Emerging Methods of Signal Timing Optimization

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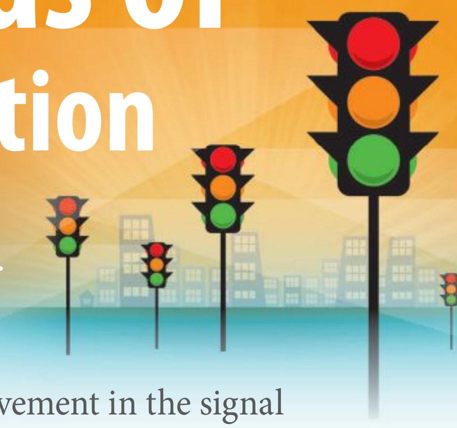

Many believe that there is little room for improvement in the signal timing optimization process. To the contrary, recent advances imply that the current practice is far from perfected. Rapidly evolving intelligent transportation system (ITS) technologies are not close to being used to their full potential. Multimodalism and "complete streets" are hot topics within the Institute of Transportation Engineers (ITE), but their connection to signal optimization is not being made. Advances in optimization theory have not yet made an impact on signal timing. Computer speeds have increased exponentially, making it possible to deploy optimization methods that are much more powerful and much more computationally expensive. Alternative intersection designs are going viral, but the research on optimizing these facilities has only just begun. Finally, connected and autonomous vehicles could drastically improve traffic flow and traffic safety, but they may upset the way that transportation engineers traditionally do their jobs. With all of these changes looming, are you ready for 21st century signal timing?

In this article, we discuss four emerging areas of signal timing optimization: data-driven performance measures, improved heuristic methods, alternative intersection and interchange methods, and multimodal intelligent traffic signal systems

Emerging Methods

1) Data-driven Performance Measures

In their landmark 2014 *ITE Journal* article, "Automated Traffic Signal Performance Measures," seven transportation engineers from Indiana, Minnesota, and Utah previewed the benefits that are possible from real-time signal status and/or signal detector monitoring.[1] Now more than a year later, researchers and practitioners are learning how to leverage these technologies and make them more practical. The Automated Signal Performance Metrics (SPMs) are a revolutionary and deceptively simple approach to troubleshoot, alert, prioritize, and optimize traffic signals. An SPM system collects high-definition data from a traffic signal controller and generates a series of visual metrics. SPMs allow the user to quickly assess the historical operation of a traffic signal, including the actual time used by each phase, the frequency of pedestrian actuations, and how many vehicles are arriving during a phase's green interval. Consulting SPMs are the ideal first step for all concerns and questions about signal performance. Quickly identifying the problem generally results in addressing issues more quickly and efficiently.

SPMs support the concept of "Why model what you can measure?" An SPM system can reduce or eliminate the need for models in the signal optimization process. By reducing dependence on data collection and models, there are fewer issues during implementation caused by uncalibrated models. Final optimized timing plans are developed quicker and cheaper, and tend to perform better. The complexity of true adaptive control, and its dependency on perfectly functioning detection to operate without failure, may not be appropriate for corridors with predictable traffic. For these corridors, SPMs can operate as a human-in-the-loop adaptive system, helping agencies to maintain timing plans and equipment.

A new metric developed at Purdue University was recently tested on Foothill Blvd in Salt Lake City, UT, USA.[2] The Purdue Link Pivot metric is an offset optimization tool that uses detection in advance of the stop bar to estimate when vehicles arrive at the intersection. With the signal's phase data, it can calculate the number of vehicles arriving during the green interval. Purdue Link Pivot is able to use this data from all main street approaches on a corridor to automatically generate offset changes to optimize corridor arrivals on green. Foothill Blvd was retimed in May 2013 and achieved an overall arrival on main street green of 80 percent. In May 2015, before Purdue Link Pivot was used, the system had degraded to an arrival on green of 77 percent. Without models, data collection, or extensive field observation, Purdue Link Pivot optimized the corridor offsets to achieve 79 percent arrivals on green. Figure 1 shows the impact of the recommended offset changes to arrivals on green at each approach along Foothill Blvd. This new metric allows us to easily monitor and maintain the performance of our optimized signal timing plans without costly retiming efforts, or waiting until system performance has significantly degraded.

