Kadence

A Kimley-Horn Software Solution

AN OVERVIEW

by Douglas Gettman, Ph.D.

Kimley»Horn

Expect More. Experience Better.

The Kadence system optimizes traffic signal timing to balance performance benefits for safety and efficiency. The system is not intended to replace 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 cycles. This frequency can be configured by the traffic engineer for each signal by TOD, if desired. The field controller then begins operating with the new coordination timings with full control over phase gap-out, pedestrian timings, TSP, EVP, flashing yellow arrow, and all other base operation timings. 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.

The offset tuning algorithm searches for better offsets in a range instead of only considering fixed changes (+5, 0, -5). By selecting larger search bounds (+/-10s), Kadence can quickly find the correct offset solution when the current offset is poor. Kadence also uses a configurable percentage improvement threshold to ensure that changes produce appreciable improvements.

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

- Tune splits, offsets, cycle, phase sequence
- Configurable tuning frequency
- Configurable objectives by TOD/DOW
- Supports flashing yellow arrow
- Supports any NTCIP compliant firmware
- Balances the needs of arterial
- and side street performance
- Supports Interchanges
- Tunes up to 16 phases and 4 rings

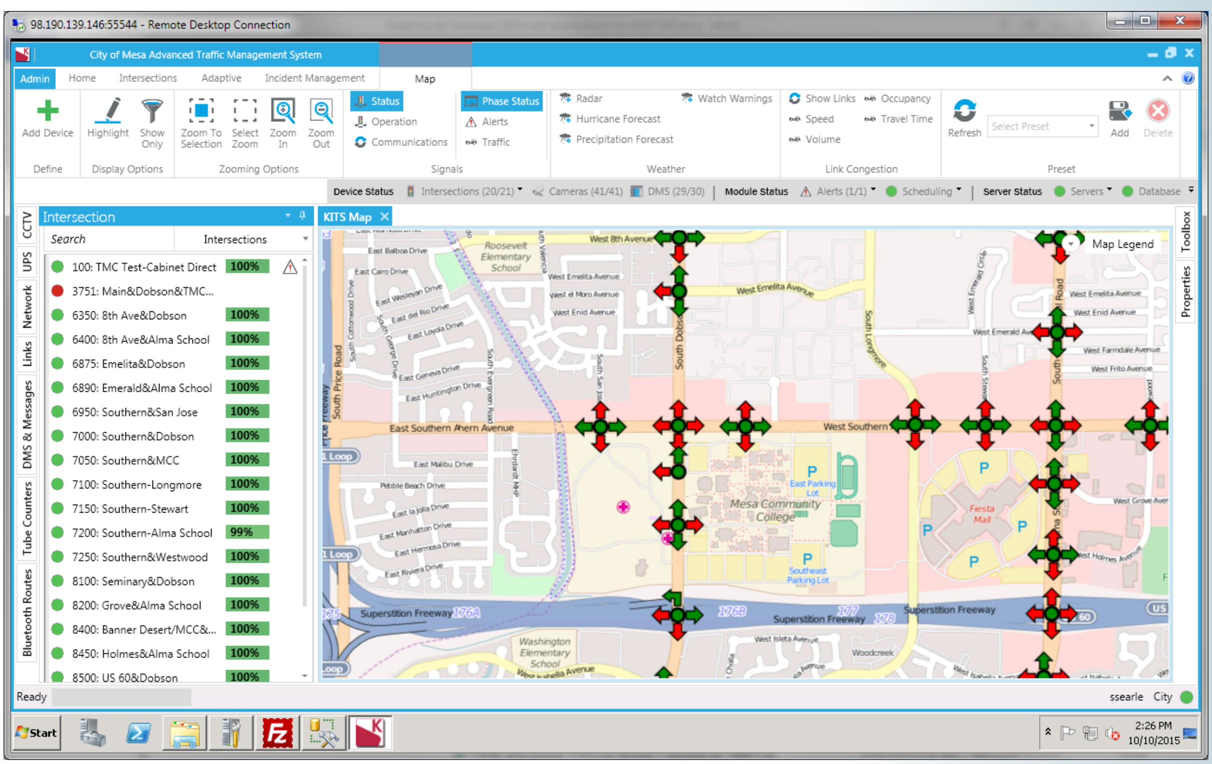
DETECTION

- Stop bar detection
  - Cycle tuning
  - Split tuning
  - Phase sequence tuning
- Upstream/exit detection
  - Offset tuning
- Better if detectors in each lane are on separate channels
- 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**
- **Cycle time change step size**
- **Phase omit below a cycle threshold**
- **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 and maximum splits**
- **Critical phases for cycle tuning**

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**

Maximizing 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).

- **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

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 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 on adjacent signals.

The user can specify the minimum percentage of improvement in arrivals on green (e.g. 10% or 15%) to implement an offset change. This feature prevents the system from making offset changes when improvement are not appreciable.

Each controller considers a range of offset settings: no change, adjust up to X seconds earlier, or adjust up to X 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).

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 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.

- **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**

Manage the Length of Queues

Current algorithms in Kadence explicitly measure queue lengths and use the estimates of length of queue in tuning offsets. By considering the standing queue length at the start of green, the upstream arrivals are tuned to arrive just as the queue is dispersed. In oversaturated conditions where not all of the queue is discharged during the green time, splits are adjusted first and then cycle time if necessary. Queue lengths are balanced by modifying splits, offsets, cycle time, and phase sequence. Queue mitigation algorithms are based on our research in NCHRP 03-90. 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 on a given oversaturated route. This heuristic increases the downstream output rate and constrains the upstream input rate to disperse the residual queueing.

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 straight-forward fashion, if the cycle time is increased by four 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 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).

- **Modern software architecture**
- **Modern high-speed IP communications**
- **Windows 10 and Windows Server 2016+**
- **Controllers are accessible directly by any existing ATMS and Kadence**
- **User-definable parameters**
- **No risk of controller getting stuck or skipping phases**
- **Pedestrian, transit priority, and preemption support**

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. These algorithms make the system applicable to a much wider range of situations including grids and interchanges.

Time of Day Timing Plan Tuning

Kadence updates your baseline timing plans on a user-configurable basis, such as every two weeks. Our artificial intelligence algorithms analyze the actions of Kadence over the time period and update the baseline settings accordingly. For example, if Kadence typically runs a 160s cycle length for the AM peak period and this cycle time is routinely reduced to 140s day after day, we update the time of day plan to start Kadence with a 140s cycle time. This helps to make Kadence faster and more responsive, but also to respond to seasonal changes such as summer periods without daily school traffic, or to new developments such as housing or businesses that result in more traffic on a Kadence route. The updates to the baseline plans also mean if communications are ever severed, the most up-to-date plans will be running.

Before and After Comparison Tool

Kadence includes a built-in before and after analysis tool. Kadence can be configured to calculate ATSPMs (the same ATSPMs used by Kadence to run in real-time) when Kadence is OFF. These metrics (Phase utilization, arrivals on green, and queue lengths) can be calculated with the signals are running in coordination or in free. The user can select any time period to compare performance of Kadence ON versus OFF, or comparing Kadence operations in AM or PM peak, by week or month, day of the week, or any other user-configurable time period. Graphical charts and displays easily show the improvements of the system by phase, by signal, and also rolled up into corridor or group performance.

