GIS-based Decision Support Tool for the Evaluation and Selection of Adaptive Traffic Control Strategies on Transportation Networks

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ABSTRACT

With a number of adaptive signal strategies to choose from and an ever increasing cost of deploying new technologies, there is a need for transportation professionals to carefully determine optimal locations of a specific adaptive signal control strategy in order to maximize its benefits. An interoperable decision support system which not only gives a recommendation about the best network location for deployment, but also provides a seamless data exchange between various data sources will be extremely helpful. In this study the development of a prototype geographical information system (GIS) based decision support system (DSS) to address some of these issues is presented. First, a novel software bridge is implemented to ensure data exchange between the most widely used traffic signal optimization and analysis software, Synchro and the developed GIS-based DSS prototype. A macroscopic simulator, a rule-based expert system built up using various sources, and a benefit-cost analysis module that are integrated parts of this unique GIS-based DSS tool are then described in detail. Case studies that make use of the developed tool are also presented.

INTRODUCTION

One of the key elements of Intelligent Transportation Systems (ITS) is traffic adaptive signal control systems. The traffic engineering community has more than 40 years of experience with computer-controlled traffic signals. Although potential benefits of adaptive traffic signal control strategies have long been recognized by the traffic community, the lack of dependable implementation strategies and a wide-range of performance results (shown in Figure 1a) created skepticism towards these systems among traffic engineers. Figure 1a adapted from Gartner et al. (1995) (1) shows an enlarging performance envelope for different control generations (GC) that become more traffic adaptive with the increasing number of generation. Each generation envelopes the capabilities of the lower generation as shown in Figure 1b. Gartner et al (1995) (1) attributes this large envelope of performance, which covers both losses and gains in performance, to the problems associated with the internal modeling accuracy and logic of the control strategies, as well as to the implementation location and traffic-specific factors. (2)
The main driving force behind work described in this paper was the research sponsored by FHWA. Following the Urban Traffic Control System (UTCS) experience sponsored by FHWA in the 1970’s, the most recent of these efforts is RT-TRACS project. (4,5)

The objective of this paper is to present a GIS-based Decision Support System which
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combines a rule base with a customized macroscopic traffic simulation to decide about the deployment of a certain type of traffic control system on a specific intersection. There are four main factors that should be considered in assessing the impacts of implementing adaptive signals namely:

1. Geometric configuration of signalized intersection(s)
2. Current and projected traffic conditions
3. Various characteristics of the transportation corridor in which traffic signals are located
4. Adaptive control strategy

Thus the proposed GIS-based DSS would primarily require two sets of databases, namely, the traffic analysis database and geo-spatial database. The traffic analysis database consists of traffic flow, intersection geometry and signal database. The integration of a traditional traffic analysis and signal database with GIS would give the complete advantage of GIS functions such as advanced visualization tools, location-based search, efficient representation of the transportation network, integration of other infrastructure data such location of power and communication lines, right-of-way information with traffic signal data, and the ease of large data set manipulation in real-time including on-line traffic data.

**REVIEW OF DECISION SUPPORT SYSTEMS IN TRANSPORTATION**

Decision Support Systems (DSS) in transportation have been used to serve in a wide variety of areas from infrastructure management and maintenance, to transportation planning, to highway safety and emergency management. Jha (2003) developed a criteria-based DSS for deciding the highway alignment based on the cost, its effect on the environment, and effect on other adjacent facilities. (6) Chou et al. (2007) developed a combined DSS that helps in the utility adjustment among various contractors in highway construction. (7) Choi et al. (1996) developed a GIS-based DSS which helps in analyzing the optimal route alignment selection. The tool combines a transportation planning tool with optimal alignment selection and economic feasibility on a geo-spatial framework. (8) Borne et al. (2003) proposed a DSS methodology for the public transportation regulator to deal with the size of the operating fleet in order to provide a certain level of service to the customers, taking into account the uncertainty caused due to congestion, incidents, etc. (9) Chassiakos et al. (2005) developed a DSS methodology to propose counter-measures for highway traffic accidents based on a knowledge base consisting of expert opinion and past experience. (10) This system also integrates accident and environmental characteristics, and maintenance history of the road section. In all the studies above typical features are, the size of the system in question, the uncertainty involved in various facets, and qualitative nature of some components. As a result most of these systems cannot be formulated as an optimization problem. This aspect provides the motivation for using expert systems for the problem.