Beyond real-time signal status and/or signal detector monitoring, some cities are monitoring traffic performance measures to augment their signal timing practices. The city of Mesa, AZ, USA is transitioning towards a more automated system, which will facilitate traffic signal responses to abnormal increases in travel times. Companies such as SMART Signal Technologies have begun automating the process of improving traffic flow along signalized arterial corridors, through systematic monitoring of arterial road traffic.[3]

2) Improved Heuristic Methods

At the 2015 ITE Mid-Colonial Annual Meeting held in Arlington, VA, USA, signal system engineers discussed their standard practices. They admitted that their signal timing tools produce consistently poor solutions. To compensate for this they routinely spend an inordinate amount of time in the field, timing their system manually, while using the software solution as a starting point. The poor performance of signal timing tools is often attributed to insufficient calibration and/or data collection. However many do not realize that within top-selling desktop software products and real-time adaptive control solutions, the mathematical optimization methods are relatively weak and outdated. This was once necessary in the 1990s or early 2000s, as the typical computer speeds were too slow to execute heuristic (self-adapting) algorithms known to be more powerful. However over the past two decades, computer processing speeds have improved dramatically. We should move past accepting low-quality solutions. Powerful heuristic methods are becoming more practical with each passing year. Unfortunately many product vendors seem content to rely on older methods, even when the advanced algorithms could potentially reduce vehicle delays by another 33 percent, solely on the basis of superior mathematics. Figure 2 illustrates the concept of solution quality versus computer run time, in which powerful heuristic methods deliver far superior outcomes but require much longer computer run times to deliver those outcomes.[5]

In the summer of 2014, the first international conference on applied optimization was held in Kos Island, Greece. Rest assured that optimization experts gathered from around the world were not debating the merits of obsolete methods like Equisat, hill-climbing, Webster's method, and the greedy algorithm, which are more deserving of being in a mathematical museum, rather than playing an important role in timing our signals. Instead, they were giving

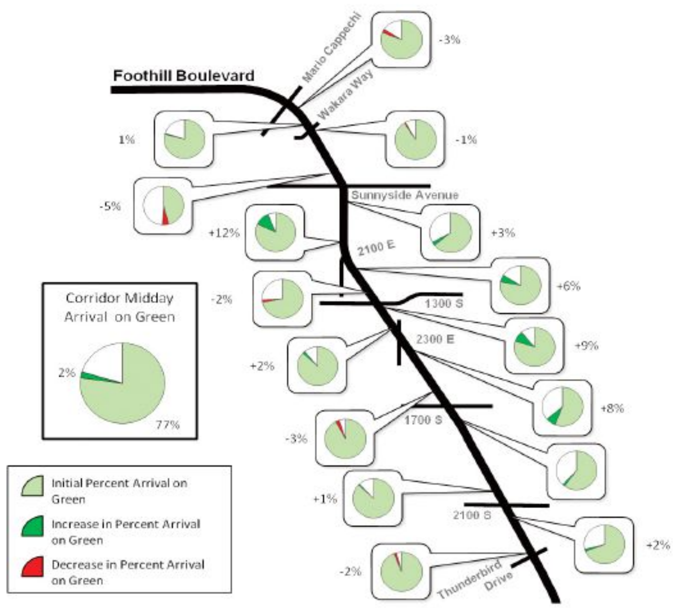

Figure 1: Data-Driven Offset Optimization Benefits[2,4]

