

**ENHANCEMENT OF AN EXPERT SYSTEM FOR AN
ADVANCED TRAFFIC CONTROL SYSTEM FOR
CORRIDOR TRANSIT OPERATIONS**

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Prepared for

CVEN 689

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August 1994

SUMMARY

This paper presents the results of the testing of an experimental expert system developed by the author to reduce automobile and train delays along a Light Rail Transit route. It provides a short literature review on the subject of signal control along a light rail route. It also describes some of the logic used in the development of the expert system.

Testing was done to compare the signal timing strategies produced by the expert system to simulations of the network operating under no light rail transit priority at every intersection as well as full priority for light rail vehicles at every intersection. The results showed, that for the two tested networks, the expert system produced lower train travel times and similar automobile delays than the strategy of providing no priority to light rail vehicles at every intersection.

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INTRODUCTION

Mass transit has long been used in an attempt to decrease congestion by giving an alternative for commuters to automobile traffic. As passengers choose mass transit systems over automobiles, automobile congestion should be reduced. However, before motorists will leave their vehicles in favor of mass transit systems, they need to be shown that mass transit is faster and more convenient than automobile travel. This has generally been accomplished by keeping parking and travel costs lower and the time savings greater with transit as compared to driving and parking an automobile.

Capital construction costs, however, continue to rise, which limits the possible types of transit systems that cities can install. Bus systems, however, are popular, and are being used widely. Light Rail Transit (LRT) is also becoming more popular for a number of reasons. Most notably that they can share the roadway with automobiles, bicyclists, and pedestrians, and they do not require grade separation.

Background

For transit operations, specifically bus and LRT systems, it is becoming increasingly more important to present the consumer with accurate arrival time information, as well as reducing delay along any given route. Most traffic control strategies, however, are relatively limited in how they treat transit arrivals at an intersection. The present strategies either give priority to automobile traffic, or provide varying degrees of priority for the transit vehicle. Giving priority to automobile traffic will most likely increase delay to passengers on transit vehicles. However, without careful design and operations of signal systems, giving priority to transit vehicles can significantly increase delay to automobiles.

A variety of traffic signal strategies have been examined and used to control at-grade intersections where LRT vehicles and automobile traffic meets. Recent research has focused on where to give LRT vehicles priority, and where to give priority to automobiles. Arguments have been put forth that the decision on the level of priority to give to an LRT vehicle should be dependent upon cross street traffic volumes and potential delay to LRT passengers (1,2). It has been suggested that train control at various intersections should be performed through the use of a microcomputer system. Accomplishing microcomputer control of LRT vehicles and the surrounding signals could be achieved through the use of an expert system (3).

Previous Work

Within the last year, an expert system has been developed by myself that determines the signal control strategy at each intersection along an LRT route. Upon testing the system, the expert system control strategy reduced transit delay without increasing automobile delay. This expert system and the results and conclusions obtained from preliminary tests are contained in Reference 4 (4). Although the results from the tests were positive, there were a few recommendations for future enhancements to the system. It was determined that there were a few programming errors in the expert system that need to be repaired. It was also assumed that the specific network configuration that the system was tested on had a large impact on the success

of the tests. The expertise solicited to create the expert system came from limited sources, and it is hypothesized that a larger knowledge base could improve the expert systems performance.

The previous expert system also relied on fuzzy logic. Fuzzy logic is a method of modeling continuous process through the use of sets with "fuzzy" endpoints. Fuzzy logic was used for the first system to save some programming time. Instead of using absolute values for traffic volumes, (i.e. 500-600 vph) it allowed the user to choose the traffic as being either high, medium, or low. For this experiment, the fuzzy logic will be replaced with the more traditional method of using specific numbers.

Study Objective

With the traffic control systems that are in operation today, it should be possible to determine the potential delay to transit and automobile passengers. Systems such as the Automated Traffic Surveillance and Control (ATSAC) in Los Angeles, Split Cycle Offset Optimization Techniques (SCOOT) system, and Optimization Policies for Adaptive Control (OPAC) system are constantly updating signal settings based on current, or real-time traffic volumes. Theoretically, this information could be used to reduce delay to both transit passengers as well as automobile traffic. The objective of this project is to use traffic volumes, as well as the number of passengers on an LRT vehicle to determine which signal control strategy should be used at each intersection along an LRT route. For this study, static, or non-changing, information will be used, and the potential benefits of using advanced technology in the form of an expert system will be investigated.

To accomplish these objectives, four tasks were completed.

1. Identify the existing control strategies.
2. Using a theoretical LRT route, briefly examine the impacts each of these strategies has on automobile traffic and LRT delay.
3. Develop and test a prototype expert system to choose control strategies along two existing LRT corridors. This will be accomplished with a transit simulation program.
4. Draw conclusions on the potential impacts of changing control strategies based on real-time traffic data.

Organization of Report

Following the introduction, the report is organized into five additional chapters. Chapter 2 provides the background information on different signal and priority systems. Chapter 3 contains the results of the analysis of traffic and transit Measures of Effectiveness (MOEs) for an isolated intersection that were determined before writing the expert system. Chapter 4 describes the expert system and the knowledge base used to build it. Chapter 5 details the analysis of two light rail corridors operating with the expert systems suggested levels of control. Finally, chapter 6 contains the conclusions and recommendations from this research.

SIGNAL AND PRIORITY SYSTEMS

Discussion of Alternatives

Since LRT operates at-grade, or on the same, level as other automobile traffic, it's impacts on the traffic network are much more severe than systems which are grade separated. Mitigating these impacts is one of the primary research objectives of those considering the installation of LRT. Presently, there are three types of control at intersections along an LRT route. The three forms of control are based on the level of priority given to the LRT. These three forms of control are:

- No Priority,
- Partial Priority, and
- Full Priority.

These three levels of LRT control are achieved differently depending upon the signal system in operation at each intersection. The two forms of intersection control in widespread use today are pretimed and actuated control. The three levels of LRT control are achieved differently depending on the intersection control.

No Priority Schemes

Where the LRT has no priority, the LRT vehicle behaves as an automobile. The LRT is assigned to an associated automobile phase (ie. 2&6 on a standard NEMA controller). When the LRT arrives at an intersection, it must stop, just like an automobile, if the signal is red. The train must wait for a green indication to progress through to the next intersection. If the LRT has no priority at an intersection, no phases are skipped or shortened to advance the train through, as the other priority schemes allow. Pretimed and actuated signals have no significant differences in their treatment of a train if there is no priority for the train at an intersection.

Partial Priority Schemes

Partial priority schemes generally operate in pretimed signal operations. In partial priority schemes, the train associated automobile phase is extended longer than normal. If the train is scheduled to arrive at the intersection before it's associated phase is green, the phase will turn green earlier than normal. If the train, however, is scheduled to arrive shortly after the associated phase is scheduled to return to red, the green window will be extended. How early the signal turns green, and how long it will be allowed to remain green is determined in advance by the transportation engineer who designed the signal.

Partial priority schemes that operate with actuated controllers are similar to pretimed controllers. In partial priority schemes with actuated controllers, when the signal receives a priority call, it cycles through a number of minimum greens until the associated phase is reached. The minimum green times it cycles through may not always be the minimums for pedestrian clearance or driver expectancy. Instead, they are minimums designed to service some traffic before giving priority to the LRT. However, since the minimum green times are generally shorter

than the normal green times, the LRT is serviced after a shorter delay than it would have had had the signal been operating without priority for the LRT.

Full Priority Schemes

In a full priority system, the signal attempts to give the associated LRT phase a green indication when a train is detected. This is done in essentially the same manner for both actuated and pretimed signals. The signal has a pre-determined minimum green times that are used to respond to a train detection. These green times are not necessarily the same minimum green times used for actuated traffic control. They are used to send the signal from whatever phase it is in to respond to the train. For the signal to skip phases, these minimum green times can be set to zero, and immediately after timing out whichever phase the signal was presently servicing, it will dwell in the trains associated automobile phase until the train exits the intersection.

Full priority systems with pretimed controllers have one difference with actuated controllers operating with full LRT priority. Pretimed controllers are generally coordinated with other signals either along an arterial, or within a network. Therefore, when a signal is pre-empted to allow a train to pass through, the signal is most likely no longer coordinated with those around it. Present systems allow the signal to dwell in the coordinated phase in what is known as "recovery" time every cycle until the signal reattains coordination with the remainder of the signals in the system.