**Knowledge-Based Expert Systems**

Knowledge-based expert systems (KBES’s) use human knowledge to solve problems in real life that would normally require human intelligence. These systems collect small
fragments of human knowledge into a knowledge base, which is used to reason through a problem, using appropriate knowledge. This information/knowledge database is based on a set of defined attributes that form input to the problem statement. These inputs resemble a set of conditions for which a user likes to know how a particular system would perform when given such input. This input can also contain qualitative variables the effect of which is determined by expert opinion.

KBESs are widely used in solving engineering problems. For instance diagnosis of car engine problems, design of retaining walls, safety evaluation of construction projects (11), and prediction of incident clearance durations (12) have all be addressed using KBESs.

Another important aspect of expert systems is their ability to represent uncertainty explicitly. In this study domain, uncertainty can be due to the large number of special cases that exist in a large problem domain (the arterial transportation network of New Jersey) or simply due to the incomplete information. Thus, it is important to incorporate the effect of uncertainty when making decisions. Even early KBESs such as MYCIN / EMYCIN developed to diagnose diseases used certainty factors discussed in Ozbay and Kachroo (1998) (12). The contribution of various factors to the outcome of a specific rule is represented using weights that depend on the certainty, which is attached to each of the factors. This is accomplished via a valuation process.

This valuation process is developed using a value function that estimates the “utility” of deploying adaptive control strategies at a certain location. This process of estimation of value function for decision making for public agencies was first proposed by Saaty. (13,14) Saaty described this process as an Analytical Hierarchy Process and proposed the estimation of the parameters or weights of a value function that ranks the alternatives using input form real-world decision makers. The proposed value function can be of the following form:

\[ w_1x_1 + w_2x_2 + \ldots \ldots \ldots + w_nx_n = \sum_{i=1}^{n} w_i x_i \]

where,

\[ w_i = \text{weights for each variable} \]

\[ x_i = \text{considered performance measures from Simulations and KBES} \]  \hspace{1cm} (1)

In the developed prototype DSS, knowledge obtained from different sources including previous studies and experts, macroscopic and microscopic simulations were also combined by using weights using an approach similar to the one described above. These weights were determined based on the perceived reliability of specific information.

**OUTLINE OF THE PROPOSED DECISION SUPPORT SYSTEM**

Use of a decision support system helps the transportation professional with the complex nature of deciding on the best individual or series of traffic intersections for the implementation of adaptive traffic control. A decision support system that can address
various aspects of this potentially very large problem domain will be ideal in this case. The main functionality of this tool will be to eliminate unpromising candidates and rank top candidates using benefit-cost analysis approach that is widely accepted as a decision making tool by many state DOTs. The important components of the proposed GIS-based DSS (shown in Figure 2) are:

1. GIS-based Interface: As a preliminary step, the input-output module allows for easy visual selection of intersections with the help of GIS software and integration of various lane, volume, timing and phasing databases that reside in Synchro software.
2. Macroscopic intersection simulation program (MISP): A simulation tool for the macroscopic simulation of selected intersections that is available in the DSS database. Simulations using MISP are performed for each intersection and each strategy selected in the previous step. The macroscopic simulation results can also be compared with the optimized pre-timed traffic control strategy estimates.
3. Rule-based Expert system module: The rule-based expert system module decides whether a selected adaptive control strategy would work for a selected intersection. The rules are developed using previous field implementation results of various adaptive control strategies and limited-yet-targeted microscopic simulation results conducted by the research team. This module determines potential candidates for implementation based on the rule base and the results of the MISP described in the preceding step.

Due to the heuristic nature of the problem, there is no closed-form objective function that can be calculated for each intersection in the decision-making process. The selection process requires the incorporation of heuristic knowledge, the way human experts employ in the case of many engineering problems. Thus, a rule-based expert system was developed using the well-known steps of an expert system development process namely (15, 16):