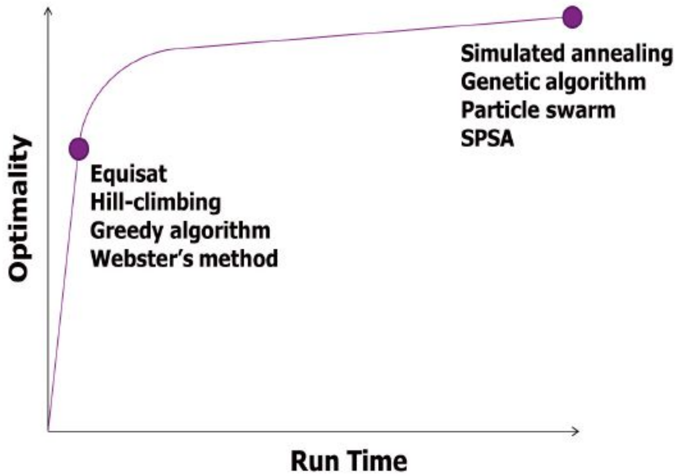

Figure 2: Concept of Optimality versus Run Time[5]

presentations and publishing papers based on more powerful methods, including those on the right side of Figure 2.

Given that the powerful heuristic methods require much longer computer run times, one might assume they could not be deployed within adaptive signals, which perform real-time optimizations in less than one minute. However given the improved speeds of today's computers, if the *Highway Capacity Manual* (HCM) signalized analysis methods were used to evaluate candidate timing plans, the powerful heuristics could find absolute optimum solutions within minutes.[6] And if "playbooks" of pre-optimized starting points could be stored in the controller's memory, based on congestion levels and time of day, the powerful heuristics could reach absolute optimums within seconds. Traffic engineers are frustrated by the fact that popular adaptive algorithms are secret, unpublished, and proprietary. HCM-based optimizations based on transparent heuristic methods could end this uncertainty, and perhaps achieve superior outcomes.

3) Alternative Intersection and Interchange Methods

The Federal Highway Administration (FHWA) is continuing their efforts to mainstream the alternative intersection and interchange designs. These facilities have the potential to produce significant improvements in both traffic operations and traffic safety, in a cost-effective manner, and within the footprint of existing infrastructure. These designs often have two-phase signals that provide signal operators with many optimization options. Although construction of these facilities is rapidly escalating, research on best practices for timing their signals has only recently intensified.

An example of an alternative intersection with great potential for signal optimization is the synchronized street, a.k.a. restricted crossing U-turn (RCUT), j-turn, or superstreet.[7] The great news for optimization on a synchronized street is that the signals on each side of the arterial are independent of each other. This allows perfect progression—the possibility of progression bands as large as the green times—on each side of the arterial, at any speed, cycle length, and signal spacing. The two directions of the arterial can even have different cycle lengths. Signal operators at a synchronized street have endless flexibility to craft plans that favor certain movements, change speeds, minimize pedestrian crossing delays, or favor bus movements, for example. Figure 3 shows that RCUT intersections between conventional intersections can allow great two-way progression on an arterial where that would otherwise be impossible.

An example of an alternative interchange with great potential for signal optimization is the diverging diamond interchange (DDI).[8] DDIs do not have the perfect progression capabilities of the synchronized street, but they do provide signal operators with

