AN OVERVIEW OF

Kadence

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Kimley-Horn
Expect More. Experience Better.

The Kadence system extends from the base ACSLITE algorithms developed by FHWA from 2002 through 2007. Dr. Douglas Gettman was the principal investigator for ACSLITE on behalf of FHWA. ACSLITE is now deployed in over 25 jurisdictions and Kadence in four locations.

The Kadence system optimizes traffic signal timing to balance performance benefits for safety and efficiency. The system is not intended to replace or obviate the need for sound traffic engineering, but rather to supplement the traffic engineer's toolbox with another tool that can handle fluctuations in demand and short and long-term changes in land use and traffic patterns.

Kadence is comprised of five principle algorithms for tuning signal splits, offsets, cycle time, phase sequence, and TOD schedule.

In the Kadence approach, new signal timing parameters are downloaded to field controllers every 3-4 cycles. The field controller then begins operating in an actuated-coordinated with these new settings. Based on past experience with adaptive systems that override the controller's timings every second (RHODES, OPAC, SCOOT, SCATS, and InSync), this methodology of downloading new timings is more reliable, safer, and less error prone. In addition, Kadence is proven to require minimal capital investment, infrastructure, detectors, configuration, and calibration. The system produces improvements to travel time and system delay over actuated-coordinated operation with TOD plans over time.

In addition to the implementation of three optimization algorithms (cycle tuning, cycle selection, and phase sequence selection), several other key enhancements have been implemented in Kadence. The system requires three cycles of good observations of phase timing and detector data before making decisions but now checks every 30 seconds to identify if that requirement is satisfied. This improves the responsiveness of the system versus the fixed-horizon scheme (5 minutes, 10 minutes) implemented in the baseline ACSLITE system. The offset tuning algorithm has also been enhanced to search offsets in a range instead of only considering fixed changes (+5, 0, -5). By selecting larger search bounds (say, +/-10s), Kadence can quickly find the correct offset solution when the current solution is poor.

Kadence has been integrated with VISSIM using Virtual D4 controller firmware. This provides rapid prototyping and testing of any real-world situation with accurate controller parameters and real-world operation. Kadence has a variety of configurable parameters to tailor the operation to the expectations any agency. Certain adjustments can be disallowed and some phases can be excluded from optimization to address specific locations. All parameters can be customized by pattern.

KADENCE FUNCTIONALITY EXCEEDS ACSLITE

- **Tune splits, offsets, cycle, phase sequence**
- **Tune faster and more often**
- **Tune more parameters and more configurable**
- **Support flashing yellow arrow**
- **No need for special firmware**
- **Balance the needs of arterial and side street performance**
- **Interchanges**
- **16 phases and 4 rings**

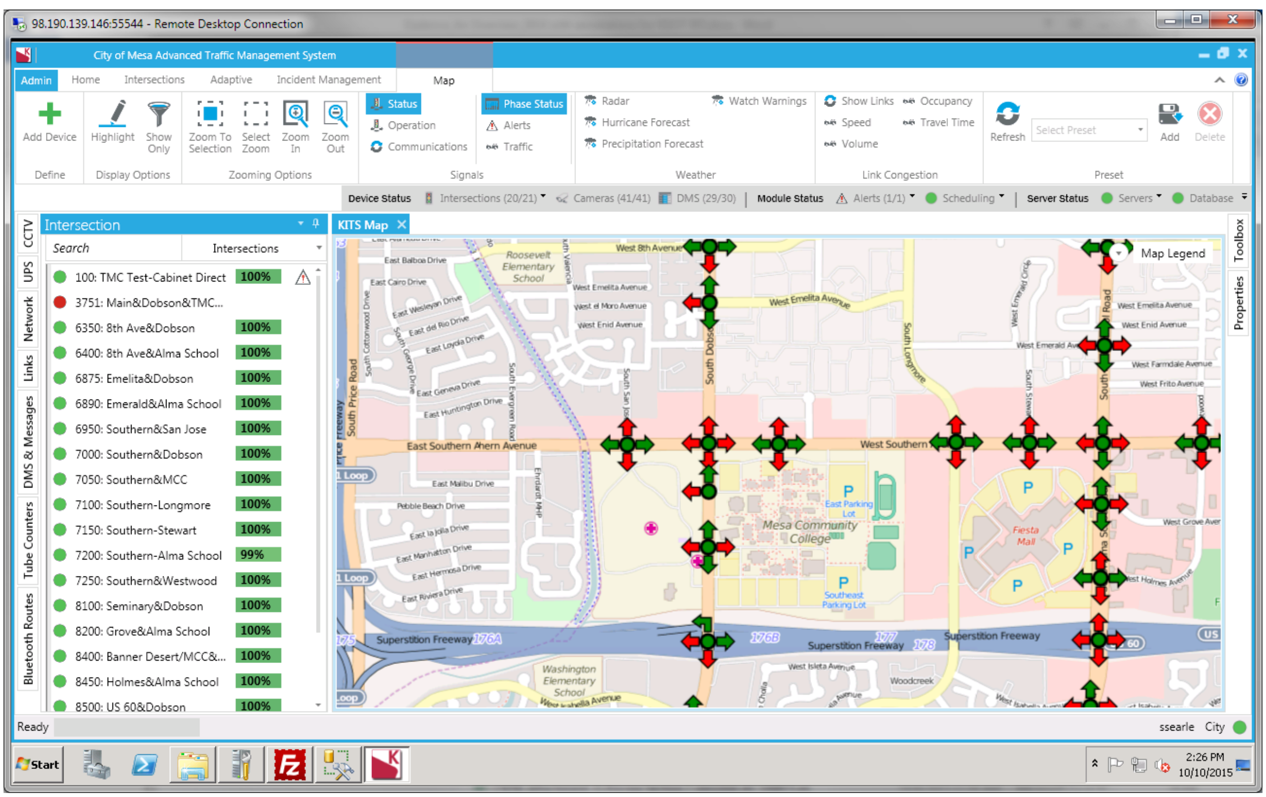
DETECTION

- **Stop bar detection**
  - Cycle tuning
  - Split tuning
  - Phase sequence tuning
- **Upstream/exit detection**
  - Offset tuning
- **Better if lanes are separated, but not necessary**
- **Tolerates malfunctioning detectors**

Configurable parameters (by pattern) include:

- Exclude any phase from split tuning
- Exclude or allow any lead-lag sequence
- Exclude or allow cycle tuning
- Exclude or allow offset tuning
- Configure maximum deviation of splits from pattern values
- Configure maximum deviation of offsets from pattern values
- Configure minimum and maximum cycle time
- Exclude or allow cycle selection
- Select any phases for coordination biasing
- Configure operation by TOD and Pattern
- Configure minimum splits

All Kadence algorithms and services operate at a central TMC. There are no field hardware components to install or maintain. If a Kadence algorithm fails, controllers will return to their normal TOD operation. In addition, Kadence can be turned ON or OFF from central and scheduled to run on a time-of-day, day-of-week schedule. When Kadence is OFF, the controller will return to their regular non-adaptive operation as programmed in the controller (TBC coordination or free, as configured). Kadence does not send hold or force-off commands to controllers, or suppress phase calls, so there is no risk of a controller getting stuck in a certain phase. All controller features operate normally including pedestrians, transit priority, and preemption. Kadence can run alongside an existing central system on an IP network using NTCIP or AB3418 protocols, depending on what is supported by the field device.



Internet map and real-time signal status

KADENCE CAN MEET A VARIETY OF AGENCY OBJECTIVES

1. Maximizing throughput on a coordinated route
2. Providing smooth flow on a coordinated route
3. Providing access equity for all phases at an intersection
4. Manage the length of queues
5. Optimize operation to minimize phase failures
6. Combinations of these objectives

Maximize the Throughput on a Coordinated Route

Kadence maximizes throughput on a coordinated route by using a combination of offset tuning, split tuning, cycle tuning, and phase sequence selection. Kadence tunes offsets to provide smooth flow, which increases the throughput on the route by reducing stops. By tuning (increasing) the coordinated phase splits, more time can be provided to that route when the level of traffic on the side streets and other competing phases is reduced. In the split tuning algorithm, coordinated phase utilization measures can be biased so that more time for that movement is protected which provides more opportunities for progression along the route. If the coordinated phases are over a specified threshold for phase utilization, the cycle time can also be increased to provide additional throughput on the critical route. In addition, Kadence can modify the phase sequence to a lead-lag combination for left turns to increase the amount of time that the critical through route receives if there is very low opposing left-turn volume.

For example, a change from lead-lead to lag-lead would be predicated if:

- Phase 5 has a heavier utilization than phase 1
- Phases 2 and 5 have heavier total utilization than phases 1 and 6

Offsets are then adjusted after the sequence change is evaluated and a similar comparison is done for the other barrier group (phases 3, 4, 7, and 8).