IMPLEMENTATION

Kadence is operating on more than 500 traffic signals in North America as of August 2020 including systems in California, Florida, Arizona, Ontario (Canada), Texas, and Pennsylvania. Systems will be online in Virginia and Illinois in 2021. Kadence includes at no additional charge all KITS traffic signal management tools and features. Kadence can be deployed alongside any existing ATMS when the signals communicate over IP networks using NTCIP. Signal Controller Types

- **Econolite ASC/3, Cobalt, EOS**
- **Siemens SEPAC NTCIP**
- **McCain 233, Omni**
- **Fourth Dimension D4**
- **LACO4E**
- **Caltrans TSCP**
- **Siemens NextPhase**
- **Intelight MaxTime**
- **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**

- **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**

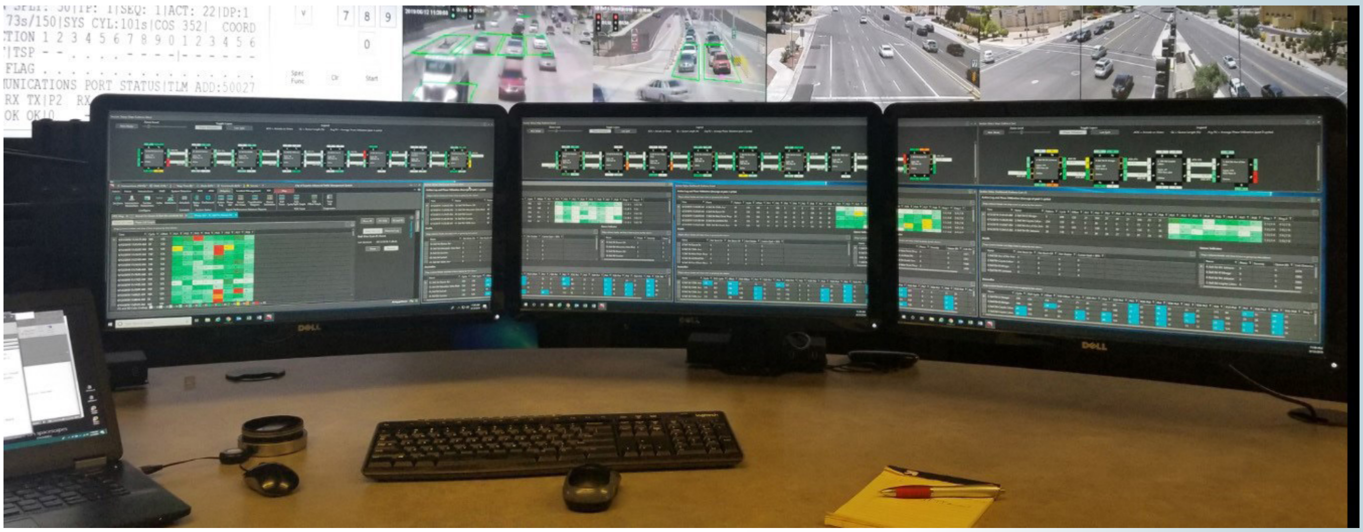
Training

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.

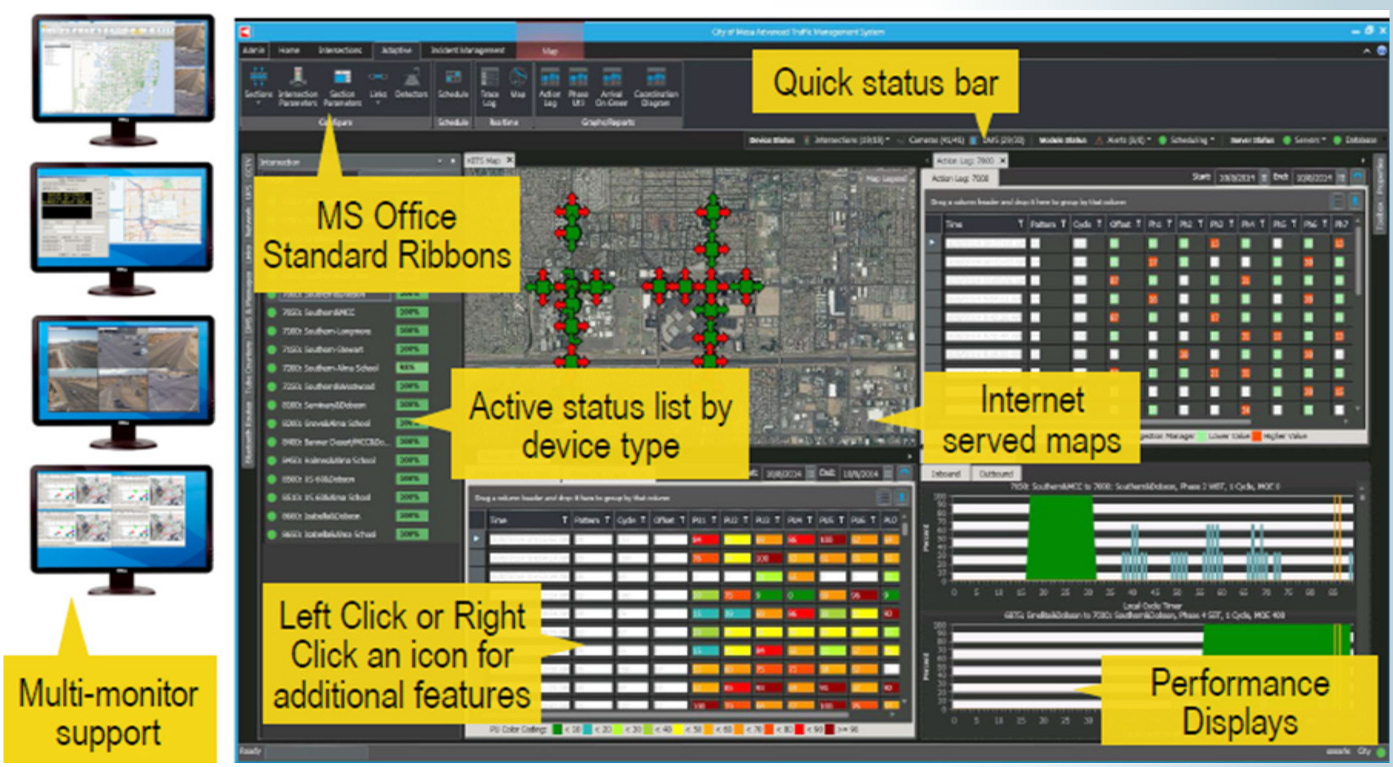
Maintenance & Support

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.
Updates can be provided seamlessly with remote VPN access.

