated designs
Median U-Turn	Echelon
Jughandle	Center Turn Overpass
Superstreet	Single Point Urban Interchange
Paired Intersections	Single Roundabout Interchange
Continuous Flow	Double Roundabout Interchange
Continuous Green-T	Michigan Urban Diamond
Modern Roundabout	Contraflow Left Interchange
Quadrant Roadway	Single Loop Interchange
Bowtie	Tight Diamond Interchange
Double Wide	Windmill Interchange
Split Intersection	Diverging Diamond Interchange

After users choose the target type of UAID, the following eight aspects of information can be acquired from the knowledge base:

- Design Description: which uses a brief description and an illustrative figure to clearly and accurately describe how an unconventional intersection operates.
- Visual Animation: which is created with the animation tool embedded in the simulation software VISSIM to give users a visualized impression on the features of an unconventional design type
- Image Library: which provides images about planning, geometric design, signal and signs setting related to each unconventional design type.
- Evolution of Design: which introduces the history of a design type.
- Design and Operations: which itemize the advantages and disadvantages of an unconventional design
- Studies and Research: which summarizes the related studies in the literature.
- Lessons Learned: which reports the experiences and lessons of using an unconventional design by various transportation agencies.

- Locations Found: which lists the locations where a specific unconventional design has been applied.

Some snapshots of several aspects of information of each UAID design in the knowledge base are given in Figure 4_1, 4_2, and 4_3.