1. Knowledge acquisition: This step involves meeting with experts, review of documents in the area, and conducting simulation and site studies to acquire the required knowledge to be used in the development of the rule base.
2. Knowledge elucidation: This step involves processing of expert knowledge to clarify different aspects of the input acquired from the experts and other sources. The knowledge in this study was categorized to develop simple general rules that are applicable to generic intersections, performing under various traffic and network conditions.
3. Knowledge representation: This step is the development of a rules or rule base using the expert knowledge obtained and processed previously. In this step, C and Visual Basic (VB) programming language was used to code the simple rules developed in the previous step.
4. Implementation: This step involves the implementation of expert rules. In this case, the rule base was developed in the form of a database of rules that represent various factors related to the intersections and recommendations in the form of if-then rules. These rules were incorporated into the prototype GIS-based DSS.
Figure 2 Proposed Decision Support System

- Signal Inventory/Traffic Flow Database
- Geographical Information System (GIS) based Interface
- Macroscopic Traffic/Signal Control Simulation Model
- User Input

1. Finished Evaluating List of Strategies Intersections?
   - Yes: Rule-Based Expert System Module for the Selection of Feasible Intersections
   - No: Perform Benefit-Cost Analysis

2. Perform Benefit-Cost Analysis

3. Final Recommendation about the Feasibility of Implementing OPAC/SCOOT/SCATS

4. New Intersection?
   - Yes: Rule-Based Expert System Module for the Selection of Feasible Intersections
   - No: STOP
GIS-BASED INTERFACE

Input-Output Module
The input-output module of the DSS selects an intersection for adaptive signal control and undertakes the exchange of data such as traffic demand, timing plans, and geometry. Software packages such as Synchro, Corssim, and Paramics store data in a package-specific format. To run simulations with adaptive control, it is necessary to pass this information to prototypes. These prototypes have been developed using C and Visual Basic programming languages. Various databases required for each package can be generated by decoding the file formats. Hence it would be expeditious to store intersection details in a GIS database and use this information for simulation. In this study, Geomedia Professional (GMPro) was used to create the GIS-based application, while Synchro files of calibrated networks were used to generate the highway intersection database.

In this application, a GIS map is developed based on a menu-driven, easy-to-access approach. Menus enable the users to view data in a similar format as Synchro. This is an attractive feature for traffic engineers who are familiar with Synchro. For importing and exporting data from Synchro to GMPro and vice versa, a customized Visual Basic software bridge is developed. GMPro can read traffic data from Universal Traffic Data Format (UTDF) files with .csv extensions (comma-separated (.csv) file format) and export it to an MS Access Database. The UTDF is a standard format used by traffic engineering software packages and a readable format used to exchange traffic data for Synchro. The MS Access database can be accessed for viewing or editing through the GMPro bridge. The edited files can then be converted into UTDF files, which can be easily imported back into Synchro. Figure 3 gives a representation of the unique software bridge implemented as part of this study.
Figure 3 Block diagram for input-output module and software bridge

Features of User Interface

Developing a customized map of intersections of selected arterials (Figure 4 a): A statewide map was developed in GMPro using Visual Basic 5.0 programming language. Dynamic segmentation was performed using the databases of the control points and structures for three routes selected by the agency (NJDOT) namely, portions of Routes 10, 18, and 23. The points feature for the network and control_points tables are related with a common attribute, namely “sri”. Distributed attributes are defined in the parameter file to enable the visual representation of the intersections on the GIS map. A known marker is used as the referencing system in the modular GIS environment, and the output data to be stored in the parameter file are selected as the point features.
Figure 4 Customized map (a) and User Interface (b) developed in GeoMedia Professional
Developing Customized User Interface in Visual Basic (Figure 4 b): The customized user interface has three command buttons for different types of data exchange:

- Show data
- Import data
- Export data

**Show Data**
When the user activates the “Show Data” button, the customized VB application is connected to the related database for the specific data type through the Open DataBase Connectivity (ODBC) feature. As the user interface applet appears, data can be viewed in the exact similar fashion as in Synchro. The applet gets the data from the application protocol, which is one layer below the applet in the protocol stack.

**Importing Data**
When the user activates the “Import Data” button, the application accesses UTDF data files exported from Synchro, reads data record by record, and inserts the records into the MS Access data files. There is a separate database for each type of data:

1. Lane Data
2. Layout Data
3. Volume Data
4. Timing Data
5. Phasing Data

To locate Synchro data in the GMPro application, the UTDF data must be first imported into the MS Access database. Compared with UTDF files saved in .csv format, it is easier to maintain and update data in MS Access database using GMPro. A customized “split” module enables the data from various intersections with different geometries and phases to be seamlessly imported and exported.

