

1. Report No. TTI/ITS RCE-95/01		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Real-Time, Multimodal Traffic-Adaptive Diamond Interchange Control System: Laboratory Demonstration				5. Report Date June 1995	
				6. Performing Organization Code	
7. Author(s) Steven P. Venglar and Thomas Urbanik II				8. Performing Organization Report No.	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. DTFH61-93-X-00017-004	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Interim: January 1994 - December 1994	
				14. Sponsoring Agency Code	
15. Supplementary Notes Research supported by a cooperative agreement from the Federal Highway Administration, ITS Research Center of Excellence Program. Additional support for this research is provided by the Texas Department of Transportation, the Texas Transportation Institute, and the Metropolitan Transit Authority of Harris County (Houston METRO), Texas. Research Project TM-01: Develop Real-Time, Multimodal Traffic-Adaptive Diamond Interchange Control System					
16. Abstract Components of the transportation system that are most susceptible to the negative effects of congestion are those that link or transition between modes or facilities. Diamond interchanges provide a controlled means of accessing freeways from the arterial street system and from the freeway. Physically, diamond interchanges are made up of two intersections along the arterial street that are formed at intersections with freeway ramps. The diamond interchange offers the unique opportunity to integrate many innovative technologies into a system that is small enough to be manageable, yet complex enough to present a challenging control environment. Developing a real-time, multimodal, traffic-adaptive interchange control system is a research objective of the Texas A&M Intelligent Transportation Systems (ITS) Research Center of Excellence Program at the Texas Transportation Institute.  This research effort will integrate a variety of technologies into a single control system that will increase traffic performance and demonstrate ITS concepts for advanced traffic management systems. Through the use of video imaging equipment, traffic information processing, and real-time optimization and control, road users will experience less delay, less congestion and fewer safety problems at diamond interchanges.					
17. Key Words Real-Time Traffic Control; Real-Time Optimization Video Imaging; VMEbus computer system; Open Architecture Controller; Diamond Interchange Control; PASSER III; Dynamic Lane Assignment			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 30	22. Price



**REAL-TIME, MULTIMODAL TRAFFIC-ADAPTIVE DIAMOND INTERCHANGE  
CONTROL SYSTEM: LABORATORY DEMONSTRATION**

by

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Research Report 95/01  
Research Study No. 72350  
Research Project TM-01: Develop Real-Time, Multimodal Traffic-Adaptive  
Diamond Interchange Control System

Sponsored by the  
Texas A&M ITS Research Center of Excellence

June 1995

TEXAS TRANSPORTATION INSTITUTE  
The Texas A&M University System  
College Station, TX 77843-3135



## ACKNOWLEDGMENTS

The Smart Diamond project was successfully developed and demonstrated in the laboratory because of the dedicated efforts of many individuals. Project participants are listed below.

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# TABLE OF CONTENTS

LIST OF FIGURES .....	viii
SUMMARY .....	x
INTRODUCTION .....	1
Background/Purpose .....	1
Project Partners .....	3
SMART SYSTEM DESIGN .....	5
Video Imaging Equipment .....	6
VMEbus Computer System .....	8
Database .....	8
PASSER III Optimization Manager .....	10
Controller Manager .....	11
Incident Detection Algorithm .....	11
Bus Priority Algorithm .....	12
Other Features .....	12
NEMA Controller .....	13
Lane Assignment Sign and Hardware .....	13
Simulator .....	14
LABORATORY DEMONSTRATION .....	15
EXPECTED BENEFITS .....	17
REFERENCES .....	19



## LIST OF FIGURES

Figure No.	Page
1. Diamond Interchange .....	2
2. Smart Diamond System Design .....	6
3. Data Exchange Within the Smart System .....	9



## SUMMARY

Real-time adaptive signal control has the potential to increase the operational efficiency and safety of existing roadways. Unfortunately, traffic control equipment used in the past is neither capable of generating adequate traffic descriptive information nor communicating effectively as a system. Technological advances in video imaging and open architecture signal controllers have the potential of overcoming these limitations and creating the necessary infrastructure for real-time control. An example of real-time control of signals and lane use is the Smart Diamond, a development project underway at the Texas A&M ITS Research Center of Excellence. Phase I of this research has developed the system design and constructed the system to the point of laboratory demonstration.

One of the more common types of interchanges, especially in areas with limited right-of-way, is the diamond interchange. Due to the complexity of traffic movements occurring within urban interchanges and increasing levels of demand, many diamond interchanges are experiencing serious congestion. The closely-spaced traffic signals with high-volume turning traffic create a complex control scenario. The diamond interchange offers the unique opportunity to integrate many innovative technologies into a system that is small enough to be manageable, yet complex enough to present a challenging control environment.

Research in diamond interchange control, documented in this report, integrates a variety of technologies into a single control system that will increase traffic performance and demonstrate ITS concepts in advanced traffic management systems. Video imaging equipment is used to provide input to a VMEbus computer system. Contained within the VMEbus computer system are programs to sort the input; run an optimization program that uses PASSER III, a diamond interchange optimization program, to make signal and lane assignment decisions for optimal interchange control; and, download the optimal settings to signal control equipment and lane assignment signs. A simulator was used during laboratory testing to “close the loop” by providing real-time traffic input and responding to the signal and lane assignment outputs from the VMEbus computer system.