Cycle Selection

Throughput is also improved on coordinated routes by determining a decision to either implement the cycle time that is next in the TOD schedule earlier or later than was originally planned. This can be used in conjunction with the cycle tuning method (discussed below) or alone. This allows the system to adapt to changes to the beginning or end of peak periods. The same evaluation approach for the incremental cycle tuning algorithm described previously is used but rather than changing the cycle just a few seconds, the system enables the new cycle time immediately and recalculates splits and offsets appropriately.

The algorithm begins considering implementing the next pattern in the TOD schedule early if it less than a configurable number of minutes before the next pattern change time. For example, this threshold time might be set to

ADAPTIVE CONTROL METHODOLOGY

- **Data-driven parameter tuning**
- **No calibration**
- **No specific detector length**
- **Degree of saturation**
  - » Current and trend
  - » Cycle, split, and phase sequence
- **% arrivals on green**
  - » Current and trend
  - » Offset

30 minutes prior to the schedule change so if the pattern is scheduled to be adjusted at 10:00am, the algorithm will begin considering implementing the next pattern at 9:30. If the thresholds for phase utilization are not exceeded to implement a lower or higher cycle, the current cycle is retained. If the phase utilization thresholds are not exceeded after the scheduled time to change to the next cycle, the system can keep the current pattern in operation. After a configurable amount of time, however, the system will transition to the next pattern in the TOD schedule.

Provide Smooth Flow Along Coordinated Routes

Tuning offsets improves progression performance along primary routes for phases that are coordinated. Offset tuning algorithms are particularly straightforward. The proven and robust methodology used in ACSLITE is used in Kadence with several key enhancements.

The concept of the data-driven offset adjustment algorithm is to maximize the number of vehicles arriving during the green phase. Periodically, small, incremental adjustments are made to the offset to maximize the total proportion of cyclic flow arriving to a green light. This concept is then expanded to consider and mitigate the effects of such modifications to the offset value for multiple approaches (including the consideration of cross-coordination on all four approaches) and the effects of changes at a given intersection on adjacent intersections.

A user-configurable maximum deviation from the original setting (either an increase or decrease to the offset value) is defined for each offset to restrict the algorithm (if desired) from drifting too far away from the original solution. The user can also specify that this value is unbounded, which allows the system to search for any offset. For example, if the initial offset is 20s and the maximum deviation is set to 10s, the algorithm will be restricted to implement offsets with the range of 10s to 30s. Each controller considers a range of offset settings: no change, adjust up to seconds earlier, or adjust up to seconds later. The adjustment maximum step size, , is a user-configurable value. If the value is set at 10, for example, Kadence will search offsets in each step in the range of (+10, +9, +8, +7, …., 0, -1, -2, -3,….., -10). If the difference in the % arrivals on green between the evaluated offsets is not greater than small amount of improvement, say, 5%, the controller will remain at the current offset. This reduces transition events that do not result in significant improvement to performance.

Distribute Phase Times in an Equitable Fashion

Splits are tuned by collecting volume and occupancy data from detectors at the stop bar of the intersection, which is similar to the methods used by SCATS and SCOOT. The algorithm attempts to equalize the degree of saturation on all the phases at the intersection. This algorithm also allows coordinated phases (or any phase, but this biasing is typically applied to coordinated phases) to have biased splits, so that progression is protected when the saturation level of the coordinated phase is lower than that of side-streets. Without such biasing, split adjustment methods that equalize the degree of

KADENCE ADAPTIVE CONTROL PROCESS

- **Poll controllers for phase and detector data**
- **Calculate new splits, cycle, offset, sequence**
- **Does not need split libraries**
- **Download new pattern data to scratch pattern**
- **Command controller to scratch pattern**
- **Controller responsible for normal operation at the intersection**
- **Kadence does not override the operation with holds/ force off**
- **Minimal transitions**

BENEFITS of KIMLEY-HORN and KADENCE

- **Direct access to system designers, developers, and integrators**
- **Continuous path of future innovation**
- **License valid for all of district without any additional fee**

saturation on all phases tend to focus more on providing adequate LOS on side streets while degrading progression along a critical route.

Any phase can also be determined to be left out from the split tuning process. This is commonly applied to phases on minor side-streets that very occasionally experience bursty traffic flows that do not last more than a few minutes. In the absence of regular arrivals, the splits will be adjusted to the minimum possible value. Since the absence of traffic on the side-street will naturally result in additional time to the main street when the phase is skipped, the side-street phase may be set by the traffic engineer to a reasonable value that provides adequate LOS during the burst and kept fixed. Kadence will adjust the other parameters as appropriate. A good example for this would be the exit from a church. The split adjustment algorithm takes minimum and maximum constraints into account, and allows the user to either adhere to pedestrian crossing times or not. If the pedestrian crossing times are allowed to be larger than the split, then when a pedestrian pushes the button requesting service, the intersection will likely go into transition. In areas with low pedestrian volume, this is typically acceptable operation. If pedestrian volumes are quite high, it is more typical that the crossing constraints would be considered as minimum phase durations.

Manage the Length of Queues

Current algorithms in Kadence do not explicitly measure queue lengths or use estimates of length of queue in making decisions. Queue lengths are balanced by modifying splits, offsets, cycle time, and phase sequence and changing the time that TOD plans are started and stopped in the TOD schedule. In 2016, we will add algorithms for managing queues based on our research in NCHRP 03-90. A methodology was developed that tunes splits on a route based on measurement of the degree of oversaturation.

This process uses the TOSI (temporal oversaturation level) and SOSI (spatial oversaturation level) measures to determine the amount of green time to add and subtract, respectively, from a phase. This heuristic is denoted as the forward-backward procedure (FBP). Simply speaking, there are two ways to deal with oversaturation: one is to increase the downstream output rate and the other is to constrain the upstream input rate. These capabilities will be added to Kadence.

At an Isolated Intersection, Optimize Operation With a Minimum of Phase Failure

Cycle time is adjusted on a section- or arterial-wide basis to provide adequate capacity to operate all of the signals under capacity and reduce the occurrence of phase failure. Kadence uses a heuristic rule to adjust the cycle time up or down a given step size. In a straightforward fashion, if the cycle time is increased by 4 seconds, then every phase on the controller gets a proportion of the additional time.
For example, if there are four phases per ring, one additional second is provided for each phase split. The split adjustment algorithm will refine the splits at a later step if this allocation results in uneven phase utilization. The step size is user-defined. Minimum and Maximum cycle limitations are imposed including limitations by minimum green, pedestrian clearance times, and user-defined minimum and

BENEFITS of KADENCE

- **No "recipes", simple setup and operation**
- **Proven and reliable operating mode**
- **Effective in delaying onset of oversaturation and clearing congestion after peak period**
- **Effective in reacting to incident conditions and adjusting to long-term changes in traffic patterns**
- **Inexpensive to deploy and expand, made in USA**
- **Continuous path of innovation including features for oversaturation**

maximum cycles. As a reliability measure, there must be at least 3 cycles of vehicle-occupancy data for critical phase utilization monitoring detectors in the system to execute the cycle tuning algorithm.

This methodology will tend towards longer cycles during peak periods as traffic demand builds, which is generally accepted as an appropriate strategy. Recent research (NCHRP 03-90) we conducted is indicating that when the conditions are extremely oversaturated, shorter cycles will provide more efficient throughput. These improvements or algorithms have not yet been integrated into the system but are planned for future work. This will improve the capability of Kadence to provide sound decisions during incident response conditions, such as heavy diversion of flows from a freeway to a parallel arterial or frontage road system.

The cycle tuning algorithm used in Kadence extends from a “critical intersection” algorithm. The phases that are designated to be checked in the cycle tuning algorithm are determined by the user. When the average phase utilization on these critical phases is above the user-defined threshold (say, 80% phase utilization) to increase the cycle, a given (the user-defined step size) number of seconds are added to the cycle time. Similarly, the system cycle time is decreased by a fixed number of seconds when the average of the phase utilization on the critical phases is less than a lower threshold (say, 50% phase utilization).

A Combination of Two or More of These Strategies

Kadence balances and optimizes combinations of operational objectives by running multiple algorithms together. Each algorithm can be enabled or disabled by pattern, so cycle tuning or other algorithms can be deliberately disabled by the traffic engineer by time of day. Five principle algorithms are included in Kadence for tuning splits, offsets, cycle time, and phase sequence. Based on the configurability of the system by TOD pattern, each of these objectives can be addressed at different times. The original ACSLITE system was designed for coordinated arterial corridors to provide smooth flow and address access equity. The additional features and algorithms added to Kadence in the last 3 years make the system applicable to a much wider range of situations including grids and interchanges. Additional features planned in the roadmap will extend Kadence’s applicability to oversaturated conditions and diversionary routes and groups.