**Exporting Data**
It involves Updating, Saving and Exporting. Each step is explained below.

The user may update the data for any intersection on the GIS map via the “Update data” button in the customized user interface (as shown in Figure 5). The “update query” completes the updates through the ODBC connection built for each database. The user can also view and analyze the effects of the updates in Synchro. To maintain permanent data consistency, the update process takes place only in the database and not in Synchro. The user always imports data back in Synchro to view the updates in Synchro.

When the user activates the “Save Data” button, the updated data are sent to the lower application layer. The application is connected to the database through ODBC to enable data access.

When the user activates the “Export Data” button, the application loads and updates data into the UTDF files. Synchro not only writes data to the UTDF files, but also reads the data. The client can then run simulations in Synchro / Simtraffic or any other compatible software to see the effects of the updates after importing the UTDF files through a
The lack of readily available computer implementations of popular adaptive signal control algorithms required the development of prototypes of these algorithms from scratch using the information available in the literature. Macroscopic simulation of prototypes of adaptive control strategies such as SCOOT, SCATS, and OPAC were developed using C and Visual Basic (17). It is faster to run simulation in C language compared to any of the other simulation packages mentioned previously. These faster macroscopic simulations would also help in understanding the limitations of the prototypes and developing solutions to the possible problems that might arise. This situation was especially encountered in OPAC where three prototypes were being developed before conducting OPAC simulations in the Paramics simulation model as described in Doshi et al. (2006) (18). These prototypes were then connected to the rule-based expert system developed using the GMPro GIS package and Synchro to macroscopically evaluate the behavior of different control strategies at various intersections.

Two types of simulations were performed to study the performance of adaptive prototypes. Macroscopic simulation models were developed using C and Visual Basic Programming Language. An API was developed using Paramics Programmer V3.0 to be
used with Paramics simulation package for the microscopic simulation. Macroscopic simulation models were tested first, because these simulations run faster compared to microscopic simulation model. The process involved in testing the prototypes is illustrated in Figure 6 and the selection procedure is described below.

Figure 6 Methodology for evaluation of adaptive signal prototypes in GIS-based DSS
Validated simulation models are constructed based on the field data of traffic flow and pre-timed signal timings. Next for each of OPAC-like, SCOOT-like, SCATS-like and pre-timed strategies the delays on main street, cross street and total delay on each phase is calculated. The prototype with the least total delay is chosen as satisfactory. In order to re-evaluate this process for varying minimum and maximum cycle time, green time and split (which are taken as user input), each of these parameters is incremented and delays are calculated. Then these prototypes are applied to calibrate the microscopic models of New Jersey State Route intersections. The simulation results for these intersections are analyzed to see under what type of network conditions the selected adaptive signal control strategies give benefits when compared with pre-timed signal control and when they fail to generate any benefits. Please refer to ([17]) and ([18]) for a detailed description of this process.

**RULE-BASED EXPERT SYSTEM DEVELOPMENT**

The rule-based expert system module was developed to evaluate the performance of various adaptive traffic signal control strategies for a selected intersection operating under various network conditions.

The rule-based expert system module is based on the method of classification commonly called as a learning method in the fields such as statistics. The classification method is a two-step process. In the first step, a model is built to analyze available sample space based on a set of attributes, while in the second step; the same model is used to classify future sample space. The decision tree classifier was selected, among the available models, because it can generate understandable rules and perform classification without much computational need as soon as the attributes important for prediction/classification are identified ([18]).

The method of classification was implemented using the following procedure:

*Identification of attributes important in the classification procedure*

A thorough literature review was conducted to identify the attributes that would be useful in the classification process. The following parameters describing a network were selected as the set of attributes:

1. **Level of Saturation**
   1. Undersaturated (v/c ratio < 0.7)
   2. Saturated (0.7 < v/c ratio < 1)
   3. Oversaturated (v/c ratio >= 1)

2. **Intersection Spacing**
   4. Close (within 300 feet)
   5. Distant (greater than 300 feet)
   6. Grid network

3. **Cross Street Demand**
   7. Low (< 400vphpl)
8. High (> 400 vphpl)

4. Traffic Volume
   9. Constant – Number of vehicles per cycle (or specified time interval) is almost constant
   10. Varying – Large variation in number of vehicles within one cycle

5. Number of Phases in Each Cycle
   11. Two (simple phasing)
   12. More than two (complex phasing)

Knowledge Acquisition

Due to the scant availability of literature on the real-world application of adaptive signaling, the sample space created based on the literature review was very limited, and it covered only a few combinations of the above described network attributes. To expand the sample space for the decision tree classifier, results were derived from the microscopic simulation results of adaptive signal prototypes. OPAC, SCOOT and SCATS prototypes developed by the research team were tested using Paramics microscopic simulation tool (18). The intersections selected for microscopic simulations had different characteristics and they covered all possible sample space for the identified attributes of isolated intersections.