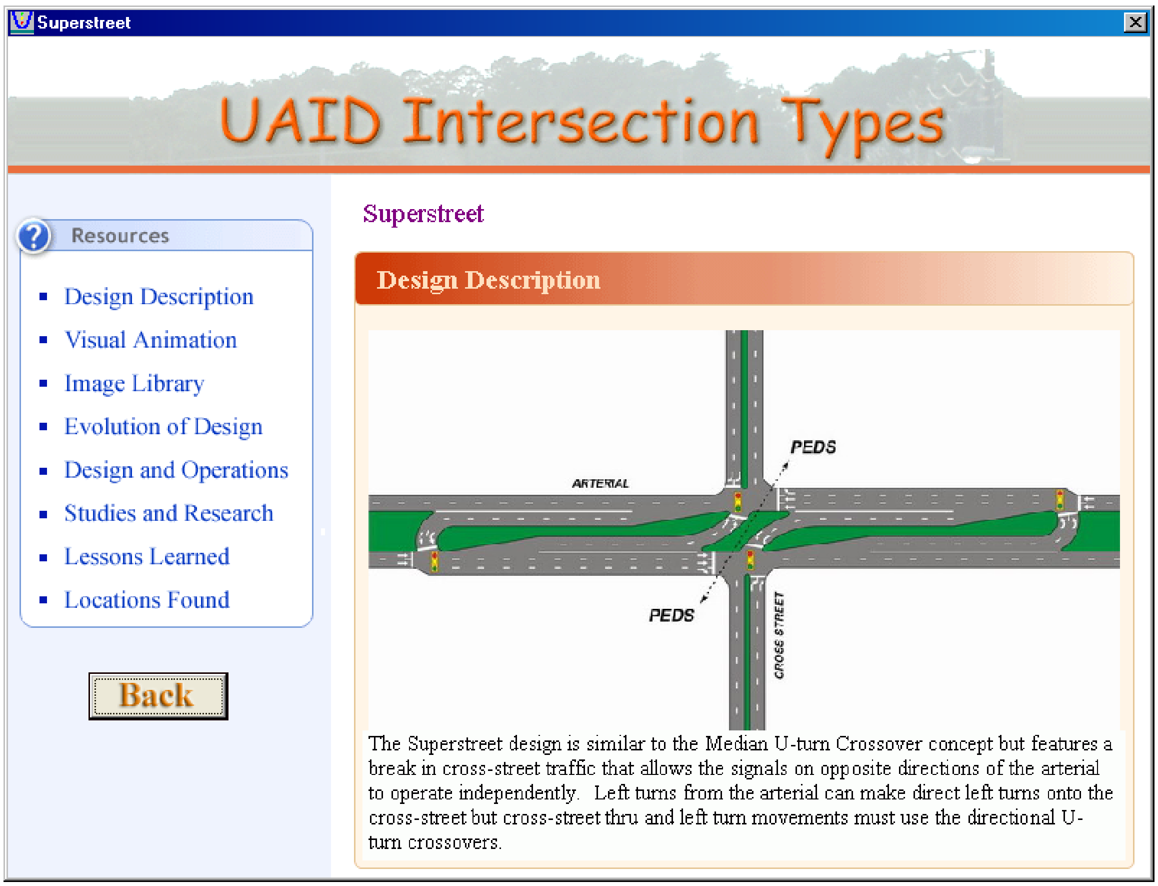


Figure 4_1. A snapshot of the Design Description of Superstreet

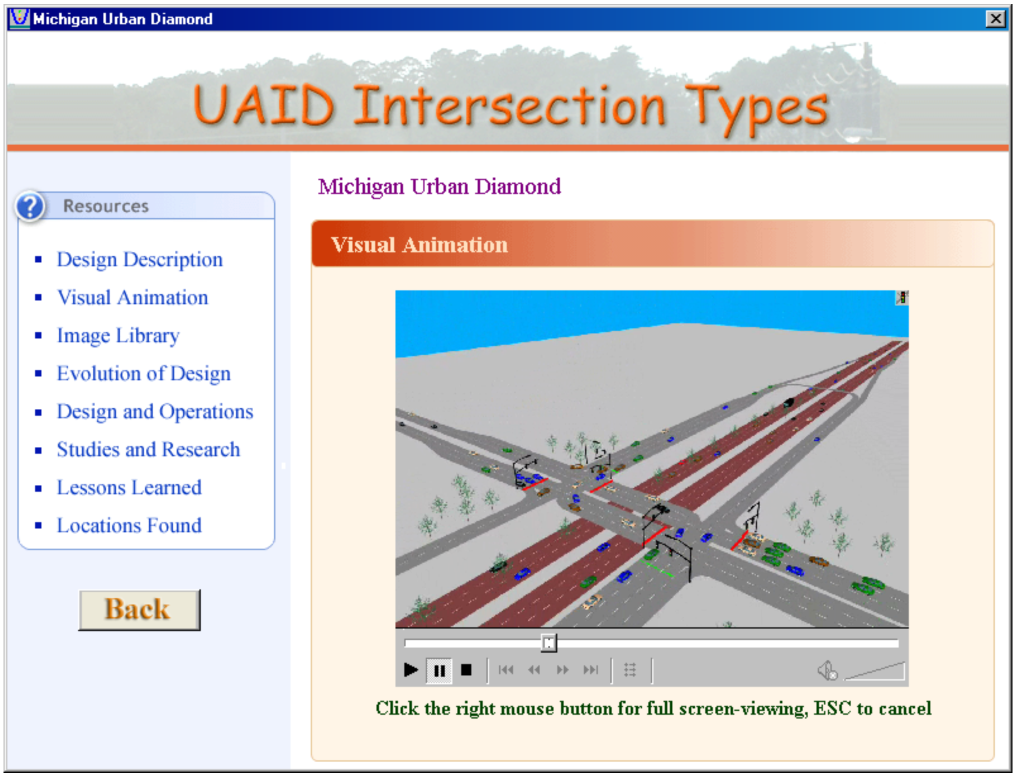


Figure 4_2. A snapshot of the Visual Animation of Michigan Urban Diamond

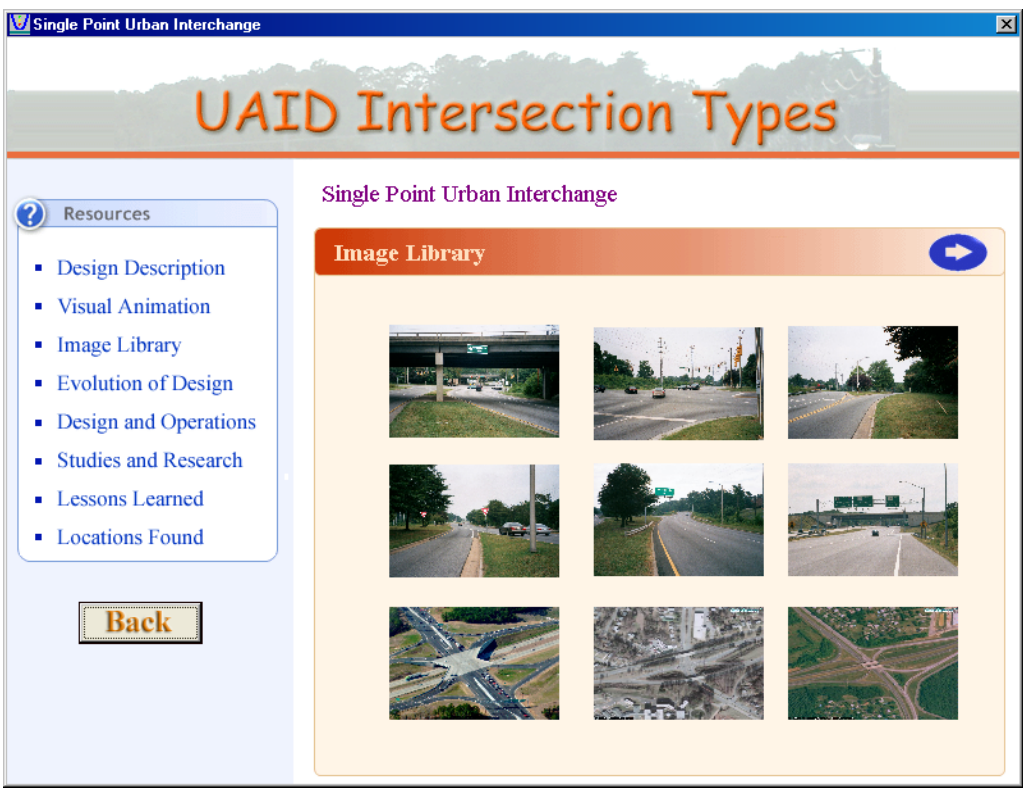


Figure 4_3. A snapshot of the Image Library of Single Point Urban Interchange

Interactive Analysis Tools

Two approaches are available for the module of interactive analysis tools in the current version of the UAID program. One is the CLV based approach, while the other is the Neural Network based approach. The rest of this section will detail the procedures of these two approaches in evaluating the performance of an unconventional intersection design type.

