AI In Advanced Traffic Management Systems

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Abstract

Traffic management systems have historically been limited to addressing the control of street signal lights. Algorithmic solutions to this problem have proved to be very restrictive, while expert system solutions have only shown valid results with small signal networks. None of these approaches has addressed the need for management of the overall transportation system of surface streets, interstate highways, public transportation, and emergency vehicle response. Georgia Tech has developed a distributed blackboard system designed for advance traffic management in large urban areas. Knowledge sources in the system address problems in traffic control, monitoring, congestion prediction, adaptive communication, and incident management. The knowledge sources exploit rule, frame, script, and neural network representations to solve individual traffic management problems that appear on the blackboard data structure. The resulting traffic management decisions are then implemented and evaluated through simulation.

1 Introduction

The goal of an Advanced Traffic Management System (ATMS) is to efficiently manage existing transportation resources in response to dynamic traffic conditions. An advanced traffic management system must incorporate all modes of transportation if it is to provide an effective management solution [Sabounghi, 1991]. For example, the coordination of automobiles can not be addressed without incorporating the special needs of buses, trucks, taxi cabs and emergency vehicles.

A key support system in the ATMS architecture is the Advanced Traveler Information System (ATIS). The goal of ATIS is to provide every traveller with real-time access to information on traffic conditions, travel options, special event updates, and route information for a given metropolitan area. In addition, information on accommodations and services would be provided to travellers staying in the area. Inputs into ATIS would include:

- traffic management decisions
- model predictions
- traffic congestion reports
- police/public safety reports
- event schedules, attendance, & status
- transit schedules and status
- airport schedules and status
- ship line schedules and status
- commercial trucking
- commercial traffic reports
- weather reports
- emergency calls
- incident reports
- traffic spotters
- traffic sensors
- video cameras
- cellular phones
- sites of interest
- directory of accommodations
- directory of service

This information provides a comprehensive view of the current state of the transportation environment and forms the core database which ATMS would draw upon during its decision-making process. In addition to supporting ATMS, ATIS would directly supply travellers with information on

- the best routes to take,
- the best mode of transportation available,
- the existence and availability of services,
- in-vehicle hazard warning and road signing,
- parking availability, and
- predicted congestion areas by time of day

Utilizing the ATIS information database described above, ATMS will manage traffic by making and implementing control decisions on all aspects of traffic flow. Decisions will not only optimize traffic flow, but must also address any environmental impacts. For example, decisions on routing traffic through alternate side streets must consider the effect automotive pollution will have on that environment. Specific ATMS tasks will include:

- predictive traffic flow modeling
- traffic congestion monitoring
- coordinated signalization of surface street lights
- ramp metering onto congested highways
- opening of reserved lanes and reversible lanes
- road access monitoring and control
- electronic enforcement of traffic regulations
- incident detection algorithms
- request for police/emergency vehicles
- demand management
- automated toll collection

The methods ATMS will employ to manage traffic are numerous and include signal lights, changeable highway signs, ramp metering, reversible lanes, emergency vehicle displays, in-vehicle hazard warnings, and in-vehicle road signing. Figure 1. summarizes the ATMS/ATIS information, data, and control flows.

An ATMS utilizes three basic components to maintain an efficient flow on roadways: [1] traffic control, [2] incident management, [3] and motorist information systems. These subsystems must work in concert in order to maintain a balance of traffic flow. For example, a traffic control plan is of little value if it cannot respond to accidents or other incidents that occur and notify motorists to avoid the problem area.

ATMS are currently in the deployment stage; however, many countries have already developed and installed the basic elements of the management systems. Traffic control algorithms are now beyond the stage of simple time of day signal plans as many of today's systems have adaptive control capabilities. The SCOOT and TRANSYT control algorithms are used to minimize the sum of average queues, examine the number of times vehicles have to stop, and determine the adverse effects this has on traffic in the region being controlled [Robertson et al., 1991]. The SCOOT system requires initial system parameter tuning in order assure that its models agree with traffic observations. Effective control can thus be established with these models, however periodic re-calibration is required to ensure the performance of the system [Clowes, 1982]. The SCOOT system is currently used in China and the United Kingdom.

In Taiwan, the Computerized Dynamic Traffic Control Systems (COMDYCS) were developed by the National Cheng-Kung University. The first system, COMDYCS-I sets a signal timing schedule based on prevailing traffic patterns and preset look-up tables. COMDYCS-III utilizes stepwise adjustment of signal timing, along with predefined traffic models, to logically decide on signal timing plans [Chen et al., 1991].