Based on the above network attributes, one can have a number of combinations for specifying network conditions. For example, one condition can be an oversaturated isolated intersection with a high cross street demand, varying volume and complex phase pattern, whereas another example could be an undersaturated arterial, with low cross-street demand along its intersections, with varying volumes and simple phase pattern. Using the literature and the microscopic simulation results a rule base was created for each the combination of network attributes. (Please see (15) for further details)

It was observed that results from field implementations, simulation results, and prototype simulations vary for each adaptive control strategy. Hence, each result has to be assigned a weight and a final utility based on how reliable each output is considered and as a performance measure for the reliability of field implementation, expert simulation and prototype simulation results. It is logical to assign more weight to field implementation results because these results are obtained under real-world conditions and less weight to simulation results, because there are certain assumptions involved while obtaining them.

Assigning Weights to Knowledge (Information) Obtained from Different Sources or Variable Accuracy

Field Implementation Results: More weight was assigned to field implementation results because these results are obtained under real-world conditions. Lower or higher weights can be applied for particular cases.
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Expert Simulation Results: Simulations performed by commercial providers of the control strategies are considered as expert simulations. The accuracy and reliability of the simulations are limited by the type of package used and type of calibration and modeling efforts undertaken (e.g., different packages use different distributions for arrivals, and algorithms). In this case, weight assigned was slightly lower compared with field implementation results.

Microscopic Prototype Simulation Results using Paramics: These models are built by Rutgers researchers and clearly represent basic features of modeled control strategies. It is thus important to emphasize that the prototype of a control strategy is not the same as the actual control strategy. Prototypes were developed from the available information about the control strategy. They may or may not represent correct version of the strategies currently being used. Hence, less weight was assigned to these results. The weight assignment was performed in the following fashion:

1. Field Implementation / Expert Simulation / Prototype Simulation - 0.40 / 0.35 / 0.25
2. Expert Simulation / Prototype Simulation - 0.60 / 0.40
3. Field Implementation / Prototype Simulation - 0.65 / 0.35

So, for instance, if there is a 2% decrease in delay from field implementation and an 8% decrease from prototype simulation, then we can say that the expected decrease would be 0.65*0.02 + 0.35*0.08, which amounts to 4.1%

**BENEFIT-COST ANALYSIS MODULE**

To determine the cost effectiveness of adaptive control algorithms, a cost-benefit analysis module was developed and integrated into the DSS software. This module is capable of running benefit-cost analysis for a period of 20 years. The benefit-cost analysis module calculates the benefit-cost ratio, net present value of the project, and rate of return for the control strategy selected.

The NPV is appropriate for comparing the differential economic worth of projects while evaluating project alternatives that result in equal categorical benefits but unequal costs. All benefits and costs over an alternatives’ life cycle are discounted to the present, and the costs are subtracted from the benefits to yield an NPV. If benefits exceed costs, the NPV is positive and the project is worth pursuing. NPV is given by the following equation:

\[
NPV = - \left[ C \sum_{t=0}^{T_c} \frac{T_c}{(1+r)^t} \right] + \sum_{t=T_c}^{T_c+T} B_t \left[ \frac{(1+g(t)(t-T_c))}{(1+r)^t} \right] + R - M
\]

Where,

\[
B_t = (R - C) (1+g(t)(t-T_c))
\]

(2)
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C = Total project cost ($)

\[ T_c = \text{Construction period of the project (assumed 4 years for all projects)} \]

\[ T = \text{Expected life time of the project (assumed to be 20 years for all projects)} \]

\[ B_t = \text{Monetary value of benefit (travel time savings, reduction in emissions etc.)} \ (\$) \]

\[ g(t) = \text{growth rate in year } t \]

\[ R = \text{fair box revenue} \]

\[ M = \text{annual operating cost} \ (\$) \]

\[ r = \text{interest rate} \ (\%) \]

The maintenance cost is considered as a negative benefit.