Approach 1: The CLV Based Approach:

This methodology aims to perform a systematical evaluation from various aspects as listed in below:

- *Capacity*. This key idea in this part of analysis is to measure the ratio of Critical Lane Volume and Capacity, which is performed through the following procedures. Firstly, an unconventional intersection is decomposed into several conventional intersections. Then the capacity and Critical Lane Volume is calculated for each sub-intersection based on relations from Highway Capacity Manual, while the worst CLV/C value will be used as the score for this evaluation index. Due to the reduction of signal phases and some increased clearance time, the capacity of UAID designs is different from the capacity of conventional intersections (SHA guidelines use 1600 vph)). The UAID capacity can be calculated with Equation 1.

$$\text{Capacity} = S - \left[\left(\frac{3600}{C} \right) \cdot \left(P \cdot (L + ct) \right) \cdot \left(\frac{S}{3600} \right) \right] \quad \text{(vph)} \tag{1}$$

Where S =ideal saturation flow (1900vph in HCM),

C=cycle length,

P=number of phases,

ct =additional clearance (sec),

L=lost time

- *Crash Data*. Here the crash rate *E* for each decomposed intersection is computed from the regression relation built by Hauer [10], etc, which is shown in Equation 2. Here *F1* is the through volume, *F2* is the left-turn volume, while *b0*, *b1* and *b2* are regression parameters. Then the sum of the crash rates over all sub-intersections are used as the safety index;

$$E = b0 * F1^{b1} * F2^{b2} \qquad (2)$$

- *Ideal Volume Conditions*. This index is used to capture the absolute value of the difference between the actual traffic volume pattern and the ideal traffic volume pattern specific to each unconventional design, which are predefined based on experience;
- *Left Turn Penalty*. This part of analysis assigns a penalty to the target design type based on the magnitude of the left-turn volumes, which aims to consider the extra distance left-turns volumes have to travel or the additional stops they have to make when traversing the unconventional intersection, as shown in Equation 3;

$$\text{Left Turn Penalty} = \Sigma\, [(\text{Art} + \text{Cross})\, V_{LT} \times D + (S-1)] \;/\; 1{,}000{,}000 \qquad (3)$$

Where V_{LT}: Left turn volume,

Art: Arterial

Cross: Cross Street

D: additional left turning distance in FT,

S: maximum potential number of stops

- *Right of way*. This index is computed from Equation 4, which considers various geometric parameters, including the number of through lanes *TL*, the number of turning lanes *TuL*, shoulder width *SW* and median width *MW*;

$$\mathrm{ROW} = \mathrm{TL} \cdot 24 + \mathrm{TuL} \cdot 12 + \mathrm{MW} + \mathrm{SW} \cdot 2 \quad [\mathrm{ft}] \tag{4}$$

- *Magnitude of costs*. The items considered for major design expense are the pavement area, grade-separation structure (if necessary), drainage and signalization. Note that there are no actual costs computed, just a comparison to basic conventional unit costs; Some default magnitude of Costs in UAID program are list in Table 2;

Table 2. Magnitude of Cost for UAID Designs

At-grade Design	Magnitude of Costs	Grade-separated Design	Magnitude of Costs
Conventional	1.0	Single Point Urban Interchange	6.0
Median U-Turn Crossover	1.3	Echelon Interchange	5.5
Jughandle	1.3	Center Turn Overpass	3.5
Continuous Flow Intersection	1.2	Michigan Urban Diamond	6.5
Superstreet	1.4	Single Roundabout Interchange	4.0
Two Lane Roundabout	1.2	Double Roundabout Interchange	4.5
Split Intersection	1.6	Contraflow Left Interchange	4.0
Quadrant Roadway	1.8	Tight Diamond Interchange	5.0
Bowtie Intersection	1.4	Single Loop Interchange	4.0
Paired Intersections	1.8	Windmill Interchange	4.0
Double wide Intersection	1.6		

- *Priority movements*. This index is concerned with the performance of the intersection, i.e., whether the traffic flows can be balanced, arterial favored or highly unbalanced;
  - UAID assigned optimal priority condition (Arterial/Cross Street volume splits), based on knowledge of operations and analysis

- Balanced flows (near 50/50 split)
- Somewhat favor Arterial (60/40 to 70/30 split)
- Heavily favor Arterial (greater than 70/30 split)

- Actual split calculated from input volumes;
- Scoring: Point assigned for absolute difference between actual and ideal splits.