The Los Angeles Automated Traffic Surveillance and Control (ATSAC) system is a responsive control system used for signal light control [Rowe, 1991]. By comparing actual surveillance data gathered from the area to available model data, a signal timing

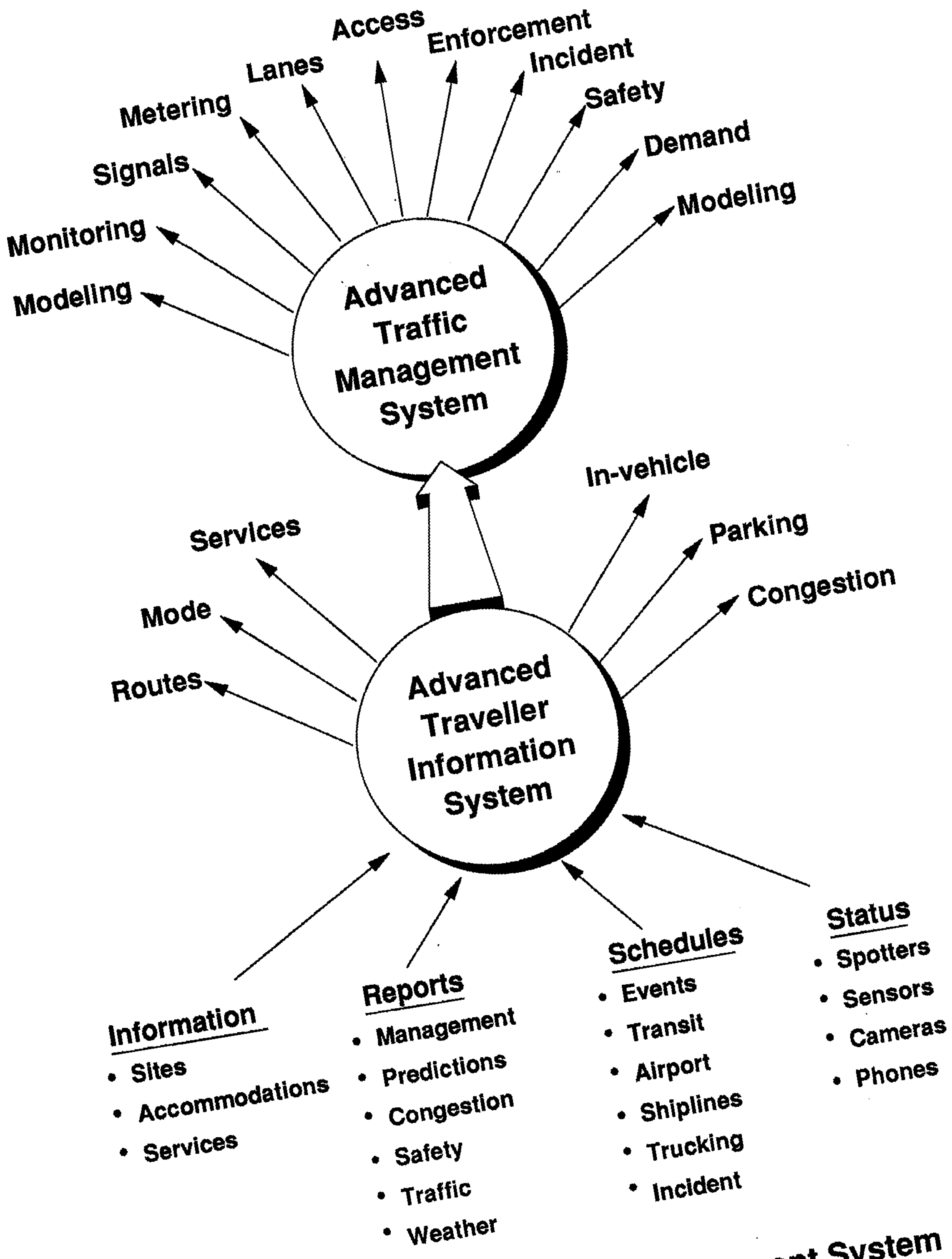

Figure 1. Advanced Traffic Management System

plan is selected. Future plans for ATSAC include development of an expert system which will assist in identifying non recurring congestion and provide assistance based on previous experience of the most effective methods of alleviating traffic for different categories of nonrecurring events.

The Sydney Coordinated Adaptive Traffic System (SCATS), developed in Australian but deployed in Hong Kong and Singapore, is one of the most advanced systems in the world. The SCATS program uses local computers to gather real-time traffic information which is relayed to a central regional computer. The central computer then chooses a skeletal signal timing plan based on the information gathered. However, parameters within these plans are adjusted dynamically by the central computer based on the real-time feedback at the local level to optimize traffic flow [Lowrie, 1982].

