REALBAND: An Approach for Real-Time Coordination of Traffic Flows on Networks

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An approach is proposed for real-time coordination of signal phase timings for a network. Currently, network coordination is done using off-line methods, such as MAXBAND, PASSER II, and TRANSYT, which are based on average traffic volumes for various movements. On-line approaches such as SCOOT adapt off-line methods by constantly inputting updated average volumes computed from detector data over the "last" decision horizon. REALBAND first identifies platoons and predicts their movement in the network (i.e., their arrival times at intersections, their sizes, and their speeds) by fusing and filtering the traffic data obtained, from various sources, in the last few minutes. An approximate traffic model, APRES-NET, is used to propagate the predicted platoons through the network for a given time horizon. The signals are set so that the predicted platoons are provided appropriate green times to optimize a given performance criterion. If two platoons demanding conflicting movements arrive at an intersection at the same time, then either one or the other will be given priority for green time, or one of them is split to maximize the given measure of performance. This study discusses how such conflicts are resolved and the corresponding algorithmic procedure of REALBAND.

Since the early 1970s, several cities in the United States, Australia, Europe, and elsewhere have implemented traffic control systems in which a network of intersections is centrally controlled by a mainframe or a minicomputer. Most of these systems have (*a*) magnetic loop detectors near the intersection to detect arriving vehicles and (*b*) a microprocessor-based local controller at each intersection where traffic control parameters are input manually or downloaded through communication links, such as telephone lines, twisted pair cable, or cable television lines.

Current implementations, even those that are state of the art, have some drawbacks due to inherent technological constraints imposed on the system design. However, these drawbacks are gradually being eliminated with the rapid advances in detector, communication, and computer technologies provided by the Intelligent Transportation Systems (ITS) program in the United States, and similar high-technology-based programs in Europe and Japan.

These modern technologies, combined with methodological advances in control theory and operations research, can be used to develop a control system for real-time traffic management to improve overall traffic system performance. A hierarchical control architecture recently proposed by Head, Mirchandani, and Sheppard (*1*) uses the capabilities of modern technologies and exploits availability of real-time data. The system that is being developed based on this architecture, referred to as RHODES, calls for a modular implementation of the subsystems responding to the various hierarchical control functions within the control structure, namely network load control, network flow control, and intersection control. The hierarchical control system is schematically represented in Figure 1.

This study deals with the second level of the hierarchy: network flow control. At this level, decisions and actions for real-time coordination of traffic flows on the network are implemented by coordinated intersection phasing. This has proven to be a challenging real-time control problem.

Prototypical off-line approaches to network coordination are TRANSYT (*2*), MAXBAND (*3*), and PASSER II (*4*), the latter two being predominately for arterial coordination. Although the original MAXBAND model allowed the optimization of signal timings in a network, the model has been used primarily for coordinating arterials. Recent enhancements of MAXBAND, embodied in MAXBAND-86 (*5*) and PASSER IV (*6*), have made its implementation to grid networks possible; however, applications to actual networks are still lacking.

The basic ingredients of these methods include (*a*) a traffic flow model and (*b*) an algorithm for optimizing a specified performance criterion (this criterion could be a weighted sum of several performance indices). For example, in TRANSYT, vehicles are "loaded" onto the network at given origins and are propagated through the network in accordance with a traffic flow model. Traffic controls affect the movement of these vehicles, and numerical optimization (gradient search) is performed to find controls that optimize the specified performance criterion. In MAXBAND and PASSER II, vehicles are loaded on an arterial, and traffic signals on that arterial are coordinated to optimize a performance criterion, which often relates to the number of stops. Because these are off-line methods, assumptions on the traffic loads are based on historical average volumes, which are uniformly loaded onto the arterials. This results in an assumption of platoons of uniform size and identical speeds.

A notable extension is the MULTIBAND model (*7*), which allows the bandwidth in each section of an arterial to be different. This accounts for turn-in and turn-out traffic that causes volume differences in the various arterial sections. Although simulations have shown that MULTIBAND performs better than MAXBAND, it is still an off-line method that uses historical average volumes and assumes platoons of uniform size and identical speeds on the arterial sections.

TRANSYT may be used in an on-line fashion to compute signal settings every few minutes and download those settings to the field. In a way, this is exactly what SCOOT (*8*) does. However, the current versions of SCOOT that the authors know about have the disadvantage that platoons in the network may not experience sufficient platoon progression, or any other desired platoon-based performance. Ad-hoc approaches have been suggested to enhance SCOOT to consider platoon progression; however, to the authors' knowledge, these have not been implemented. Although

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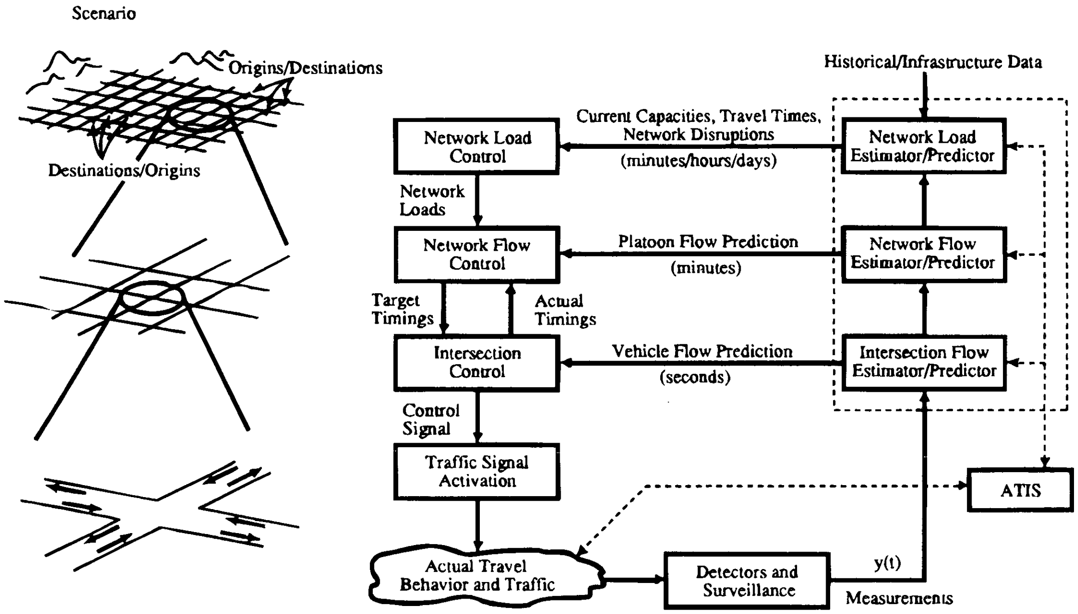


FIGURE 1 Hierarchical control architecture for traffic management.