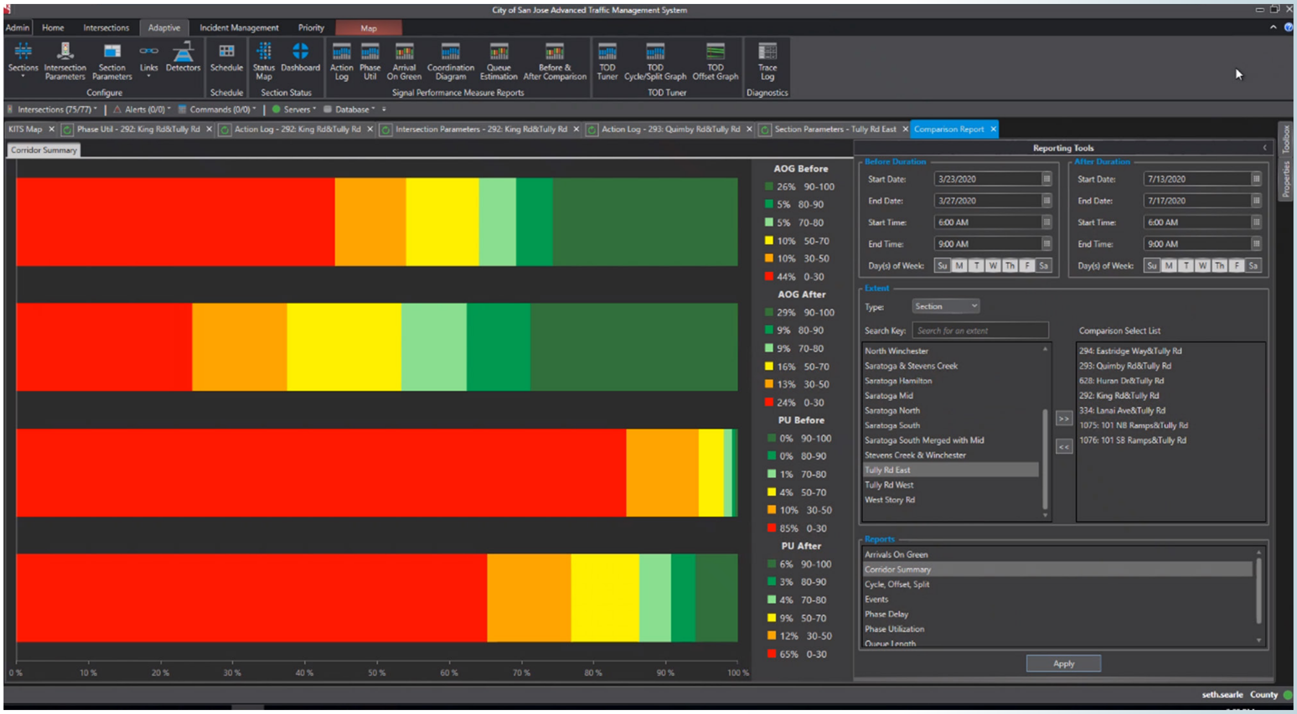
SCREENSHOT GALLERY



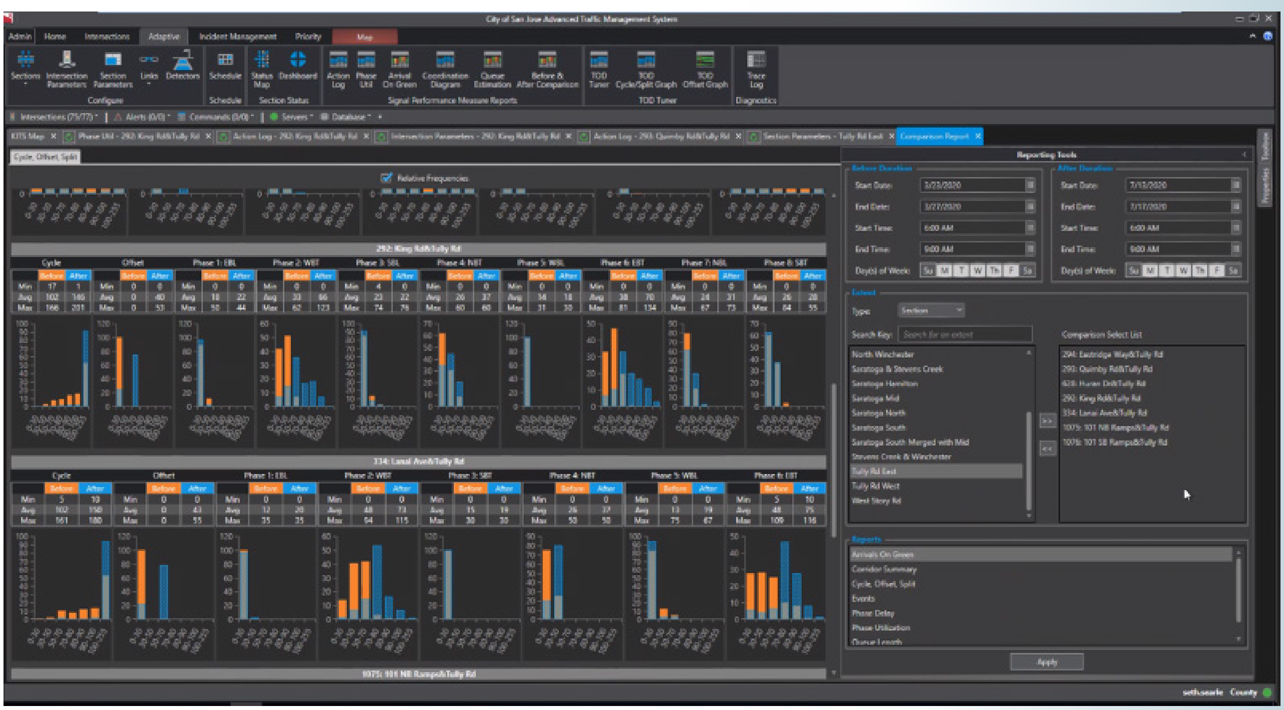
Kadence GUI across multiple PC monitors in a TMC