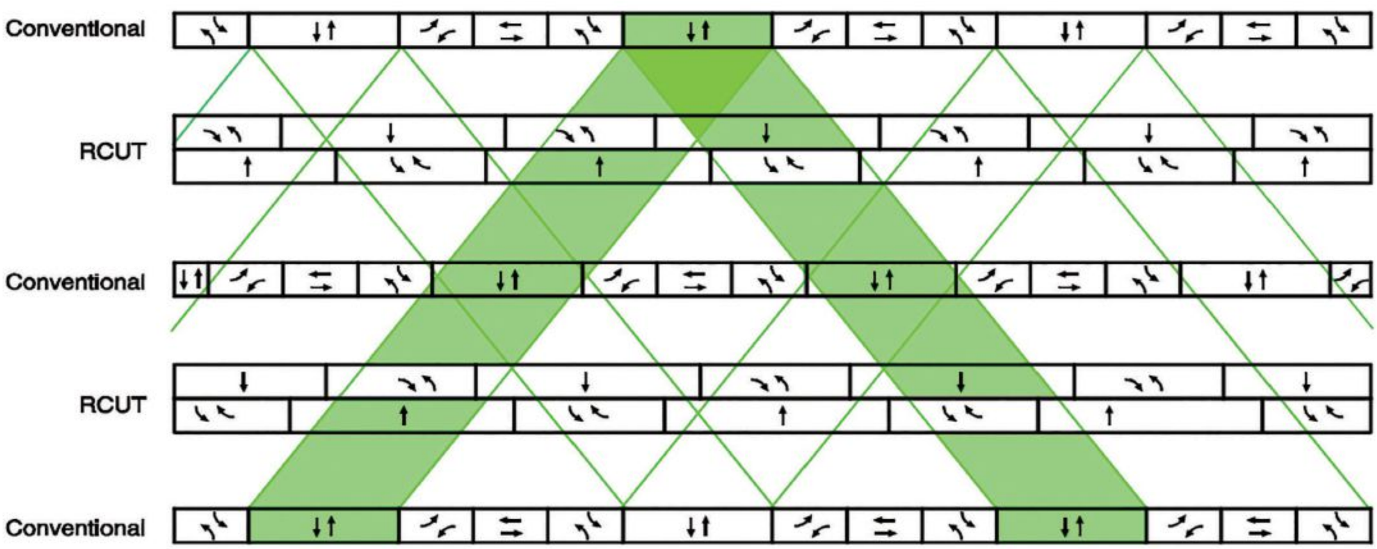

Figure 3: Example of two-way progression on an arterial with RCUTs and conventional intersections[7]

many optimization choices. Signal operators can choose which through direction or turning direction to provide with optimum progression, whether to provide protected pedestrian phases, the number of controllers, the number of rings, the phase sequence, and other parameters. National Cooperative Highway Research Program (NCHRP) project 3-113 is underway to explore the signal options at a DDI and should produce a guidebook for designers and operators by the middle of 2016.

The continuous flow intersection (CFI), also known as the displaced left-turn (DLT) intersection, might be the world's most operationally efficient at-grade intersection design. However, the relatively large footprint has disadvantages related to access management and construction costs.[9,10] Offsets at the satellite intersections must be set properly, so that left-turners are guaranteed continuous flow at the main intersection. Traffic flow efficiency appears to be highly sensitive to junction spacings and queue clearance times, implying that an integrated optimization approach (i.e., timing plus geometry) might be ideal.

Finally, easy-to-use analytical procedures for alternative configurations are expected to be published shortly, in an HCM update. Not all engineers have the resources to frequently perform micro-simulation studies, so these HCM methods are expected to bring practical analysis of alternative intersections to a wider audience. Moreover, given that the HCM methods are much less computationally expensive than micro-simulation, this opens the door for HCM-based signal timing optimization of these facilities.

4) Multimodal Intelligent Traffic Signal Systems (MMITSS)

As discussed in the introduction, the practice of signal timing optimization is beset by inertia. In their proposal for the MMITSS project, leading researchers stated that traffic signal control has experienced very few fundamental improvements in the past 50 years.[11] Instead, the changes have been gradual and incremental. By harnessing the power of connected vehicle technology, the MMITSS concept proposes to revolutionize adaptive signals in ways that can mitigate traffic congestion in some cases, and implement multimodalism in others. Not only is the traffic engineer expected to achieve operational improvements that supersede conventional actuated and/or adaptive technology, they are also expected to control priority weightings assigned to any given travel mode (e.g. single occupant vehicles, high occupancy vehicles, mass transit, freight trucks, emergency vehicles, bicycles, and pedestrians). Figure 4 illustrates the MMITSS environment.

During the recent FHWA research into MMITSS, field prototype testing was performed in Arizona. Micro-simulations were also used to predict the impact of MMITSS on traffic networks in Arizona and Virginia. These studies found that MMITSS was more effective than conventionally-optimized signals in reducing delays, due to the connected vehicle technologies. Moreover, when desired by the operator, MMITSS successfully prioritized freight and/or transit modes of travel, although this would often increase delays for the passenger cars.