The benefit-cost ratio method is generally used when project funding is restricted. The benefit-cost ratio is obtained by placing the present value of benefits in the numerator and present value of cost in the denominator. The cost includes only the construction cost as in the NPV. The benefit-cost ratio is given by the following equation:

\[
BCR = \frac{\sum_{t=1}^{T_c} \frac{T_c}{(1+r)^t}}{\sum_{t=T_c+1}^{T} (1+r)^t \left[ (1+g(t))^{(t-T_c)} + R - M \right] + \sum_{t=1}^{T_c} \frac{T_c}{(1+r)^t}}
\]

Benefit-Cost Ratio, (3)

Rate of Return is given by the following equation:

\[
RoR = \frac{NPV}{C} = \frac{\sum_{t=1}^{T} \frac{T_c}{(1+r)^t}}{\sum_{t=1}^{T_c} \frac{T_c}{(1+r)^t}}
\]

Rate of Return, (4)

**Implementation of Benefit-Cost Analysis Methodology**

The first step in implementing the benefit-cost analysis is to make a list of costs and benefits that are expected from the project. After a detailed literature study it was found that infrastructure costs associated with adaptive traffic signal control include:

1. Cost for a dedicated communication line
2. Central software cost
3. Operator hardware cost
4. Cost of local controllers
5. Detector cost
6. Labor cost for maintaining signal timings etc.

A communication line may be a typical leased line, a fiber optic line, or a copper cable
line. Each of these lines has a different initial, as well as maintenance costs. Central software (SCOOT, SCATS, OPAC) generally depends on adaptive control system providers. Operator hardware generally includes a workstation, a platform for the workstation, and a LAN system. This hardware may be installed centrally or at multiple locations depending on the type of adaptive traffic control system being considered. The cost of the local controller may vary depending on whether current controllers need an upgrade or new controllers should replace them. The type of detectors to be used is generally specified by the system providers; however, inductive loops are widely used. Labor cost includes cost of a transportation engineers and signal technicians who are required for signal-timing tuning at different times as well as other labor work required at the signalized junction. The maintenance cost for the infrastructure system is considered as a negative benefit while calculating the NPV of benefits.

IMPLEMENTATION OF RULE-BASED EXPERT SYSTEM FOR DEVELOPMENT OF SELECTION STRATEGIES

The rule-based expert system developed was tested on certain New Jersey Highways. The calibrated networks of Route 10, 18 and 23 that were earlier developed in Synchro were used by the rule-based expert system program to test three adaptive control strategies. Isolated intersections on these arterials were selected and adaptive control strategies such as SCOOT-like, and OPAC-like algorithms were simulated. The main aim of such case studies is to know how SCOOT-like, and OPAC-like work under similar network conditions.

The output of such case studies is a decision, which would be based on two criteria:
2. Macroscopic Simulation Results for Each of the Adaptive Control Strategy

The results will suggest whether adaptive strategies work on given intersection based on prototypes and whether previous implementation results (from knowledge base) also suggest good performance under given network conditions.

The case studies discussed in the next section compare simulation output for adaptive control with pre-timed simulation. The reduction in delays compared to the fixed signal timing strategy constitutes the basis for the benefits used by the benefit-cost analysis module. Finally, a benefit-cost analysis was performed. Hence, the “decision” along with simulation output and benefit-cost analysis helps to simplify the selection strategy for adaptive control systems for a given network condition.

CASE STUDIES

Many state departments of transportation are in the process of upgrading its traffic signal systems with a long-term goal of replacing the existing system with the state-of-the-art computerized adaptive signal systems. There is a growing need for devising an “optimal
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"site selection process" for maximizing the return from upgrading signals selected from a quite large pool of candidate sites. With the seemingly ever-increasing traffic volume in New Jersey, NJDOT is also in the process of upgrading the signal system in order to mitigate the urban congestion. Among the major signalized routes, Route 10, Route 18 and Route 23 were included in this study. Two applications of the DSS are presented below for varying network and traffic conditions.