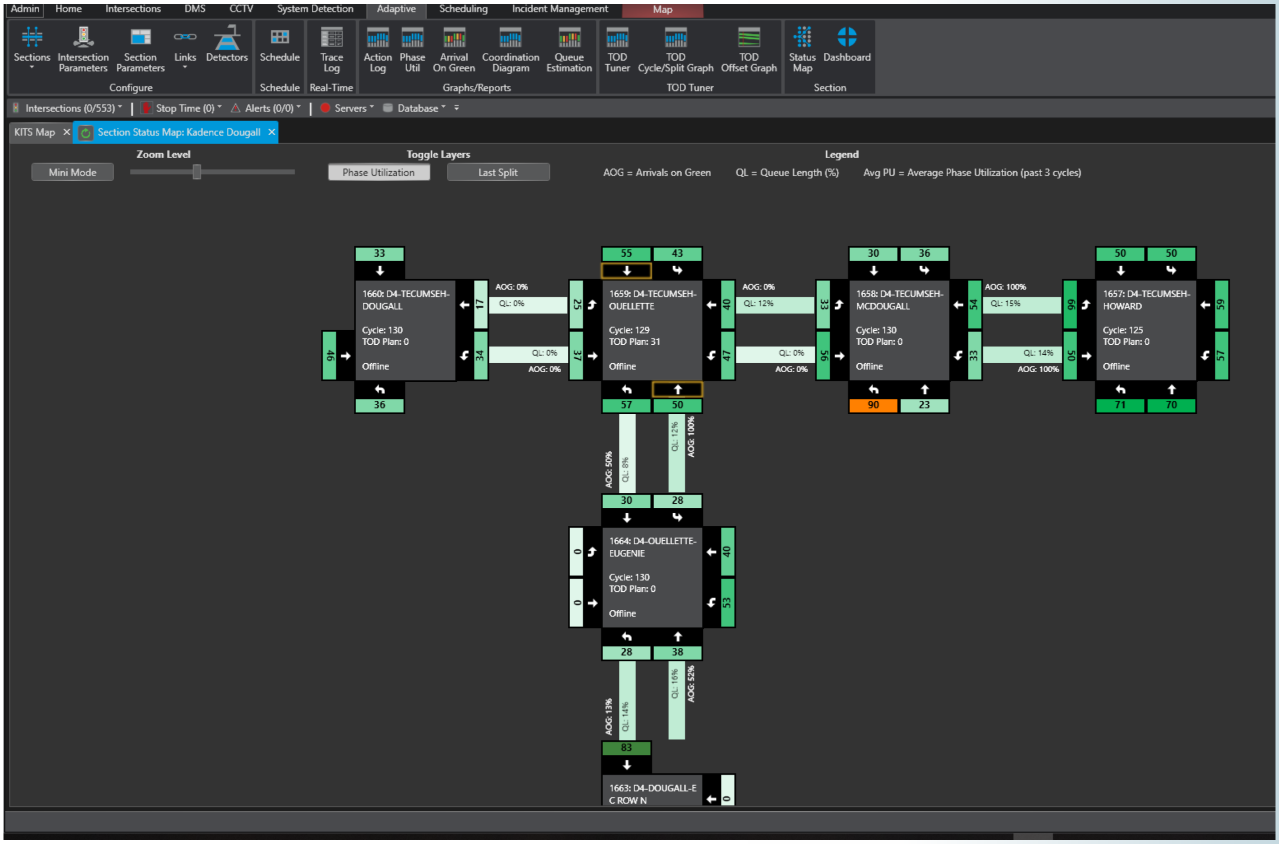
Easy-to-use modern GUI



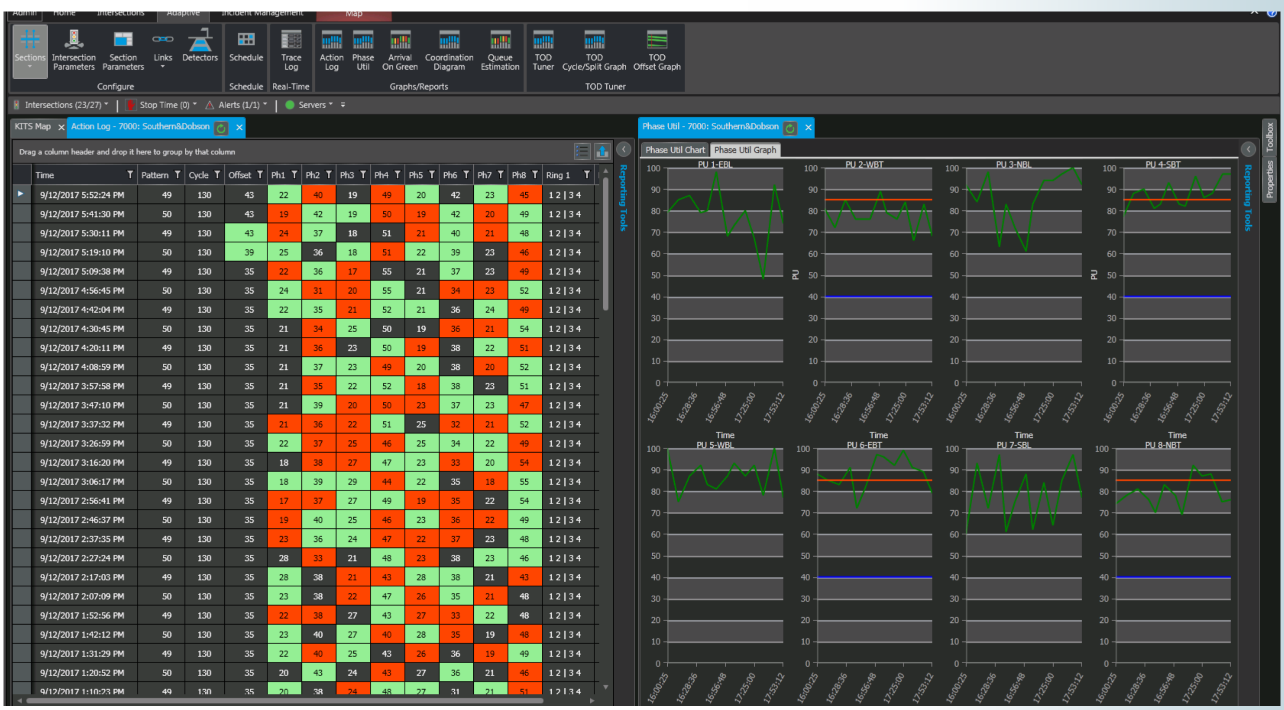
Before-and-after corridor report



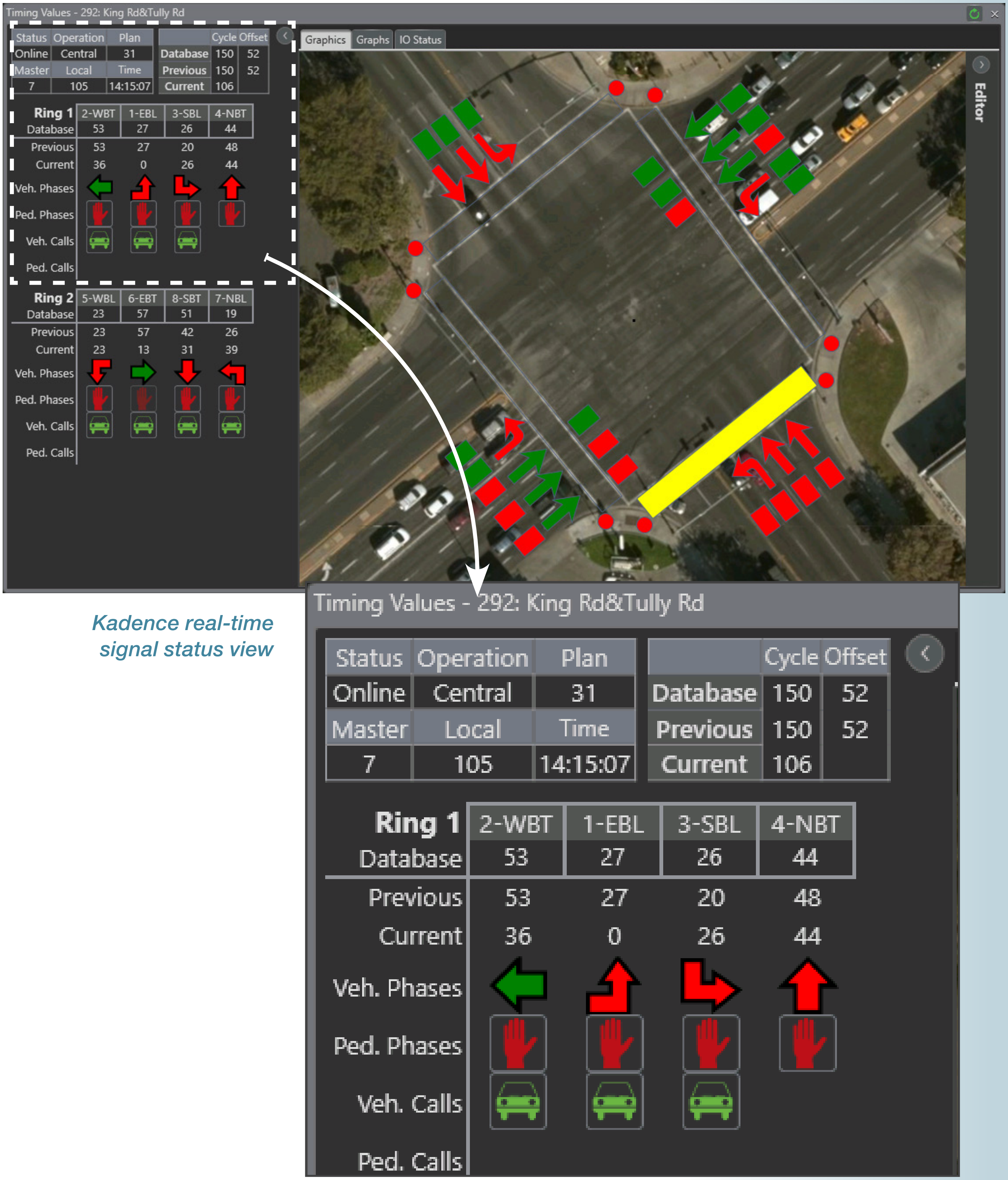
Before-and-after signal report