- *Area type*. This index refers to the difference between the actual area type and the ideal area conditions predetermined for each unconventional type, such as the signal spacing, undeveloped quadrants, and type of development frontage (urban, suburban, or rural);
- *Pedestrians*. This index relates to the number of crossings, crossing distance, the number of stages required for crossing and crossing conflict points.

$$\begin{aligned}\text{Points} = &\sum_{\text{Arterial}}(\text{X}, \text{Stage}, \text{FFRT}, \text{UCLT}, \text{UCRT}) + \\ &+ \sum_{\text{CrossStreet}}(\text{X}, \text{Stage}, \text{FFRT}, \text{UCLT}, \text{UCRT}) - 4\end{aligned} \tag{6}$$

Where: X: Volume of pedestrians, valued from 0 to 3

Stages: number of roadways (stages) required for crossing;

FFRT: Distance of crossings, valued from 0 to 3

UCLT: number of uncontrolled left turns;

UCRT: number of uncontrolled right turns

After an index is calculated for each aspect, the CLV based approach will compute the total score using the weighting factors assigned to each aspect. These weights can be either user-input values, or the default values for different evaluation types as listed in Table 3. The design with a lower total score has a better ranking.

Table 3. Weighs for Different Evaluation Types

	Operations	Safety	Area/Context
Capacity	35%	20%	10%
Safety/Crash Rate	10%	45%	0
Ideal Volumes	25%	0	0
Left Turn Penalty	15%	15%	0
Right of Way	0	0	15%
Magnitude of Cost	0	0	15%
Movement Priority	15%	20%	0
Area Type	0	0	45%
Pedestrian Movements	0	0	15%
Total	100%	100%	100%

The most important aspect in the evaluation of unconventional intersection is the capacity analysis, which is done with a CLV investigation in this approach. For the majority of the unconventional designs, one location consists of not only one main intersection (such as a conventional design) but also several signal-controlled points. The CLV method analyzes each signalized point as a separate sub-intersection and chooses the worst case, while no interactions between the sub-intersections are considered. Therefore the CLV analysis may provide biased approximation for unconventional designs.

Approach 2: The Neural Network Based Approach:

In acknowledge of the aforementioned limitation of the CLV approach, a new method employing neural network models is also included as the interactive analysis tools in the proposed UAID system. This method aims to estimate the average delay of each intersection design, which will be the only performance index related to traffic analysis.

Then, it will be integrated with the other three aspects computed similarly as in the previous CLV-based approach, so as to generate the final evaluation results.

For each unconventional design type, the current program embedded a pre-trained three-layer back-propagation neural network model. The training data set is generated in the microscopic simulation software VISSIM 3.61, with a set of carefully designed scenarios to capture the influence of traffic volumes and cycle length variations on the average vehicle delay. The trained neural network model will then be used to estimate the delay for the real world traffic volumes and cycle length, if its corresponding unconventional design type needs to be evaluated.

A detailed introduction of the neural network models, including the experiment design, model training and testing, is available in the literature [11]. The validation results have indicated that the estimated delay from the neural network is sufficiently reliable for the purpose of performance comparison between unconventional intersections.

Output Module

The output module aims to provide text or map based information in the knowledge base according to users' search criteria and to present detailed evaluation outcomes from the interactive analysis tools. Since this module is integrated with the knowledge base and interactive analysis tools, its design will not be elaborated here. The output interface is shown in Figure 3 and Figure 4 in the knowledge base section, or Figure 11 in the following case study.

4. Case Study

This section aims to provide a description of the proposed UAID program with an example application. The scenario designed in the case study is given next, followed by a step-by-step illustration of procedures to evaluate different unconventional designs under the given scenario.

Scenario Designed for the Case Study

To facilitate the illustration, this section defines the following scenario to present the applicability of the UAID program.

- A four-approach intersection needs to be designed;
- There are 3 through lanes for the arterial and 2 through lanes for the minor road; one left lane and one right lane for all approaches;
- Cycle time is set as 120s;
- Turning volumes are shown in Table 4.

Table 4. Turning Volumes for the Each Approach

(vph)	Left Turn	Through	Right Turn
EB	600	2000	350
WB	550	1750	300
NB	250	800	225
SB	200	600	175

Step 1: Open the main interface of the UAID program as shown in Figure 5, and then click the Interactive Analysis Button to enter the interactive analysis module.