In all of the priority and partial priority schemes, two detectors are used to detect the train and determine when it has left the intersection. The first detector is generally located about 5 seconds up-stream of the intersection. When the train passes over this detector, the signal begins pre-empting the current cycle to allow the train priority. A second detector is located immediately after the stop bar in the intersection. Once the train has passed over this detector, a timer begins counting down a certain length of time to allow the train to clear the intersection to return the signal to normal operations. This detector is also used to verify that the train passed through the intersection. If, for some reason, a call was placed by the first detector and the signal was pre-empted, but the train was delayed, the signal will continue through it's cycle, giving minimum times to every phase, and once again give priority to the LRT.

Dynamic Priority Schemes

In a full priority system, trains can still be delayed because they may be forced to slow down as they approach an intersection. The driver of the train, much like an automobile driver, must make a decision about when to stop depending on the present signal status. Traveling at normal speeds (35-55 mph), it can take an LRT vehicle 150 feet to come to a stop. If the associated phase for the train is red when the train crosses this point, the train must begin to stop. However, before the train reaches the intersection, the signal may turn green, and the train should then accelerate through the intersection. However, slowing down, and then accelerating unnecessarily delays the train.

The Chicago Circulator Design Team (5) has prepared a train strategy to alleviate this delay. Their dynamic priority system uses a variety of systems to identify and track individual vehicles. The system works by having a central computer "know," at all times, exactly where

each train is. The system then works in conjunction with the signal and the train operator to have the train arrive at the intersection immediately after the associated train phase begins. The system constantly adjusts train speeds and phase length information, in essence having the operator and the signal "negotiate" with one another, to determine the optimal train arrival time.

Progression Band Schemes

One final method of signal priority schemes involves the use of progression bands along LRT routes between stations. These progression bands are developed assuming the train leaves a station at a certain time during the cycle. A progression band is provided along the route allowing the train to pass through each intersection between stations without any delay from traffic signals. Progression systems have been used effectively in San Diego and a number of other areas (6,7). The problem with progression schemes is the potential for delay at the stations. The trains only have a small progression band to allow un-hindered travel, however, for the trains to enter this band, they must occasionally wait an entire cycle at the station of the first intersection after the station for the start of the band, causing added delay to the train and it's passengers.

EVALUATION OF CONTROL STRATEGIES

Once the various signal control strategies and LRT priority schemes were determined, simulations were run to attempt to determine the impacts of each strategy. A corridor with two signalized intersections was created for testing. The network observed can be found in Figure 1. These tests were conducted to determine the impacts of four of the previously discussed strategies had on automobiles and LRT vehicles. The four strategies are:

- No priority, pretimed controller,
- Full priority, pretimed controller,
- No priority, actuated controller, and,
- Full priority, actuated controller.

TransSim II

The corridor was simulated with a transit simulation called TransSim II. TransSim II was written by JRH Engineering to model traffic and transit operations along an LRT corridor. TransSim II was chosen as a model for a number of reasons. Most notably, TransSim is relatively easy to use, and thus did not require a lot of time to be spent in setting up the simulations. TransSim II also allows the user to change the control strategy at each intersection without strenuous effort (5,8,9).

Preliminary Testing

Because modeling every possible traffic pattern with every possible priority strategy would be impossible in the limited time allowed, only certain traffic patterns and control strategies were investigated for the expert system. Each intersection in the corridor consisted of a four-legged intersection with two through lanes and one left turn bay per approach. Traffic was assumed to be balanced so that an equal volume was approaching on each leg of the intersection. Standard National Electronic Manufacturing Association (NEMA) phasing with leading left turns was assumed as well.

Three traffic volume levels were tested: 400, 800, and 1200 vph per approach. Ten percent of the approaching vehicles were assumed to turn left. Average delays were examined for the through movement at one of the two intersections in one direction on both the main and cross-streets, as well as an average for the entire intersection. The average train delay at that intersection was calculated as well.

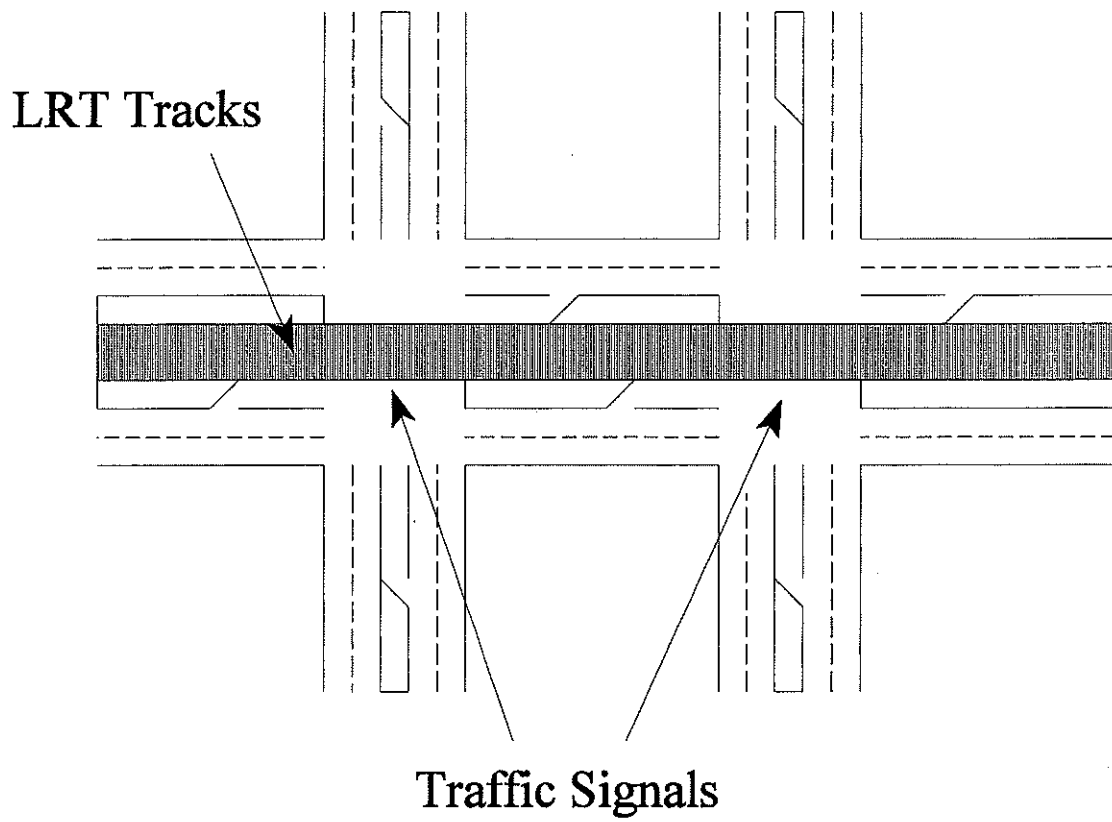


Figure 1. Schematic of corridor used for preliminary tests of intersection delays.

Data were collected for the four most widely used strategy and signal type combinations. For actuated controllers, delay was calculated with no priority and full priority schemes. For pretimed controllers, delay was calculated for partial-priority systems, as well as full and no priority schemes. The dynamic full priority system used in Chicago was not tested because most systems don't have the capability to operate under that control strategy.

Preliminary Test Results

Table 1 shows the results of the tests at 400 vph. Table 2 shows the 800 vph test results, and Table 3 shows the 1200 vph test results. The results are also shown graphically in Figures 2, 3, and 4 respectively.

Table 1. Intersection Delay results, 400 vph per approach.

	Cycle Length (sec)	Main St. delay (sec/veh)	Cross St. delay (sec/veh)	Signal delay (sec/veh)	Train delay (sec)
Pretimed	90	23.6	22.6	26	31.7
Full priority/coordinated	90	26.0	20.8	33.2	9.5
Fully actuated	n/a	10.7	17.8	16.1	9.4
Full priority	n/a	11.0	13.4	13.6	3.6

Table 2. Intersection Delay results, 800 vph per approach.