Case Study 1: Route 23 and Boonton Avenue

Table 1 Results of Case Study 1

a) Traffic Demand

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<th>Left</th>
<th>Through</th>
<th>Right</th>
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<tbody>
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<td>Eastbound</td>
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<tr>
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b) Signal Timing Plan: Pretimed Control

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<td>Movements</td>
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<td>NB, SB</td>
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<td>Amber + All Red</td>
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c) Signal Timing Plan: OPAC-like Control

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<td>Min. Green Time</td>
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<tr>
<td>Max. Green Time</td>
<td>105</td>
<td>35</td>
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<tr>
<td>Amber + All Red</td>
<td>5</td>
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d) Signal Timing Plan: SCOOT-like Control

<table>
<thead>
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e) Macroscopic Simulation Result

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<th>MOE</th>
<th>Pre-timed</th>
<th>OPAC-LIKE</th>
<th>SCOOT-LIKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Intersection Delay</td>
<td>46.61</td>
<td>17.36</td>
<td>20.36</td>
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<tr>
<td>Total Delay (phase 1)</td>
<td>40.61</td>
<td>7.49</td>
<td>11.58</td>
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<td>Average Delay (phase 1)</td>
<td>15.22</td>
<td>5.62</td>
<td>8.88</td>
</tr>
<tr>
<td>Total Delay (phase 2)</td>
<td>6.0</td>
<td>9.87</td>
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<tr>
<td>Average Delay (phase 2)</td>
<td>16.67</td>
<td>54.86</td>
<td>47.83</td>
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f) Rule base

<table>
<thead>
<tr>
<th>Level of Saturation</th>
<th>Undersaturated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection Spacing</td>
<td>Isolated</td>
</tr>
<tr>
<td>Cross Street Demand</td>
<td>Low</td>
</tr>
<tr>
<td>Phase Pattern</td>
<td>Simple</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCOOT</th>
<th>SCATS</th>
<th>OPAC</th>
<th>RHODES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Signal Control</td>
<td>Optimized Pre-timed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Travel Time</td>
<td>-10.2%</td>
<td>-8.2%</td>
<td>-12.911%</td>
</tr>
<tr>
<td>Average Intersection Delay</td>
<td>9.0%²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Delay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stopped Delay</td>
<td>-62.0%</td>
<td>-26.6%</td>
<td>-24.16%² to -39.1%³</td>
</tr>
<tr>
<td>Control Delay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Number of Stops</td>
<td>“Not Significant”¹</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References
3. Paramics Simulation of OPAC like prototype.

g) Result of Benefit-Cost Analysis

<table>
<thead>
<tr>
<th></th>
<th>OPAC-LIKE</th>
<th>SCOOT-LIKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>114836.00</td>
<td>60208424</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>1.23</td>
<td>79.37</td>
</tr>
<tr>
<td>Rate of Return</td>
<td>0.23</td>
<td>78.37</td>
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</table>
Analysis:
According to the macroscopic simulation results (refer to Table 1) it can be seen that the OPAC-like prototype gives lower delays compared with pre-timed signal control. However the benefit-cost ratio for OPAC is very low compared with SCOOT-like strategy. The primary reason for this is that the amount of benefit that the OPAC prototype gives is not sufficient to cover the infrastructure and maintenance cost for this control strategy. Detailed analysis of the simulation results showed that the operations and maintenance cost of OPAC-like strategy are much higher compared with SCOOT-like. This intersection has about 12 lanes and OPAC-like strategy needs four detectors to estimate arrivals and queue per lane. Hence the number of detectors needed in OPAC increases four times compared to SCOOT-like strategy. This is a primary reason for lower benefit-cost ratio for the OPAC-like strategy.

Case Study 2: Route18 and Eggers/S. Woodland St.

<table>
<thead>
<tr>
<th>Table 2 Results of Case Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Traffic Demand</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Eastbound</td>
</tr>
<tr>
<td>Westbound</td>
</tr>
<tr>
<td>Northbound</td>
</tr>
<tr>
<td>Southbound</td>
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</table>

b) Signal Timing Plan: Pretimed Control

<table>
<thead>
<tr>
<th>Movements</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB, SB</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Green Time</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Amber + All Red</td>
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<td></td>
</tr>
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</table>

c) Signal Timing Plan: OPAC-like Control

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. Green Time</td>
<td>75</td>
</tr>
<tr>
<td>Max. Green Time</td>
<td>110</td>
</tr>
<tr>
<td>Amber + All Red</td>
<td>5</td>
</tr>
</tbody>
</table>

d) Signal Timing Plan: SCOOT-like Control
Mudigonda, S., Ozbay, K., Doshi, H.