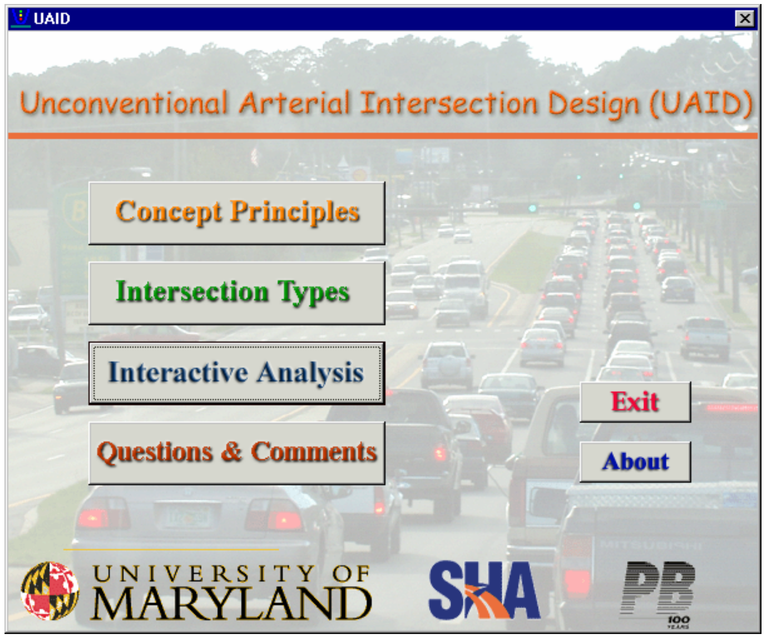


Figure 5. Main Interface of the UAID Program

Step 2: Select the evaluation type or assign the weighting factors.

Figure 6 shows the interface for this step. Three evaluation types for different functions can be selected with default weighting factors, or users can choose to define their own weights through the direct input. Besides, this step also requires user to select either at-grade or grade-separated designs. For this case study, the evaluation type is selected as “operations” and the weights for the capacity factor is set at 100% to focus only on the capacity.

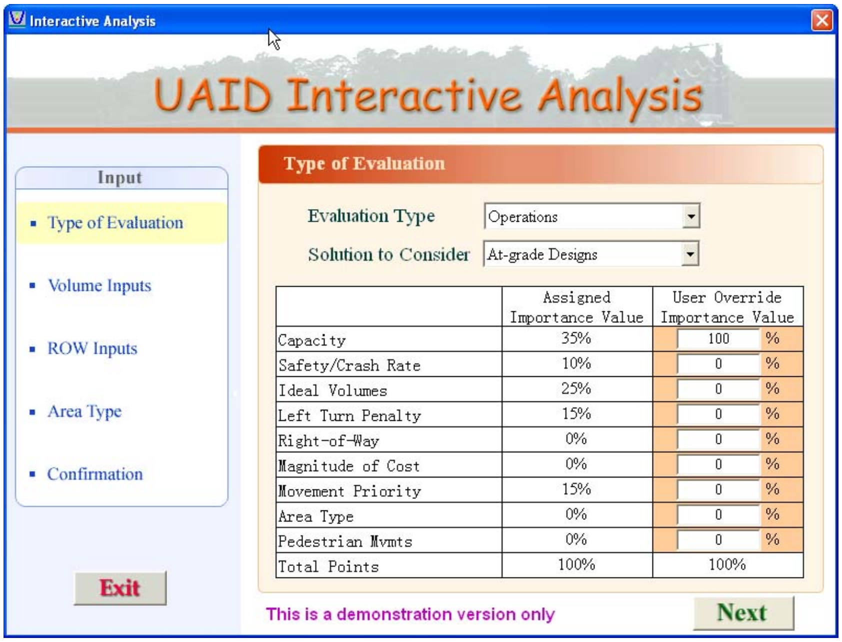


Figure 6. System Interface to Input Evaluation Type and Weights

Step3: Finalize the candidate Unconventional Intersection types.

In this step, users can eliminate some unconventional intersection types for further evaluation in an interface as shown in Figure 7. For example, since the Continuous Green-T design is not suitable for 4 approaches intersection and Modern Roundabout design is not possible to handle this amount of traffic volumes, the case study will eliminate these two types for the candidate list.

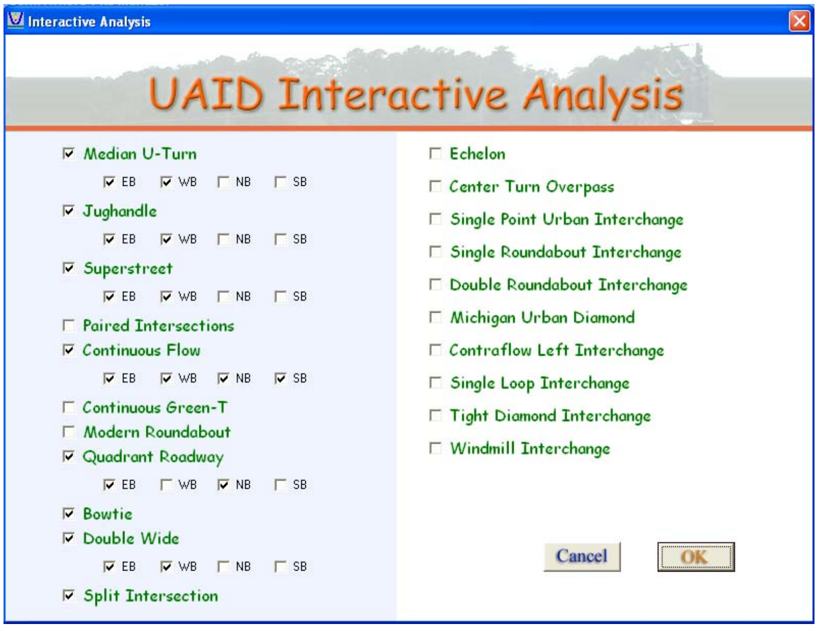


Figure 7. System Interface to Finalize the List of Candidate Unconventional Designs

Step 4: Input lane configurations and volumes.