FEATURES of KADENCE

- **Modern software architecture**
- **Modern high-speed IP communications**
- **Windows 7+ and Windows Server 2008+**
- **Controllers are accessible directly by both KITS and Kadence**
- **User-definable parameters**
- **No risk of controller getting stuck or skipping phases**
- **Pedestrian, transit priority, and preemption support**

IMPLEMENTATION

Kimley-Horn has designed, deployed, and supported over 45 adaptive traffic signal system projects throughout North America including systems in California, Florida, Wisconsin, and Arizona from a variety of system providers. With Kadence, Kimley-Horn has implemented the ASCT system in Austin, TX, Mesa, AZ, Menlo Park, CA, Windsor, ON, Tallahassee, FL, Philadelphia, PA, and Miami FL, with several other cities planned in 2016. Kimley-Horn is truly different than the other system providers since we are committed to tailoring system features for agency needs; we've done that with our KITS ATMS deployments for over 20 years and will continue to do so with Kadence.

Signal Controller Types

- Econolite ASC/3
- Siemens SEPAC NTCIP
- McCain 233
- Fourth Dimension D4
- LACO4E
- Caltrans TSCP
- Siemens NextPhase
- Any other NTCIP 1202 compliant controller

Implementation Timeframe

After the configuration and deployment of detection, the system can be implemented in just a few days. The larger the number of intersections and interchanges that are included, the longer the process of verification will take. The basic process is as follows:

- Automatic import of phase parameters from KITS database
- Configure detectors
- Configure links / adjacency
- Configure algorithm parameters
- Enable monitoring mode, evaluate data
- Enable adaptive mode

Training

At least two structured training sessions are typically provided to agency staff. Kimley-Horn has extensive experience in providing training on ATMS and ASCT systems. We anticipate two four-hour sessions on Kadence operation and two four-hour sessions with hands-on operation. Additional phone, on-site, and remote support will always be available to the agency during the implementation and operation phases of the deployment.

Maintenance & Support

Kimley-Horn will provide on-site, remote, and phone support to the agency regarding Kadence for a yearly lump sum maintenance fee. Level of services can be tailored to your needs and desire for operations assistance. Kadence runs on a standard Windows-based server computer. Hardware warranties and support are provided directly from the computer manufacturer. There are no field components to be maintained or upgraded. Software updates are provided during the maintenance period as appropriate. Typically with remote VPN access, updates can be provided seamlessly.

VALUE-ADDED SOLUTIONS

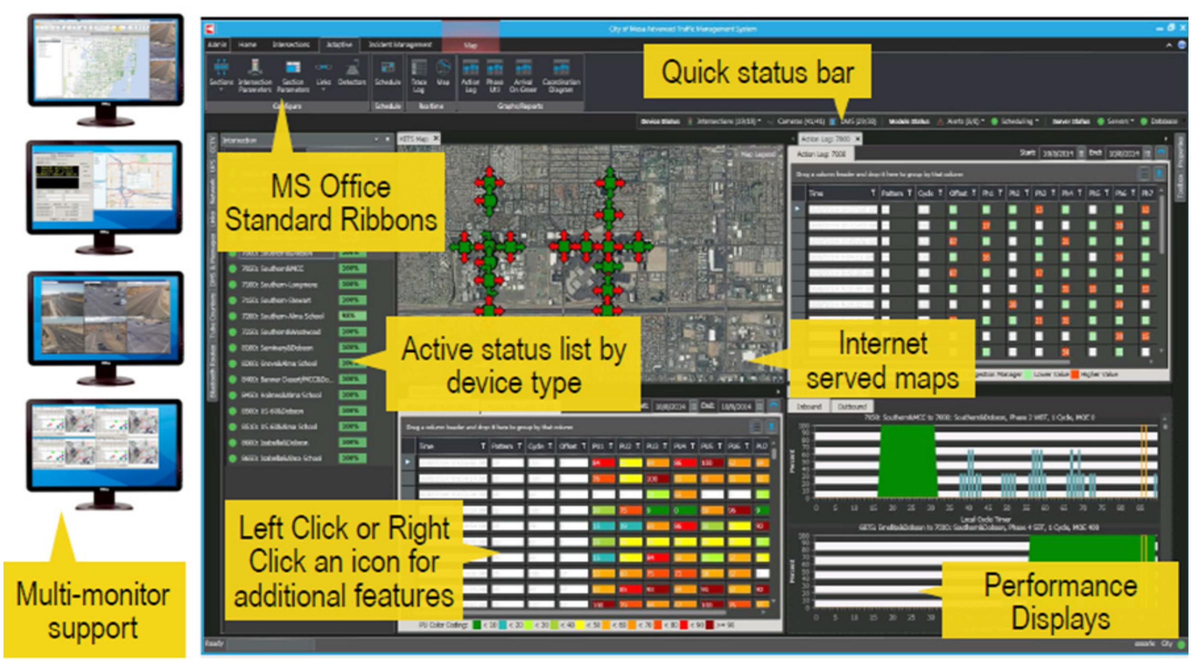
In addition to the features identified above, Kimley-Horn has developed a validation system and tools as part of the FHWA every day counts program. This system can be used to validate that Kadence is meeting its objectives by independently testing the match between the objective and the measures collected by Kadence. This open-source web-based performance measurement system includes integration of the following data sources:

- Bluetooth travel time systems
- Travel times from GPS probe smartphone apps (iPhone, iPad, Android phones, and Android tablets)
- High-resolution phase timing data from controller logs (ASC/3)
- Traffic counters, such as tubes or mid-block stand-alone sensors

This system can produce reports and graphics that indicate that Kadence (as well as traditional signal timing operations) is meeting the goals of any agency. These measures and reports include:

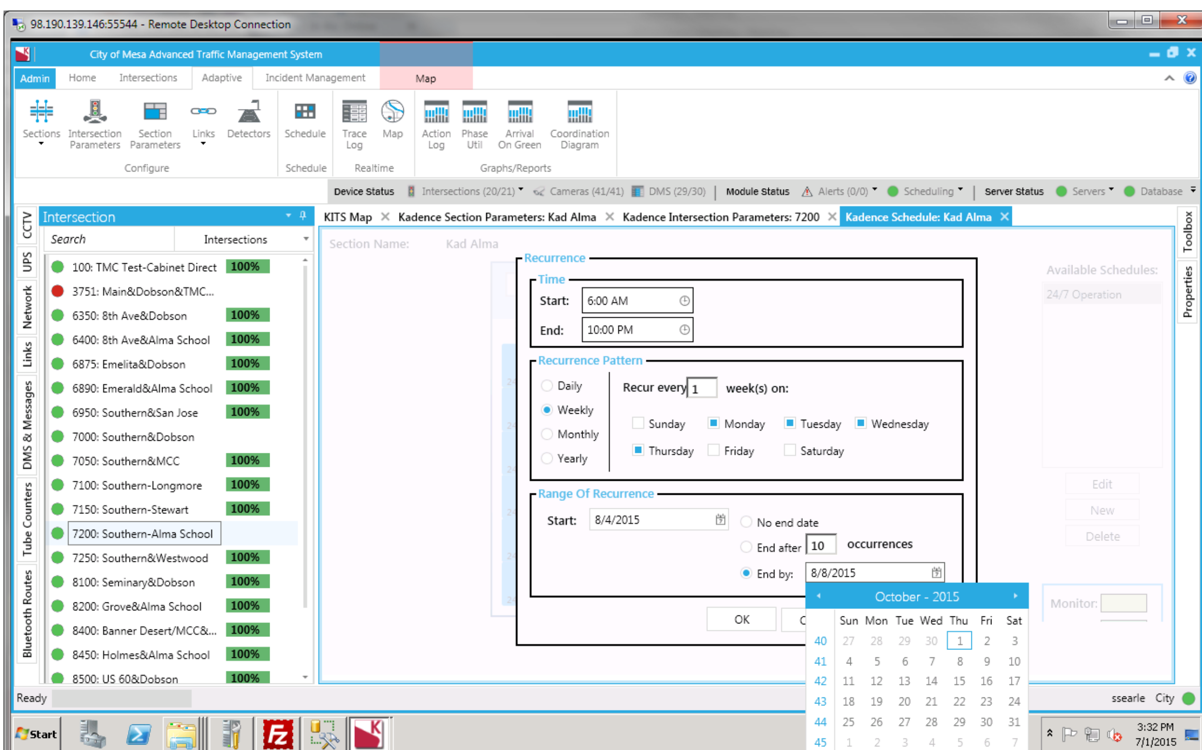
- Speed vs distance graphs comparing GPS probe runs
- Throughput measurements comparing ASCT with traditional coordination
- Travel time reliability metrics
- Comparisons of Bluetooth travel times with traffic counts
- Plots of split performance over time
- Plots of cycle performance over time

