TRICEPS/CARTESIUS: An ATMS Testbed Implementation for the Evaluation of Inter-Jurisdictional Traffic Management Strategies

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INTER-JURISDICTIONAL TRAFFIC MANAGEMENT STRATEGIES

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ABSTRACT

This paper describes the initial testing and evaluation of one of the key components of the Testbed Real-time Integrated Control and Evaluation Prototype System (TRICEPS). TRICEPS is a software platform that facilitates the implementation and evaluation of a wide range of algorithms for traffic control and Advanced Transportation Management Systems (ATMS). TRICEPS supports research activities by providing consistent interfaces for transportation management modules to both simulated and real-world environments. One of the key components of the TRICEPS platform is a distributed architecture for the provision of real-time decision support to Transportation Management Center (TMC) operators, that provides a set of core transportation management applications for multi-jurisdictional traffic control and incident management on freeway and arterial networks. The architecture hosts algorithms for the estimation of current traffic conditions, the analysis of incident characteristics and the formulation of multi-decision-maker traffic control plans, using advanced methodologies for cooperation and conflict-resolution. The process of evaluation of such methodologies using the TRICEPS platform, while aimed at demonstrating the effectiveness of the cooperative approach, also provides a demonstration of platform functionality for range of related applications.

INTRODUCTION

The Advanced Transportation Management Systems (ATMS) Testbed sponsored by the California Department of Transportation (Caltrans) is an ongoing multi-year research and implementation project at the Institute of Transportation Studies, Irvine (1). The Testbed includes computerized laboratories, where algorithms are developed and tested, and the connection to the real world transportation system, through a state-of-the-art data communication network. The Testbed provides an environment for the development, implementation, and evaluation of advanced transportation management strategies and technologies.

The laboratory is a testing ground for the development of particular ATMS modules and of integrated ATMS applications. An ATMS module is an algorithm that processes data to produce a particular type of output (e.g., a traffic control algorithm). An ATMS application is a particular configuration of ATMS modules that are integrated to manage and control transportation system operations. Thus, an ATMS application is a distributed algorithm with various modules performing various tasks.

Based on these concepts, a distributed computing platform was designed to implement ATMS applications from existing Testbed research components. The first generation of this idea, based upon the UCI Distributed
Algorithm Testing Environment (ELUCIDATE), demonstrated proof of the concept by integrating a series of analysis modules (2, 3). This platform was used in the validation of a traffic congestion management module using simulated data (4), but lacked the robustness needed for general application. This initial attempt at developing an implementation platform led to an architecture paradigm shift from ELUCIDATE to a commercial CORBA implementation (using the Orbix Object Request Broker). This second (current) generation implementation platform has proven to be more robust, and could thus be used for the evaluation of transportation management algorithms.

The objective of the Testbed was to construct an implementation platform that provides it with “plug and play” capabilities for the testing and evaluation of ATMS modules. Such modules can be configured in an existing or a new ATMS application, simply by developing the interfaces required for their connection with other modules, without the need to modify or develop the required additional infrastructure. Any particular ATMS application is connected to both simulated and real-world data, so that its effectiveness can be first assessed in the laboratory and then evaluated in the field. This concept has been implemented with the development of TRICEPS (Testbed Real-time Integrated Control and Evaluation Prototype System), which consists of the control subsystem of the Testbed ATMS workbench and a set of evaluation tools. TRICEPS is structured to interface both with real-time data provided through the Testbed’s ATMS real-time data intertie as well as with simulation data provided by the Testbed’s traffic simulation software. The architecture of TRICEPS allows for the introduction of a full range of current and evolving control and management techniques. The Testbed involves a number of local and regional transportation agencies including Caltrans District 12 (Orange County), the City of Anaheim, and the City of Irvine. Within the intertie architecture, CORBA clients were developed, that provide the ATMS applications with the transportation management infrastructure of these agencies. Data from these external agencies include standard inductance loop detectors (ILD), traffic signal and ramp meter parameters, and changeable message signs (CMS).