TRANSYT has been modified to include progression opportunities (*9*), it has not been implemented for real-time applications. It is not clear whether this approach is amenable for real-time applications due to its excessive computational requirements. Furthermore, TRANSYT, and for that matter SCOOT, do not explicitly consider the currently measured, in real-time, traffic flows (i.e., platoons and their speeds), but instead take the current data and assume a uniform flow of the current volumes.

THE "REALBAND" APPROACH

The approach presented in this study explicitly considers available real-time information for computing signal timings. It first identifies platoons and predicts their movement in the network (i.e., their arrival times at intersections, their sizes, and their speeds) by fusing and filtering the traffic data obtained, from various sources, in the last few minutes. An approximate traffic model is used to propagate the predicted platoons through the network for a given time horizon. The signals are set so that the predicted platoons are provided appropriate green times to optimize a given performance criterion.

Two platoons demanding conflicting movements may arrive at an intersection at the same time. In that case one will be given priority on the green time, or one of the platoons will be split to maximize the given measure of performance. Optimally resolving such conflicts in real time is the main objective of the algorithm presented, which, for brevity, is referred to as *REALBAND.*

The time-distance diagram on a single arterial is shown in Figure 2. The goal of off-line arterial progression algorithms, such as MAXBAND and PASSER II, is to set the signal timings so that the

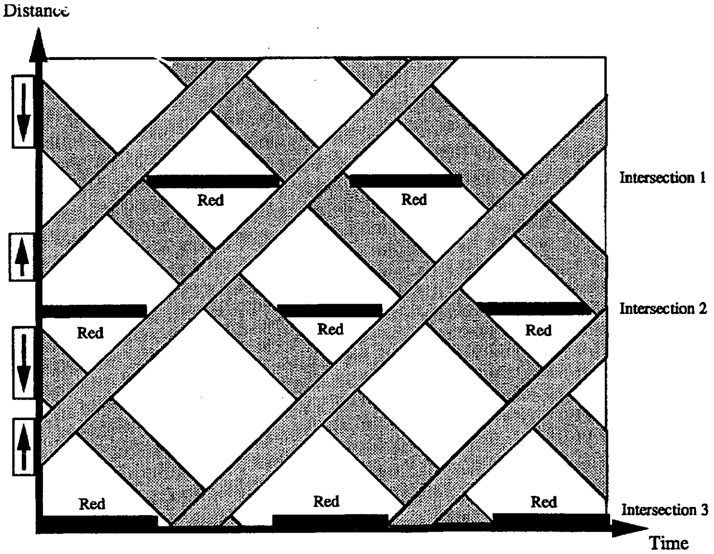


FIGURE 2 The MAXBAND concept.

number of vehicles that can traverse the arterial in either direction without stopping (other similar criteria may be incorporated) is maximized. The figure shows these bands of green times. Note the following drawbacks: it is assumed that sets of platoons of equal size are distributed in a cyclic manner, and that platoons travel at the same constant speed.

The time-distance diagram in Figure 3 (*a*) shows platoons of different sizes and different speeds. Because the green times required for these platoons are different from those required for the uniform case shown in Figure 2, the smooth anticipated progression is disrupted. By slightly adjusting the red times, it may be possible to reinstate the green bands for the given platoons with their own sizes and speeds [see Figure 3(*b*)]. Of course, the identified platoons on the cross streets must also be considered when the green times are adjusted so that cross street traffic does not get delayed unnecessarily; *REALBAND* does consider this. Platoon dispersion and compression, although not shown in the figure, may also be included. Also, the illustrations do not show turning vehicles, which could increase or decrease platoon sizes and the speed differences given in the figures also have been purposefully exaggerated. This is so that the proposed concept for network flow control is more easily visualized. The approximate flow prediction model (discussed later) addresses each of these characteristics.

If the intersecting platoons fit exactly within the red times shown here, then it is not necessary to resolve green-time demand of conflicting movements. On the other hand, if flows at an intersection produced a concurrent green-time demand for conflicting movements, then the conflict must be resolved by determining to which movement the green time must be allocated. Figure 4, which shows platoons on two other perpendicular arterials at Intersections 2 and 3, illustrates this scenario.

REALBAND makes a forward pass in time. When a conflict arises a decision node in a tree is formed; the types of decisions at this node include: (*a*) give green time to Platoon A, (*b*) give green time to platoon B, or (*c*) split Platoon A (or Platoon B, because only one or the other platoon needs to be split). Each branch of the tree is propagated over time to keep track of the total performance up to the decision node plus the performance on the link associated with the potential decision. An implicit approximation is used on the additive nature of the performance measure to propagate from node to node in the decision tree.

Figure 5 gives the current prediction of the movement of the platoons shown in Figure 4. The first demand conflict arises between Platoons N and W3 at Intersection 3. To resolve the conflict, Platoon N (Figure 6) is split or platoon W3 is stopped (Figure 7). Considering the resulting predictions shown in Figure 6, the next conflict arises between Platoons S and E3. Here the decision is either to stop Platoon S (Figure 8) or Stop E3 (Figure 9). In this way, a decision tree is formed that keeps track of various candidate decisions as demand conflicts arise. For this illustration, the decision tree for the predictions that arise for various decisions is given in Figure 10.