The interface windows shown in Figure 8 are used for users to input the intersection lane configurations and turning volumes. Note that the volume input interface (as shown in Figure 8_2) will pop out after the “Lane Group and Volume” button is clicked, and its design features are consistent with the lane configurations already input in the interface in Figure 8_1.

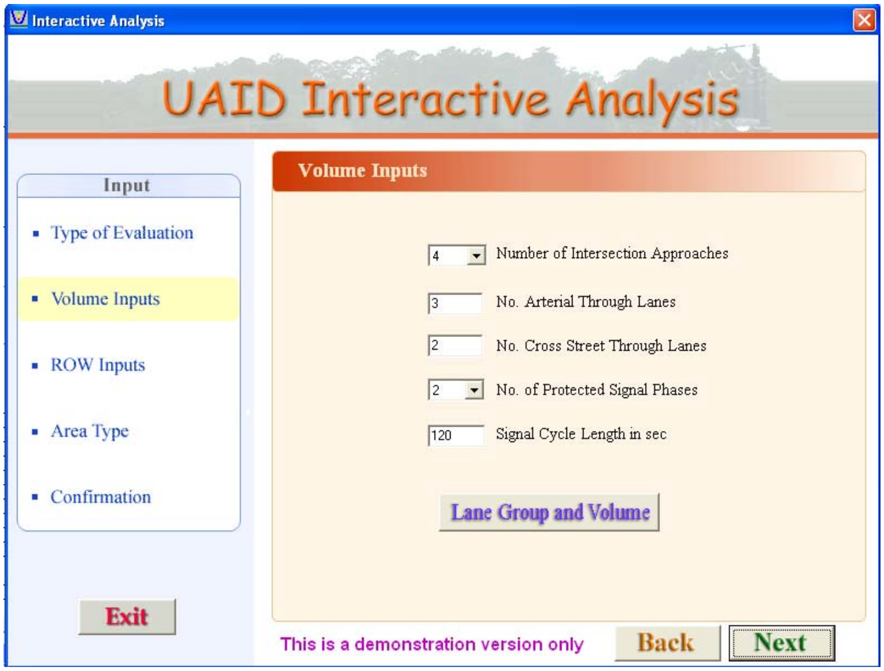


Figure 8_1. System Interface to Input Lane Configurations

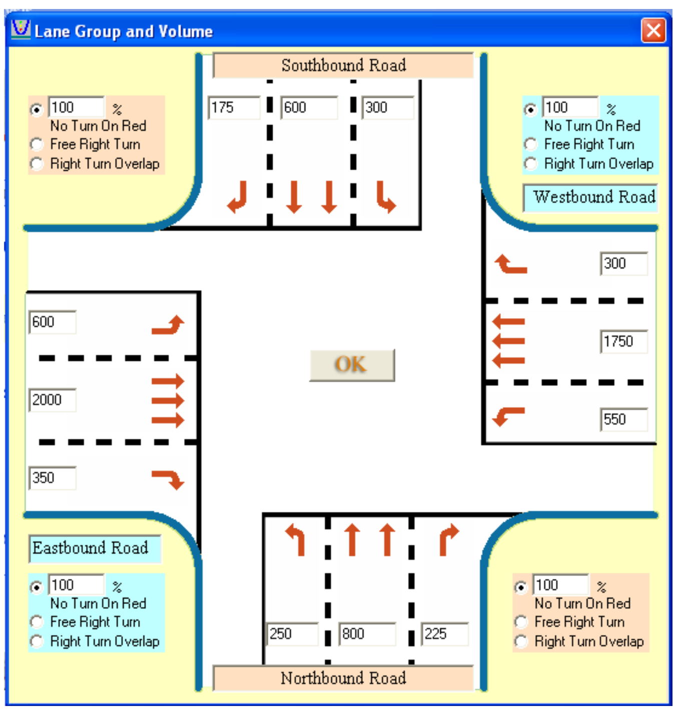


Figure 8_2. System Interface to Input Volumes

Step 5: Input other parameters, such as Right Of Way and Area Type

Figure 9 and Figure 10 show the interface to input other parameters. However, since we didn't choose ROW and Area Type as the evaluation factors in this case study, theses two sets of parameters need not to be input.