TERMINUS extends the philosophy of all these systems further by applying a neural network optimization model to actual traffic flow data to determine signal light setting that will produce the most efficient flow. Similar to SCATS it will utilize real-time data gathered at the local level to determine the signal light configuration. However, TERMINUS does not utilize a pre-programmed plan, unique configurations are determined in real-time for the current situation. This allows more adaptability in the system, because even the most thought detailed plans cannot account for unique situations that occur in every day traffic.

The two primary tasks of an incident management systems are detection and notification. Traffic incidents are typically reported by motorists or enforcement agencies. ATMS detection and response steps, however, are more automated. In 1996 Montreal's Freeway Traffic Management Systems (FTMS) will be operational. This system will utilize closed-circuit television cameras over a 35 kilometer corridor of the city's most heavily congested freeways for automatic incident detection and variable message sign control. FTMS will advise motorists of problems on their current routes allowing drivers to seek alternate routes [Case et al., 1991].

Variable message signs are the most commonly used form of Motorist Information Systems currently in use. However, more elaborate systems are currently being tested and developed. Japan's Road Automobile Communication Systems (RACS) and Advanced Mobile Traffic Information and Communication Systems (AMTICS) are vehicle on-board driver information systems. RACS and AMTICS utilize CD-ROM digital maps, as well as microwave and cellular links to local traffic centers, to display problems and alternate routes to drivers on monitors located inside the vehicle. Similarly, Europe's DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) and PROMETHEUS (Programme for European Traffic with Highest Efficiency and Unprecedented Safety) programs are on-board driver information systems that use network communication to aid motorists [French et al., 1991].

2 ATMS System Architecture

The application of artificial intelligence technology to Advanced Traffic Management Systems (ATMS) has been a focus at Georgia Tech for several years. Specifically, an ATMS blackboard architecture (Figure 2.) has been developed as the core of our AI traffic management research [Gilmore, 1990].

Blackboards are distributed problem solving architectures capable of supporting parallel expert systems, each focused on a separate area of expertise but contributing to overall system goals [Nii, 1986a and 1986b]. The main components of a blackboard architecture are the central blackboard data structure, the independent problem solvers or knowledge sources, and the control module. The central blackboard data structure is the hierarchical solution space for the problem solving process. It maintains the global information posted by knowledge sources that is required to formulate problem solutions.