When the time horizon is reached, associated with each end node will be the total cost of the all the decisions leading up to the node on the path from the root of the decision tree to the end node (leaf) of the decision tree. Selecting the one with minimum cost provides the least cost trajectory of conflict resolution decisions. A final backward pass provides a phase plan within the time horizon considered for the identified platoons. This is passed to the third level of the hierarchical traffic control system (intersection control logic) as constraints (and, hence, an initial cut at a sequence of phases) that specify the "winning phase" from the outcome of each conflict resolution on the optimal root-to-leaf path in the decision tree. Further optimization is performed at the intersection level, at which more detailed data on individual vehicle movement are gathered. For the platoons shown in Figure 4, choosing the path with optimum performance (in this case minimum total delay), the resulting optimal decisions from the decision tree are shown in Figure 11, which includes the red and green times for the N-S arterial. It indicates that at Intersection 3 Platoon N should not be stopped but Platoon W3 should be stopped and, later, Platoon E3 should not be stopped but Platoon S should be stopped, when the corresponding demand conflicts arise.

The advantages of the *REALBAND* approach include:

1. Using real-time data, REALBAND explicitly identifies the platoons and predicts their movement in the network; the method also sets traffic signals to respond to the identified platoons.
2. REALBAND does not necessarily require a predetermined sequence of phases. The output provides an initial cut at a sequence of phases for further optimization at the lower intersection level.

A final issue that needs to be resolved in the REALBAND method is the computation of performance measures, (e.g. the total number of stops, total delay, etc.). To do this, concepts from TRAF-NETSIM (*10*) and TRANSYT are used to create a quick-and-dirty simulation to evaluate the performance of a set of signal settings. For real-time applications, these performance measures are needed quickly so that the performance criterion may be optimized in real time. A detailed simulation becomes computationally unwieldy when the simulation model is used as a function evaluator (i.e., for evaluating the performance function for each candidate signal setting) in an optimization routine. To be in the proper range for the optimizations being performed at the intersection level, only approximate values for optimal signal timings are necessary at this second level of hierarchy. The simulator, to evaluate performance measures in *REALBAND*, is referred to as the *Approximate Prediction in Response to a Signal Network* (*APRES-NET*) model (*11*).

The flow chart for the algorithmic process for network flow control optimization is given in Figure 12. To begin the recursion it is suggested that an initial signal plan be given so that the network flow control optimization begins in the proper range. The initial plan may be obtained from an off-line method such as TRANSYT using volumes obtained from the upper level network load control module (if available) or using historical data.

To use the fast simulation model for function evaluation, the spatial region for the simulation model must be bigger than the area of control for network coordination so that the movements of all real-time platoons within the region of control can be predicted for several minutes in the future. Figure 13 (*a*) shows the region of control for the network flow control logic, and Figure 13 (*b*) shows the area simulated using the *APRES-NET* simulator.

IMPLEMENTATION ISSUES AND SOME RESULTS

Although Figure 12 shows a rather simple flow-chart, the following issues must be considered for the code to be effective in providing good if not optimal solutions and efficient for real-time applications.

- Filtering detector data for identifying platoons,
- Initialization of *REALBAND,* and
- Propagating *REALBAND* through time using *APRES-NET.*

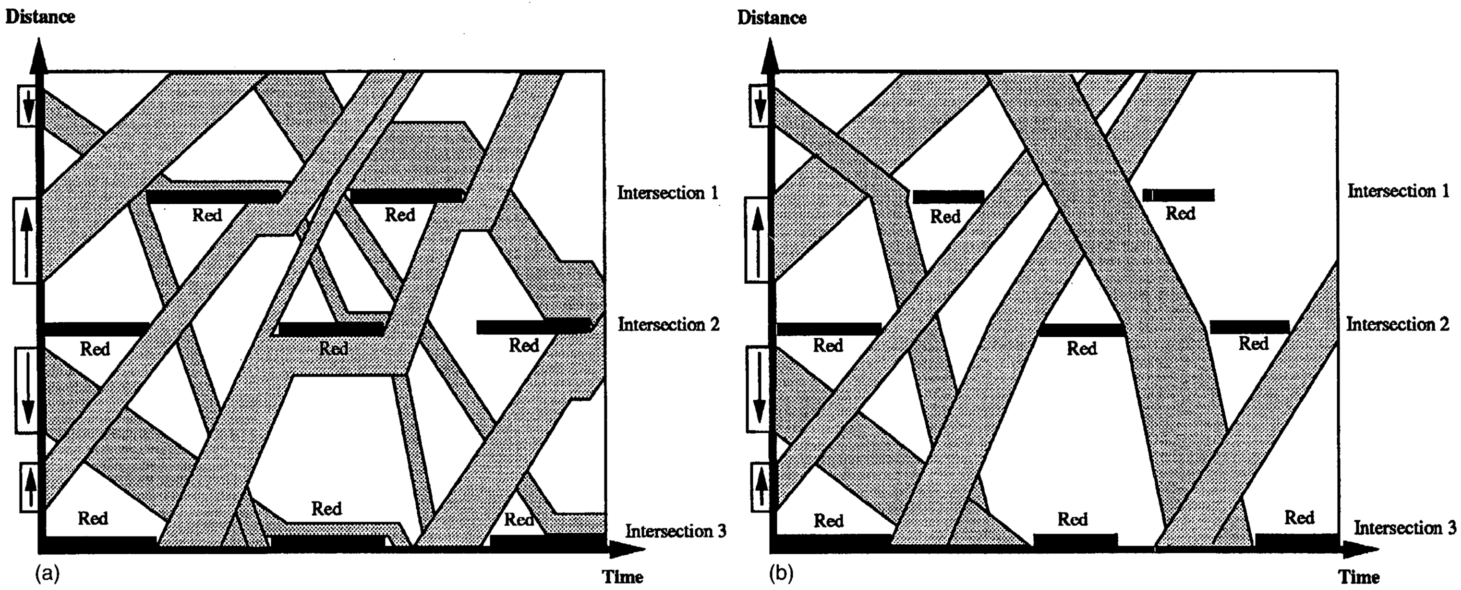


FIGURE 3 (*a*) Actual MAXBAND performance; (*b*) the REALBAND concept for single arteries.

