# Towards Semi-Automated Arterials: Dynamic Traffic Signal Control with Time-Dependent Variable Speed

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This paper presents a framework and demonstrates the feasibility of an advanced concept for traffic control on congested urban arterials. The main idea of semi-automated arterials is to utilize a dynamically optimized time-dependent variable speed as an additional signal control parameter. In a semi-automated arterial, speeds would be automatically optimized and set by a central computer. They would change between links and over time in response to changing traffic conditions. Drivers would follow the optimized speed as they enter a link. Once an optimal speed has been set for a link, it remains constant until the control cycle ends. Link speeds would be updated only at the end of every control cycle. The control cycle may change in length as system conditions evolve. The new control concept was tested on a congested arterial with multiple links. The arterial system was modeled as a discrete event time varying dynamical system with a control period spanning several cycles. System throughput was maximized subject to such critical operational measures as intersection blockage, queue spillbacks, and other relevant traffic operation measures. Genetic Algorithms (GAs) were used as an optimization tool. Results show that the semi-automated arterial concept will significantly improve traffic flow. The new control concept is suitable for on-line implementation in an ITS setting. Key words: signal control, variable speed, congestion.

## INTRODUCTION

Urban traffic congestion is becoming a fact of life in many urban and suburban areas in the U.S. and elsewhere in the world. More than 70% of the U.S. urban peak-hour traffic is congested (*1*). Furthermore, traffic jams contribute substantially to air pollution. And travel demand continues to far outpace provision of roadway capacity. For example, for the Washington DC area, vehicle miles of travel (VMT) are expected to increase by 75% between 1990 and 2020; whereas lane miles of capacity are expected to increase by only 22%. Consequently, vehicle hours of delay are projected to increase by 480%, and 85% of regional travel is expected to occur on congested roadways (*2*). There is little reason to believe that congestion problems will go away by simply building new capacity. A different approach is needed to better manage and utilize existing transportation systems. In urban areas, traffic signal control plays a major role in the quality of traffic operations. As part of that, more advanced traffic signal hardware and control procedures are needed.

This paper presents a framework for an advanced signal control scheme. In this scheme, speed is introduced as control parameters as opposed to a soft constraint. Speed is optimized and allowed to vary over time and space. The optimized speeds are then integrated into a dynamic signal control algorithm.

## BACKGROUND

Traditionally, traffic signal operations are optimized using the control variables of splits, offsets, and phasing. These parameters are usually designed to respond to traffic conditions, including desired speed, so that traffic progression is attained or delay is minimized. Either way, speed is used as an input on the assumption that it is fixed and that its value is "optimal." But little examination of how speeds are normally set reveals that an optimal speed value should be a function of traffic conditions, which, in turn, is time-dependent. In the past, technical difficulties in reliably detecting traffic conditions may have been a serious hindrance in devising time-dependent changeable speeds based on real-time traffic information. Time has changed and with it comes a host of new technologies that are changing the way we do business, including traffic sensing and traffic signal operations design. It is becoming increasingly possible to reliably, but not perfectly, detect traffic conditions in real time. This, in turn, makes it feasible to vary speed based on field traffic information.

The concept of variable speed in traffic control is not new. It has been successfully used on freeways for quite some time particularly in Europe. It seems timely to start exploring the feasibility of applying a similar concept on signalized arterials. That is, vary speed dynamically on arterials and use it as an additional control parameter. This is what this paper is set out to explore.

This paper presents a framework for an algorithm that dynamically optimizes speeds on arterial links and uses them as additional control parameters. The optimized speeds are integrated, in parallel, into a dynamic signal control algorithm (*3*). Genetic Algorithms (GAs) were used to solve the optimization problem. The GAs' adaptive, robust, directed search and flexible form of the objective function make them an ideal solution technique for dynamic control problems similar to the problem formulated in this paper.

## NEW CONTROL SCHEME

The key feature of the control scheme of this paper is to dynamically vary speed and use it as a control variable. Speed is optimized in parallel with the other control variables based on evolving traffic conditions. The role of speed in this control scheme comes into play in adapting the values of offsets to traffic conditions on downstream links so that output is maximized and intersection blockage is prevented. Specifically, offsets between neighboring arterial approaches are set based on queue length and the available space on a link. Speed

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determines the time needed to travel the available space on the link (i.e., the distance between the upstream intersection and the downstream queue). This time element is a component of the offset-determining algorithm. Hence, different speeds would result in different offsets for the same queue length and the same available space on a given link. In this framework, speed, in effect, is optimized to produce system-optimal performance (as opposed to link-optimal). Vehicle acceleration and deceleration rates are assumed constant.