One of the key components of the TRICEPS platform is a distributed environment for the provision of real-time decision support to Transportation Management Center (TMC) operators, that provides a set of core transportation management applications for multi-jurisdictional traffic control and incident management. Indeed, the spatial and administrative organization of transportation management agencies in metropolitan networks requires a coordinated solution effort that preserves the different levels of authority, guarantees privileged data control, and in general reflects the inherent distribution of the decision-making power. A coordinated response to congestion avoids the implementation of operations that may otherwise conflict, and therefore be counter-productive. To
address such issues, the multi-agent real time system CARTESIUS (Coordinated Adaptive Real-Time Expert System for Incident management on Urban Systems (5)) was developed and incorporated within the TRICEPS platform. CARTESIUS employs advanced cooperation and conflict resolution methodologies for coordinated traffic management operations among multiple agents.

The TRICEPS/CARTESIUS platform is designed to work in three operational modes which make it an extensible ATMS that can be used to optimize, control, and manage real-world traffic, as well as allow for the investigation of individual ATMS technologies without relying on field implementation of the detection and sensor hardware:

- **Simulation Mode** provides an interface between CARTESIUS and data from two traffic simulators that provide microscopic, low-level sensor data and are particularly suited for modeling driver response to the provision of traffic information. Simulated data is used for testing (prior to implementation) and for data synthesis, when complete coverage of real-data is not available.

- **Real-time Mode** uses a real-time, CORBA-based (Common Object Request Broker Architecture) data communication link with the California Department of Transportation (Caltrans) District 12 (Orange County) data server which provides 30-second measurements from loop detectors, the current state of ramp meters and Changeable Message Signs on the Orange County freeway network, and video camera data. Real-time Mode with real-time data is the prototype interface for real-time traffic management.

- **Integrated Mode** allows the simulation of near-future traffic states based on current conditions for the evaluation of alternative traffic control response schemes. This mode involves initializing and continuously synchronizing simulation with real-time data and performing faster-that-real-time simulations before or during the implementation of actual responses to traffic conditions.

The operability of the three operational modes has been, thus far, only partially tested. Current tests involve the validation of the data communication interface, the calibration of the simulation tools, the evaluation of an AID algorithm, and the training of TMC operators. The TRICEPS platform was used in simulation mode to validate the ability of the multi-decision-maker algorithm in CARTESIUS in providing effective traffic control response to the occurrence of incidents. The environment was used to create a wide range of incident test scenarios based on which a quantitative and qualitative evaluation of the algorithms was performed. Results of the evaluation demonstrate the validity of the CARTESIUS approach in reducing congestion both at the local and network-wide level.
In the remainder of this paper, the main characteristics of the CARTESIUS approach and the validation results of its methodology are described.

**ADDRESSING INTER-JURISDICTIONAL COOPERATION: CARTESIUS**

The distributed architecture in CARTESIUS is composed of two interacting, real-time problem-solving agents that communicate with each other through a fast TCP/IP-based real-time protocol. The agents are able to perform cooperative reasoning and resolve potential conflicts for the analysis of non-recurring congestion and the formulation of system-wide ATMS/ATIS response strategies (6). As shown in Figure 1, the two agents are decision-support systems for a TMC operator. One agent supports incident management operations for a freeway subnetwork and interacts with a human operator at the TMC of a freeway management agency. The other agent supports operations for the adjacent arterial network, and interacts with an operator at the local city TMC. Each module continuously receives real-time measurements from traffic detectors and a description of the current status of the control devices (signals, ramp meters, and CMS) under the jurisdiction of the corresponding agency. The modules provide the operators with traffic control and traveler information recommendations in response to the occurrence of incidents. These recommendations consist of a set of alternative, network-wide strategies, composed of suitable settings for signals, ramp meters and CMS. The agents provide an explanation of the reasons why each strategy is proposed and an estimation of the benefit it is expected to provide.

The uniqueness of the CARTESIUS approach lies in the efficient integration of existing techniques for real-time generation and assessment of appropriate control strategies, with emphasis on the coordination between multiple decision makers in a multi-criteria environment. The analysis of the network state and the search for suitable control plans is based on a structured combination of heuristic approaches and well-established traffic control algorithms (7, 8) in a general distributed framework that provides the means for cooperation and conflict resolution.

**Agent Organization and Data Sharing**

An organization based on two interacting agents, as opposed to one using a central module with coordinating functions, was dictated by the following considerations. First, the need to have control decisions ratified by TMC operators and the lack, within the administrative organization of transportation management agencies, of an authority able to coordinate and potentially override control decisions made by either of the agents, limited the power of the coordinating module. Once the functions of the coordinating unit reduced to mere message
passing and automatic (unmanned) decision-making, it was decided to eliminate the coordinating module, by allowing the agents to share some information and introducing a degree of computation redundancy. Thus the agents were provided with the ability to resolve inconsistencies through the definition and verification of inter-agent constraints, and to decide when it is necessary or convenient to interact with another agent and what type of information should be exchanged.