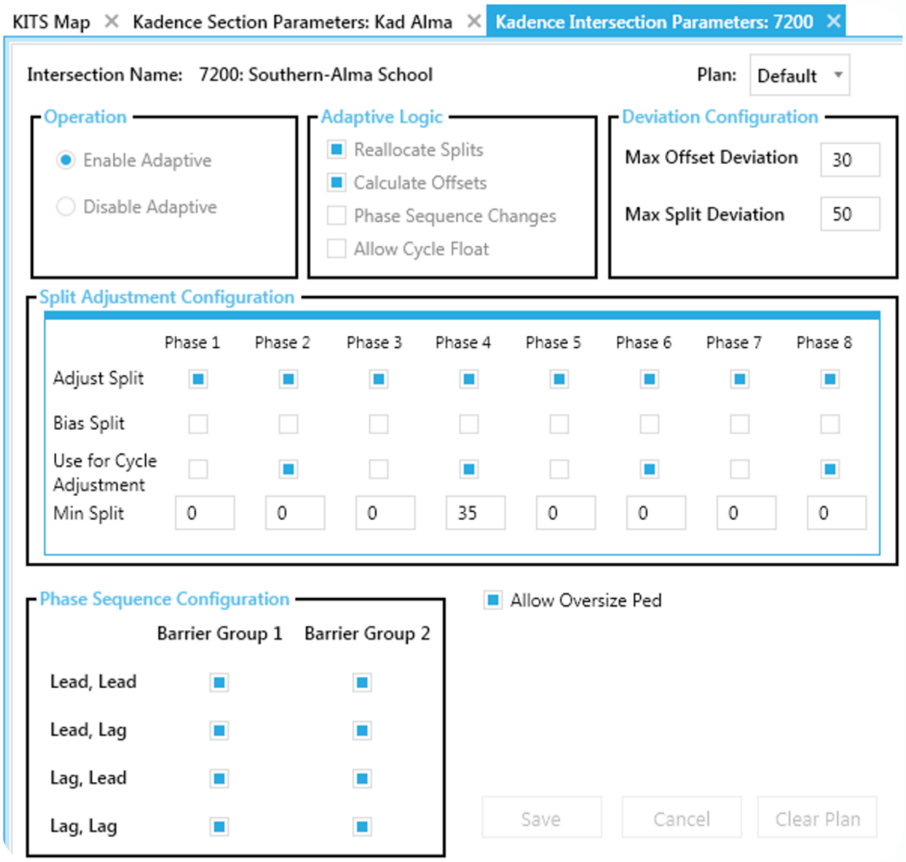
Corridor status display



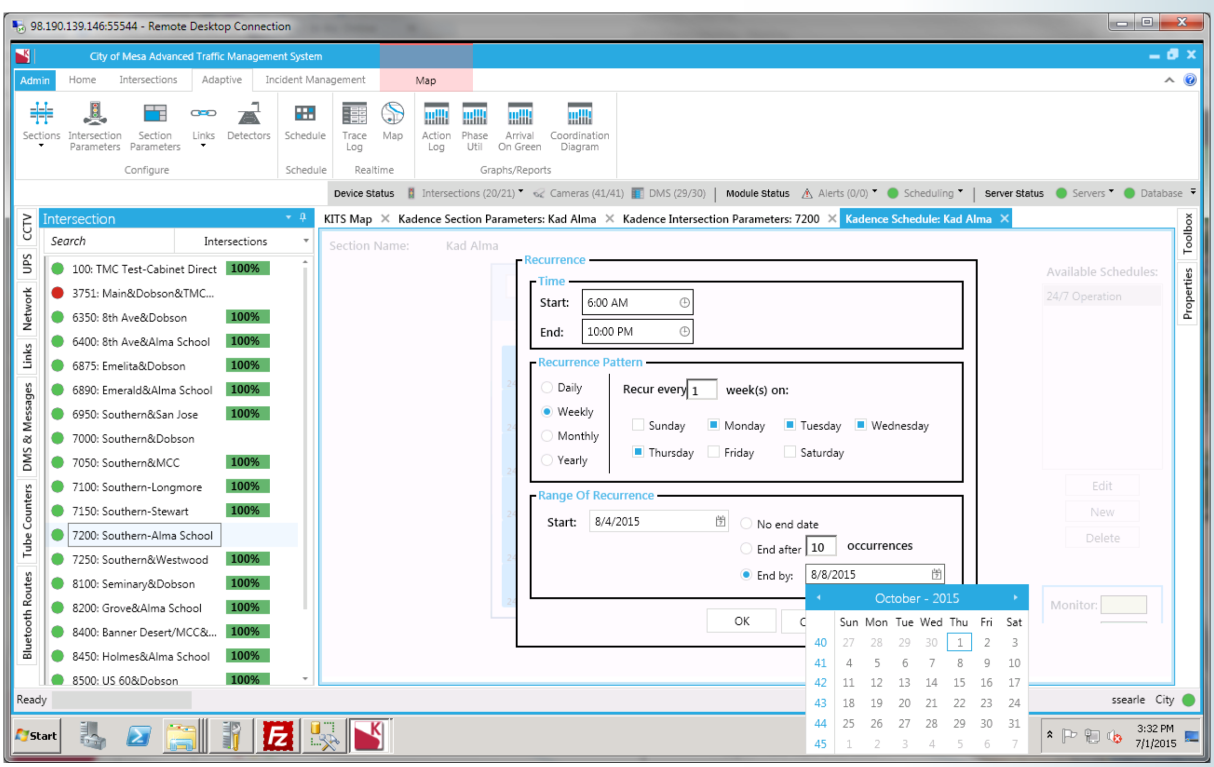
Dockable screens



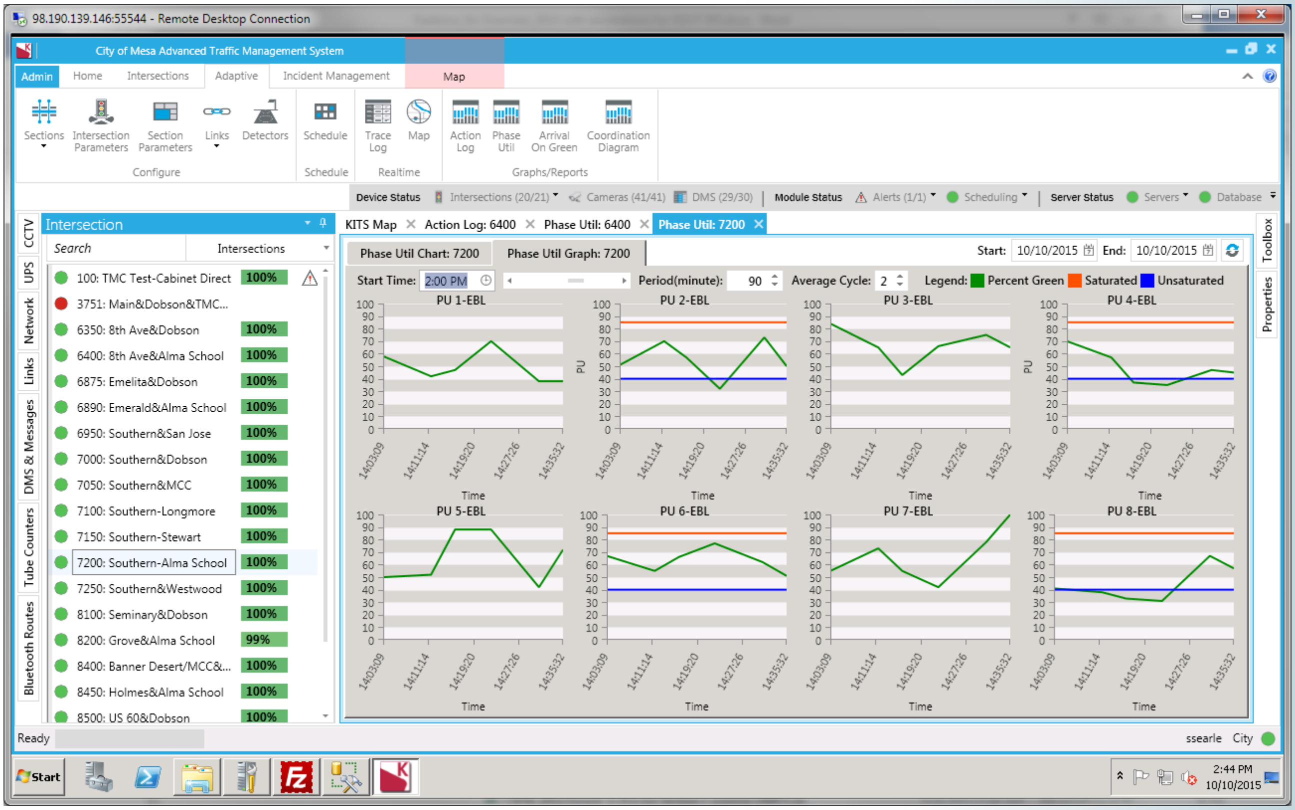
Kadence real-time signal status view



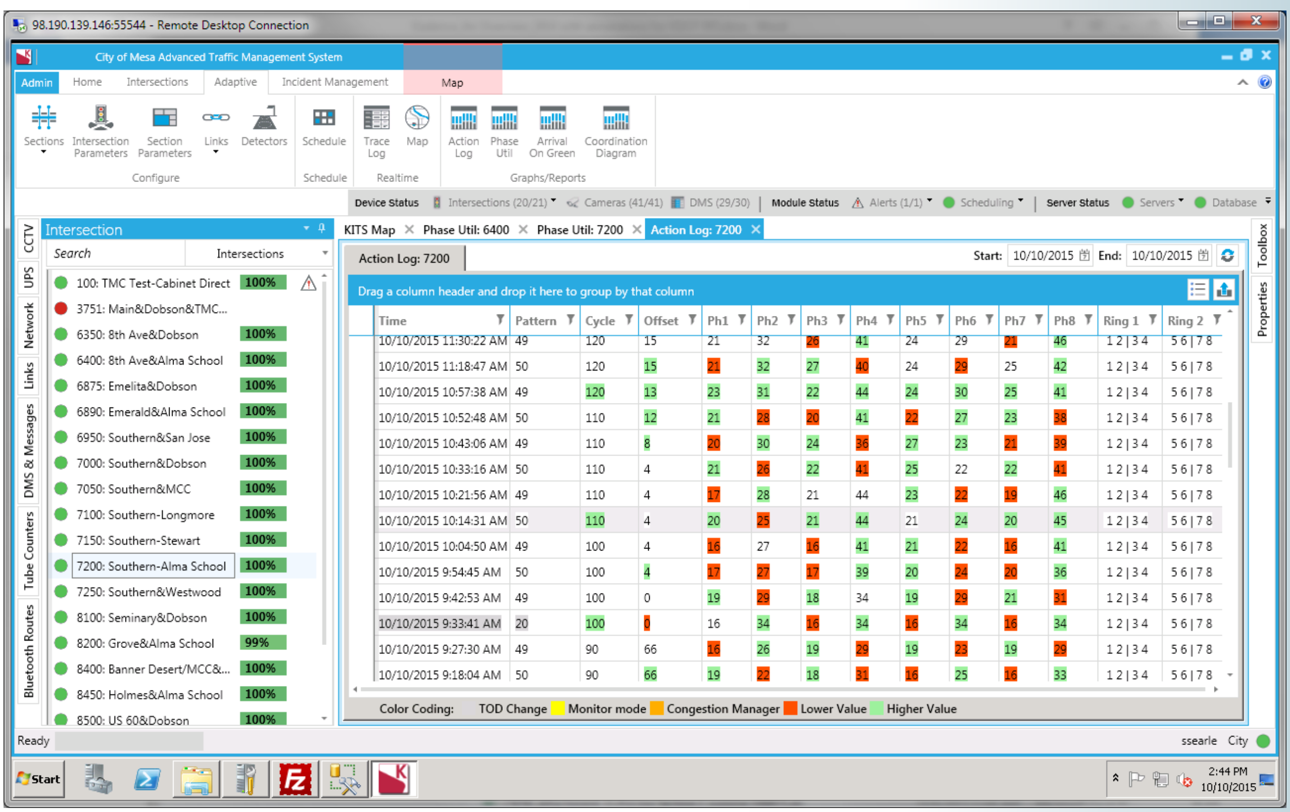