Through the use of video imaging equipment, traffic information processing, and real-time optimization and control, road users will experience less delay, less congestion and fewer safety problems at diamond interchanges. In later project phases, the Smart system will be installed in the field and evaluated for improved traffic performance over existing control methods. Smart Diamond development will eventually incorporate incident detection, transit priority, railroad control signal integration, and links to existing arterial street signal systems for optimal area traffic control.

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## INTRODUCTION

Trends in the transportation engineering profession are leading toward systems integrated across modes and have the potential for dynamic response to real-time conditions. Mandated by legislation such as the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991, transportation professionals are beginning to plan and implement systems that provide mobility more efficiently and safely. The result is an organized approach to making more productive use of the existing infrastructure. Efforts include all forms of low technology and high technology enhancements to systems operated by existing transportation providers ranging from state departments of transportation to air and rail carriers.

Unfortunately, we may not realize benefits of current technologies that relate to transportation problems because of the funds necessary to pursue high technology development and the risks of unproven applications. As part of a nationwide initiative to further transportation efficiency and safety goals through technology, the Research Center of Excellence program enables researchers in centers around the United States to apply technologies that can enhance the operation, management, and integration of multiple modes of the U.S. surface transportation system. The Texas A&M Intelligent Transportation System (ITS) Research Center of Excellence is conducting such research in public transportation services, traffic management services, international border transportation services, institutional and nontechnical issues, and technology integration issues.

Components of the transportation system that are most susceptible to the negative effects of congestion are those that link or transition between modes or facilities. In roadway networks, interchanges are the links between freeway and arterial streets. One of the more common types of interchanges, especially in areas with limited right-of-way, is the diamond interchange. Due to the complexity of traffic movements occurring within urban interchanges and increasing levels of demand, many diamond interchanges are experiencing serious congestion. The closely-spaced traffic signals with high-volume turning traffic create a complex control scenario. The diamond interchange offers the unique opportunity to integrate many innovative technologies into a system that is small enough to be manageable, yet complex enough to present a challenging control environment.

Research in diamond interchange control, documented in this report, integrates a variety of technologies into a single control system that will increase traffic performance and demonstrate ITS concepts in advanced traffic management systems. Through the use of video imaging equipment, traffic information processing, and real-time optimization and control, road users will experience less delay, less congestion and fewer safety problems at diamond interchanges.

## BACKGROUND/PURPOSE

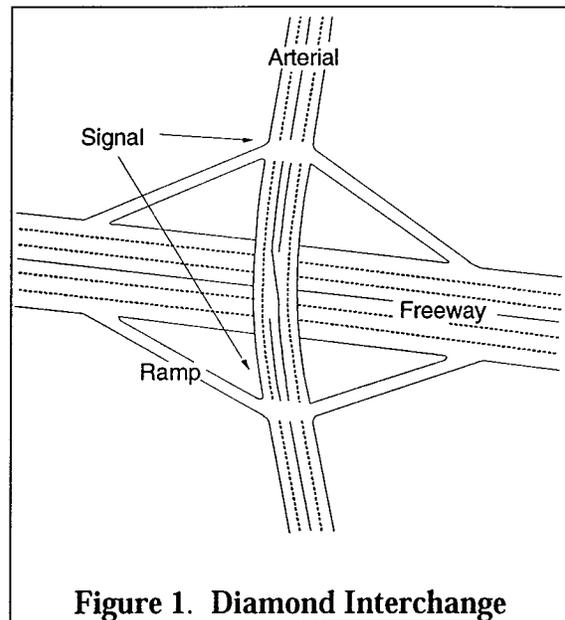
The integration of state-of-the-art technology into the monitoring and control of all modes of transportation has created the ITS concept, formerly known as the Intelligent Vehicle-Highway System (IVHS) concept. ITS technologies are currently being developed and tested for applications such as weighing vehicles while in motion, automatic toll collection, and freeway surveillance, just

to name a few [1]. One area that will undoubtedly see benefits through real-time data collection, storage, and analysis is traffic control at intersections. In particular, major intersections, including diamond interchanges, must operate successfully for varying demands throughout the day or motorists will experience excessive delay and possible safety problems.

The geometry of a diamond interchange involves two intersections, created by junctures with freeway exit and entrance ramps, along an arterial street in close proximity to one another (see Figure 1). Several types of intersection control strategies exist for these interchanges -- each operating successfully with particular quantities and balances of traffic demand [2]. Some variations of standard control strategies, known as three-phase strategies, treat the intersections more independently and have lower road-user delay than most alternative timing strategies. Other strategies, labeled four-phase, treat the intersections as one system and are appropriate for situations where queuing between the intersections becomes a concern and/or an imbalance in ramp volumes exists. Modern intersection controllers can change control strategies according to the time of day as daily traffic conditions are known to change, but they are not sensitive to day-to-day fluctuations in demand or overall increases in demand as an area is developed. The lack of flexible control created by timing plans based on historical traffic volume counts can lead to inefficient signal operations that typically cause excessive delay and queuing problems.