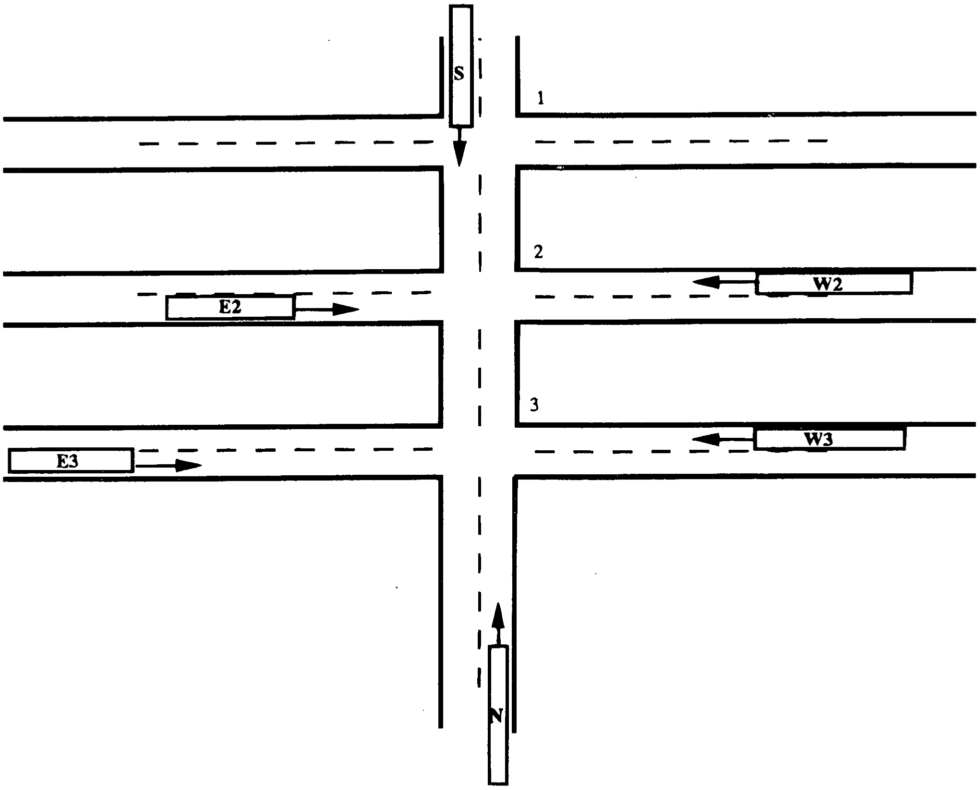


FIGURE 4 REALBAND example network.

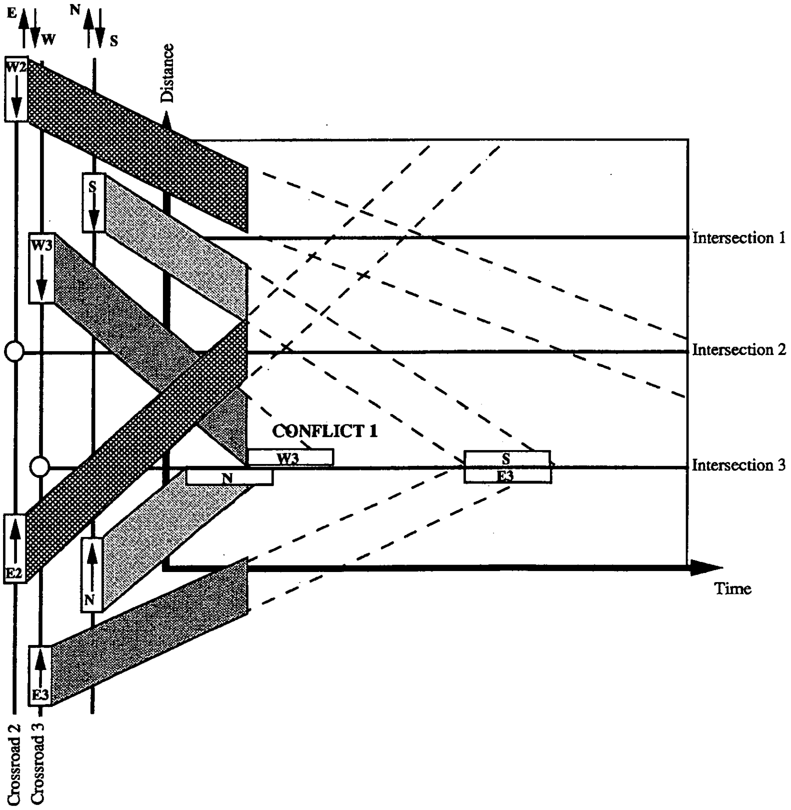


FIGURE 5 Current prediction of platoon movement.