SCREENSHOTS

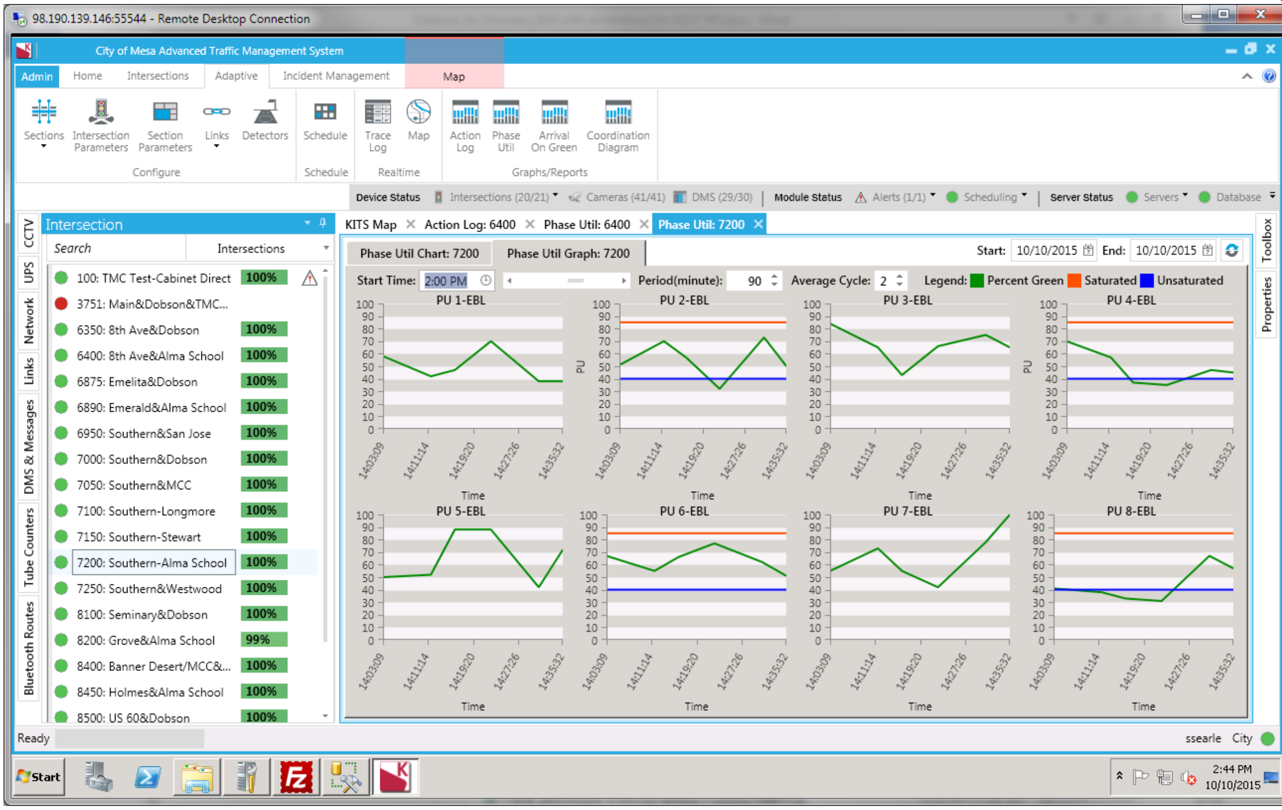


Kadence modern GUI interface

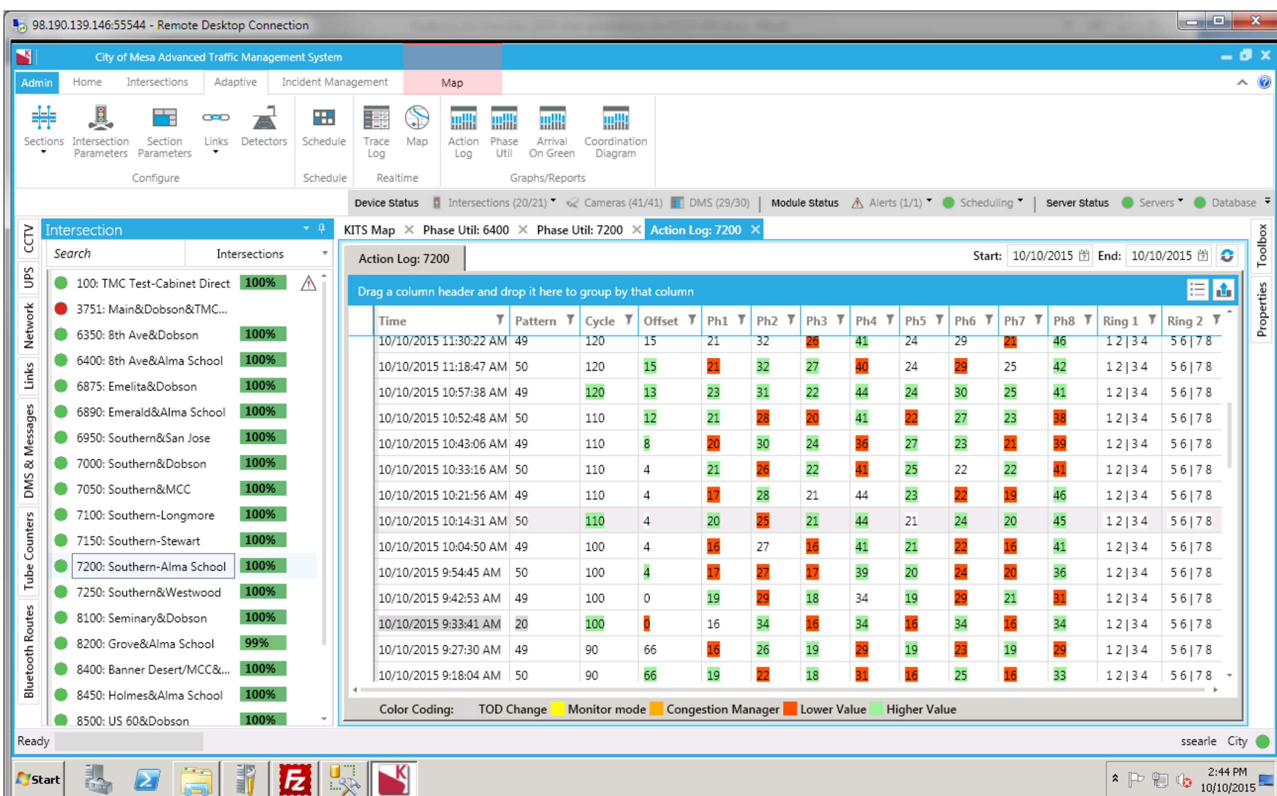
Configurable intersection parameters



Scheduling Kadence ON/OFF times