Common practice for timing diamond interchanges involves data collection during the peak hours of a "typical" day of the week and, time permitting, a cursory examination of traffic volumes during off-peak periods and on weekends. Engineers analyze the collected information by hand or use an off-line computerized optimization program and include the results in a report. Signal technicians translate the report recommendations as signal settings and make the changes at the signal controller. The process produces neither a timely solution nor a solution that is responsive to changes in traffic patterns, especially since agency budgets permit the process only once every couple of years. The most advanced traffic control systems currently in widespread use are traffic actuated only for individual intersections. Even these systems do not communicate well between signals on one street, much less in a network. Evolution toward centrally controlled systems occurred in the recent past, but these systems often only enable efficient switching between several pretimed network strategies.

Changes to the geometry of a diamond interchange occur even less frequently than signalization changes, due in no small part to the fact that these projects must compete with all other projects for which an agency is responsible and within the budget constraints of that agency. Whereas such



improvements may take place once every 10 or 15 years, growth in the area served by the interchange can cause drastic changes in traffic patterns and volumes in as few as two or three years. Results can be as minor as lane designation that is not ideal for current traffic patterns and as major as a complete shortage of interchange capacity. An improved, "Smart" diamond controller is one positive step toward solving the shortcomings of existing controllers and interchange evolution. The purpose of Smart Diamond research is to develop an advanced traffic controller that uses the latest data acquisition, processing, and computer tools in a real-time environment to provide safe and efficient traffic control.

## **PROJECT PARTNERS**

Cooperation between public research organizations and private companies has been essential throughout project development. Representatives from the Texas Transportation Institute (TTI) and the Texas A&M University System (TAMUS), Louisiana State University (LSU), Automatic Signal/Eagle Signal (Eagle), and Condition Monitoring Systems (CMS) contributed to the project. National Sign and McCain Traffic Supply also furnished equipment.

The Texas Transportation Institute organized the Smart Diamond development effort. Participants in the project brought management, communications, traffic and transportation engineering, and computer science experience to the project. TAMUS members of the team participated in electronics and computer science for the project, contributing to the database design and coding for the Smart system. LSU used innovative electronics technology and traffic engineering with the support of National Sign and McCain Traffic Supply to develop signs and signals for the Smart Diamond. Eagle used electronics and traffic engineering experience to integrate existing traffic control methods and improve the reliability of the Smart system hardware. The Texas Department of Transportation, also a partner in the funding of the Texas A&M ITS Research Center of Excellence, provided signal control cabinet hardware and signalization expertise. Finally, CMS brought video imaging technology (previously used in the defense industry) to the project.



## SMART SYSTEM DESIGN

Existing diamond interchange signalization practices and facility improvements often fail to accomplish the long-term objective of efficient and safe operations simply because they are not sensitive to the current and changing demands of traffic and transit. By design, the Smart system is inherently capable of monitoring and responding to real-time transportation needs. The Smart Diamond controller automates the interchange space and green time optimization process and applies the computed settings. Both the system and the controller are "open" architecture designs. System operators can add modules to the controller for additional computational, data storage, and/or communication purposes. Similarly, operators can add components of the Smart system for new functionality or subtract components unnecessary for an application. For instance, a Smart system installed in a location without a nearby railroad intersection would not require the communications and algorithms designed to optimize interchange performance during train passage (though the capability to handle this scenario will be built into the Smart system).

The Smart Diamond advanced controller system design includes video imaging equipment, a Versa-Module Eurocard (VME) bus computer system and software, a standard National Electrical Manufacturer's Association (NEMA) controller and signal hardware, a simulator resident on a personal computer, fiber optic lane assignment signing, and sensing and communications capabilities (see Figure 2). Software and hardware required to connect each of these components together were also necessary.

The system inputs include the data made available by the video imaging equipment and, in the future, transit detection systems and railroad passage sensors. The database in the VMEbus computer system receives this information and sends it to the optimization manager, or expert system. At the highest-order decision level, the expert uses current and historic traffic trend information to determine the optimal phasing strategy for the diamond. Then, the expert compares demand within an interchange approach to compute lane assignment and demand across approaches to determine signal settings. The Smart system safety checks the signal setting and lane assignment configurations and passes them to the signal controller and the lane assignment signs. The rest of this section discusses the components of the Smart system.

## VIDEO IMAGING EQUIPMENT

Video imaging equipment serves as the front-end sensing mechanism for the Smart Diamond interchange controller. Whereas controllers today primarily use loop detectors (wire loops laid in sawcuts in the pavement) as sensors, the Smart Diamond will use video cameras and image processing software to detect and classify vehicles in the traffic stream. Beyond providing the