The control optimization problem is structured as a discrete event time-varying dynamical system. The optimal arterial control formulation is:

Find the trajectory of control variables

$g_{(k)i}$ (green splits)
$Speed_{(k)i}$ (speeds)
$Offsets_{(k)i}$ (offsets)

That maximizes the objective function:

$$\sum_{\text{all approaches}} \sum_{\text{all cycles}} \text{System output (Link} - \text{vehicles)} \times \text{Speed}$$

Subject to the constraints on the state variables

$q_{(k+1)i} = q_{(k)i} + AV_{(K)i} - DV_{(k)i}$ (queue formation and dissipation models)

and the control variables

$g_{(k)i\ min} \leq g_{(k)i} \leq g_{(k)i\ max}$ (domain of green splits)
$Speed_{(k)i\ min} \leq Speed_{(k)i} \leq Speed_{(k)i\ max}$(domain of speeds)

$Offsets_{(k)i} = f(\text{ queue length}_{(k)i}, \text{space}_{(k)i}, \text{speed}_{(k)i})$

Where q is the queue length, AV is volume of arriving traffic, and DV is volume of departing traffic. The cycle number is referred to as *k*, and *i* is the link, or approach number.

The decision variables in this optimization problem are green splits (hence cycle length), offsets, and speeds. Speeds were allowed to vary between 15 to 40 ft/sec. Phasing was not optimized. The algorithm was applied to a congested system of seven intersections for a duration of ten cycles. Micro-Genetic Algorithms (micro-GAs) were used for optimization. Micro-GAs were used because of their ability to overcome combinatorial explosion and their flexibility in formulating the objective function. The results are discussed next.

## EVALUATION AND DISCUSSION OF RESULTS

Several measures of effectiveness (MOE) were used to evaluate system performance with variable speed. The results were contrasted to system performance where a constant speed of 40 ft/sec is used. All inputs and parameter values were the same for the variable and constant speed schemes. Overall, using the scheme of variable speed appears to improve system performance. Specific results are discussed below. All results are presented on a per lane basis.

### Number of Stops

A vehicle is said to have stopped if it is unable to leave the link during the same cycle it enters in. The number of stops provides a general measure of quality of progression, fuel consumption, and vehicle emissions. Figure 1 shows the number of stops per unit of output for each link for both variable and constant speed control schemes. The number of stops is lower under the variable speed scheme, and for the entire system there were 25% fewer stops. At the link level, the number of stops was generally lower under the variable speed scheme. The trend between individual links varied; two of the links experienced more stops under the variable speed scheme.

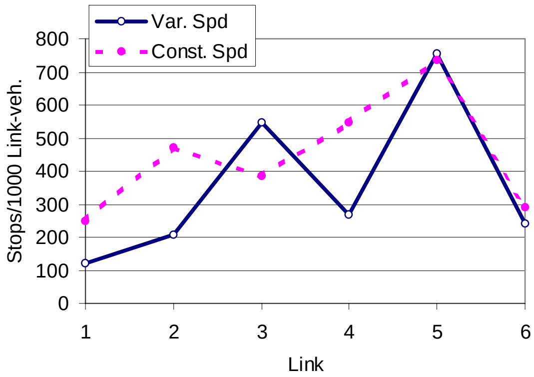

**FIGURE 1 Variation of number of stops on system links**

The lower number of stops with variable speeds is expected. The algorithm has a "system view" of traffic conditions, or, in other words, it can "see" beyond the immediate downstream link. This makes it possible to employ a speed value that is system-optimal as opposed to link-optimal which would be the case if speed selection is left to drivers. In real-world conditions, drivers can see only conditions on the link they are driving on. Hence, they select a speed they think optimal for that link only to find themselves forced to stop at intersections further downstream. Employing variable speed, in effect, overcomes this condition. That is, it takes the decision of selecting speed from drivers and gives it to the system "central controller," which, in turn assigns speeds to system links so that the overall system performance is optimal.