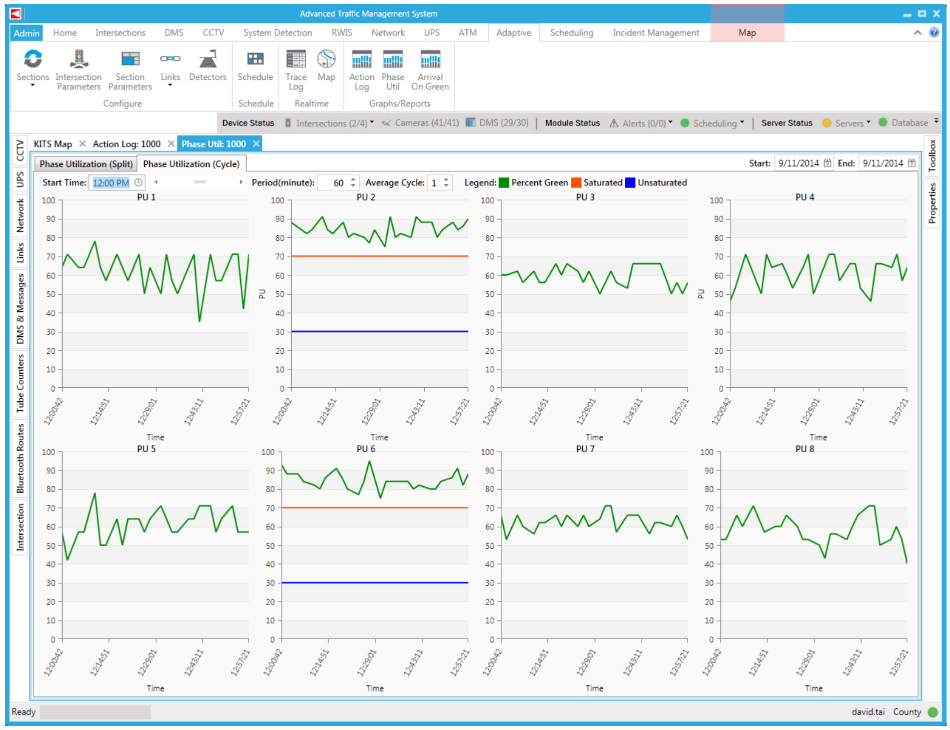


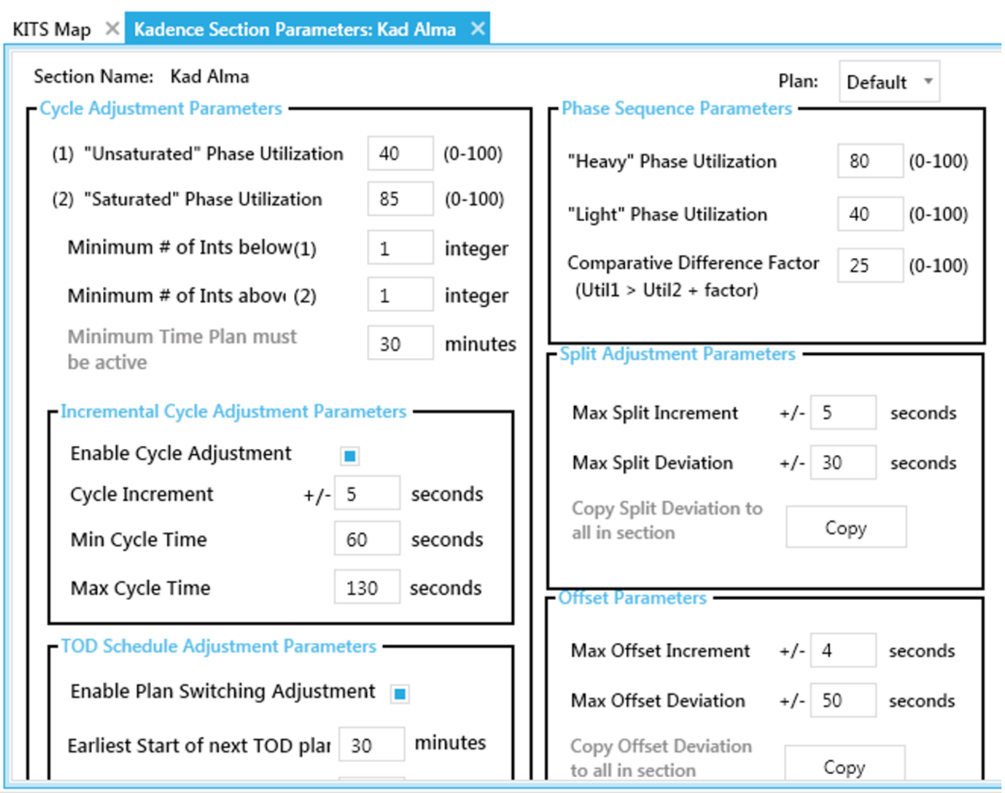
Flexible graphing displays for phase utilization



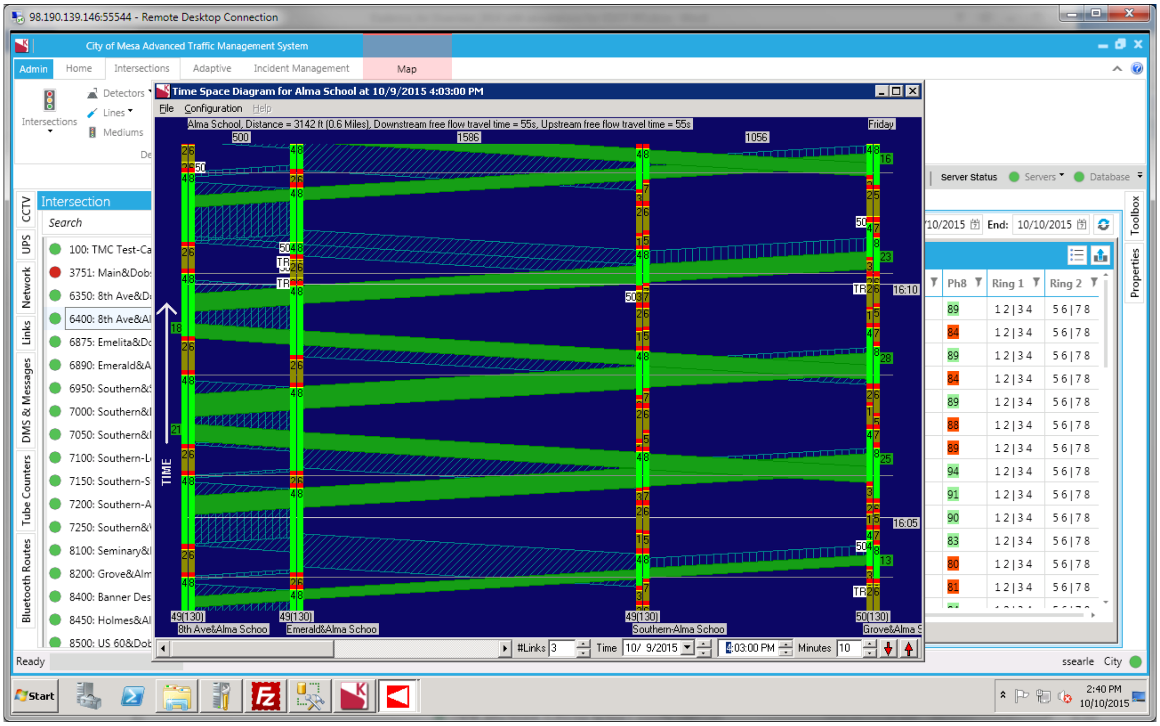
Action log of all adjustments including color coding