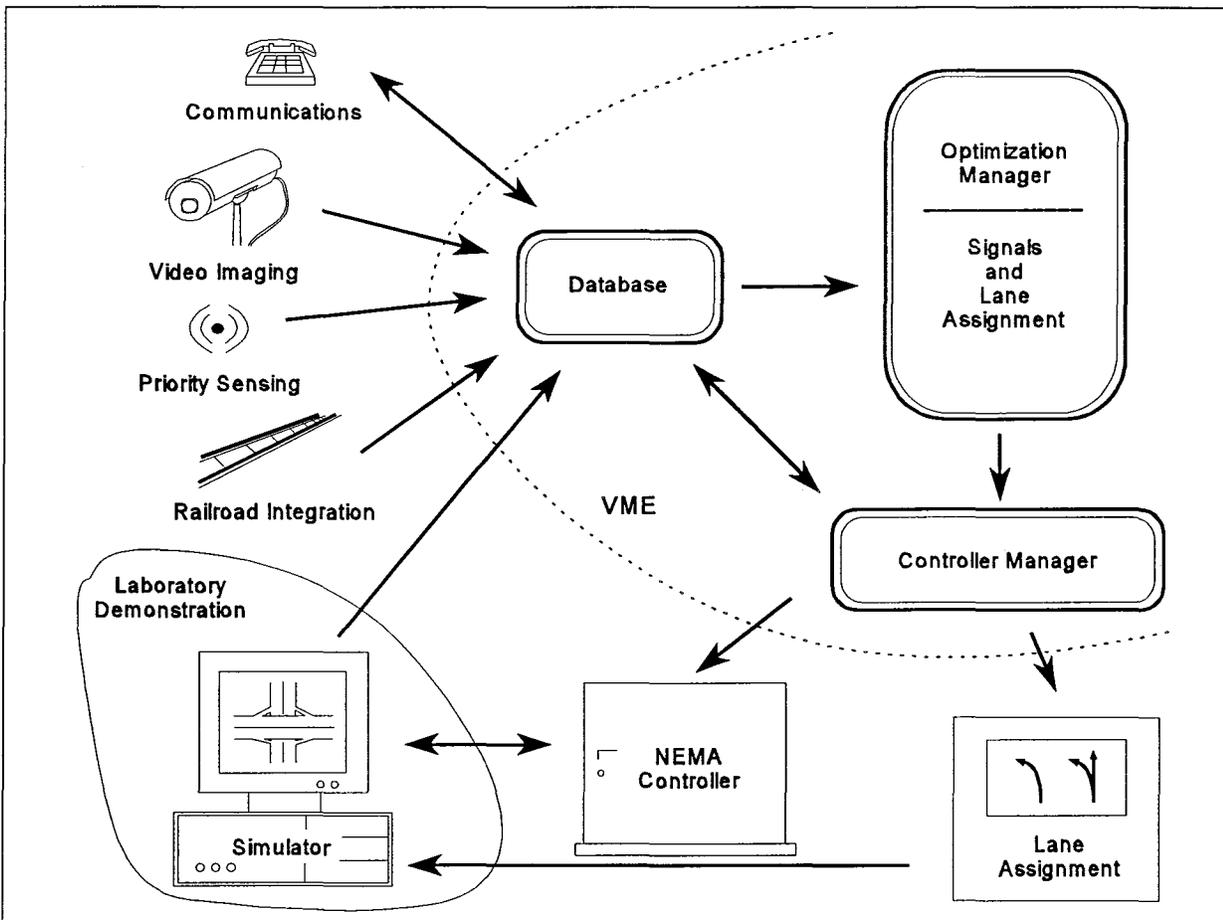


Figure 2. Smart Diamond System Design

point-type detection information provided by loops, such as vehicle presence and volume, the video imaging equipment can track vehicles approaching the interchange and provide profiles of traffic density on the interchange approaches. Such "wide-area" detection information provides the Smart Diamond controller with more accurate and descriptive information than has previously been available.

The video detection relies on the fact that the orientation of the lanes on the roadway remains constant (given constant camera location) despite the number and type of vehicles on the roadway. Rather than analyzing data in two dimensions, the video system allows one-dimensional data processing by considering intensity variations along scan lines in a lane (parallel to the lanes). The equipment identifies a region-of-interest (ROI) as a region where a vehicle exists, despite its type. After all vehicle ROIs in all lanes are found, the system uses a classification procedure employing vehicle length differentiation to separate cars and trucks in the traffic stream.

Condition Monitoring Systems is the private company developing the video system, known also as the MOBILIZER system. Beginning in June 1994, researchers from Texas A&M University worked with CMS to develop a vehicle classification algorithm for the MOBILIZER system. In the Smart Diamond project, the MOBILIZER system will send vehicle mix information to the Smart controller and keep the controller informed of the approach of heavy vehicles. Because the MOBILIZER system also tracks vehicles, the information sent to the controller can initiate controller response to heavy vehicles, perhaps as signal extensions, to minimize the capacity and flow effects of heavy vehicles in the interchange.

CMS also began a development effort to enhance the MOBILIZER system's ability to provide the detailed information required by the Smart controller. In previous applications, CMS had used the MOBILIZER system only on uninterrupted facilities, such as freeways. The signals and nature of diamond interchanges create an interrupted flow condition whose analysis information requirements are different from those of freeways. Specifically, CMS began modifying the video imaging system to count vehicles and group them according to the turning movements they made at the interchange. CMS also created algorithms to report the length of vehicular queues at the intersections of the interchange. This information served three primary purposes. First, converted queue counts provided stopped delay information to track the performance of the Smart system. Second, the software that optimizes the signal settings in real time included the queue lengths. And, the Smart controller used the information on queue spillbacks in the interior of the interchange to identify safety problems to minimize. The project team anticipates that CMS will deliver the MOBILIZER system in early 1995.