Configurable intersection parameters



Scheduling Kadence ON/OFF times

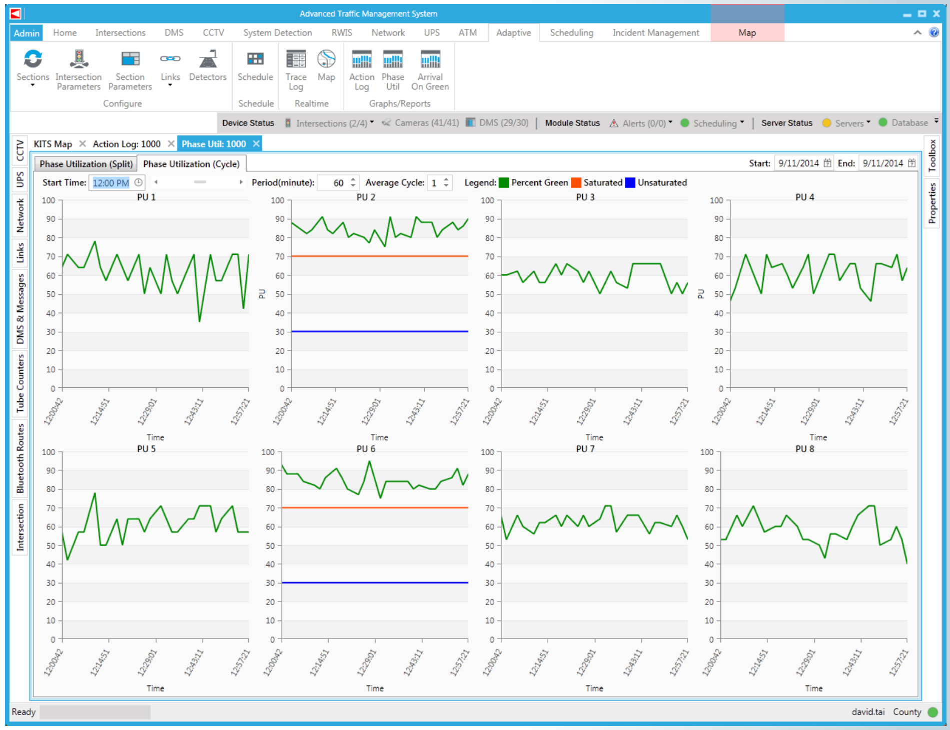


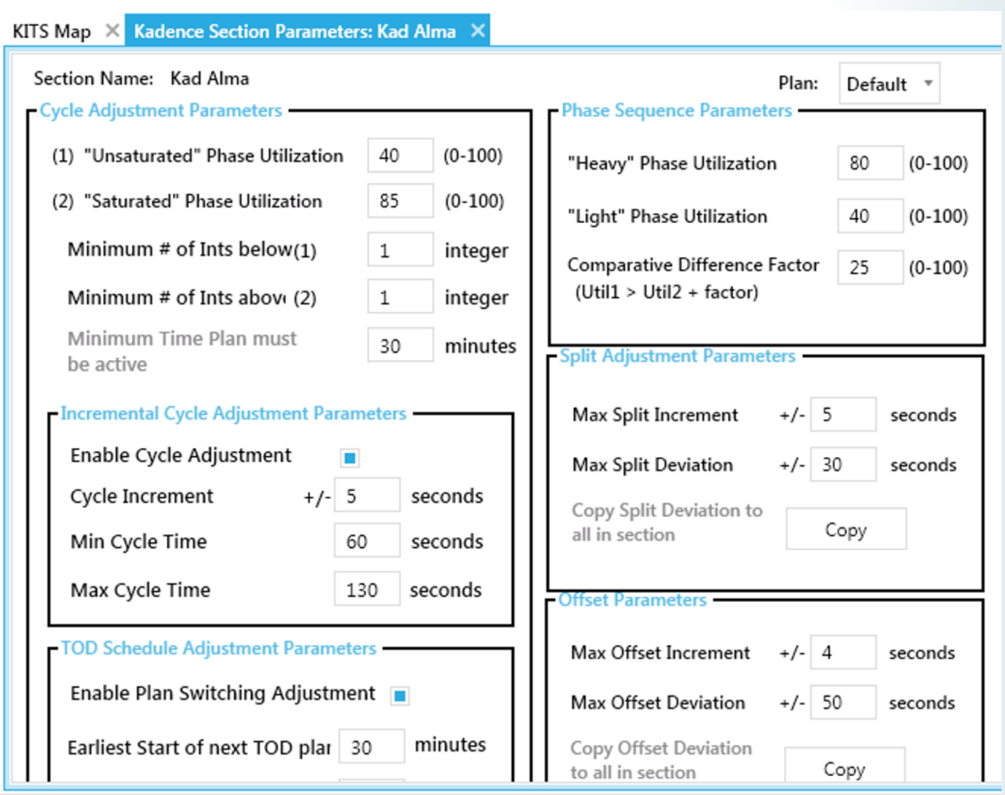
Flexible graphing displays for phase utilization