	Cycle Length (sec)	Main St. delay (sec/veh)	Cross St. delay (sec/veh)	Signal delay (sec/veh)	Train delay (sec)
Pretimed	90	26.5	25.5	31.4	32.0
Full priority/coordinated	90	31.4	26.6	62.6	6.0
Fully actuated	n/a	20.1	27.1	26.1	20.5
Full priority	n/a	19.5	23.8	23.8	3.2

Table 3. Intersection Delay results, 1200 vph per approach.

	Cycle Length (sec)	Main St. delay (sec/veh)	Cross St. delay (sec/veh)	Signal delay (sec/veh)	Train delay (sec)
Pretimed	115	56.5	45.5	61.6	47.4
Full priority/coordinated	115	81.8	50.7	110.14	6.0
Fully actuated	n/a	49.0	50.8	54.4	44.6
Full priority	n/a	46.2	59.9	63.0	4.7

Intersection Delays

400 vph per approach

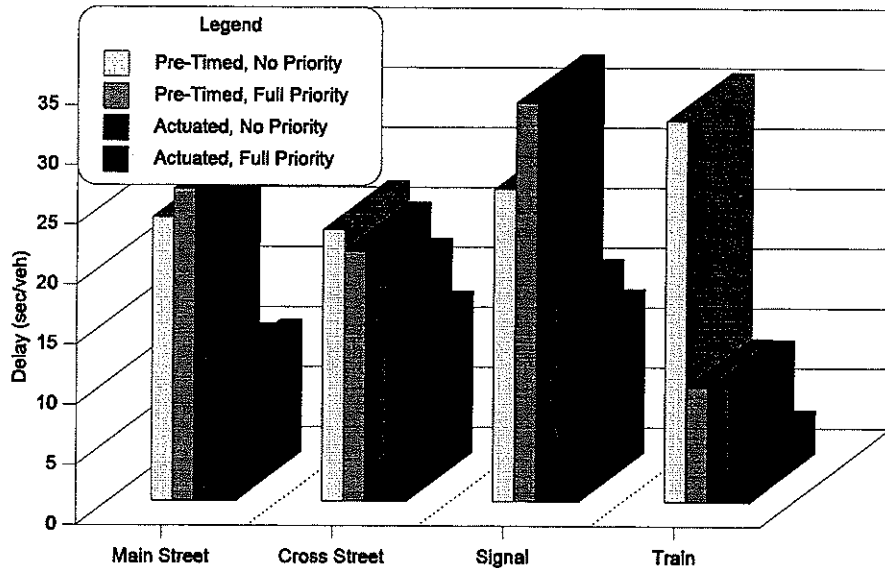


Figure 2. Preliminary test results for 400 vph per approach.

Intersection Delays

800 vph per approach

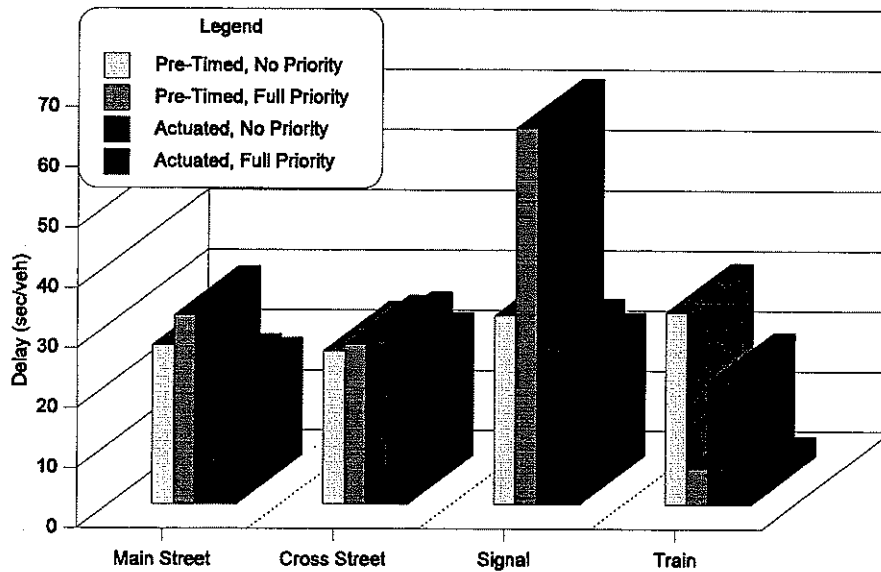


Figure 3. Preliminary test results for 800 vph per approach.

Intersection Delays

1200 vph per approach

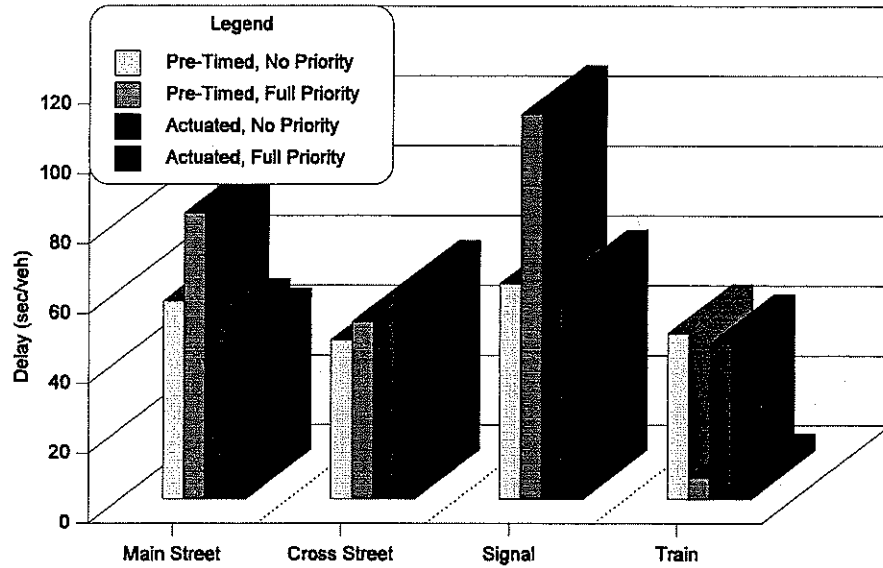


Figure 4. Preliminary test results for 1200 vph per approach.

Delay Differences in Intersection Priority Schemes

Automobile Delay

There are a number of relationships that can be drawn from these MOEs. In an actuated system, where the two priority schemes for LRT are actuated and full LRT priority, the delays at 400 and 800 vph are relatively insignificant. The differences in automobile delays increase by about five seconds per vehicle when priority is given to LRT on the main and the cross streets. Signal delay, however, increases significantly, from 31.4 to 62.6 sec/veh, for the 800 vph per approach case as priority is given to the LRT at a pretimed signal. At 1200 vph, the signal delay increases from 61.6 to 110.1 sec/veh in the same scenario. These increases can most likely be attributed to left turns that are either insufficiently serviced, or not serviced at all for a number of consecutive cycles. Although left turns were not investigated for this project, they should not be forgotten in the future.

At 1200 vph, the differences in delays are more pronounced than at the lower traffic volumes. In pretimed control with 1200 vph, cross street delays increased by about five seconds, however, at the lower volumes, the delays differed by only about one second, with the 400 vph test actually reducing delay on the cross street as train priority was added. Under actuated control, the signal delay increased as priority was added in the 1200 vph test. However, train priority actually decreased signal delay for automobiles when priority was added to an actuated controller.

Train Delay

Adding priority to the intersection had significant impacts on the delays to the LRT system regardless of traffic volume or type of intersection control. Figures 2, 3, and 4 all show definite decreases in train delay when priority is added to the intersection. For pretimed controllers, train delay when there is no LRT priority appears to be about one third of the cycle length. For instance, a 90 second cycle length was used for the 400 and 800 vph tests, and train delay in each case was approximately 31 seconds per train. Giving the train priority, however, reduces the train delay from 31 seconds to less than ten. For the longer cycle lengths in the 1200 vph test, train delay was reduced from over 47 seconds per train to six with a pretimed controller. Giving the train priority at an actuated signal had similar results.

Discussion of Preliminary Test Results

Pretimed Controller

The problem of incurring high delays to the cross-street traffic is rectified in the full priority scheme using pretimed controllers. For the signal to return to coordinated operations, the signal needs to dwell in the coordinated phase. The coordinated phase was assumed to be for the cross-street for these tests. Since the signal is dwelling in the coordinated phase, more green time is given to that phase every time a train receives priority. However, green time on the non-coordinated phases, the main street phases in these tests, is reduced, and higher delays are incurred at all traffic volumes tested.