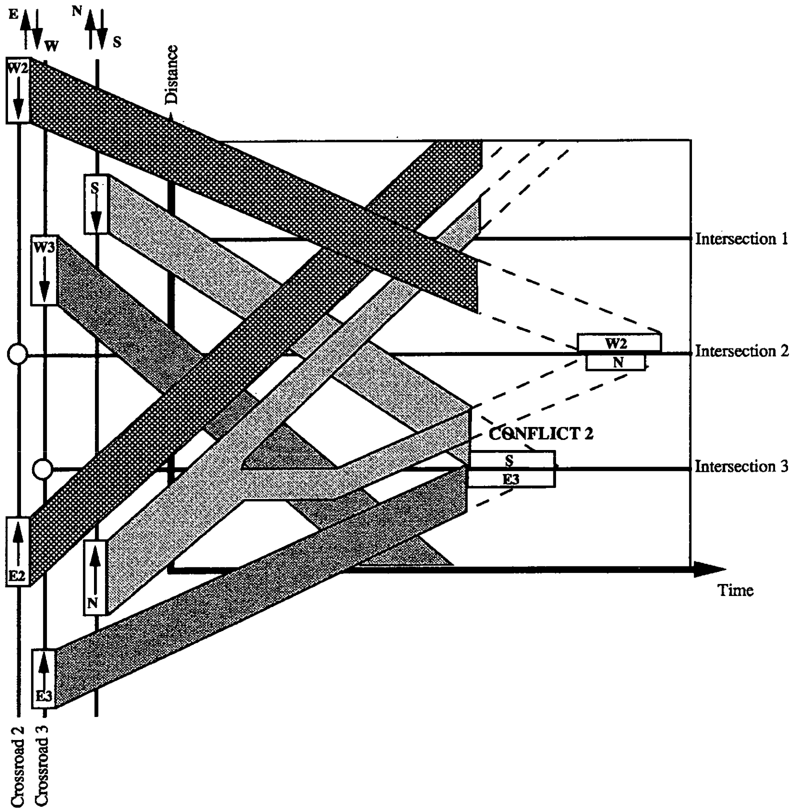


FIGURE 6 Decision to split Platoon N at Intersection 3.

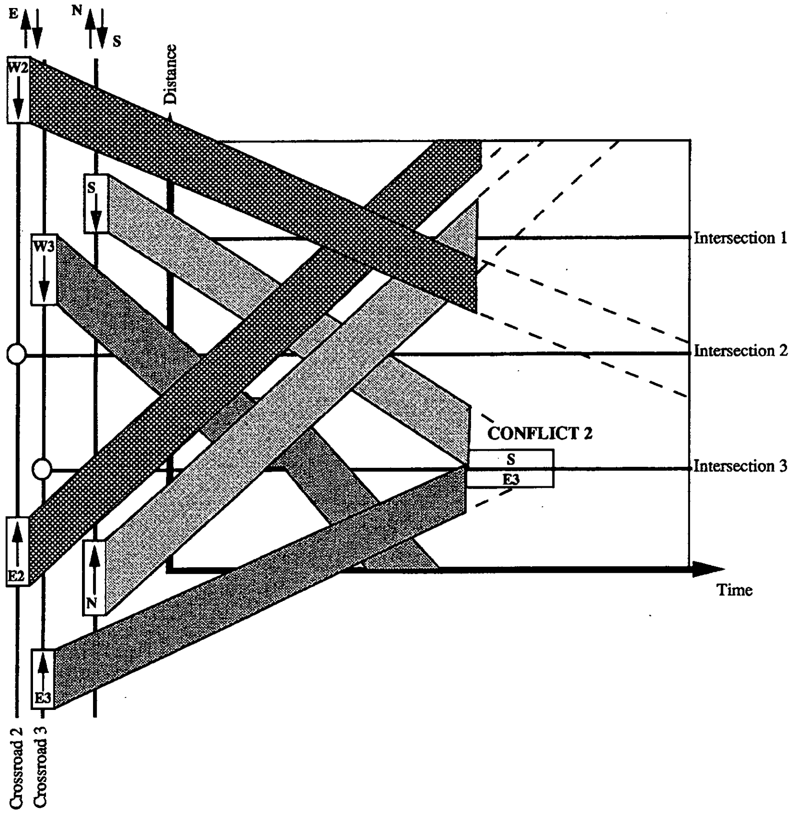


FIGURE 7 Decision to stop Platoon W3 at Intersection 3.

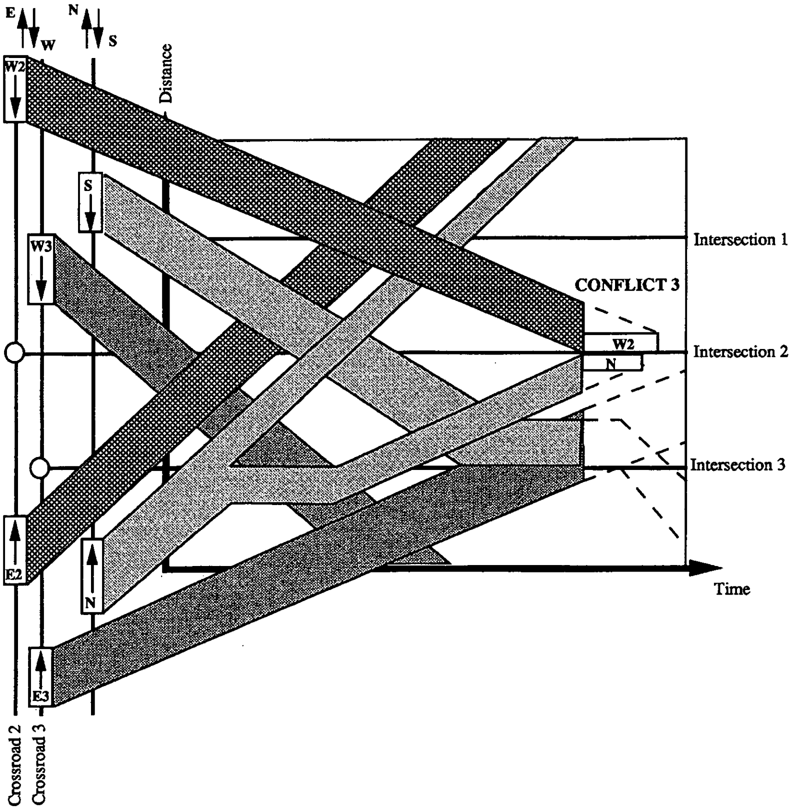


FIGURE 8 Decision to stop Platoon S at Intersection 3.