Action log of all adjustments including color coding

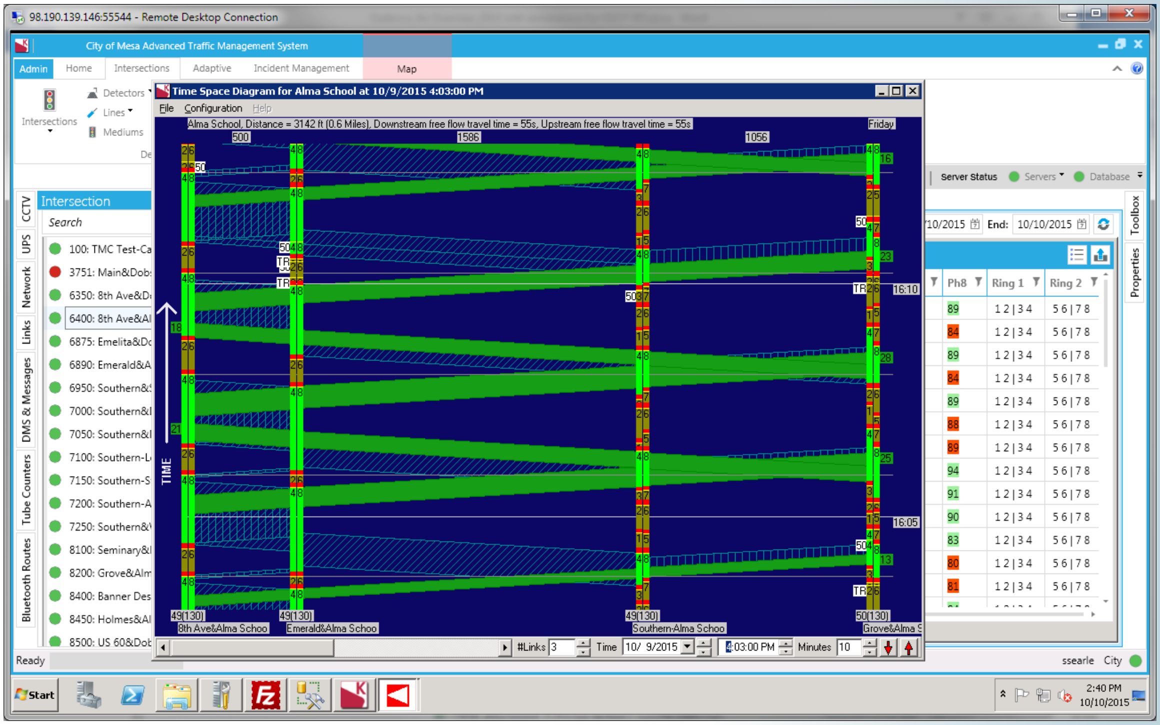
Phase utilization graphs show when critical phases are oversaturated

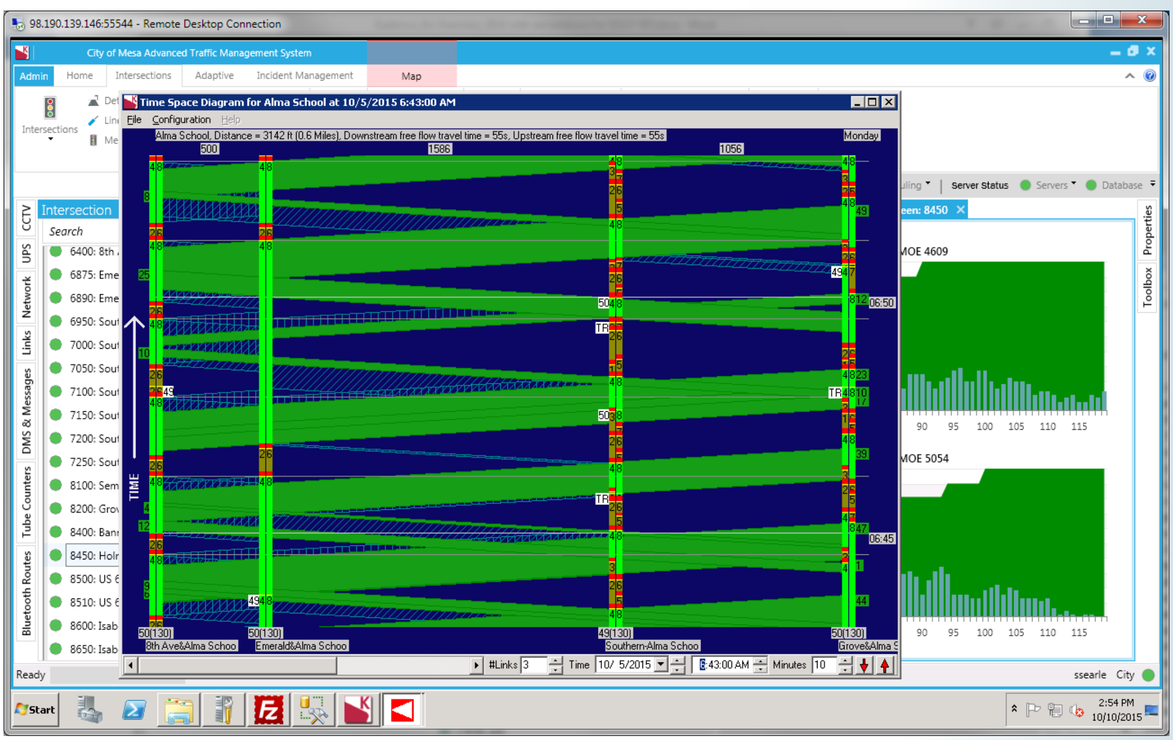




Kadence section configuration parameters

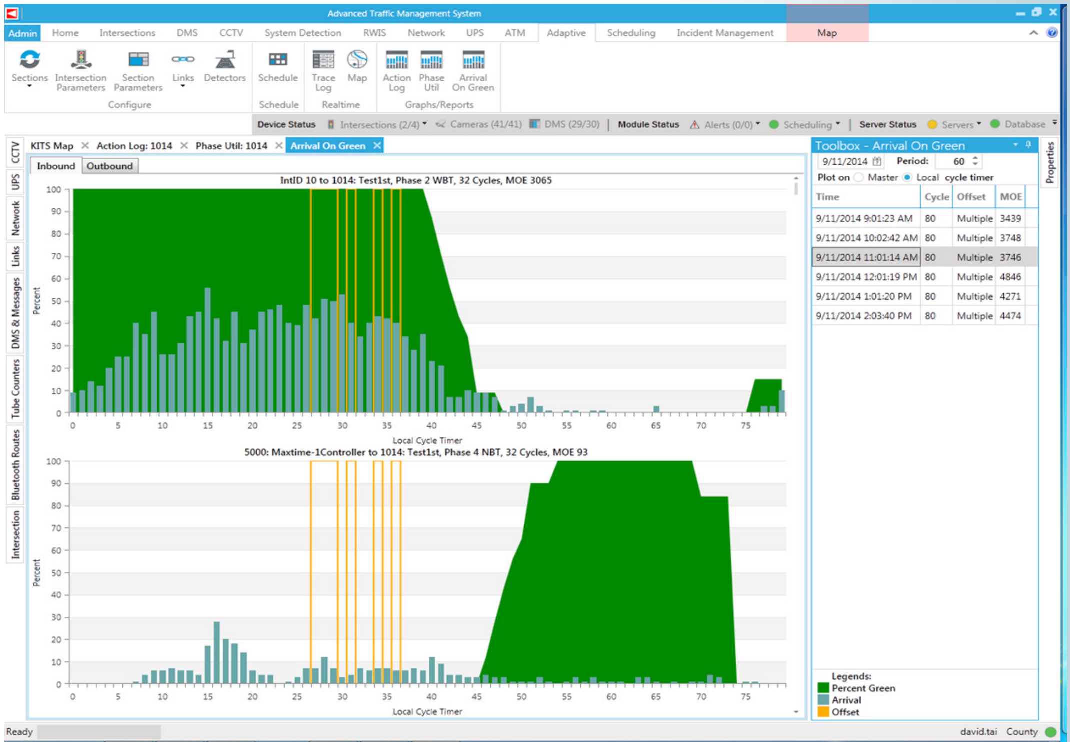
Real-time historical time-space display showing Kadence green bands