Partial Priority

Although train delay was reduced as priority increased, delay to vehicles increased significantly as can be seen in Tables 1, 2, and 3. There are two variations to full priority that can be successfully used to significantly reduce automobile delay as compared to full priority schemes, while reducing train delay as compared to not giving the train any priority. Partial priority schemes can be beneficial in both actuated and pretimed intersections. Partial priority should most likely be used when traffic on the main street outweighs traffic on the cross streets. Since partial priority only reduces green time from the phases immediately preceding and following the associated phase, it will generally have the greatest impacts on left turning traffic, and should most likely be used in areas where left turning traffic is either light or not allowed.

For actuated control, partial priority can be obtained by forcing the controller to service certain phases before giving priority to the LRT vehicle. As discussed earlier, in full priority systems, when the signal receives a call from the train, it cycles through a set of minimum green times. For full priority, the green times for the phases not associated with the train are programmed to zero seconds. These minimum greens could be increased to allow either cross street traffic or left turning traffic to dissipate slightly before giving the train priority. Since programming this type of control is highly traffic dependent, it was not tested for this project.

THE EXPERT SYSTEM

The concept of this expert system was initially developed in the fall of 1993 at Texas A&M University. An early prototype of the expert system was developed and tested. Although the results were promising, a lot of work would have been required to make any minor improvements to the system. To improve the system, numerical values were assigned for the traffic levels instead of calling traffic volumes high, medium, or low, among others. This chapter will define the various parts of an expert system, as well as the logic used for this particular system.

What is an Expert System?

Expert systems are one of the first practical uses of Artificial Intelligence. Expert systems are designed to solve real problems in specific, restricted domains by reasoning through the problems in the same manner as a human expert. Expert systems use knowledge about a system, and draw conclusions through various rules that are programmed into the system. The advantages expert systems have over using humans are numerous, however the most noted is their speed. Expert systems are able to sort through the large quantities of data available in a real time situation and respond in a short amount of time, while a human would most likely get lost while sorting through the data.

Steps in an Expert Systems Development

Developing an expert system requires a number of steps. These steps include: knowledge acquisition, coding, and validating the expert system. A brief description of the process follows.

Knowledge Acquisition

The first step in building an expert system is to acquire the knowledge and hueristics, or rules of thumb, about the domain for which the expert system will be written. For this system, the knowledge was obtained from the results of the tests performed in the previous chapter. The tests were used as a reference point to begin development. From the data collected, and the analysis performed, specific rules were developed. These rules are described in a later section.

Building the Expert System

Once the knowledge was obtained and organized, the system had to be written. An Expert System Building Tool (ESBT) was used to develop the expert system. ESBT's are often used to write expert systems for a number of reasons. Most notably, ESBT's are used because they can greatly reduce the amount of time required to develop an expert system in comparison to the amount of time required if a traditional programming language such as Fortran or Pascal was used. For this system, an ESBT developed by NASA called CLIPS was used.

The Knowledge Base. The knowledge base is the actual expert system, which consists of two parts: facts and rules. The rules contain the logic required for the expert system to make it's decisions. They contain all of the knowledge obtained in the previous chapter. This knowledge

was then coded into CLIPS, and from these rules, signal priority for LRT systems was generated. The facts contain all of the possible information about the LRT, the surrounding arterial system, and the intersections along the route.

The Facts. The facts can be broken down into two sections:

- Intersection Information, and
- LRT Information.

Each of these three sections contains a wide variety of information. From this information, the expert system uses the rules and then makes decisions.

The intersection information focuses on the traffic volumes and the geometry of the intersection. The program takes the maximum volume from both the main street and the cross street at each intersection to begin its decision making process. The expert system also requires needs to know the type of control presently at the intersection, whether it is actuated or pretimed. Finally, the number of lanes and turn bays at each approach are required.

The LRT information is the occupancy level of the train, as well as the suggested priority level. The occupancy level of the train is the number of passengers presently on board the train. The expert system assumes that the capacity of the train is 200 people.

The suggested priority level within the LRT information allows the user to suggest to the expert system that the train be given a certain priority at intersections where the traffic volumes and ridership of the train are not enough information for the expert system to determine a priority. The users preference is the last criterion used to determine the level of priority for the LRT.

The Rules. The rules comprise the knowledge and the "thinking process" that drives the expert system. The rules for this system can be broken up into two distinct sections:

- Administrative Rules, and
- Priority Rules.

The administrative rules take care of all of the record keeping within the expert system and any other rules not directly related with the decision making process. The priority rules are the rules that define which priority scheme to use based on the facts entered in by the user of the system.

Developing the Expert System

This remainder of this section will explain what knowledge was used, and how, in building the expert system. Appendix A contains a copy of all of the priority rules. Due to a lack of space, the entire expert system code is not presented in this report.

The expert system knowledge revolves around six facts or pieces of information at each intersection. These six facts are:

- Train volume,
- Present operating scheme,
- Automobile volume by approach,
- Intersection geometries,
- Train headways, and
- Suggested LRT priority.

The following sections describe how each of these pieces of information work in conjunction with one another in the expert system to attempt to determine the optimal operating scheme at each intersection along a chosen corridor.

Train Volume

As stated earlier, it is assumed that the train has a capacity of 200 passengers. One of the potential benefits of this type of expert system is an overall reduction in person delay. By using the train volume, the potential delay in terms of person-hours could be determined, and compared to the potential delay in person-hours for automobiles and passengers who may experience added delay at an intersection where an LRT may be given priority. This expert system is not sophisticated enough to perform those delay calculations. Therefore, the system attempts to give added priority to the LRT based on the volume, or number of passengers, in the train, as well as the hourly traffic volumes at the intersection.

Present Operating Strategy

The present operating strategy sets the limits for the suggested priority level. If the intersection is operating under pretimed conditions, it cannot switch to free actuated operation. Likewise, an actuated controller will most likely not be able to operate as a full priority, coordinated pretimed controller. Therefore, if the signal is presently pretimed, the expert system will recommend that it operate with either no priority, partial priority pretimed, or full priority, coordinated pretimed. Likewise, if the signal is operating under actuated control, the expert system will recommend that it operate with either no priority, or under full priority, free actuated. The expert system also assumes that every input intersection can switch between LRT priority and no priority operating schemes.

Automobile Volumes

The automobile volume by approach is used for a number of steps in the decision making process. The first step is to determine the total number of vehicles traveling through that intersection in a one hour time period. In a real-time system, this would be done by transforming shorter counts into one hour counts. For instance, a five minute count could easily be multiplied by 12 to obtain an hourly flow rate. As shown earlier, as automobile volume increases, automobile delay increases as well (Chapter 3, Tables 1, 2, and 3, and Figures 2, 3, and 4). For properly timed pretimed controllers, train delay with no priority will be increase as traffic volume increases too, since as traffic volumes increase, the cycle length generally increases as well.

Secondly, automobile traffic volumes per approach is important in determining the level of priority that the train should receive. The earlier testing in Chapter 3 revealed that different

control strategies may be more appropriate depending upon which approach has the highest volumes.

Pretimed Controllers. For pretimed controllers, if a majority of the traffic at the intersection is traveling parallel to the LRT tracks, partial priority allocates more green time to that movement than to the cross street. However, if there is more traffic on the cross street, coordinated full priority control gives the train higher priority while dwelling in cross street green to get the signal back in sync with the others in the network.

Actuated Controllers. For actuated controllers, there are only two strategies possible with the expert system: no priority and full priority for the LRT. Unlike full priority with pretimed controllers, however, automobile delay at high traffic volumes does not significantly increase over the no LRT priority scheme. For high volumes on the cross street, however, giving the LRT full priority can adversely affect traffic since the green phase for the cross streets is likely to be shortened whenever the LRT receives priority.

Intersection Geometries

The intersection geometries are used to give the expert system an idea about how high the traffic volumes are. Delays will be significantly different on a one lane approach as compared to a two lane approach with the same traffic volume.