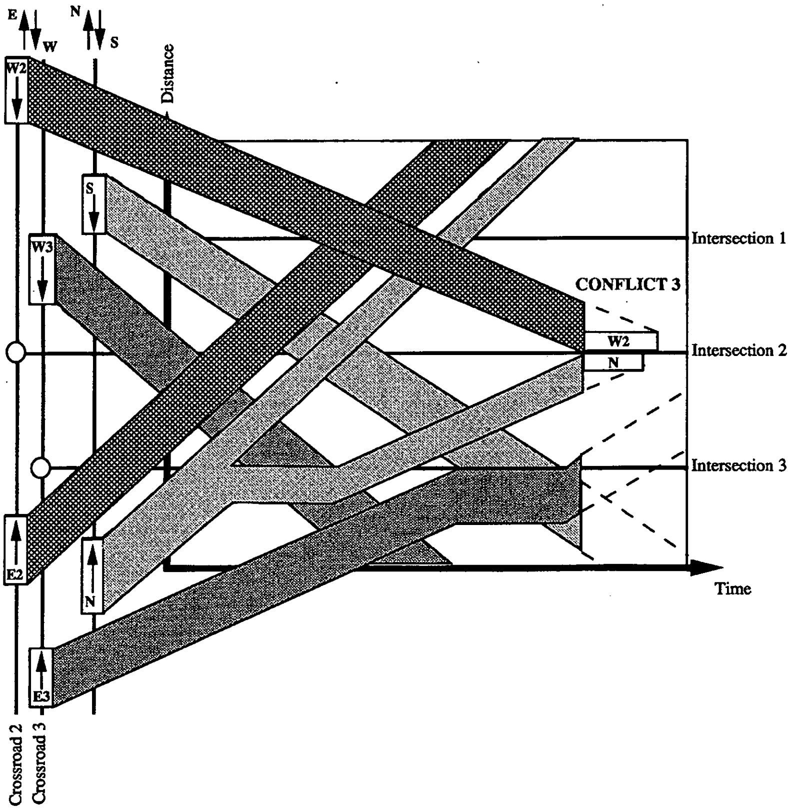


FIGURE 9 Decision to stop Platoon E3 at Intersection 3.

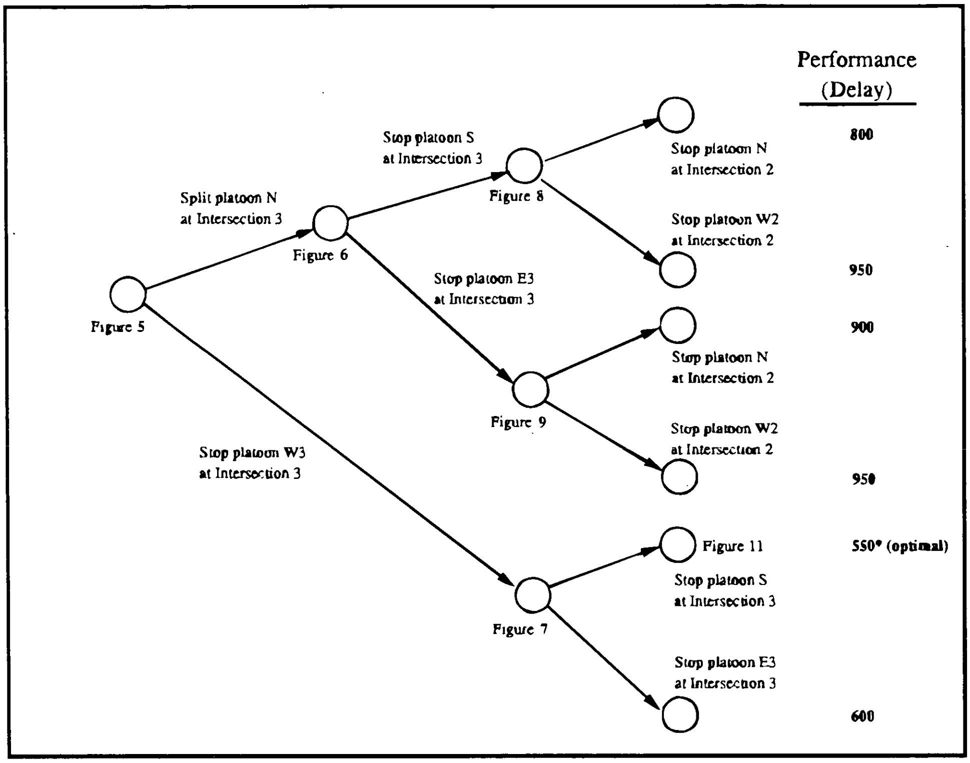


FIGURE 10 Decision tree for an illustrative problem.