Phase utilization graphs show when critical phases are oversaturated

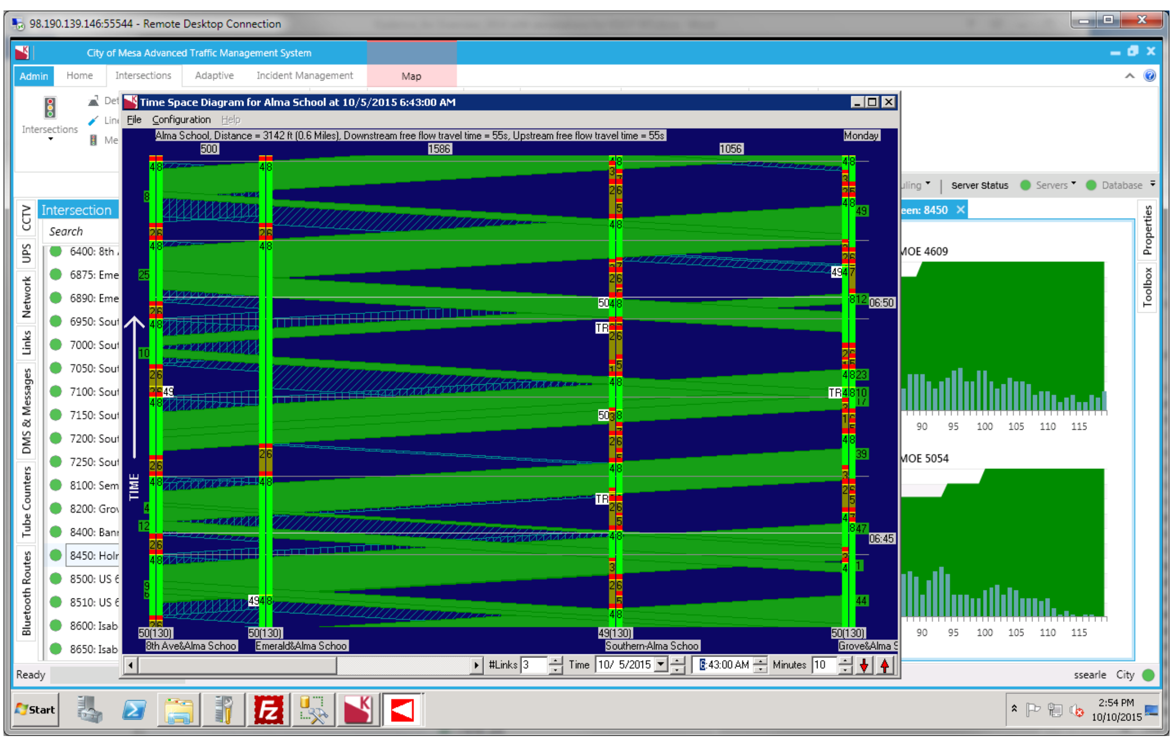




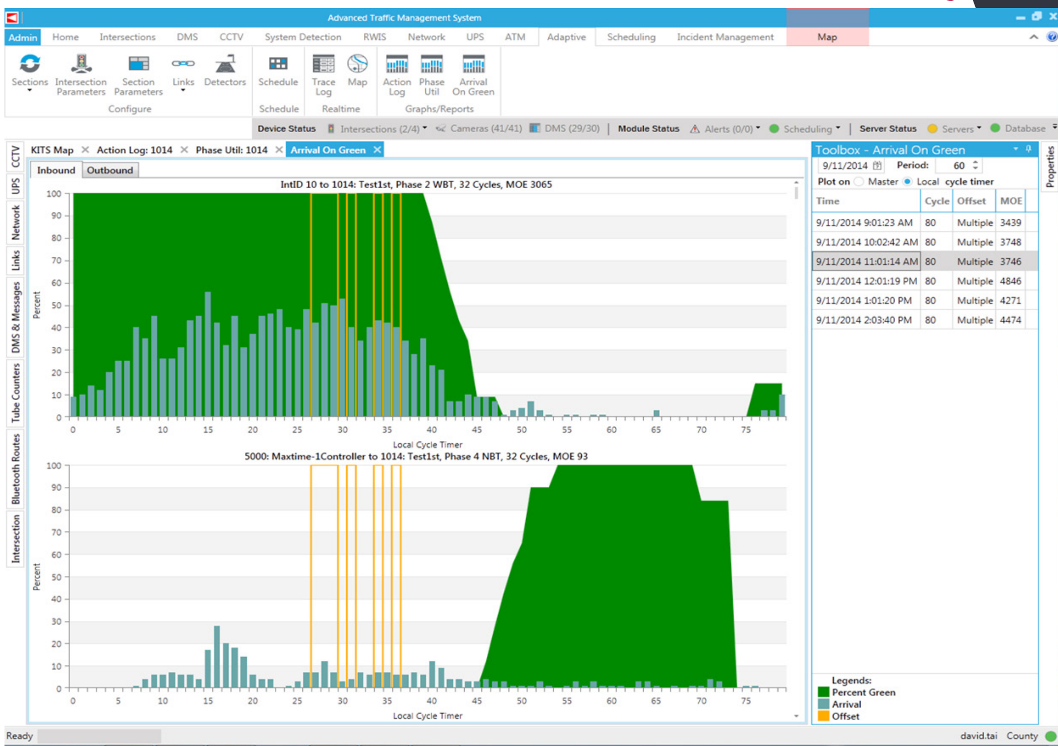
Kadence section configuration parameters



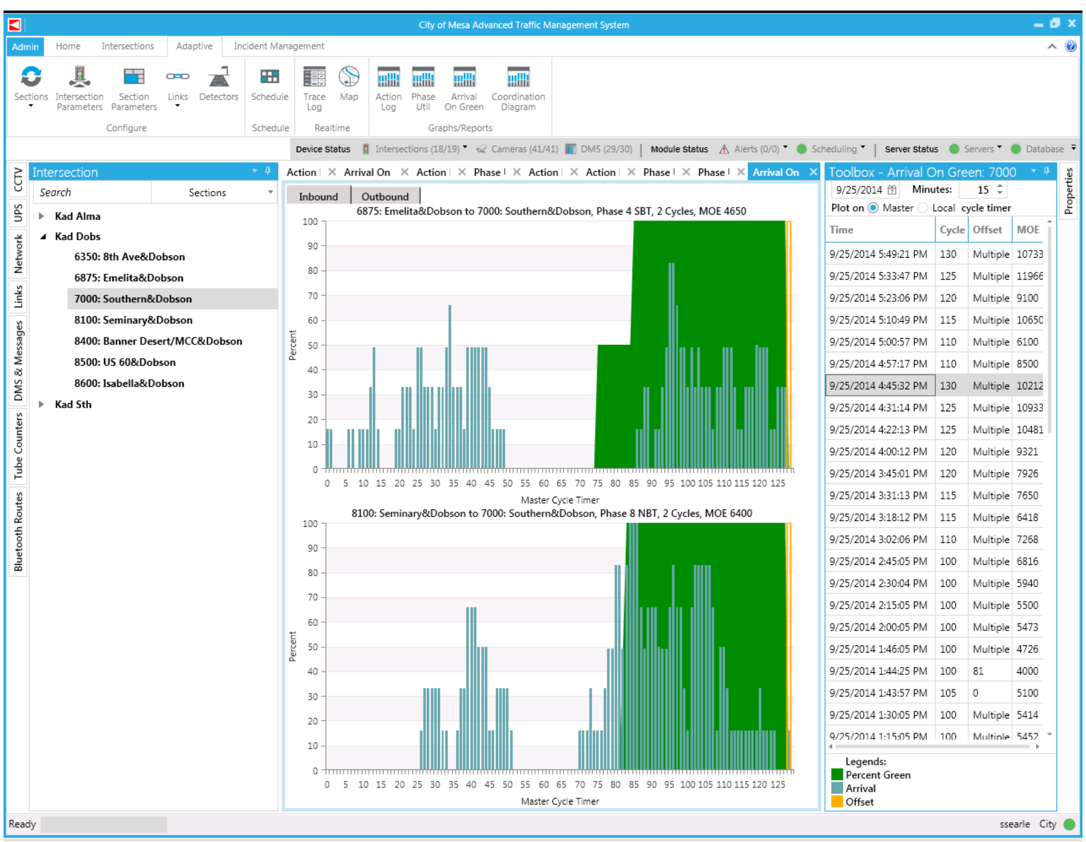
Real-time historical time-space display showing Kadence green bands



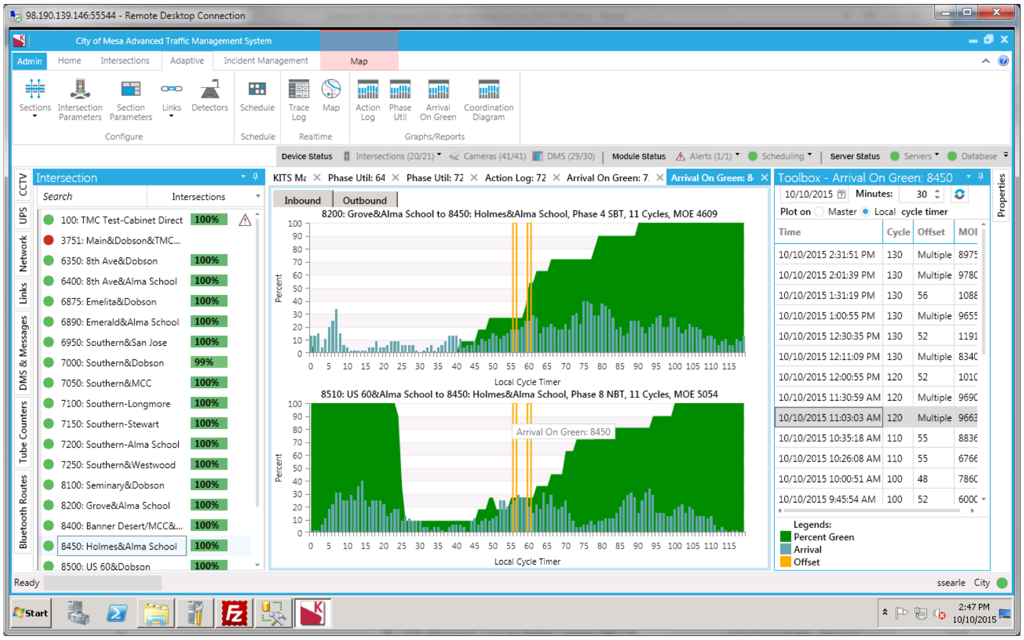
Two-way progression at certain times of day