Train Headways

The train headways are used by the expert system in an effort to estimate delay by knowing how often traffic has the possibility of being pre-empted for an LRT vehicle. As train headways increase, the potential impacts on traffic decrease, since there are fewer potential interruptions to traffic. As train headways decrease, more trains will be crossing through the intersection, and there will therefore be more potential interruptions at the intersection.

Suggested LRT Priority

Finally, the user has the opportunity to "suggest" to the expert system a priority level for the LRT in case the volumes, headways, and geometric information is not enough. The expert system only uses this suggestion as a last resort. This priority level is only given once for each network rather than each intersection. It is assumed that this last resort of sorts will be suggested by others than a transportation engineer.

Steps to Achieving Real-Time Control

There are a number of steps that must be realized in the development of an expert system. In the past, there has been a hesitation to permit a computer to completely operate anything that can directly affect people. This reluctance must be alleviated through positive testing and analysis during limited operations. Developing any type of system that allows computer control of traffic and signals must evolve through a set pattern (10).

The First Generation

The first step or generation would be a completely off-line system. These systems use set traffic volumes and a fixed or assumed train volume. This information is coded into the expert system, and a strategy for each intersection is output to a computer screen or printer. It is then up to the traffic engineer to manually change the operating scheme at each controller. This type of control lacks the ability to respond to changing traffic conditions. This expert system would be considered a first generation expert system.

The Second Generation

The next evolution, or generation would allow some traffic responsive decisions to be made. For this control, the entire network would be wired into a central computer. Traffic volumes would be constantly updated, as would train volumes. The central computer would have an expert system built into it that would take these pieces of information into account and suggest an operating strategy for the corridor to the traffic operations personnel at a control center. These persons would then be required to either accept or reject that operating scheme. If the scheme is accepted, the central computer would change the operating scheme at the required intersections. If the scheme was rejected, the corridor would continue operating as it had been.

This system could be programmed to suggest signal control strategies for every train, or in less frequent intervals of every 2 or three trains, or possibly every hour. If control schemes are suggested for every train, train headways are relatively short (6 minutes between trains), and there are multiple corridors under the central computers control, it can be seen that the amount of information being sent to the control center operators for decision making could easily overwhelm them. Since the purpose of a real-time expert system is to make decisions, and then implement them faster than a human could, a second generation would defeat the purpose of a real-time expert system.

The Third Generation

A third generation system would make use of not only existing traffic levels, but past experiences, and forecasting techniques to provide on-line decision making. The expert system would also have access to the actual number of passengers on the train. Using all of this knowledge, the expert system would recommend the most effective control strategy at each intersection along the corridor, and then implement that solution without using any third party or human interaction. The expert system would have complete control over the LRT corridor.

Why Use an Expert System?

There are a number of reasons to use expert system technology for a real-time decision making tool. It can be argued that the logic abilities of some advanced signal controllers could be used effectively at individual intersections to provide the same control decisions (11). Expert systems provide a number of advantages for this type of a control system. An advanced expert system could be used to prevent problems rather than respond to them like an individual controller would. A third generation system, as described earlier could use forecasting models, as well as a database of past solutions from which to determine a strategy. An individual

controller would only have access to the vehicle counts from detectors surrounding the intersection.

An expert system would look at the system as a whole as well. While an individual controller can only have traffic data at one specific intersection, the expert system would use information from the entire LRT corridor. With this knowledge, an advanced expert system would be more capable of making changes at one intersection without adversely affecting any others.

Finally, an expert system would allow changes as operating strategies change. Presently, the three choices for priority are none, full, and partial priority. It is extremely likely that more choices will become available in the near future. An expert system would welcome these new strategies by simply altering the rules to use these new strategies as traffic conditions warrant their use.

TESTING AND ANALYSIS OF THE EXPERT SYSTEM

Upon completion of the expert system, testing was done to compare the results of the suggested priority to the results of both full priority for every intersection and no priority at every intersection.

Tested Networks

Two networks were chosen to be modeled. The first network is a portion of the Los Angeles LRT line along Pacific Avenue in Long Beach, California, as shown in Figure 5. The modeled section is about a half mile long, with seven intersections evenly spaced at 220 feet apart. The present strategy is pretimed control, with no priority for the LRT. The second network is a ten block long section of Burnside Road in Portland, Oregon as shown in Figure 6. There are five signalized intersections which are unevenly spaced. The other five intersections have no control along Burnside Road, however traffic on the cross streets is controlled by stop signs. The total length of this section is This system is presently controlled by fully actuated controllers, and the LRT has full priority at every intersection. This network consists of five intersections, unevenly spaced, with relatively long distances between them.

Modeling Methodology

Modeling was performed by using the TransSim II computer simulation package for the same reasons given earlier. Since TransSim is a stochastic model, each priority scheme was run 10 times, and an Analysis of Variance (ANOVA) was performed to determine any differences between the strategies.

Upon determining the expert system's suggested level of priority at each intersection, it was necessary to make comparisons of various MOEs within the network. The chosen MOEs were network wide average automobile delay and LRT delay along the corridor. Three strategies were tested. They were:

1. No priority at every intersection,
2. Full LRT priority at every intersection, and
3. Control determined by the expert system, assuming 175 passengers on the LRT.

Strategies 1 and 2 are network-wide strategies, with the same priority measures at every intersection. Strategy 3 is a train specific strategy determined by the expert system.

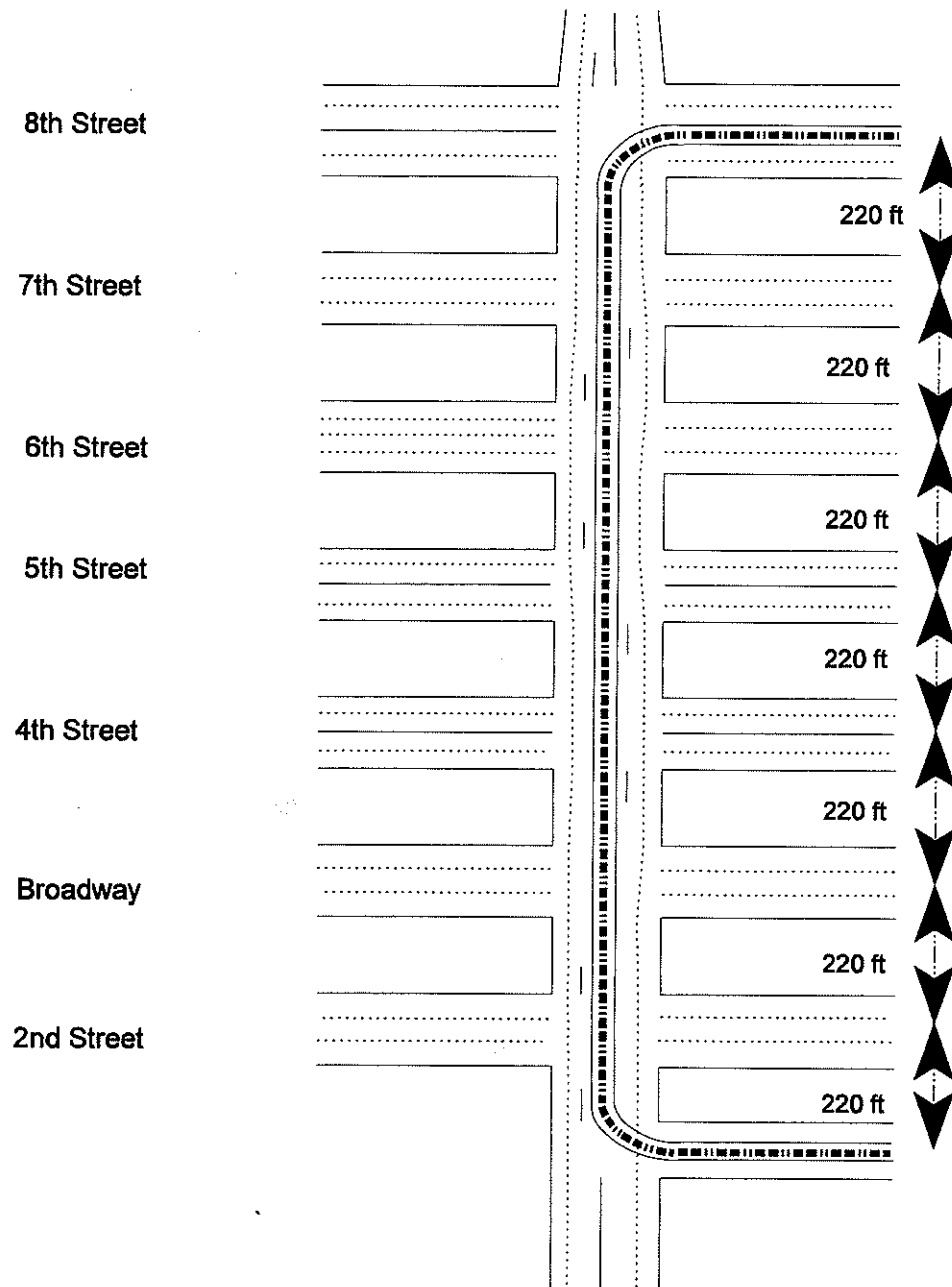


Figure 5. Pacific Avenue LRT corridor in Long Beach, CA.