The issue of data sharing is closely tied to the agent organization. A centralized database, accessible to both agents would require extensive data communications and originate potential access delays and maintenance complications. An organization in which copies of the same database were made available to both agents would call for complex mechanisms to guarantee consistency and at the same time would severely limit the system adaptability. These solutions have the advantage that, directly or indirectly, each unit has access to complete and exact data, thus making the problem solving process easier to deal with. At the same time, though, they would preclude the interacting agencies to have reserved data access, thus interfering with their desire of relative autonomy and exclusive control of their jurisdictions.

A more suitable option involves the adoption of a partitioned database, such that each agent has exclusive access to a portion of the data (the one local to its own jurisdiction) and provides the other modules with abstractions of the data that are considered relevant for the accomplishment of its tasks. Such an option allows each agent to preserve dedicated control over its portion of data, by controlling the amount and the quality of the information that is made available to the other agent. Another important advantage of this option involves the reduction of data processing that can be achieved, by having one agent process its data locally, and then making intermediate or final results of such processing available to the other agents. Given the lack of completely specified and globally accessible information, such an approach requires providing the agents with mechanisms for satisfying constraints and resolving inconsistencies, to develop a globally compatible and efficient solution.

Thus, input data describing the status of the network is made available to each agent through access to detector data on road sections that are part of the subnetwork controlled by the corresponding agency. A small redundancy was introduced for the agents to assess the status of the network at the boundaries between the freeway and the arterial network. The status of traffic controllers (signals and ramp meters) is partitioned in such a way that each agent has access to and can set only the controllers under the jurisdiction of the corresponding agency.

Data related to CMS are treated in a slightly different way: in order to guarantee consistent traveler information, predefined combinations of CMS messages are used, that include settings for CMS both on the freeway
and on surface streets. Groups of messages that initiate traffic diversion from the freeway are part of the knowledge of the freeway agent, while those that initiate traffic diversion from surface streets are part of the knowledge of the arterial agent. This is consistent with real-life scenarios, for example in California, where often Caltrans, the agency responsible for freeway operation is aware of the possible messages that the local City TMC can use, and vice versa. Nonetheless, each agency has exclusive authority over the CMS within the network under its jurisdiction.

The Interaction Mechanism

The interaction mechanism between the agents is based on the Functionally Accurate, Cooperative (FA/C) paradigm (9). FA/C is a distributed problem solving approach that is particularly suited to applications where there is a natural spatial distribution of information but where each agent has insufficient knowledge to completely and accurately solve the global problem. In the context of traffic management in metropolitan networks it is often impossible or too expensive to decompose the problem in such a way to ensure a perfect match between the location of information and data processing expertise, and the computational requirements for problem solving. On one hand, the impracticability of sharing expertise and decision-making power in a real-time context often limits the flexibility of transportation management systems, by requiring the adoption of predefined, previously established cooperation plans. On the other hand, the maintenance of accurate, complete, and up-to-date information requires too heavy and frequent communication of intermediate processing results, thus burdening the agents with high communication and synchronization delays that are not practical in real-time applications.

The FA/C problem-solving approach allows agents to cooperatively solve tasks, using only limited and uncertain knowledge of the processing performed and the results obtained by other agents. According to the FA/C approach, CARTESIUS agents cooperate by generating and exchanging partial results at various levels of abstraction, obtained during the problem-solving process. These results, which may be incomplete or inconsistent, are based on the agents' limited local view of the problem and of the solution domain. The ability to determine a local solution even in the absence of completely specified and up-to-date information and to use remotely processed data for the selection of a consistent global solution, allow the agents to reduce their communication synchronization delays.

EVALUATION OF SYSTEM PERFORMANCE

The evaluation of the ATMS/ATIS strategies proposed by CARTESIUS involved the analysis of network performance under different traffic conditions, determined by the occurrence of several types of incidents, and a
comparison between network-wide measures of effectiveness (MOE), with and without the implementation of those strategies. Three real-time ATMS/ATIS response strategies were concurrently applied:

- Adaptive system-wide ramp metering,
- Adaptive arterial traffic signal control, and
- Traffic diversion based on traveler response to CMS information.