A high rate of accurate, real-time detection from video imaging is necessary to ensure the reliability and completeness of the information being input into the Smart Diamond interchange control system. The MOBILIZER video system developed and enhanced by CMS for work with the Smart Diamond provides this information source. Though the diamond interchange simulator supplies this information during the laboratory demonstration phase, the video imaging equipment will play a major part in the field demonstration of the Smart Diamond controller.

## **VMEbus COMPUTER SYSTEM**

The VMEbus computer system, operating an OS-9 operating system, serves as the communication, data storage, and analysis hub of the Smart system. The VME platform is the one being used in the Advanced Traffic Controller (ATC) as represented by the Caltrans/City of Los Angeles 2070 specification [3]. It receives the real-time traffic data from the video imaging equipment, analyzes operational alternatives for both signal setting changes and lane assignment changes, identifies the optimum combination of settings, checks the settings for safe use, and downloads the settings to the NEMA controller and lane assignment signs. The research team purchased the VME bus system from MATRIX Corporation in July 1994 and connected to the Internet in August 1994, enabling convenient file transfer and multi-user access to the system.

### **Database**

The researchers organized the database in two parts: a real-time database of current conditions and parameters, and a historical bank of stored data. The real-time component of the database utilizes data modules that enable read and write access to an active memory buffer that the input from the video imaging equipment continuously updates. The historical, disk-access portion of the database uses existing database software for OS-9 known as Sculptor. Access routines for this software have been custom-developed. Real-time traffic descriptive data is made available to an optimization routine to make signal phasing and lane assignment control decisions.

At the heart of database communication are information transfer processes, also known as data exchange modules (DEMs). DEMs synchronize the activities of the different modules in the Smart system so that no module attempts to read information before another module has written or prepared that information. The DEMs also maintain the data generated by the video imaging equipment and other modules and pass this information to the modules requiring the data as input.

In July 1994, researchers from TTI and TAMUS finalized the list of data elements that must pass between the database, optimization manager, and controller manager within the VME. This list enabled the design of DEMs to accommodate the information exchanges, and extensive reliability testing of the data exchange process began in September. The data exchange procedure design for the Smart Diamond has proven flexible and robust, and the database is capable of evolving and expanding with the Smart system. Figure 3 illustrates all of the external and internal database links. With the large quantities of real-time information being sent in by the video imaging equipment and the analysis processing required by the Smart controller, concern was expressed that the VME processors (two Intel 486s) may not be capable of handling the processing demands of the system. Fortunately, the open architecture of the VME allows the addition of parallel processors as required.