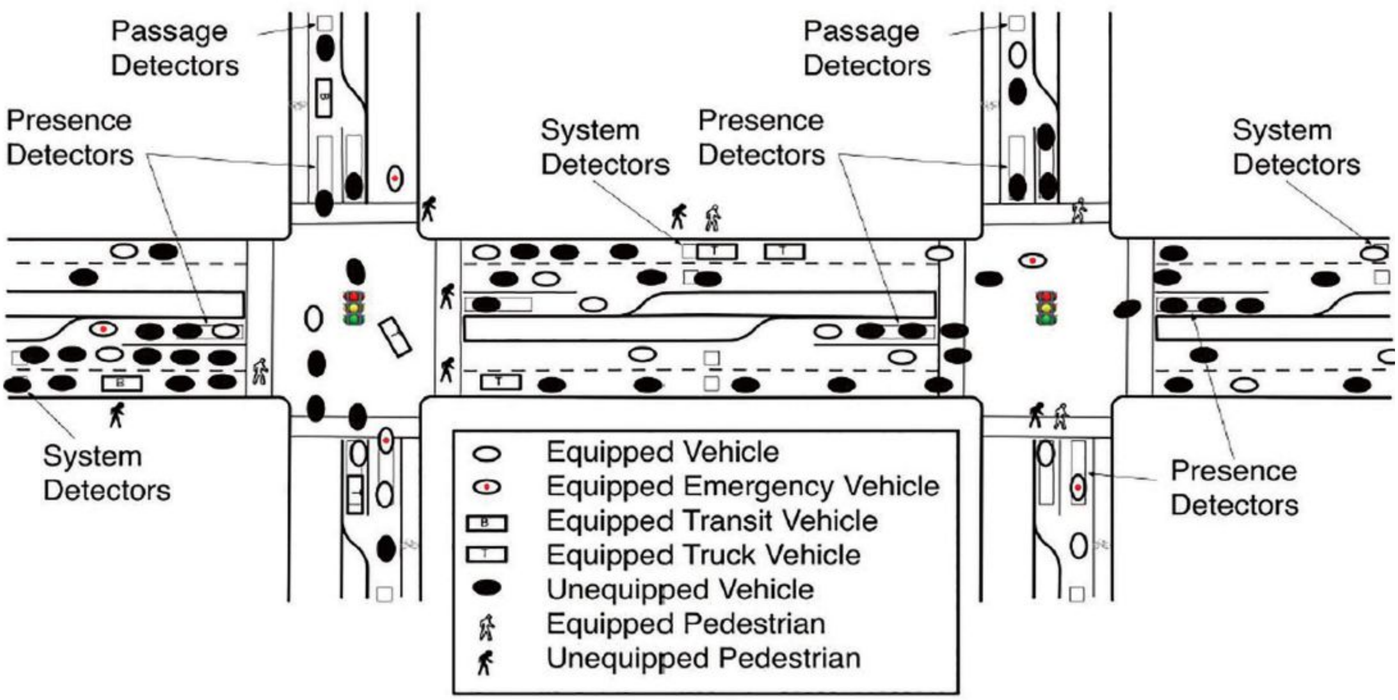

Figure 4: Typical MMITSS Operational Environment[12]

The performance of MMITSS is sensitive to connected vehicle penetration rates and traffic congestion levels, so more research is needed to optimize the technology itself. Finally, future research is expected to show that MMITSS can benefit emergency vehicles and pedestrians, especially visually-impaired pedestrians.

Conclusion: Don't Settle for Less

In many respects, the U.S. transportation infrastructure is being allowed to decay, and unfortunately signal timing is part of that trend. Transportation professionals are consistently panned by consumers and receive failing or minimally improved grades from national agencies reviewing signal timing outcomes.[13] A lack of resources and investment accounts for some of the problem, but another factor is that many of our standard practices are firmly entrenched in obsolete, 20th century concepts. This article has shown a few of the ways in which new concepts and methods make better signal timing possible. Professionals should demand evolution and improvements from adaptive control vendors, desktop software vendors, signal technology vendors, agency leaders, and political decision-makers. By rejecting inertia and embracing 21st century methods, we can move towards eliminating large swaths of unnecessary re-timing labor, unnecessary vehicle delays, unnecessary traffic congestion, and signal timings that inappropriately prioritize single-occupant cars at the expense of all other travel modes. **itej**

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