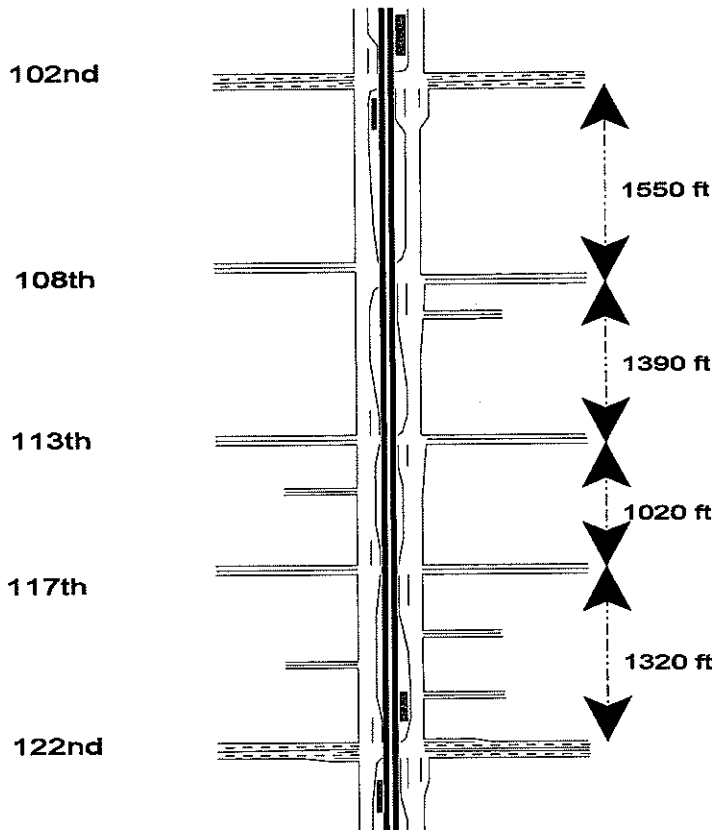


Figure 6. Burnside Road LRT Corridor (8).

Hypothesis for Tests

The testing was designed to determine if the strategies suggested by the expert system would decrease delay time, while at the same time keep increases in automobile delay to a minimum as compared to the automobile-based strategy. Likewise, testing was performed to determine if the expert system strategies would decrease automobile delay through the network without sacrificing LRT delay time in comparison to giving the LRT full priority at every intersection. The two MOEs that were studied were train travel time and average automobile delay throughout the entire corridor. The train travel times are the times it took the train to travel from one end of each corridor the other end. For the modeling, the corridors chosen were only seven blocks (one quarter mile) long for Long Beach and ten blocks (one mile long) for the Portland system.

Upon obtaining the required MOEs, ANOVA was performed to determine if the strategies were significantly different. If the means for each strategy were determined to be significantly different, Duncan's Multiple Range Test was performed to determine if the expert system strategies were significantly different from the two network wide strategies.

Study Results

Table 4 shows the mean vehicle and train delay results for the Long Beach LRT corridor. Table 5 shows the same information for the Burnside corridor in Portland.

Table 4. Results on Long Beach (Pacific Avenue) LRT corridor.

Control Strategy	Average Vehicle Delay (sec/veh)	Duncan Group	Train Travel Time (sec)	Duncan Group
No Priority, all signals pretimed	13.8	B	227.8	A
Full LRT priority at every signal	15.5	A	85.6	B
Expert system control strategy	14.4	B	108.1	C

Table 5. Results on Portland (Burnside) LRT corridor.

Control Strategy	Average Vehicle Delay (sec/veh)	Duncan Group	Train Travel Time (sec)	Duncan Group
No Priority, all signals actuated	28.1	B	324.2	A
Full LRT priority at every signal	30.0	A	276.8	B
Expert system control strategy	29.0	B	270.2	B

The first corridor studied was the Long Beach LRT corridor. From Table 4, it can be shown that there are three statistical inferences about the control in Long Beach from these results:

- Giving the LRT full priority at every intersection produced the highest automobile delays which is significantly different than the other two automobile delays (p-value < .0001);
- There was no significant statistical difference in automobile delay between not giving the LRT any priority and using the expert system to assign intersection priority; and
- All three strategies produced significantly different delays for the LRT (p-value << .0001).

The second corridor studied was the Burnside corridor. From values in Table 5, a number of statistical inferences can be drawn:

- There are statistical differences in train travel times for all three strategies (p-value < .0001);
- Giving the train no priority produced the longest train travel times (324 seconds);
- Giving the train full priority at every intersection produced statistically similar train travel times as the expert system strategy;
- There was a statistical difference between the automobile delays for the three strategies (p-value = .0191);
- Giving the LRT full priority at every intersection produced the highest average automobile delay throughout the corridor (30 seconds); and
- Giving the train no priority at every intersection produced statistically similar automobile delays when compared to the automobile delays calculated for the expert system strategy.

The results for the Long Beach LRT corridor are shown graphically in Figures 7 and 8 for the Train Travel Times and Automobile delays respectively. The same information is shown graphically in Figures 9 and 10 for the Burnside LRT corridor.

Train Travel Times

Long Beach LRT Corridor

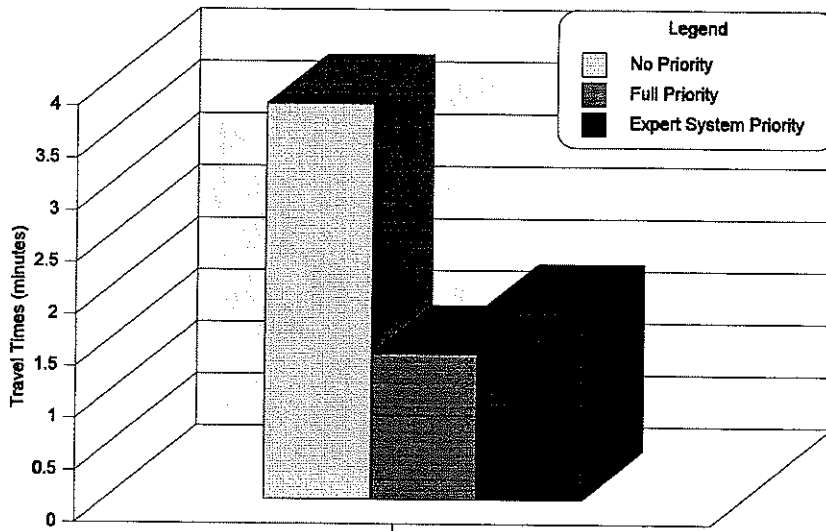


Figure 7. Train Travel Times along the Long Beach LRT Corridor.

Automobile Delay

Long Beach LRT Corridor

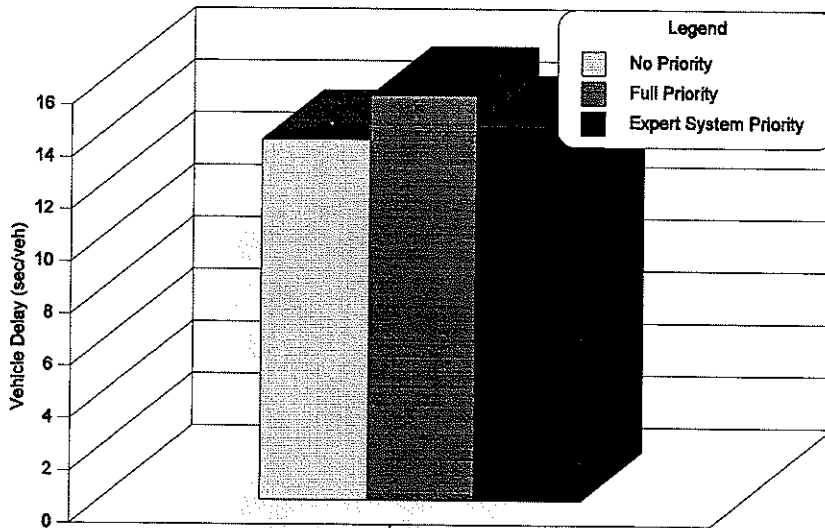


Figure 8. Automobile Delay throughout the Long Beach LRT Corridor.