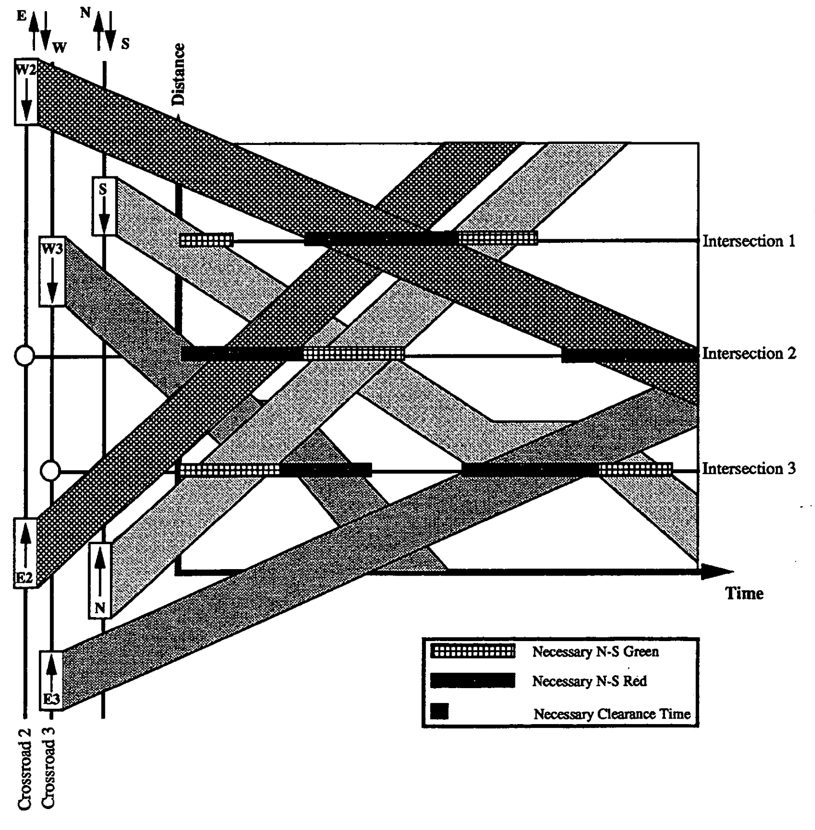


FIGURE 11 The north-south "red" and "green" phases for optimum decisions (see Figure 10).

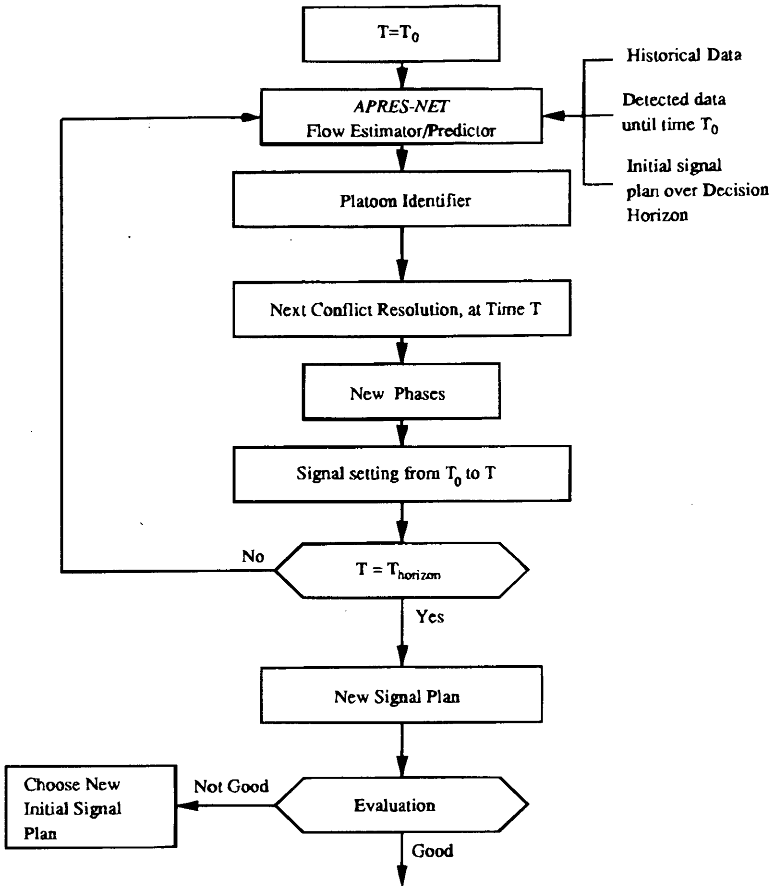
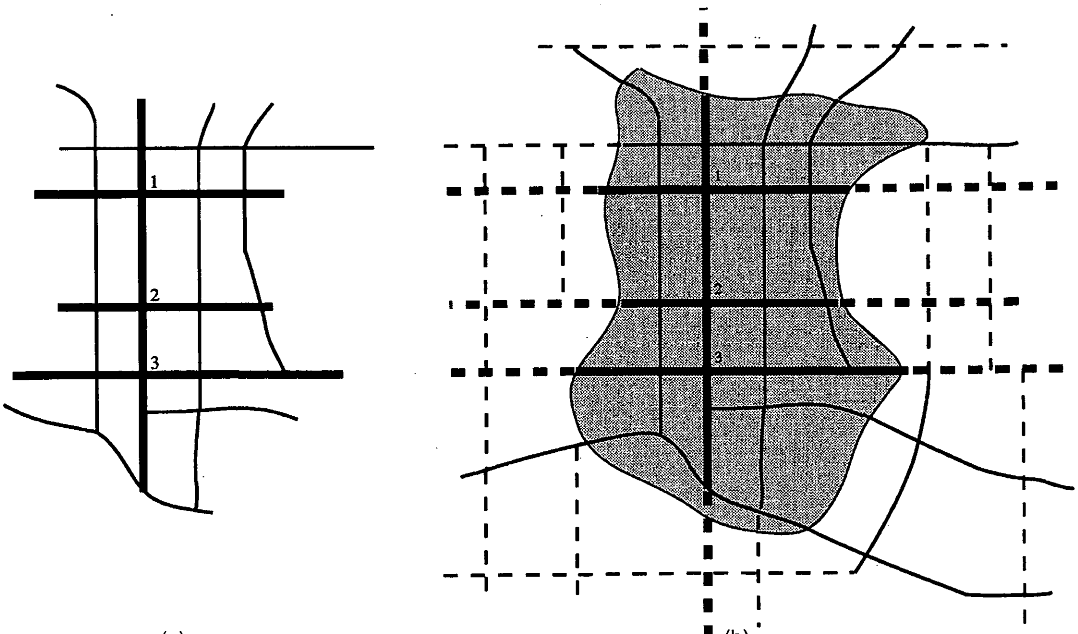


FIGURE 12 Flow chart for REALBAND.