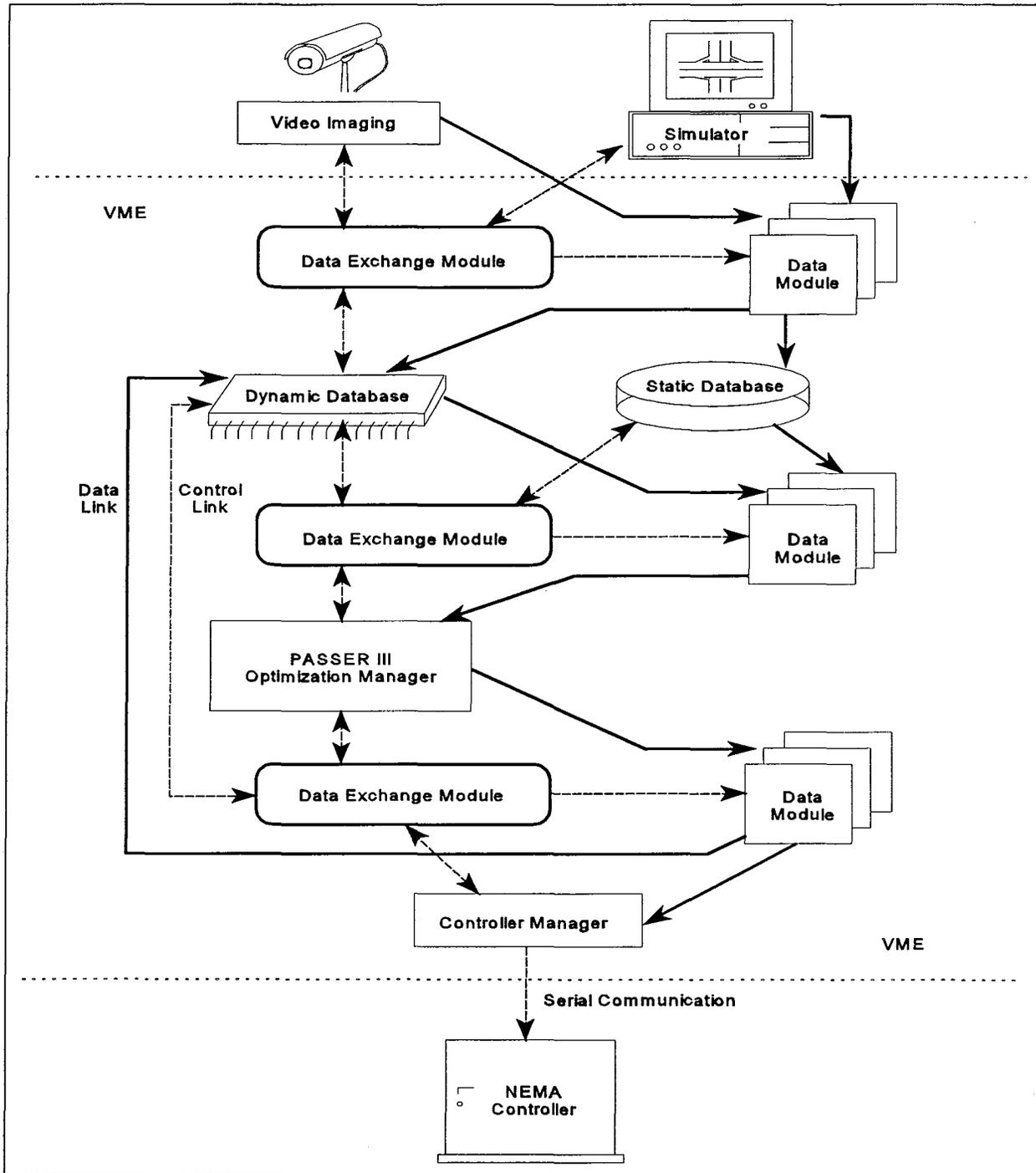


Figure 3. Data Exchange Within the Smart System

## **PASSER III Optimization Manager**

The PASSER III program [4] serves as an analytical engine for the Smart system. TTI developed PASSER III in the late 1970's as an off-line optimization program for traffic engineers examining diamond interchange operations. Given volume and roadway descriptive information, the program selects the timing strategy that produces the least vehicular delay for the diamond. TTI modified the program to produce output required for the Smart system and then installed it on the VME to run in real-time. Researchers then developed an expert system, known as the PASSER III Optimization Manager (P3OM), to assemble data as input to PASSER III, identify queuing or delay problems in the interchange, find a solution by performing iterative analyses using PASSER III, and recommend an optimum solution.

Researchers developed the first generation of the P3OM between May 1994 and September 1994. In this form, the P3OM analyzed existing conditions and developed a maximum of ten alternatives using different phasing and lane assignment alternatives. The P3OM then selected the alternative producing the least delay for implementation. This generation of the P3OM optimized using only two of the five optimization strategy options of the PASSER III program, three-phase lag-lag operation and four-phase lead-lead operation. Logic problems in switching between these two strategies in the NEMA controller caused delays when transitioning between the two. To solve the problem, the Optimization Manager used all of the three-phase options of the PASSER III program (lead-lead, lead-lag, lag-lead, and lag-lag), and the four-phase option was set aside. This solution solved the logic and transition delay problems and permitted use of four optimization alternatives of PASSER III instead of the two used previously.

In October, researchers also redesigned the previously rigid structure of the P3OM to be more flexible and responsive to dynamic, real-time traffic conditions. The current form of the P3OM performs seven analytical steps to determine optimum timing strategy, phase settings, and lane assignment at a diamond interchange. The seven steps include:

1. Read input information from the database;
2. Model the existing conditions within the interchange;
3. Identify "hot spots," or problem locations;
4. Determine potential temporal (phasing) and/or spatial (lane assignment) solutions;
5. Model the solutions to select those alternatives that improve operations;
6. Iterate steps 3 through 5 until an optimum solution is found; and,
7. Pass the phase settings and lane assignments to the controller manager for application.

The final function of the P3OM is a self-check to decide whether its function is warranted. If the optimized cycle length for the last two periods is less than 50 seconds, the P3OM assumes that the interchange will operate efficiently (i.e., during late night hours) using just the actuated NEMA controller, and the optimization manager "sleeps" until the next optimization period.

## **Controller Manager**

The Controller Manager downloads optimum settings computed by the P3OM to the NEMA controller. The Controller Manager communicates with the NEMA controller using the communications protocol developed by the controller manufacturer, Automatic Signal/Eagle Signal. Automatic Signal/Eagle Signal worked with the development team on an "as required" basis between September and December to determine the best means of downloading settings to the controller and the best configuration for the controller for flexible diamond interchange operations. Information exchanged between the Controller Manager, which resides on the VME system, and the NEMA controller, called the EPAC300, included time-of-day, phase setting maximums, and some controller configuration settings.

The Smart system used the built-in capability of the EPAC300 to alter phase sequence or settings by time of day to alter the signal settings in real time. The system uses time-based events to change between phasing strategies as conditions warrant a change. Transition from one phasing strategy to the other involves downloading a new "time," which triggers the initiation of the new strategy. The system accomplishes these steps using the Automatic/Eagle communications protocol, a version of which has been developed for this diamond interchange application on the VME.

## **Incident Detection Algorithm**

Incident detection is an essential component of the control system as incidents in congested interchanges require special attention. They can easily paralyze the traffic movements and cripple the control in the interchange (effects can rapidly propagate through the freeway and the adjacent streets). The timely and accurate detection of incidents and deployment of appropriate control strategies would provide significant benefits in reducing vehicle delay and maximizing vehicle/person movements in the diamond interchange area.