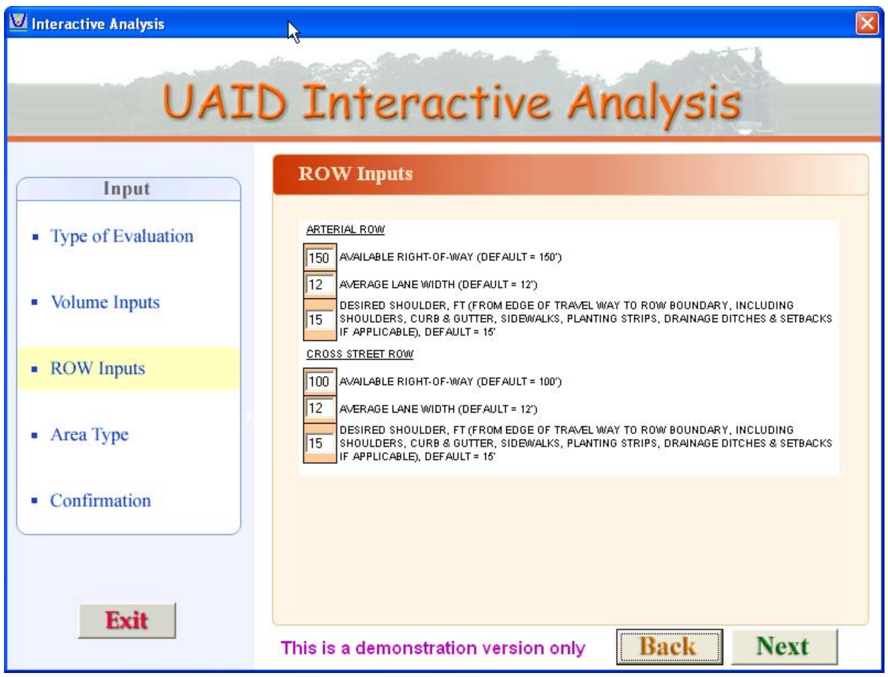


Figure 9. System Interface for Input of ROW Parameters

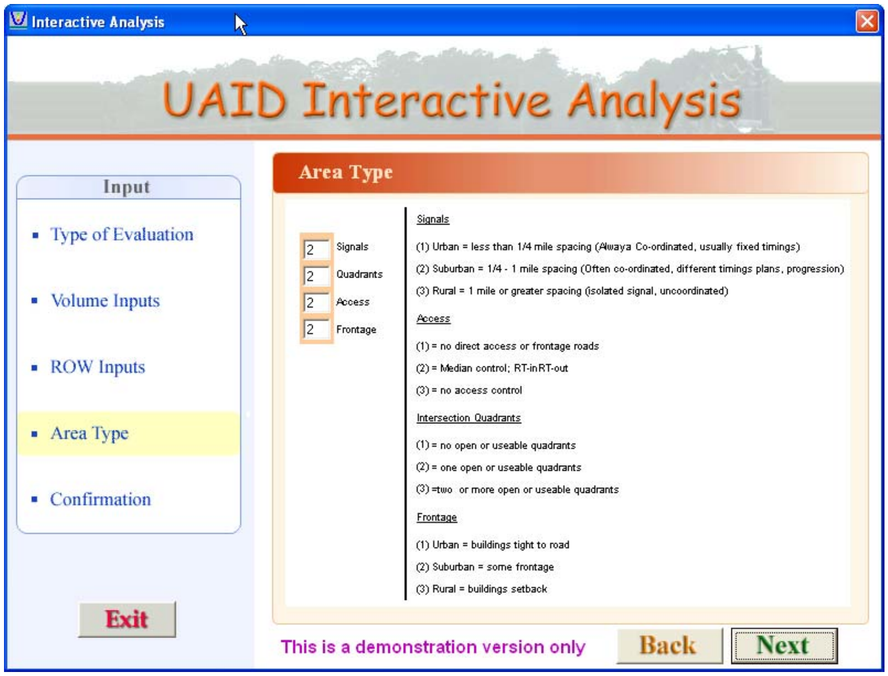


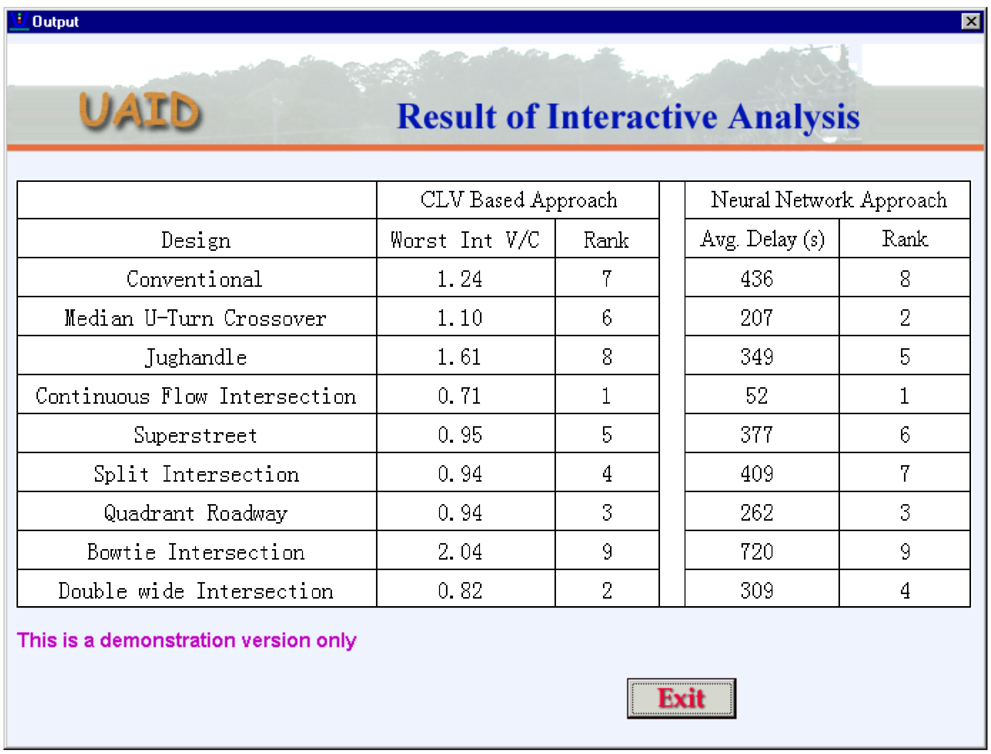
Figure 10. System Interface for Input of Area Type Parameters