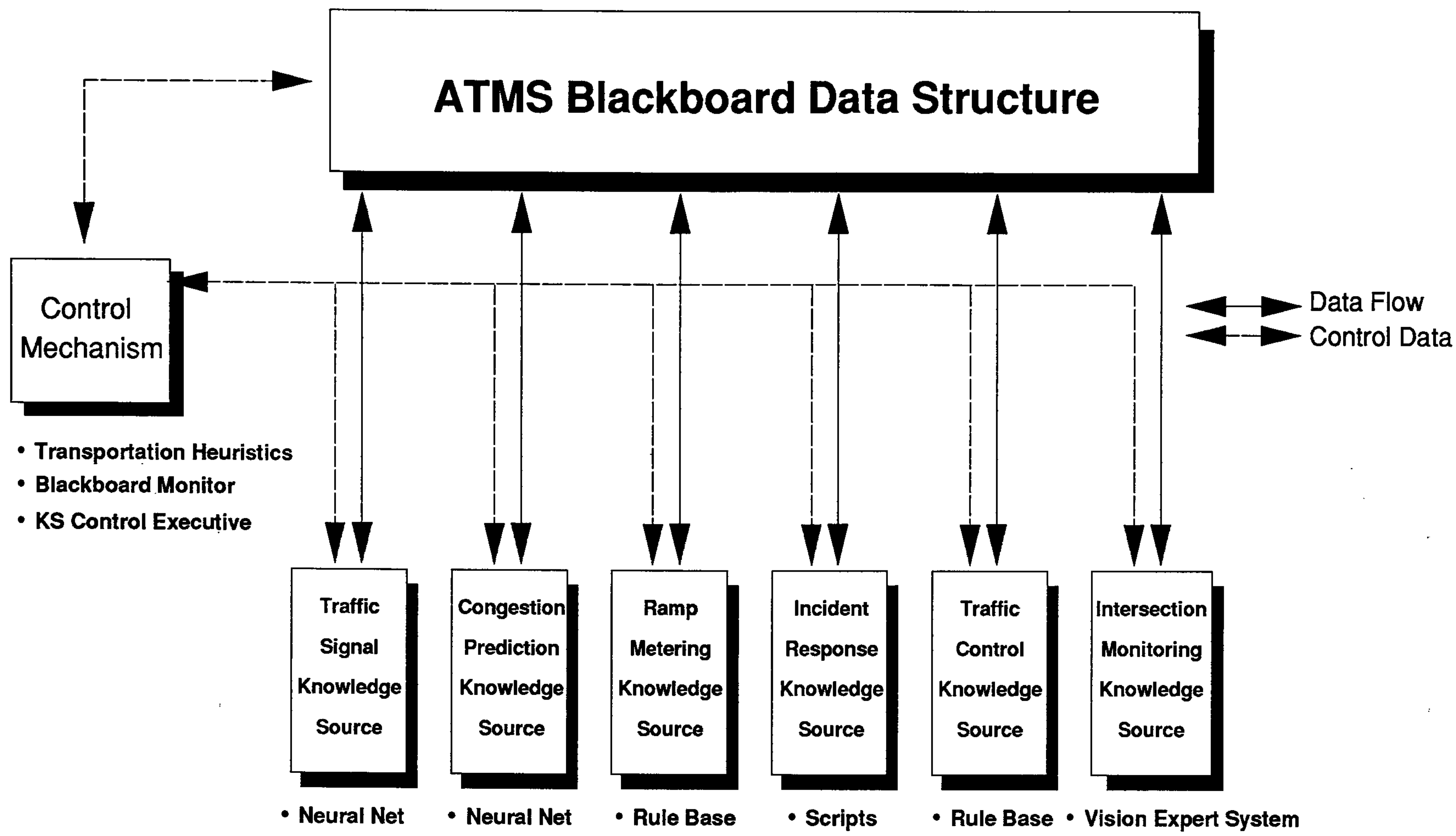

Figure 2 ATMS Blackboard System Architecture

Knowledge sources are the actual problem solving agents that are activated by blackboard data structure conditions. Each knowledge source has a specific area of application expertise (e.g., traffic signal coordination, incident management) that it contributes to the overall resolution of the data structure solution space. The design of a knowledge source is broad and may consist of heuristics, rules, algorithms, or any computerized form of expertise.

The blackboard control mechanism is comprised of problem solving heuristics, rather than application heuristics. Control is tasked with monitoring the status of the blackboard to ascertain if a knowledge source can contribute to the problem solution space, and if so, when the knowledge source should be activated/deactivated.

The ATMS blackboard architecture supports an infinite number of knowledge sources addressing a variety of traffic coordination tasks as discussed below.

2.1 Traffic Signal Knowledge Source

The traffic signal knowledge source is concerned with determining the signal light settings resulting in an efficient (versus optimal) flow of traffic at any given moment in time. Activation of this knowledge source may take two forms. First, a predetermined duration time may be employed to control the length of time a light may remain in its current state (e.g., green or the yellow red transition state) or the interval between assessments of the signal settings. The expiration of the time interval clock maintained on the blackboard data structure will trigger the activation of the traffic signal knowledge source.

Second, the posting of any form of any actual traffic incidents to the blackboard data structure requiring traffic flow adaptation will trigger the knowledge source. Third, the posting of traffic congestion predictions that may affect traffic flow will trigger the knowledge source when they exceed a dynamically adapting confidence measure. This measure weighs existing information on time of day, day of the week, affected traffic classification (e.g., rush hour, sporting events), and predicted congestion probabilities to determine the potential disruption on traffic flow should the hypothesis be valid.

Once activated, the traffic signal knowledge source examines the current street signal configuration on the blackboard data structure and determines the next array of signal light settings. The knowledge source utilizes a neural network model described in [Gilmore et al., 1992].

2.2 Congestion Prediction Knowledge Source

The congestion prediction knowledge source is tasked with examining current traffic flow information to infer whether the present conditions are indicative of pending traffic congestion. The knowledge source is activated when any one of several congestion measures (e.g., traffic queue increase, incident response impact) is present on the blackboard. The knowledge source may also be activated by the signal duration clock. In this mode of operation, an assessment of potential traffic congestion is made before the next set of signal light settings is generated by the traffic signal knowledge source.

Congestion is predicted through the use of a neural network model employing back propagation [Gilmore et al., 1993]. Trained using traffic flow data on actual evolving congestion, the knowledge source predicts the type of congestion, the affected streets and interstate highways, the amount of time until the congestion will peak, and the probability that its assessment is accurate. Each time the knowledge source is activated, it first examines whether a prediction currently exists on the blackboard. If so, the existing prediction is updated before any additional analysis occurs. This allows the system to weigh the merits of known predictions in determining whether current traffic patterns are actually separate or related events.