The MOEs considered include:

- An assessment of the network travel time reduction obtained by the implementation of incident response plans suggested by optimal deployment of the three ATMS/ATIS response strategies.
- The system's response time.
- The impact of the integration between the various control components, by comparing the effect of fully integrated control plans (freeway traffic diversion and arterial signal control) to incomplete control plans that use exclusively traffic diversion schemes.

The remainder of this paper describes the site for which the analysis was developed and the quantitative and qualitative results of the evaluation process.

**The Test Site**

The test site selected for this analysis is a subnetwork of the ATMS Testbed network, composed mainly by a highly congested corridor network in the city of Irvine, Orange County, California, as shown in Figure 2. The corridor includes 4-mile sections of the Interstate 5 and 405 Freeways, the SR-133 Freeway, and the adjacent subnetwork of surface streets. The City of Irvine Traffic Management Center (ITRAC) is responsible for traffic operations on the arterial network, with a computer-aided traffic system that controls over 240 signalized intersections, 32 of which are within the test network, and 5 arterial CMS. Signal control is fully actuated, and signal control parameters (minimum and maximum green, phase recall, etc.) are set according to a time-of-day basis. ITRAC also has control over 30 CCTV cameras located at major intersections and connected to the TMC through a fiber-optic network. Caltrans District 12's ATMS uses state-of-the-art computer, software, and communication systems to manage the flow of traffic on the county freeway network. Vital elements at the core of the system's operations include 30 CCTV cameras, 34 CMS, the Highway Advisory Radio, 278 metered on-ramps, 1,098 incident call boxes and 258 directional miles of loop detectors. Within the subnetwork for which this evaluation was
conducted, Caltrans controls 3 CMS. Ramp metering control is performed on all 18 freeway on-ramps within the network.

The two agents within CARTESIUS are able to receive real-time traffic and control data from the Caltrans District 12 ATMS, through the ATMS testbed data intertie, the wide-area communications network that links the Cities of Anaheim and Irvine TMCs to the Caltrans' District 12 TMC and to the University of California, Irvine, where the tests were performed. The communication with Caltrans District 12 ATMS provides the freeway agent with loop detector data (volume and occupancy), with CMS and ramp metering data, and with the ability to transmit, subject to Caltrans' approval, ramp metering rate control. A real-time connection between the arterial agent and ITRAC is currently under development and could not be used in this research. It will allow the arterial agent to receive traffic and control status data from the arterial system, and to transmit, subject to ITRAC approval, alternative signal timing and CMS setting plans.

The Simulated Environment

An enhanced version of the traffic simulator DYNASMART (10), available within the TRICEPS platform, was used for simulation. The TRICEPS architecture provides interfaces that simulate the functions of the Caltrans and City of Irvine traffic data servers. Traffic and control device data (detector, CMS, signal, and ramp metering data) are exchanged between the agents and the server using exactly the same interface on the client side. A time-varying OD matrix was estimated for input to the simulation, based on data from the Irvine Transportation Analysis Model (11), using standard commercial software packages.

EVALUATION RESULTS

At the core of the evaluation process was the assessment of the system's ability to provide traffic control plans in real-time response to the occurrence of incidents. Total and average travel time and traveled distance, were considered suitable MOEs, both because they provide an indication of the network level of service and because they are easily measurable using a simulator.

Network Performance

A set of 18 test scenarios was created, by running simulations of 90-minute peak periods and artificially injecting incidents (temporary reductions in the capacity of a link), by varying such characteristics as the incident location, the associated loss of capacity and the duration of the capacity reduction. In scenario 0, no incident was
included, in order to obtain estimates of the basic network average and total travel time and distance. Such estimates were used to assess the relative performance deterioration caused by the occurrence of incidents, across the different scenarios. Thus, for each case, the average travel time increase with respect to scenario 0 was measured. Two scenarios were also included that describe cases for which two incidents were injected simultaneously. In both scenarios, the first incident was simulated on the freeway, while the second was injected along one of the major paths that had been chosen by the system as a bypass for the first incident. The purpose of the latter tests was to analyze the system’s response to multiple incidents with interacting effect on each other.

For each scenario, the MOEs provided by the simulator were collected. For each test case, two simulations were executed: one, the before case, using the default control (no CMS message and the default, time-of-day signal and ramp meter timing plan), and one, the after case, implementing the integrated ATMS/ATIS control suggested by the agents, in response to the notification of the occurrence of congestion. The comparison of the network performance, through the implementation of the two forms of control (non ATMS/ATIS vs. ATMS/ATIS), provided a measure of the performance increase that can be expected when the default control is substituted with the control plans based on the responses suggested by CARTESIUS.