TTI researchers applied fuzzy logic and its application concepts to develop an incident detection algorithm for diamond interchanges. In the Smart system, fuzzy logic resolves uncertainties associated with the complex and nonlinear data supplied as inputs to the detection algorithm. The researchers conducted background review for the fuzzy logic rule base to be used in the algorithm in May and June. Then they developed and translated incident scenarios into rules in July and August. The actual incident detection algorithm was organized and flowcharted in the next few months, and the researchers translated the algorithm into C language code in December.

The algorithm utilizes multiple data elements as its input since the real-time Smart system obtains those measures through the extensive video surveillance system. These measures include: occupancy, queue length, speed, turning movement, saturation flow rate, and number of lane changes measured at each intersection approach of the diamond interchange. The algorithm implicitly looks for the abrupt changes in each measure caused by the incident by comparing the current values against the past five minute average values. Measures can be added or deleted as needed, adding flexibility to the algorithm.

The algorithm consists of four component inference modules. Respectively, these modules monitor the normality of traffic to determine the possibility of an incident, confirm incident occurrence and location, determine the severity of the incident, and check for a return to normal conditions. After an incident is cleared, the detection algorithm automatically resets itself.

### **Bus Priority Algorithm**

One unique aspect of the Smart controller is that it can grant signal priority to transit vehicles. This is not a novel concept [5], and custom software and hardware have been used for this purpose, but to date achieving it has been difficult. Because the capability to grant selective priority to transit is built into the Smart controller, only the sensing hardware to identify transit vehicles in the traffic stream is necessary. Another advanced option for the bus priority algorithm is its ability to optimize signal operations for person delay rather than vehicle delay. Essentially, this means that rather than optimizing based on how long vehicles are delayed at the intersection, optimization is based on where the most people are delayed, be they in automobiles or on transit vehicles. In effect, transit vehicles have more “weight” because they contain more people than individual automobiles. Of course, to achieve person-based optimization in the field, researchers must develop some means of communicating the number of passengers on the bus to the roadside controller.

Researchers developed the bus priority algorithm in November and December 1994. The formulation of the algorithm considers several factors, including bus schedule adherence, queue lengths in the interchange, person-delay savings due to priority, and vehicle delay impacts. The algorithm compares all these factors against boundaries to determine whether to grant priority. The algorithm also contains some advanced features, including green time compensation for shortened phases that provide the bus priority, treatment of multiple buses, and overriding priority in emergency situations. Coding and testing of the algorithm will take place in the first part of 1995.

### **Other Features**

A number of additional sensing technologies and information processing techniques are being employed in the advanced diamond interchange controller. The flexibility and functionality are being built into the system to incorporate a variety of features in the future, including heavy vehicle identification and treatment, signal integration with arterial street systems, and alternative signal operations strategies during at-grade freight rail and light rail transit passage adjacent to the diamond interchange. Each of these factors has been included as an addition to the system architecture because each can have a significant impact on interchange operations.

If the developed system is truly “smart,” it must consider the influences of these factors and optimize diamond operations accordingly. Additionally, the designers must integrate the Smart system into the roadway network of which the diamond interchange forms a part. As the project continues past the laboratory demonstration phase, the system will achieve additional functionality in these areas.

## **NEMA CONTROLLER**

The use of a standard traffic signal controller in the Smart system eliminated the extensive development effort required to develop and test this component. The NEMA controller performs the basic signal timing functions at the diamond interchange. Automatic Signal/Eagle Signal supplied an EPAC300 model controller for the diamond interchange control system. The controller is a traffic-actuated device, thus the controller settings downloaded from the VME are maximum settings rather than fixed-time settings (i.e., signal control is responsive to traffic rather than clock-based). The Controller Manager software in the VME bus monitors the status of the NEMA controller and records the status in the database. The fact that the EPAC300 is a reliable, tested piece of equipment also reduced potential liability problems. Eventually, Smart Diamond evolution will integrate the NEMA controller functions into the VME.

Between April and November 1994, Eagle worked with TTI to develop the necessary communication messages using the Eagle protocol. The system used time-of-day events, which are controller changes activated by a clock, to switch between different phasing plans. Originally, the changes were between three-phase lag-lag control and four-phase control. Researchers later discovered that controller logic structures prevented easy transition between these two alternatives. As a solution, only three-phase strategy combinations (lead-lead, lead-lag, lag-lead, and lag-lag) remained in use after November 1994. Not only were the logic problems overcome, but the use of only three-phase strategies also allowed more flexible use of the expert system's optimization capabilities, since it could now use four of PASSER III's phasing strategy alternatives instead of two.

Eagle is currently developing a 16 phase controller. This evolution in controller technology will make the NEMA controller itself more flexible and should provide a simplified method of transitioning between three-phase and four-phase operations. When the new controller's development is complete, it will be integrated into the Smart system. With four-phase transitioning easily permitted using the new controller logic, all of the phasing alternatives of PASSER III will be implementable in real-time.