2.3 Ramp Metering Knowledge Source

Ramp metering is the control of traffic on to interstate highways through entrance ramp signal lights or variable message signs. The ramp metering knowledge source is activated when sensors indicate either the existence of congestion on the highway, or a queue build-up on the entrance ramp. As the entrance ramp queue may eventually create surface street congestion, effective ramp metering is also a congestion alleviating measure.

Ramp metering is achieved through the use of a qualitative reasoning knowledge base that constitutes the knowledge source. Modified to address the temporal realities of traffic flow, the ramp metering knowledge base posts timing sequences to the blackboard to govern on coming highway traffic.

2.4 Traffic Control Knowledge Source

Signal lights are the primary form of traffic flow control in an ATMS, but two other control medium exist. *Variable message* signs are slowly being incorporated into the transportation infra structure of many large metropolitan cities. Usually positioned on interstate highways, variable message signs provide information to motorists on highway conditions and traffic problems. Messages may provide drivers with information on surface conditions (e.g., Slow To 30MPH: Ice Detected Ahead), alternative routes to avoid traffic build-ups (e.g., Alternative Stadium Route: Take Exit 13 To Avoid Delays), and updates on traffic conditions (e.g., Accident At Williams Street Overpass: Please Avoid Left Lane).

Control of *reversible lanes* allows an ATMS to support existing traffic patterns, but also adapt to dynamic traffic events. The most common existing traffic patterns are morning and evening rush hours. Reversing the middle lane on a three lane road so that it contains traffic flowing into the city in the morning and traffic leaving the city in the evening will increase the overall city travel flow. Lane reversal may also be used to increase traffic flow around areas congested due to accidents. This is particularly valuable if the accident occurs in the only available lane (e.g., the northbound lane on a three lane road in which the reversible lane is currently southbound).

The traffic control knowledge source is activated when an incident is posted to the blackboard, when congestion is detected in an area containing variable message signs or reversible lane, or when a high confidence congestion prediction is hypothesized. Rules are used to determine the most appropriate response to the existing condition. The responses may range from reversing a lane to coordinating a series of variable message signs on a highway to alleviate traffic through secondary roads. The response may also be to take no action at the current time based on the knowledge source's inference that another ATMS knowledge source will be more effective.

2.5 Assessment Monitoring Knowledge Source

Assessment monitoring in an advance traffic management system will take two forms. First, key intersections will be monitored by additional street sensors and cameras to provide human operators with detailed information on individual intersection status. Knowledge-based computer vision systems will analyze intersection imagery to verify traffic flow estimates, identify the type of congestion present, and ascertain the existence of any unreported traffic incidents. Second, an assessment of the traffic congestion predictions in various areas of the transportation network will be performed. Unsatisfied predictions will be re-evaluated and removed from the blackboard if they prove to be invalid.

The assessment monitoring knowledge source is activated by inconsistencies in traffic patterns (e.g., green signal without traffic flow) and congestion predictions. Utilizing a semantic frame representation, the knowledge source will analyze the blackboard data in order to determine incidents and events affecting traffic flow. Detected problems will be posted to the blackboard for resolution by the appropriate knowledge source.

2.6 Incident Knowledge Source

The Incident Knowledge Source is a rule-based approach to incident management. An incident is an event that restricts traffic flow or requires the routing of safety vehicles. Several types of incidents may occur in a traffic management system. First, accidents involving one or more vehicles will clearly be traffic incidents with a major impact on traffic flow. Second, road construction involving the narrowing of a road or highway will result in restricted traffic flow. Third, safety vehicle response (i.e., police, fire, or emergency vehicles) to accidents, fires, or emergencies will require special vehicle routing that will adversely effect traffic flow.

The knowledge source is activated when an incident is posted to the blackboard. Rules first determine the safety vehicle routing requirements and post updated road priorities to the blackboard for use by the traffic signal knowledge source. These priorities will result in increased traffic flow for the streets on which the safety vehicles are traveling. Traffic flow around the incident area is addressed next. Rules are used to the determine most efficient methods of alleviating traffic in the area. This results in a posting of modified weights and/or energy functions to the blackboard for use by the traffic signal neural network.

3 Summary

The research program described herein is an ongoing endeavor at Georgia Tech as part of the University's Transportation Technologies Center. Simulation results in the area of intelligent traffic signal control and congestion prediction have indicated the improvements possible through an integrated blackboard approach toward the traffic management problem. Our workshop presentation will describe the ATMS blackboard architecture, detail the application domains and triggers for each traffic knowledge source, present results of the current system, and describe the areas of future development. Future plans include the adaptation the ATMS blackboard to address the special transportation requirements Georgia will face during the 1996 Olympics in Atlanta.

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