The analysis shows that the implementation of the control plans proposed by CARTESIUS results, in general, in a reduction in the average and total network-wide travel time. The average and total traveled distance is not significantly affected by the alternative control, even though the control plans, in all test scenarios, included the use of CMS messages. This result should be perhaps attributed to the limited size of the network.

The quality of the improvement, in general, varies according to the availability of alternative routes, the amount of spare capacity on those routes, and the demand/capacity ratio on routes affected by congestion. Thus, the scenarios, described in Table 1, are partitioned according to the location of the incident. For each incident, its characteristics are: the location, the associated capacity reduction (number of lanes closed versus total number or lanes), and the duration of the capacity reduction. Table 1 shows the total and average (per vehicle) travel time resulting from the simulated scenarios. The percentage travel time difference between the before and the after case is shown (in bold). Furthermore, in order to obtain a normalized measure of the travel time reduction across the scenarios, the last two columns of the table show, for each case, the average travel time increase with respect to scenario 0, which corresponds to a no incident situation, and thus represents a common base case. For each case, the percent difference in per-vehicle travel time corresponding to the two forms of control (non ATMS/ATIS vs. ATMS/ATIS) is reported.
It is not a simple task to draw general and absolute conclusions beyond the simple observation that in almost all tested scenarios the implementation of the ATMS/ATIS control plans suggested by CARTESIUS results in an improvement of network-wide traffic conditions. In scenarios 1, 7, 10, and 14, the small capacity reduction did not have noticeable effects on traffic flow, thus no incident notification was received by CARTESIUS. Scenario 13 is the only one, among those for which CARTESIUS was used, in which no travel time reduction is observed; this is due to the fact that no alternative solution to the default control was found. It must be noted, however, that in this case, the occurrence of an incident results in a very low deterioration of average travel time, with respect to scenario 0 (0.4%). The mean percentage reduction of average (per vehicle) travel time across the 13 scenarios for which CARTESIUS received an incident notification is 7.4%. Compared to scenario 0 (the no incident case), the mean percentage increase of average travel time, caused by the occurrence of incidents, is reduced from 32.6% to 20.3%.

The reduction in average travel time ranges between 0.0% and 15.3%. The variation is due both to the different duration and capacity reduction of the incident and, perhaps more importantly, to the characteristics of its location, such as the flow to capacity ratio and the availability of alternative routes.

On average, higher performance improvements are experienced in the scenarios related to incidents occurring on freeway sections (the first 12 scenarios), in particular on the I-405 freeway southbound (scenarios 4-6). The lowest improvements are observed for incidents occurring on surface streets (scenarios 13-15). In those cases, the effect of incidents is marginal (0.4% travel time increase), thus the improvement of traffic conditions is also very small. The network performance is improved by CARTESIUS also for the cases of multiple incidents, which seems to demonstrate the effectiveness of the approach in dealing with multiple, concurrent sources of congestion.

**Response Time**

Given the real-time nature of the problem that the system is intended to address, it was important to provide a measure of the system response time. The response time is the time required by the agents to determine a list of control plans, once they have been provided by the operator with all the necessary input. In all tested scenarios, the system response time is below 22 seconds, with an average of 15.3 seconds. This indicates, in practical terms, that combined system-optimal ATMS/ATIS strategies can indeed be implemented in something close to a real-time response. These measures were obtained using a SUN Ultra 30 Workstation, with an Ultra SPARC2 processor.

**Effect of Signal Plans**
As part of the analysis of system performance, a quantitative assessment of the synergistic effect of coordination between signal control and traffic diversion was performed within the integrated ATMS/ATIS strategies proposed by CARTESIUS. For three of the scenarios for which diversion through the arterial system was recommended due to freeway incidents (scenarios 2, 5, 9), an additional simulation was performed (scenarios 2', 5', 9'), in which the adjustment to plans for signals and ramp meters suggested by CARTESIUS were not transmitted to the traffic simulator.

In each case, the network performance for the modified simulations was compared to that of the corresponding scenarios, in which the complete control directives were transmitted to the simulator. These tests were aimed at estimating the synergistic effect of integrated response control plans, by computing the reduction in the network performance caused by the lack of integration between traffic diversion control and signal and meter control.