## **LANE ASSIGNMENT SIGN AND HARDWARE**

The P3OM sends real-time, optimized settings to the NEMA controller, and it also sends lane assignment settings to the database (which resides in the VME). The registering of lane assignment changes activates a program running on the VME, and a signal with the appropriate lane designation is sent to a fiber optic lane assignment sign.

LSU, a partner in the Texas A&M ITS Research Center of Excellence, used advanced electronic communication technology with the fiber optic sign to control dynamic lane assignment within the diamond interchange. The fiber optic sign, provided by National Sign, can display a variety of lane combinations. The sign has a total of 14 different fiber bundles illuminated by individual lamps. Each lamp is rated for 5,000 hours and receives its power from a transformer that steps the 110 line voltage down to 12 volts. Since lamp failures may produce an undesired sign indication, it is

important to detect failures and use an alternate bundle to power the sign. If the controller detects a lamp failure, the system can log an alarm in the traffic signal cabinet.

If traditional cabinet sign control was used, individual conductors would have to be run for each transformer. However, researchers developed a novel sign control module. This module contains relays, current sensors, and an Echelon PLC-10 module. The PLC-10 module controls the load switches, monitors the current sensors, and actuates backup lamps when necessary. The communication technology (spread spectrum power line communication over the 110 volt power cable) can also be used to power and indicate active signal displays for traffic signals.

## **SIMULATOR**

Before placing the Smart system at an interchange, it is necessary to assemble and test the system in the laboratory. The laboratory demonstration phase uses a real-time computer simulation of traffic to provide the traffic descriptive data that, in the field environment, will be provided by the video imaging equipment. The simulator receives signal outputs from the NEMA controller and returns vehicle detections, traffic performance measures, and truck identification to the VME bus. The researchers accomplished connecting between the NEMA controller and the traffic simulator using hardwired voltage transformers and logic software. Existing simulation software could not perform all of the functions required by the simulation for the Smart Diamond, so the researchers developed custom software. As a product of that effort, the Texas Transportation Institute developed a stand alone simulation package known as TexSIM [6]. First versions of the simulator were running as early as July, and the simulator was generating the data that the video imaging equipment will supply in the field in September. The simulator was fully integrated into the Smart system in November and December for the laboratory demonstration.

The real-time version of TexSIM interacts with the NEMA controller by placing detector calls and responding to the controller responses. This closed system provides a unique opportunity to examine the traffic response to control strategies developed by the Smart Diamond system. The simulator can also simulate the presence of buses, the impacts of bus priority, and the presence of freight and light rail adjacent to the interchange.

## LABORATORY DEMONSTRATION

At the close of 1994, the laboratory demonstration phase of the project reached its conclusion. The modules that make up the system - including the simulator, VME bus computer, NEMA controller, signal display, and lane assignment sign - were functioning independently and as a system.

During the laboratory demonstration in December 1994, the simulator served as the input source for the VME. Data including turning vehicle counts, headways, and queue lengths were sent from the simulator to the VME hard drive using the Network File System. The system databased this information and sent to the P3OM for analysis. The P3OM made optimal signal and lane assignment recommendations and sent them to the Controller Manager. The Controller Manager then sent the signal settings to the Eagle controller using serial communications. Lane assignments were sent directly from the VME to the simulator using the Network File System. The lane assignment indications were simultaneously displayed on the fiber optic lane assignment sign using the Echelon power line communications described earlier.

A unique feature of the laboratory demonstration was the link created between the simulator, which was running on a personal computer, and the VME and the NEMA controller. Voltage transformers and PC logic software took the voltage directly from the NEMA controller that would normally power signal heads in the field and converted it to the appropriate signal display inside the simulator. Likewise, vehicles in the simulator tripped simulated detectors and sent voltage from the PC to the normal detector inputs on the NEMA controller. Essentially, this design "closed the loop" and created a realistic simulation of field traffic and a real use of the NEMA controller in the laboratory.

The real-world test of the Smart Diamond control concept will occur during a planned field implementation during mid-to-late 1995. At this stage, the video imaging will be fully functional as the real-time information source of the Smart controller and the simulator will be used to test the advanced features of the Smart controller as they are developed. With the video in place, an extensive data set will be developed that describes interchange performance before the Smart system is "turned on." After activation of the system, another collection of interchange data will take place. A "before and after" evaluation will demonstrate the benefits of installing the Smart controller. As researchers develop and test the software and hardware for components such as the incident detection, bus priority, and integration with rail operations and arterial signal operations, additional functionality will be incrementally added.



## **EXPECTED BENEFITS**

The product of the research is a laboratory demonstration and a field implementation of the functional components of the designed advanced diamond controller and the viability of the integrated system. Interchanges operating under the control of this system should experience optimal performance through minimal vehicular delay and no interior queuing problems.

Ultimately, the Smart Diamond control system will provide seamless integration between freeway and arterial street systems. Traffic moving from one facility to the next will realize the increased safety and reduced congestion made possible through real-time optimization and control. Furthermore, due consideration of bus and light rail transit, impacts of rail operations, and coordination with downstream arterial signals will enhance the quality of mobility. The quality of mobility will be preserved by providing due consideration to all modes and types of transport within and in the vicinity of the interchange.



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