(a) (b)

FIGURE 13 Region for (*a*) network flow control, and (*b*) simulation model.

The definition of platoons for traffic coordination depends on the level of traffic in the network. In low congestion with vehicles traveling at high speeds, a platoon may be composed of as few as three cars having an average headway of 2 secs. On a more heavily congested road, a platoon may consist of many more cars with an average headway of 1 sec. In any case, if a traffic engineer looks at vehicle detector data, that engineer can easily recognize platoons. Any platoon identification algorithm in which the goal of the algorithm is to filter out individual cars and identify platoons should be able to emulate the decisions of a traffic engineer. Several algorithms are being explored to identify platoons based on concepts of low-pass filters, threshold rules, etc. To develop the *REALBAND* algorithm, a platoon identifier was used based on two user-specified threshold parameters: maximum headway between two vehicles in the same platoon and the minimum number of vehicles that constitute a platoon. Further research and evaluation is recommended for the development of an appropriate platoon identifier.

REALBAND starts with an initial solution of phase timings and associated measure of performance obtained through *APRES-NET.* The initial phase timings could have been developed off-line using a program such as *TRANSYT* with traffic volumes obtained from the network load control level, or the initial phase timings could be given for the next few minutes. The initial phase timings define the first node on the decision tree, as shown in Figure 10. The measure of performance associated with the initial phasings becomes an upper bound (UB) on the performance because it is known that the signal network gives a feasible set of timings with at least this level of performance.

The platoon identifier then filters the detector data to identify platoons. The initial set of phasings resolves conflicts by default because traffic controllers have built-in signal phase control logic that does not permit conflicting movements at an intersection. However, examination of the platoon data from the initial run of *APRES-NET* will indicate that, at times, a platoon will be stopped or split so that another platoon can pass through a conflicting movement. *REALBAND* will identify the first time this occurs, say at time $T_0+\Delta T$. This is the first conflict to be resolved; hence, the time has been propagated by ΔT, and a new leaf node is formed in the decision tree. *APRES-NET* will then be run using the signals corresponding to having the stopped platoon pass through and the other (conflicting) platoon stopped. Then another UB is obtained, along with a new set of identified platoons (the platoons may have changed due to splitting, combination of platoons, or both). For the two sets of scenarios formed, the next conflict is identified and the process is repeated. In this manner, as *REALBAND* propagates through time, it develops a decision tree, keeping a feasible UB for the performance at each node. The algorithm terminates when *REALBAND* propagates to the planning horizon; the phase timings corresponding to the leaf node with minimum UB become the timings sent to the lower (intersection) level controllers. The algorithm can also be set to terminate when some performance threshold is satisfied with some UB (this performance threshold being given as a function of a lower bound or given a priori by the traffic engineer). Although an effective lower bound has not yet been developed for each node, the authors intend to to develop a procedure to create such lower bounds and prune the decision tree.

The authors are still conducting simulation tests for evaluating *REALBAND* performance. A 41-node, 42-link actual network (representing a section of Tucson) has been coded on *APRES-NET.* The initial phase timings have been provided by the city's traffic engineer based on TRANSYT and subsequent manual fine-tuning. In the tests, two intersections (e.g., Intersections 1 and 2) within this network were subjected to real-time control using *REALBAND.* The resulting changes in phase timings are shown in Figure 14. There is considerable difference between the initial timings and the timings downloaded by *REALBAND.* For a 200-sec planning horizon for this two-intersection problem, the total delay for the entire 41-node network decreased from 12,559 vehicle-sec to 11,275 vehicle-sec, yielding about a 10 percent improvement.

The authors are still developing an efficient mechanization for generating and pruning decision trees. Further laboratory evaluation of *REALBAND* also is planned. The network will be simulated using a micro-simulation model (TRAF-NETSIM will be used for this purpose) and will provide simulated detector data to *REALBAND* (through *APRES-NET*). *REALBAND* in turn will return to the microsimulator phase durations in real time. In this manner, it will be possible to perform considerable off-line evaluation before testing *REALBAND* in the field.

The *REALBAND* procedure for network flow control exploits the availability of real-time traffic data to control vehicular traffic through a network to optimize a given performance measure. It

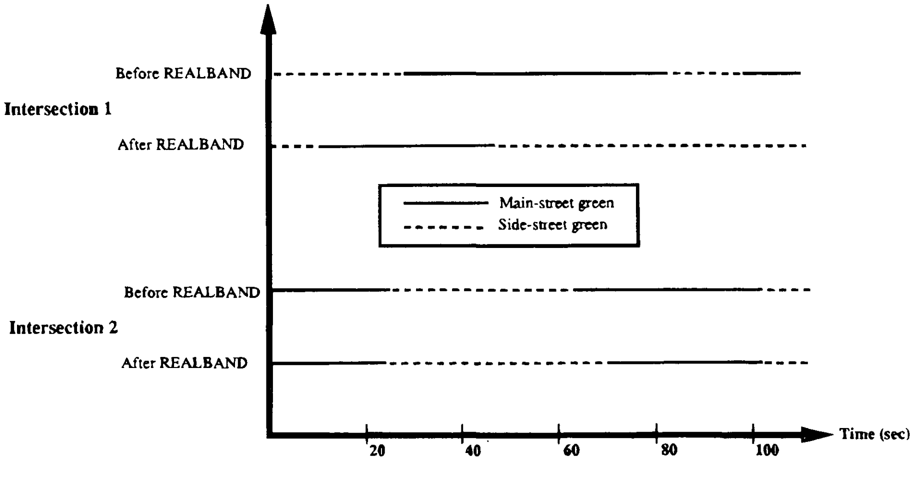


FIGURE 14 "Before" and "after" REALBAND application.

is envisioned that this procedure will be suitable for light-to-moderate traffic conditions, but not oversaturated conditions. *REALBAND* should perform as well as or better than off-line methods such as PASSER II, MAXBAND, and TRANSYT.

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