Train Travel Times

Portland's Burnside LRT Corridor

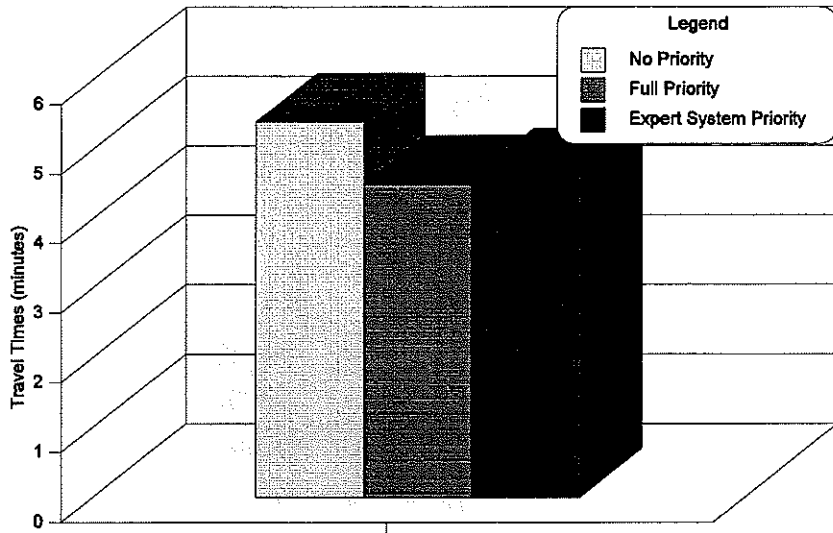


Figure 9. Train Travel Times along the Burnside LRT Corridor.

Automobile Delay

Portland's Burnside LRT Corridor

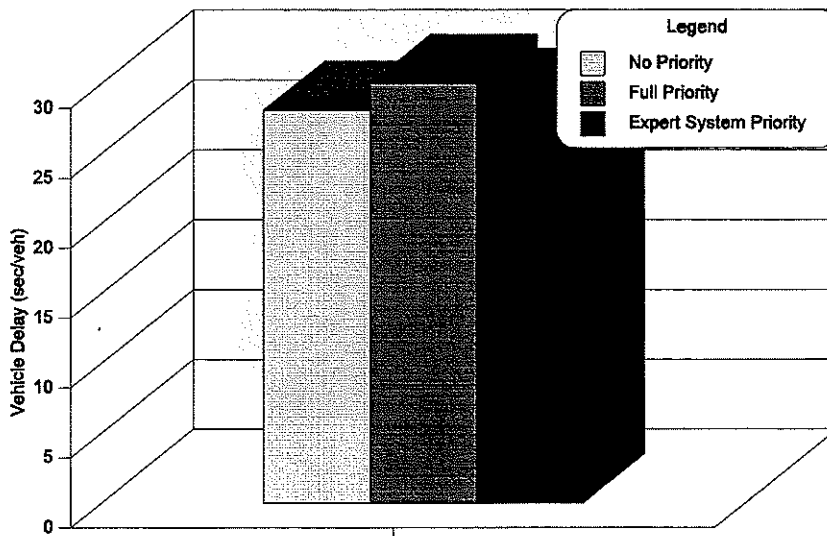


Figure 10. Automobile Delay throughout the Burnside LRT Corridor.

Impacts in Long Beach

In the Long Beach corridor, where the present operating scheme functions with no LRT priority, the expert system recommended that three intersections should be operating under partial priority control and the remaining five intersections should be operating with full priority for the LRT. This reduced travel times for LRT passengers by nearly two minutes along the route, while only increasing automobile delay by about one second.

Adding LRT priority in Long Beach reduced train travel times from 228 seconds to 86 seconds for full priority, and 108 seconds for the expert system priority (Table 4). These are significant differences. The Long Beach LRT corridor is about one quarter of a mile in length (seven blocks), and adding priority to the LRT reduced travel times by about two minutes. For a full train of 200 passengers, each train operating under the expert system's control saves approximately 6.6 passenger-hours. Without a statistically significant impact on automobile delay between the expert system control scheme, and not giving the LRT any priority, giving the LRT priority makes a lot of sense.

It is important to note, too, that the savings of 6.6 passenger hours is per train. Assuming that the headways are constant at six minutes between trains, and that the morning peak is in effect for one hour, the expert system priority level can save 66 person-hours per day, 330 person-hours per week, or 17,160 person-hours per year. Even if every passenger's time was only worth the minimum wage, this priority scheme could save the people of Long Beach almost \$73,000.00 annually. This savings is only for a small section of the LRT corridor, during one hour of operation per day as well, so the savings for the entire LRT corridor for an entire day would be much higher. It is important to remember that these savings are achieved with no adverse impact to automobile traffic.

Impacts along the Burnside Corridor

In the Burnside corridor, the expert system recommended that one intersection operate with no LRT priority, and the others operate with full LRT priority. At present, that system operates at full priority for the LRT at all times. This one change, however, slightly reduced automobile delay without any significant increases to LRT passengers. The travel time savings along the Burnside Corridor in Portland, OR are significant as well. The expert system did not produce higher travel times, statistically, than giving the LRT full priority. The expert system reduced train travel times from 324 seconds per train to 277 seconds along the one mile (ten block) section of the Burnside corridor. With the same assumptions as in Long Beach, the reduction in travel times the expert system produced has the potential of saving up to 2.67 person-hours per train, or over 6,900 person-hours per year during one hour of operation in the morning when compared to giving the LRT no priority. Again, this savings is achieved with no adverse effects to automobile traffic when compared to not giving the train any priority.

CONCLUSIONS AND RECOMMENDATIONS

In both of the previous tests, a number of relationships can be drawn about the potential impacts of a dynamic signal priority control system. The first effect is that it may not always be necessary to give full priority to LRT vehicles at all times. Along the Burnside corridor, one intersection was changed from full LRT priority to no LRT priority, without adversely increasing LRT travel times. Although the network-wide automobile delay did increase by giving full priority to the LRT when compared to not giving the LRT any priority, the effects on automobile traffic of the expert system strategy was not statistically different than having no LRT priority. The Level of Service for the corridor was not effected. However, train travel times were reduced each LRT vehicle, as was shown in Tables 4 and 5, as well as Figures 7 and 9.

In both of the corridors, automobile traffic was relatively low, which could have had an impact on the low automobile delays. It is quite possible that as traffic volumes increase throughout an LRT corridor that increasing the priority for the LRT will increase delay to automobile traffic. In a dynamic system, person-delay could be reduced significantly if LRT ridership was low by not providing the same level of priority for the LRT as would be given were the train full.

It is often argued that priority should always be given to LRT systems in an effort to present mass transit as a time saving alternative to driving. Since LRT systems are fixed track systems, and are generally radial in nature, a large number of people may not be able to use LRT as a viable alternative to their automobile. Because these people may not have a mass transit alternative to driving to and from work, they may be stuck using their automobiles to travel. If these people have to cross the LRT tracks, giving the LRT priority all of the time may be increasing the delay they experience at LRT intersections. By adjusting the level of LRT priority based on dynamic issues, automobile delay may be reduced.

One of the goals of increasing transit ridership is to reduce congestion, and therefore reduce automobile emissions. In some full priority systems, by giving the LRT full priority at all times may actually be increasing delay, congestion, and automobile emissions by pre-empting traffic signals for empty trains.

Recommendations

Throughout the writing and evaluation of this expert system, it is obvious that expert systems can, and should play a large role in advanced traffic management systems. When used correctly, the technology imbedded into expert systems, when combined with an extensive knowledge base, is a very powerful tool. They are powerful in two ways, speed, and reliability.