Table 2 shows the result of these tests. The two scenarios that involve incidents on the I-405 freeway (scenarios 2 and 5) are characterized by a clear superiority of the integrated control compared to the partial one. Scenario 9, which involves diversion from the I-5 freeway, does not show such a noticeable performance gain. This difference can be explained perhaps by considering the characteristics of the major alternative routes available for the freeway traffic in the three scenarios. In the first two cases, a portion of the freeway flow is diverted through arterial routes that cross several signalized intersections, thus the lack of coordination between diversion and signal control would deteriorate the network performance. Also, in both cases, as a consequence of congestion, arterial traffic directed to the freeway is advised to use the on-ramp downstream of congestion, thanks to the availability of arterial CMS, thus further adjustments to signal and ramp control plans are required. In the last case (scenario 9), the alternative route for freeway traffic crosses a smaller number of signalized intersections. Also, the travel time increase due to the incident in this case is lower (10.9% higher than scenario 0) than in the other cases, thus not as much diversion through the arterial streets is required.

CONCLUSION

This paper reports on the initial testing and evaluation of one of the key components of the TRICEPS platform, within the California ATMS Testbed project. The evaluation process involved the development of a TRICEPS ATMS application to assess the validity of a new distributed methodology for the provision of integrated ATMS strategies in response to congestion. Such methodology employs coordination mechanisms that support cooperation and conflict resolution between two distinct automatic problem-solving agents, within the distributed
CARTESIUS system. The agents in the system have access to separate databases and data sources, and may use different control algorithms, thus reflecting the inherent administrative distribution of data and expertise among separate management agencies. The cornerstone of this cooperative approach is the assumption that effective integrated traffic control solutions can be obtained in real-time by relaxing the requirement that agents have shared access to all globally available information. The simulation-based validation of the system performance demonstrated the effectiveness of CARTESIUS in producing real-time, integrated control solutions that reduce the adverse impact of incidents on traffic circulation, network-wide.

ACKNOWLEDGEMENTS

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REFERENCES


FIGURE 1 The distributed architecture in CARTESIUS.
FIGURE 2 The test site.
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<td>0.0</td>
</tr>
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<td>on-ramp</td>
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<td>5.26</td>
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<tr>
<td>16</td>
<td>5 N</td>
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<td>0.459</td>
<td>6.78</td>
<td>6.35</td>
<td>-6.3</td>
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<tr>
<td>17</td>
<td>5 S</td>
<td>0.601</td>
<td>0.560</td>
<td>8.09</td>
<td>7.57</td>
<td>-6.4</td>
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</tbody>
</table>

Average: -7.4 32.6 20.3

† These two columns describe the percentage difference in average travel time when each scenario is compared to scenario 0, corresponding to the no incident case.
* No incident notification to CARTESIUS.
TABLE 2 Travel time with and without signal control for incident on freeways.

<table>
<thead>
<tr>
<th>Signal coord.</th>
<th>Scenario #</th>
<th>Incident Characteristics</th>
<th>Average Travel Time (min./veh)</th>
<th>Comparison with Scenario 0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lanes</td>
<td>Duration (min.)</td>
<td>Before</td>
</tr>
<tr>
<td>0</td>
<td>no incident</td>
<td>5.24</td>
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<td>0.0</td>
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<tr>
<td>yes</td>
<td>2</td>
<td>2(4)</td>
<td>20</td>
<td>6.76</td>
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<tr>
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<td>2'</td>
<td></td>
<td></td>
<td>6.87</td>
</tr>
<tr>
<td>yes</td>
<td>5</td>
<td>1(3)</td>
<td>20</td>
<td>6.86</td>
</tr>
<tr>
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<td>5'</td>
<td></td>
<td></td>
<td>6.46</td>
</tr>
<tr>
<td>yes</td>
<td>9</td>
<td>3(5)</td>
<td>20</td>
<td>5.81</td>
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<tr>
<td>no</td>
<td>9'</td>
<td></td>
<td></td>
<td>5.35</td>
</tr>
</tbody>
</table>
LIST OF FIGURES:

FIGURE 1 The distributed architecture in CARTESIUS.
FIGURE 2 The test site.

LIST OF TABLES:

TABLE 3 Total and average travel time for the simulated scenarios.
TABLE 4 Travel time with and without signal control for incident on freeways.