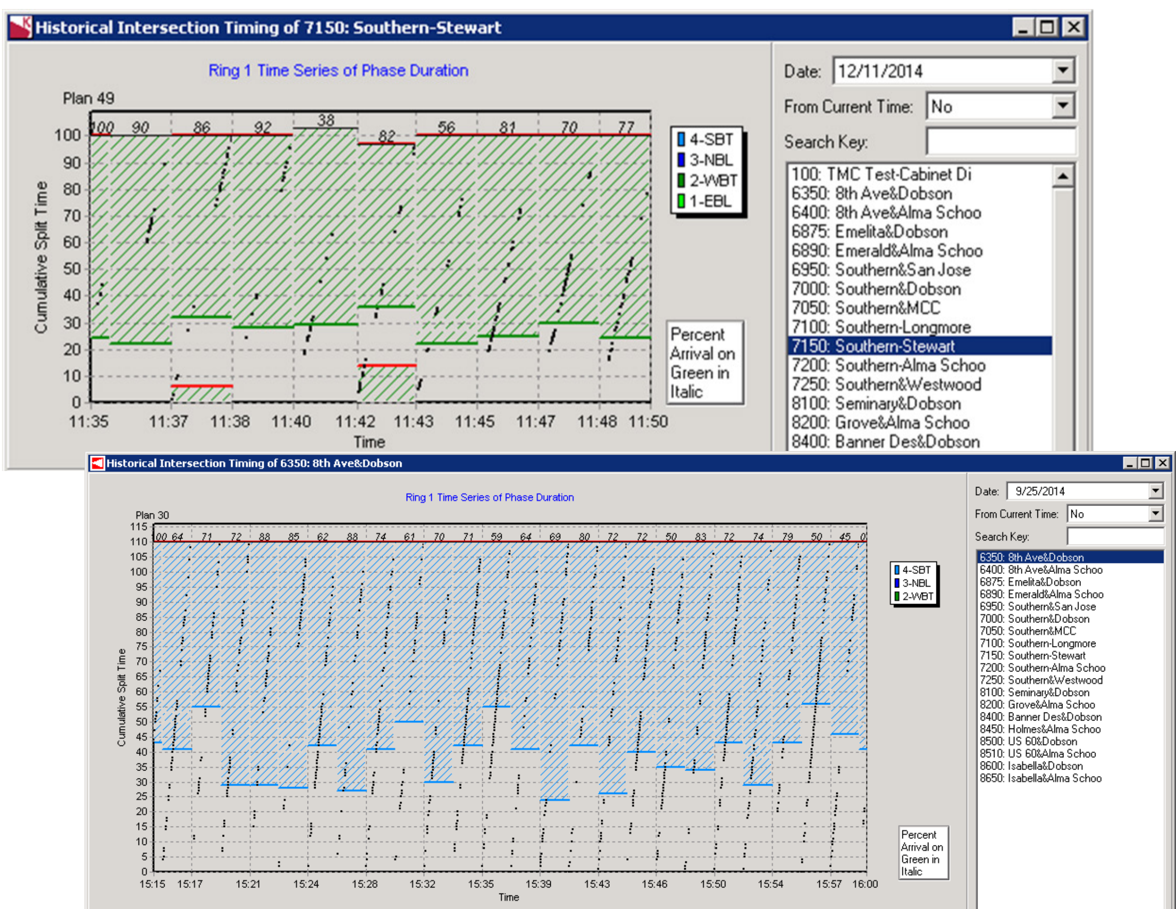
Arrivals on green display for multiple offset values (in yellow)



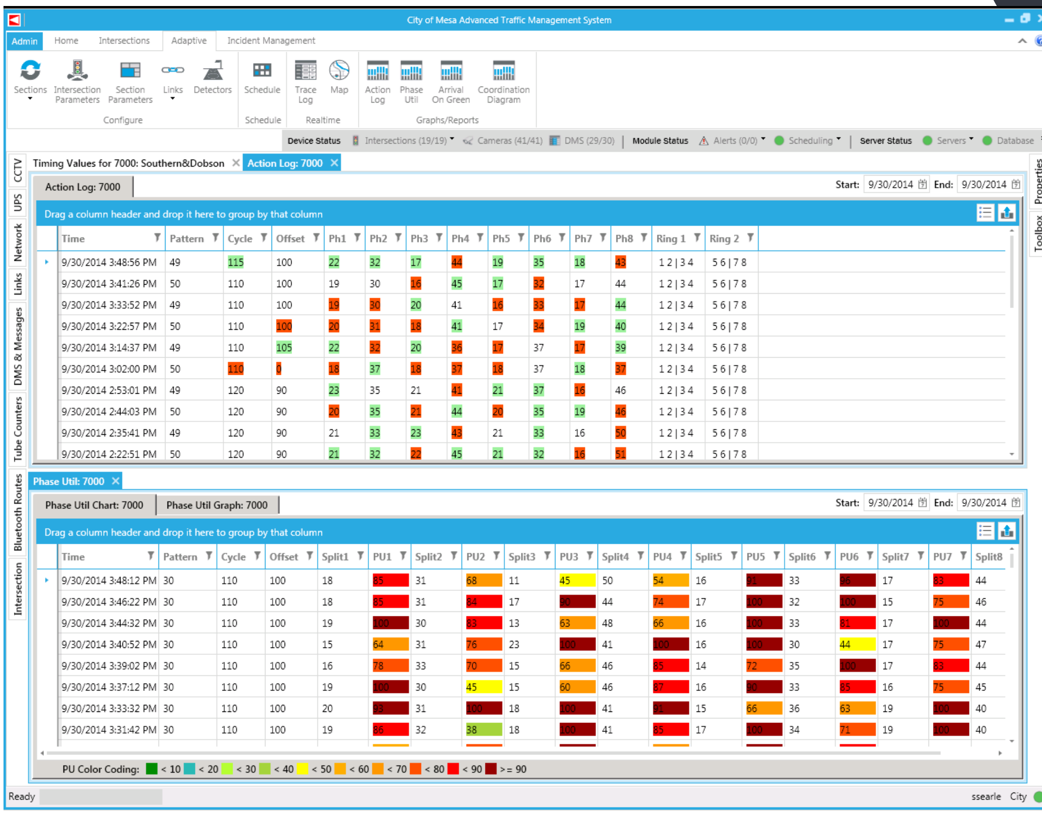
Arrivals on green display



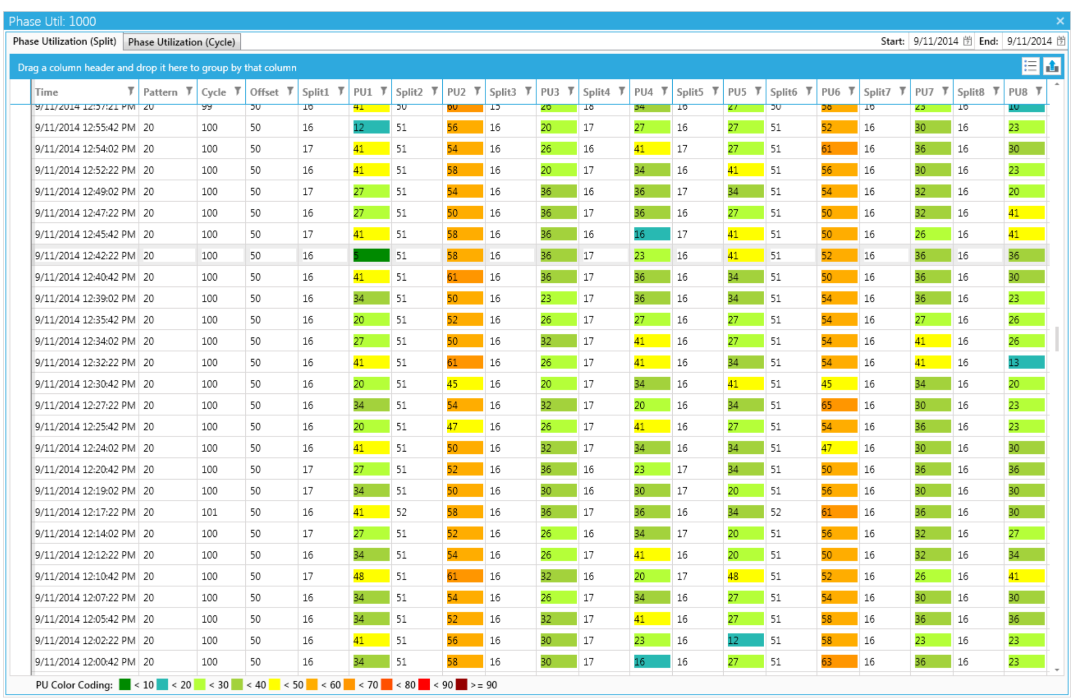
Flexible aggregation of percent arrivals on green by TOD and DOW