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Time</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Min. Green Time</td>
<td>75</td>
<td>10</td>
</tr>
<tr>
<td>Max. Green Time</td>
<td>110</td>
<td>30</td>
</tr>
<tr>
<td>Amber + All Red</td>
<td>5</td>
<td>5</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MOE Pre-timed</th>
<th>OPAC-LIKE</th>
<th>SCOOT-LIKE</th>
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<tbody>
<tr>
<td>Total Intersection Delay</td>
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<td>7.21</td>
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<tr>
<td>Total Delay (phase 1)</td>
<td>6.41</td>
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<td>15.23</td>
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<tr>
<td>Average Delay (phase 1)</td>
<td>2.86</td>
<td>2.20</td>
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<tr>
<td>Total Delay (phase 2)</td>
<td>4.06</td>
<td>4.75</td>
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<tr>
<td>Average Delay (phase 2)</td>
<td>23.43</td>
<td>54.85</td>
<td>856.02</td>
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f) Rule base

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<th>SCATS</th>
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<th>RHODES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Signal Control</td>
<td>Optimized Pre-timed</td>
<td>MOE's Compared with Baseline Signal</td>
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<tr>
<td>Average Travel Time</td>
<td>-10.2%</td>
<td>-8.2%</td>
<td>-12.911%</td>
<td></td>
</tr>
<tr>
<td>Average Intersection Delay</td>
<td>9.0%²</td>
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References

3. Paramics Simulation of OPAC like prototype.
Mudigonda, S., Ozbay, K., Doshi, H.

### g) Result of Benefit-Cost Analysis

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<tr>
<th></th>
<th>OPAC-LIKE</th>
<th>SCOOT-LIKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV ($)</td>
<td>-1097466</td>
<td>-1568961</td>
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<tr>
<td>Benefit-Cost Ratio</td>
<td>-1.02</td>
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</tr>
<tr>
<td>Rate of Return</td>
<td>-2.02</td>
<td>-9.96</td>
</tr>
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**Analysis:**
The main reason for the negative benefit-cost ratio for the OPAC-like prototype is the fact that there are 10 lanes at this intersection. (refer to Table 2) The cross-street demand at this intersection is very low. Travel time saving with the OPAC-like prototype for such intersections is not high enough to cover its maintenance costs. At a low cross-street demand, performance of SCOOT-like strategy also deteriorates and the benefit-cost ratio for this case is even less compared to OPAC-like strategy. Hence, it was concluded that SCOOT-like strategies are not as cost effective compared to the OPAC-like strategy when the cross-street demand is very low.

**CONCLUSIONS**
The development of the decision support tool helps with the analysis of the adaptive signal strategies when applied to various types of intersections. The tool allows testing OPAC-like, SCATS-like, and SCOOT-like prototypes on NJ highways through a GIS-based interface. A working prototype of the decision support system software was developed and tested. Rule-based expert system module of this prototype DSS tool helps the user to utilize past implementation results of adaptive control strategies to evaluate suitability of the intersection that is being studied. This offers a good indication of what to expect from adaptive control strategies for a given intersection.

An important feature of the prototype DSS is its ability to communicate with the standard and widely-used traffic signal optimization tool namely, Synchro. This enables the user to make changes to intersection characteristics using Synchro and then export the updated intersection to the prototype DSS. Similar modifications can also be made using the DSS tool and exported to Synchro. Thus, Synchro and the developed prototype are efficiently connected using a custom software application developed as part of this project. This new “software bridge” capability is unique and very useful when dealing with multiple routes that are geographically dispersed over the entire State of New Jersey. The user can simply use the GIS map to locate the route section and the intersection on it to conduct the analysis. The benefit-cost analysis module of the developed DSS helps to evaluate the cost-effectiveness of these systems.

Finally, case studies of adaptive control strategies on selected NJ highways are presented. This analysis highlights the effectiveness of adaptive signal strategies under different types of traffic networks. The benefit-cost analysis gives a detailed performance review of these systems in terms of benefit-cost ratio, net present value and rate-of-return.
ACKNOWLEDGEMENTS
The authors are grateful to New Jersey Department of Transportation for supporting this research effort.

REFERENCES

Mudigonda, S., Ozbay, K., Doshi, H.

Interfaces, 24(6), pp.19-34, 1994.