The speed at which today's computer systems operate have made the once distant possibility of real-time traffic adaptive systems a rapidly approaching reality. By combining the knowledge of traffic management experts with the computing speed and power of a microcomputer, tools can be developed to reduce congestion and delay before they get out of hand (10).

Reliability has long been a major question of expert system detractors. The "big-brother" thought of a computer keeping track of our highways, and eventually our vehicles, has not always been a pleasant thought. However, when properly developed, coded, and tested, the fears of computer systems malfunctioning can be easily eliminated, especially as the life or "generations" of the system are put into operations.

Further testing and revising of this system will need to be done to increase its utility. Different networks with varying geometries and volumes need to be tested as well. Having a universally adaptable system that can be put into place at more than one location would be much more cost-effective than a system completely designed for a specific LRT corridor.

Research is presently underway in developing transit "smart" intersections. Using automatic vehicle identification, or AVI technologies, a signal controller can determine if a bus or train that is approaching is either ahead of, behind, or on schedule, and can give priority to the transit vehicle to get it back onto schedule. Other smart intersection technology is using video imaging to record queue-lengths, platoon arrivals, and real-time delay in constantly optimizing traffic signal timings.

This expert system could function in real-time in combination with both of these signal control strategies. Instead of solely using traffic volumes for priority, the system could look at actual queues on the various approaches to determine the added automobile delay that priority would add to those vehicles. If necessary, to prevent an approach from locking up by spilling back into a previous intersection, the system could delay the train to keep traffic functioning smoothly.

Although the focus of this project was on Light Rail Transit systems, the same principles could be used for bus priority systems as well. However, since busses generally operate in shared lanes with automobile traffic, more information would be required than knowing that a vehicle is approaching. The use of Automatic Vehicle Identification (AVI) techniques would need to be used in conjunction with the priority scheme. In the expert system's knowledge base, a copy of each bus schedule would be stored. When a bus approaches, the expert system would determine if the bus was on, ahead of, or behind schedule, and then make the priority decisions based on that information as well as bus volume and automobile traffic information.

Overall, real-time signal control and transit priority management could have a number of other benefits as well. Although not studied for this report, it is definitely possible that by reducing automobile delay by not providing the LRT vehicle priority where priority is not needed, automobile emissions could be reduced. In systems such as Long Beach, where no priority is afforded to LRT vehicles, reducing LRT travel times could have the benefit of increasing ridership and assist in reducing the dependency on the automobile.

Innovations in the area of advanced traffic management systems are increasing rapidly. Expert systems are one of the new technologies that will bring ATMS into the twenty first century. This research is evidence that through the use of expert systems, some of the problems facing the transportation industry can be alleviated.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank God, through whom all things are possible.

This report was prepared for the graduate summer course *Advanced Surface Transportation Issues* at Texas A&M University in the summer of 1994. I would like to thank all of those involved in the class: Dr. Dudek the course instructor, and the professional mentors, Walter Kraft, Walter Dunn, Gary Trietsch, Dave Roper and Tom Werner. Their guidance and assistance during the two seminars was invaluable.

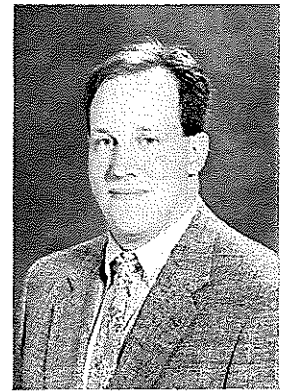
Special thanks are given to Mr. Les Jacobson for serving as my mentor for this study. His guidance during the sometimes bleak times during the preparation of this paper is very much appreciated, as was his experience with transit issues. I would also like to thank Mr. Tom Bauer of JRH Transportation Engineering for his assistance with TransSim II.

Finally, I would like to thank Mr. Steve Venglar for his assistance with this project when it was in its infancy with the first prototype expert system.

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APPENDIX

Appendix A: Rules for the Expert System

Present	Car Volume		Train Volume		V(main)/V(total)		Priority	Headways	
	At least	Less than	At least	Less than	At Least	Less than		less	greater

Actuated		1600				0.2	Full	7	
Actuated		1600				0.2	None	7	
Actuated	1600	2000	50			0.25	Full	7	
Actuated	1600	2000				0.25	None	7	
Actuated	1600	2000		50		0.25	Requested	7	
Actuated	2000	2500	66			0.33	Full	7	
Actuated	2000	2500				0.33	None	7	
Actuated	2000	2500		66		0.33	Requested	7	
Actuated	2500	3500	85			0.4	Full	7	
Actuated	2500	3500				0.4	None	7	
Actuated	2500	3500		85		0.4	Requested	7	
Actuated	3500	4500	100			0.45	Full	7	
Actuated	3500	4500		100		0.45	Requested	7	
Actuated	3500	4500				0.45	None	7	
Actuated	Any Volume					0.75	Full		
Actuated	Any Volume		150				Full		
Actuated	4500		125			0.5	Full	7	
Actuated	4500			125		0.5	Requested	7	
Actuated	4500					0.5	None	7	
Actuated		2000					Full		7
Actuated	2000	2500				0.33	Full		7
Actuated	2000	2500				0.33	None		7
Actuated	2500	3500				0.4	Full		7
Actuated	2500	3500				0.4	None		7
Actuated	3500	4500				0.45	Full		7
Actuated	3500	4500				0.45	None		7
Actuated	4500					0.5	Full		7
Actuated	4500					0.5	None		7

Appendix A: Rules for the Expert System

Present	Car Volume		Train Volume		V(main)/V(total)		Priority	Headways	
	At least	Less than	At least	Less than	At Least	Less than		less	greater

Pretimed	Any Volume					0.75		Partial		
Pretimed	Any volume						0.25	Full		
Pretimed		1600						Full	ANY	
Pretimed	1600	2000				0.8		Partial		7
Pretimed	1600	2000					0.7	Full		7
Pretimed	1600	2000	50			0.7	0.8	Full		7
Pretimed	1600	2000		50		0.7	0.8	Partial		7
Pretimed	2000	2500				0.75		Partial		7
Pretimed	2000	2500					0.6	Full		7
Pretimed	2000	2500	75			0.6	0.75	Full		7
Pretimed	2000	2500		75		0.6	0.75	Partial		7
Pretimed	2500	3500				0.7		Partial		7
Pretimed	2500	3500					0.6	Full		7
Pretimed	2500	3500	100			0.6	0.7	Full		7
Pretimed	2500	3500		100		0.6	0.7	Partial		7
Pretimed	3500	4500				0.7		Partial		7
Pretimed	3500	4500					0.4	Full		7
Pretimed	3500	4500	125			0.5	0.4	Full		7
Pretimed	3500	4500		125		0.5	0.4	Partial		7
Pretimed	3500	4500			All else			Requested		7
Pretimed	4500					0.65		Partial		7
Pretimed	4500						0.3	Full		7
Pretimed	4500		150			0.3	0.65	Full		7
Pretimed	4500			150		0.3	0.65	Requested		7
Pretimed		2000						Full		7
Pretimed	2000	2500				0.8		Partial		7
Pretimed	2000	2500					0.7	Full		7
Pretimed	2000	2500	50			0.7	0.8	Full		7
Pretimed	2000	2500		50		0.7	0.8	Partial		7
Pretimed	2500	3500				0.75		Partial		7
Pretimed	2500	3500					0.6	Full		7
Pretimed	2500	3500	75			0.6	0.75	Full		7
Pretimed	2500	3500		75		0.6	0.75	Partial		7
Pretimed	3500	4500				0.7		Partial		7
Pretimed	3500	4500					0.6	Full		7
Pretimed	3500	4500	100			0.6	0.7	Full		7
Pretimed	3500	4500		100		0.6	0.7	Partial		7
Pretimed	3500	4500				0.7		Requested		7
Pretimed	4500						0.4	Partial		7
Pretimed	4500		125			0.5	0.4	Full		7
Pretimed	4500			125		0.5	0.4	Full		7
Pretimed	4500				All else			Requested		7
Pretimed						0.65				
Pretimed							0.3			
Pretimed			150			0.3	0.65			
Pretimed				150		0.3	0.65			