Step 6: System output

After receiving input information and evaluation parameters, the program will use the CLV-based approach and the Neural Network approach to evaluate the performance of each candidate unconventional intersection. The comparison results based on the UAID interactive analysis tools will be shown in an interface window (see Figure 11).

In this case study, the evaluation results show that the Continuous Flow Intersection is the best design based on both approaches, while Bowtie Intersection is always the worst. However, some design types may rank differently under different evaluation approaches. For example, the Median U-Turn design ranks 6th in the CLV Based Approach and 2nd in the Neural Network Approach. The reason is that CLV approach picks up the worst V/C ratio among all sub-intersections decomposed from the original intersection, while the latter approach evaluates the overall delay performance of all sub-intersections.

This preliminary analysis result obtained from the UAID program can help traffic engineers choose the proper Unconventional Design (such as CFI, MUT and QRI in this case) under a given traffic demand distribution.



	CLV Based Approach		Neural Network Approach	
Design	Worst Int V/C	Rank	Avg. Delay (s)	Rank
Conventional	1.24	7	436	8
Median U-Turn Crossover	1.10	6	207	2
Jughandle	1.61	8	349	5
Continuous Flow Intersection	0.71	1	52	1
Superstreet	0.95	5	377	6
Split Intersection	0.94	4	409	7
Quadrant Roadway	0.94	3	262	3
Bowtie Intersection	2.04	9	720	9
Double wide Intersection	0.82	2	309	4

Figure 11. System Output of Interactive Analysis

5. Conclusions

The study has presented an integrated program for design of unconventional arterial intersection. The program features its integration of a knowledge-base and interactive-analysis tools, so as to assist traffic engineers and researchers in better understanding and conveniently evaluating various unconventional intersection designs. Key performance features, such as traffic analysis, safety concerns, cost estimation and pedestrian impacts, are all included in the evaluation process based on two different approaches. The case study has illustrated the user-friendliness and effectiveness of the proposed UAID system for potential system users to evaluate various unconventional intersection designs under a given distribution of traffic demand. As the use of unconventional intersection to reduce traffic congestion is relatively new in traffic engineering practice, the developed tool offers a convenient way for potential users to evaluate the trade-off among all candidate design types and greatly facilitate the selection and design of unconventional intersections prior to their implementation.

ACKNOWLEDGMENTS

The Authors wish to thank Petru Horvath for his research assistance in developing the neural network model for unconventional intersection delay estimation.

REFERENCES

[1] Reid, J.D., *“Unconventional Arterial Intersection Design, Management and Operations Strategies”*, Parsons Brinckerhoff, July 2004;

[2] Reid, J.D., Hummer J.E., *"Travel Time Comparisons between Seven Unconventional Arterial Intersection Designs"*, Transportation Research Record 1751, TRB, NRC, 2000;

[3] Reid, J.D., Hummer J.E., *"Analyzing System Travel Time in Arterial Corridors with Unconventional Designs Using Microscopic Simulation"*, Transportation Research Record 1678, TRB, NRC, 1999;

[4] Goldblatt, R., Mier, F., Friedman, J., *"Continuous Flow Intersection"*, ITE Journal, July 1994;

[5] Reid, J.D., *"Using Quadrant Roadways to Improve Arterial Intersection Operations"*, ITE Journal, June 2000;

[6] Dorothy, P.W., Maleck, T.L., Nolf, S.E., *"Operational Aspects of Michigan Design for Divided Highways"*, Transportation Research Record 1579, TRB, NRC, 1997;

[7] Bared, J.G., Kaisar, E.I., *"Benefits of Split Intersection"*, Transportation Research Record 1737, TRB, NRC, 2000;

[8] Polus, A., Cohen, R., *"Operational Impact of Split Intersection"*, Transportation Research Record 1579, TRB, NRC, 1997;

[9] Hummer, J.E., Boone, J.L., *"Travel Efficiency of Unconventional Suburban Arterial Intersections Designs"*, Transportation Research Record 1500, TRB, NRC, 1997;

[10] Hauer, E., Ng, J.C.N., Lovell, J., *"Estimation of Safety at Signalized Intersections",* Transportation Research Record 1185, 1988;

[11] Horvath, P., **"***Analyzing The Performance Of Unconventional Intersections With Simulation Data",* Scholarly Paper for Master Degree, 2005.