### System Traffic Content

System content measures the volume of traffic present on system links during a given time window. Higher traffic content means less chance for progression and more chance of stopping. Figure 2 shows the system content at the beginning of each cycle. Traffic content is lower under the variable speed control scheme than under the constant speed scheme. The trend is clearer at the link level (Figure 3). Here, we see that the variable speed scheme was far more successful at reducing standing queues. This outcome follows from the fact that fewer vehicles are arriving prematurely at the respective approaches. Flexibility in speed makes this possible.

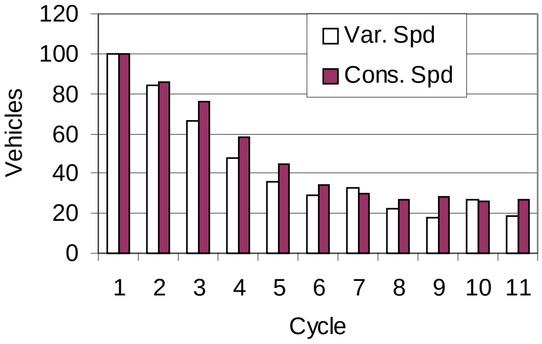

**FIGURE 2 System content of traffic over time**

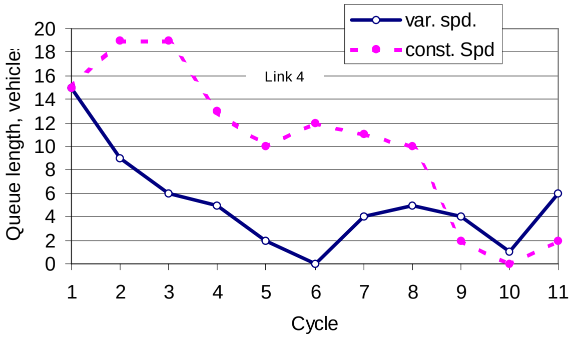

**FIGURE 3 Change of queue length with time on a typical link**

### System Output

System output, measured in link-vehicles and normalized by arterial green time, is shown in Figure 4. The output is only slightly higher under the variable speed control scheme. The experimental setup could have contributed to this marginal difference: the optimized variable speeds were allowed to vary from 15 ft/sec to 40 ft/sec; whereas under the constant speed scheme, speed was set at 40 ft/sec. The calculated average speed based on all system links (not shown) for the variable speed case was lower than that of the constant speed case.

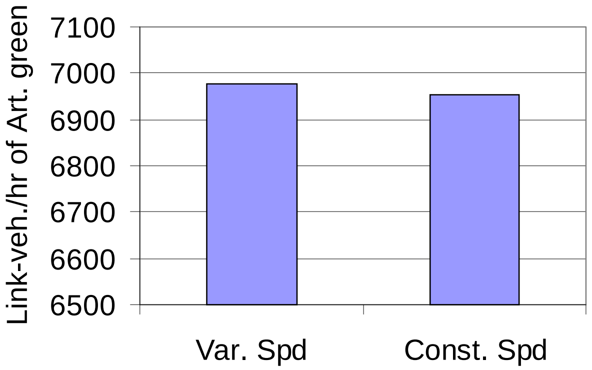

**FIGURE 4 System output for the two control schemes**

## CONCLUSIONS

This paper presents a framework for a signal control algorithm wherein speed is used as a decision variable as opposed to a soft constraint—as is traditionally the case. The algorithm treats link speeds as functions of time, dynamically optimizes them, and then uses them as control parameters besides green splits and offsets. Speed is dynamically optimized based on evolving traffic conditions. Using speed as another control parameter adds a new dimension to the control problem and hence increases the spectrum of control choices. The algorithm was tested on a congested seven-intersection arterial system. The results were then contrasted to those with constant speed. Variable speed-based control was more efficient in many respects. It resulted in fewer stops, better conditions for progression, better queue management, and more system output. This implies improved traffic flow. There would be fewer premature arrivals at intersections and formation of queues —hence shorter time to clear queues—fewer stops and “stop-and-go” maneuvers, and less interactions and complications resulting from continuous stopping and starting shock waves. Reduced fuel consumption and harmful emissions are other desirable outcomes.

The new control concept is suitable for on-line implementation in an ITS setting. It can be extended to congested networks with closed loops. The value of this procedure is more when traffic on system links varies considerably either due to geometry or traffic generation factors. In the results presented above we assumed complete driver compliance with speed—an overly optimistic assumption. This and other implementation issues will have to be addressed before variable speed type control can be implemented in real-world conditions. It is recommended that this concept of control be further evaluated and validated in preparation for implementation.

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