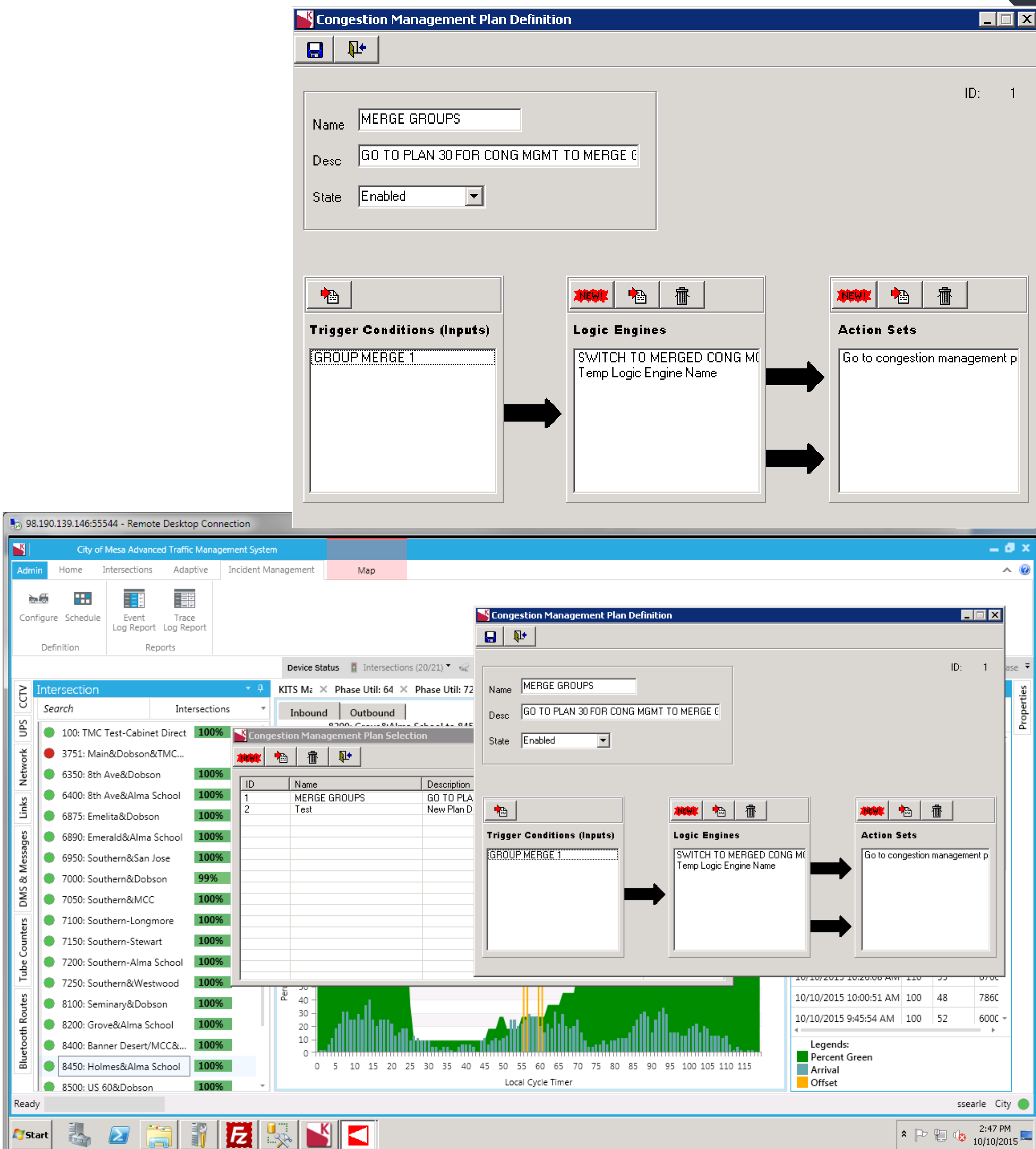
Purdue coordination diagrams showing percent arrivals on green for each cycle



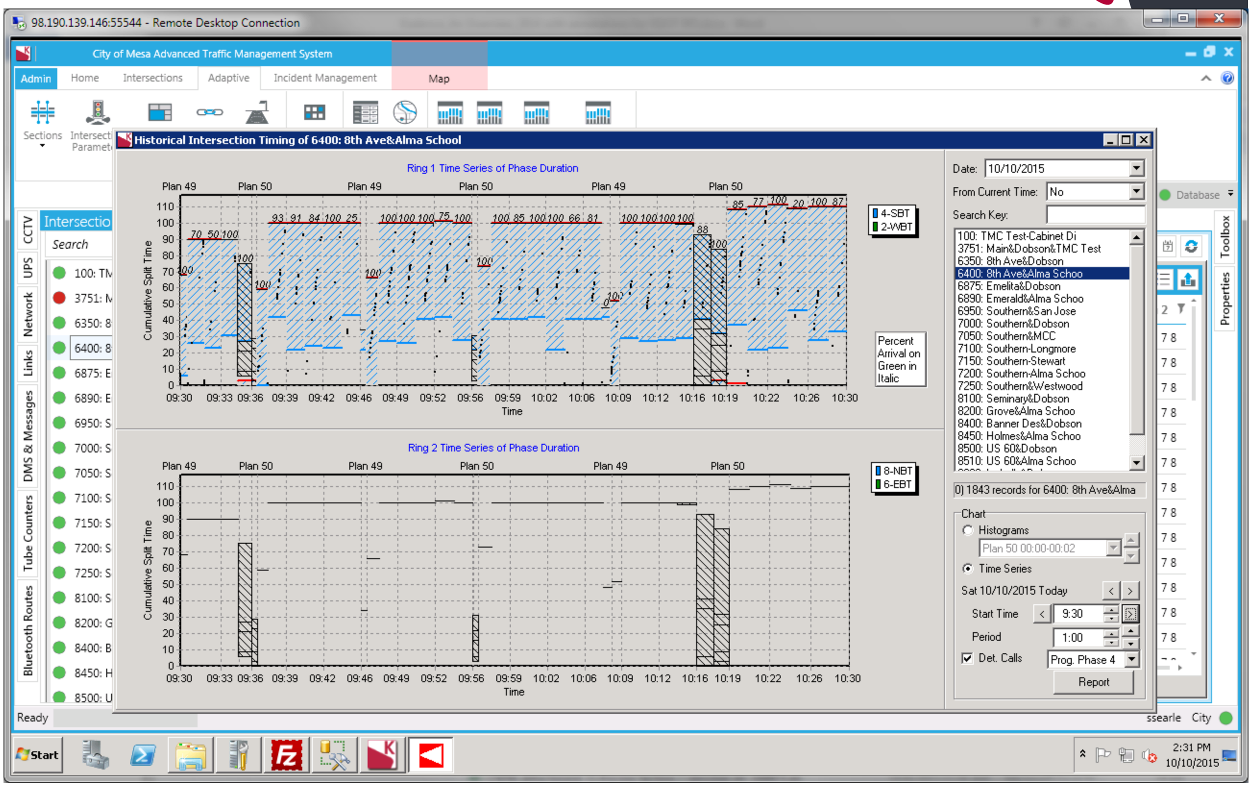
Color-coded phase utilization display and configurable docking



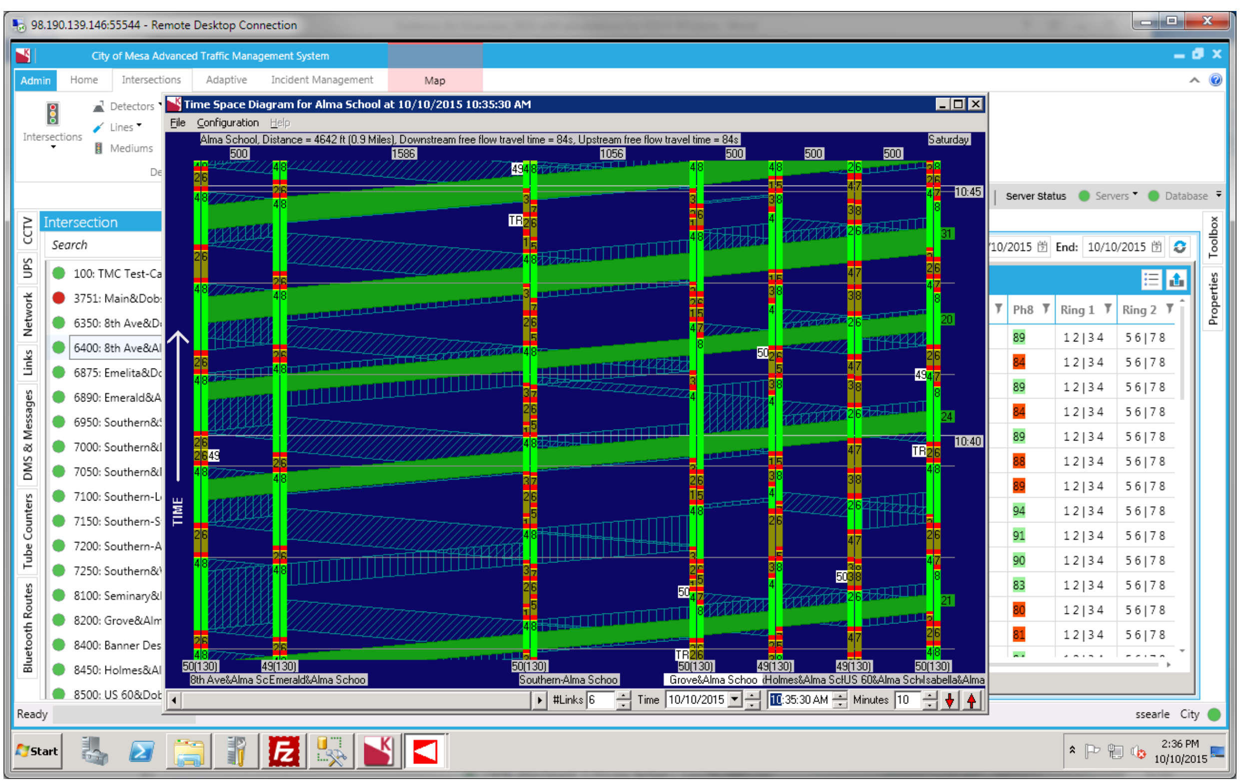
Color-coded phase utilization display with served splits



Congestion management logic configuration interface



Example display of arrivals on green in Mesa, AZ showing majority of percent arrivals above 90%



Real-time time-space diagram showing green bands along Alma School Road in Mesa, AZ