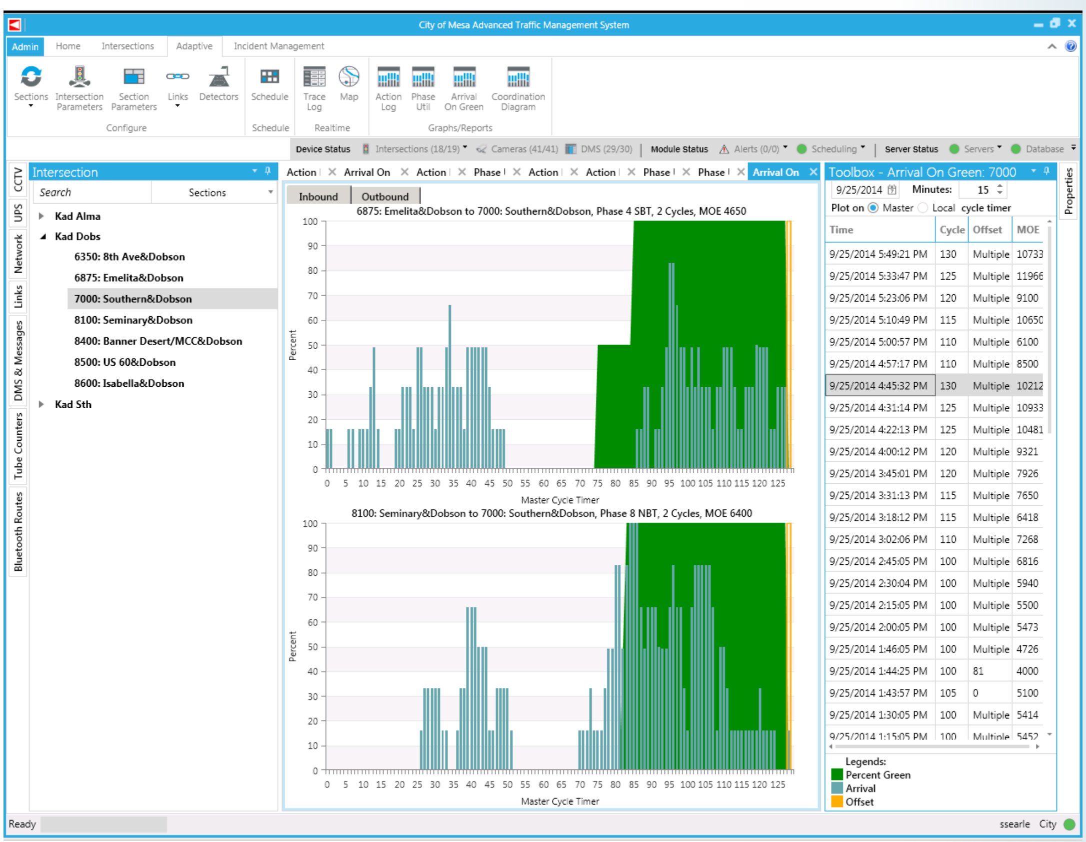




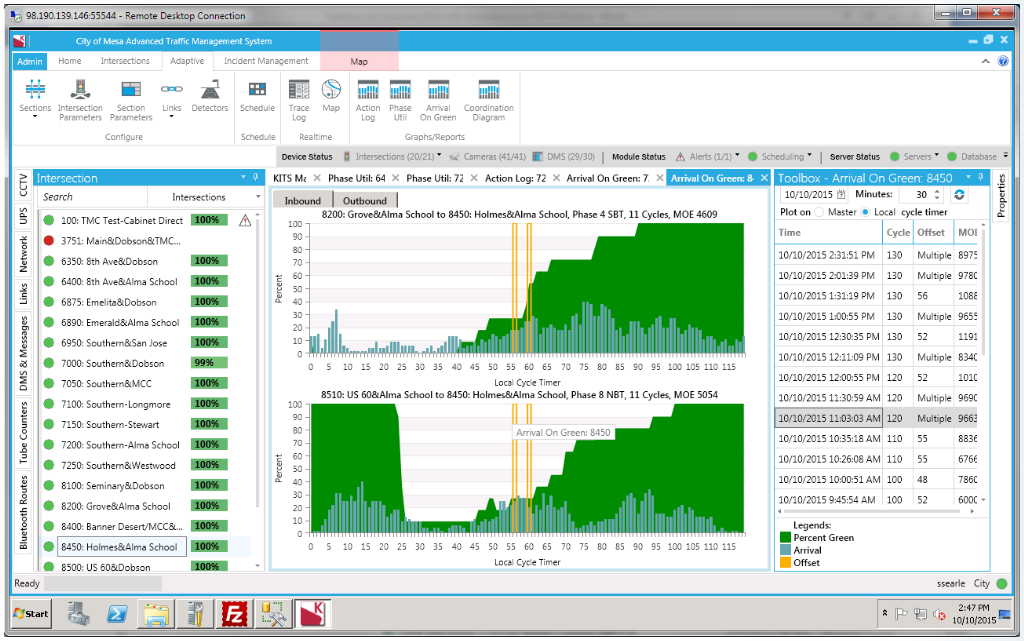
Two-way progression at certain times of day

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

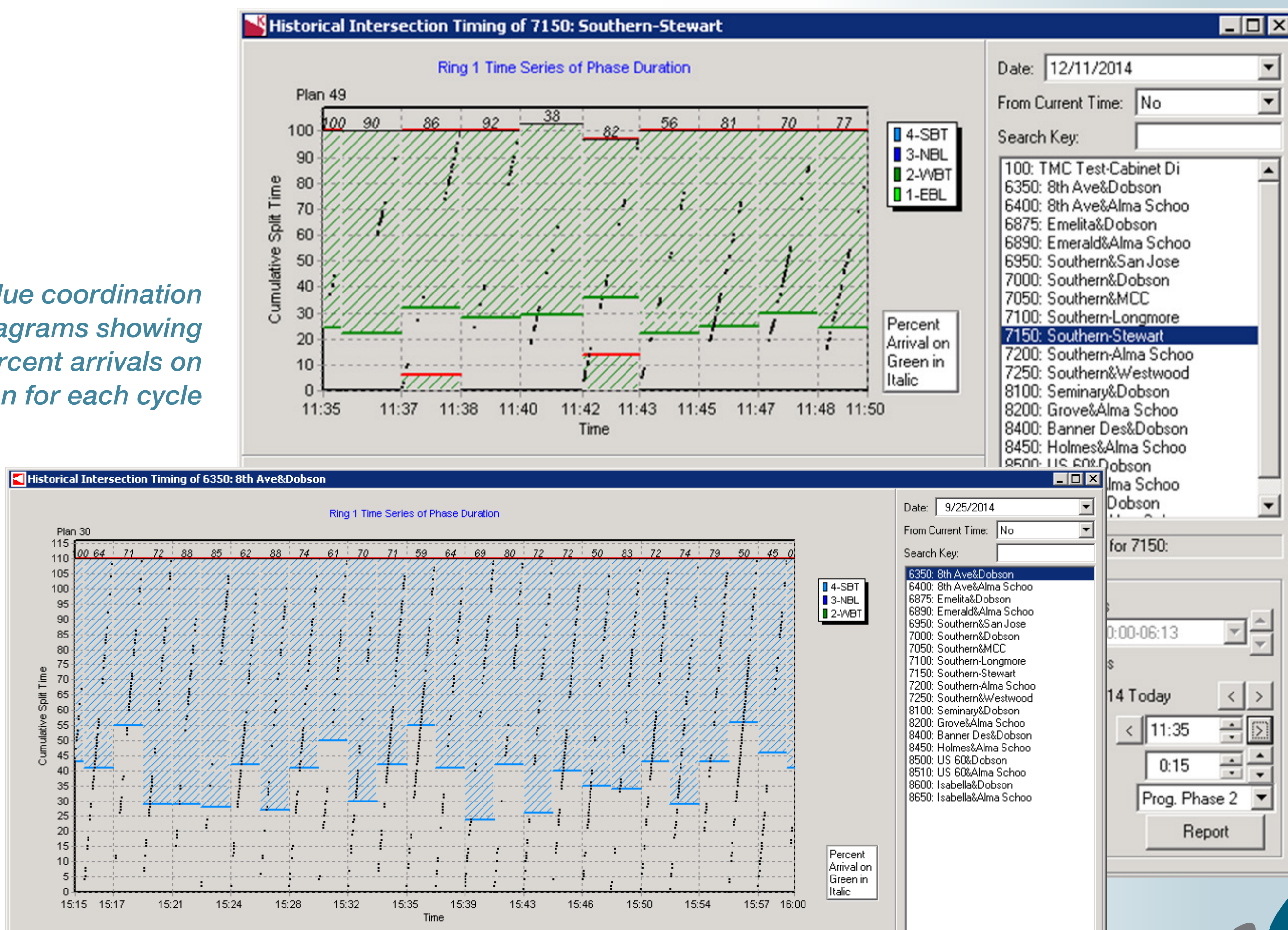




Arrivals on green display

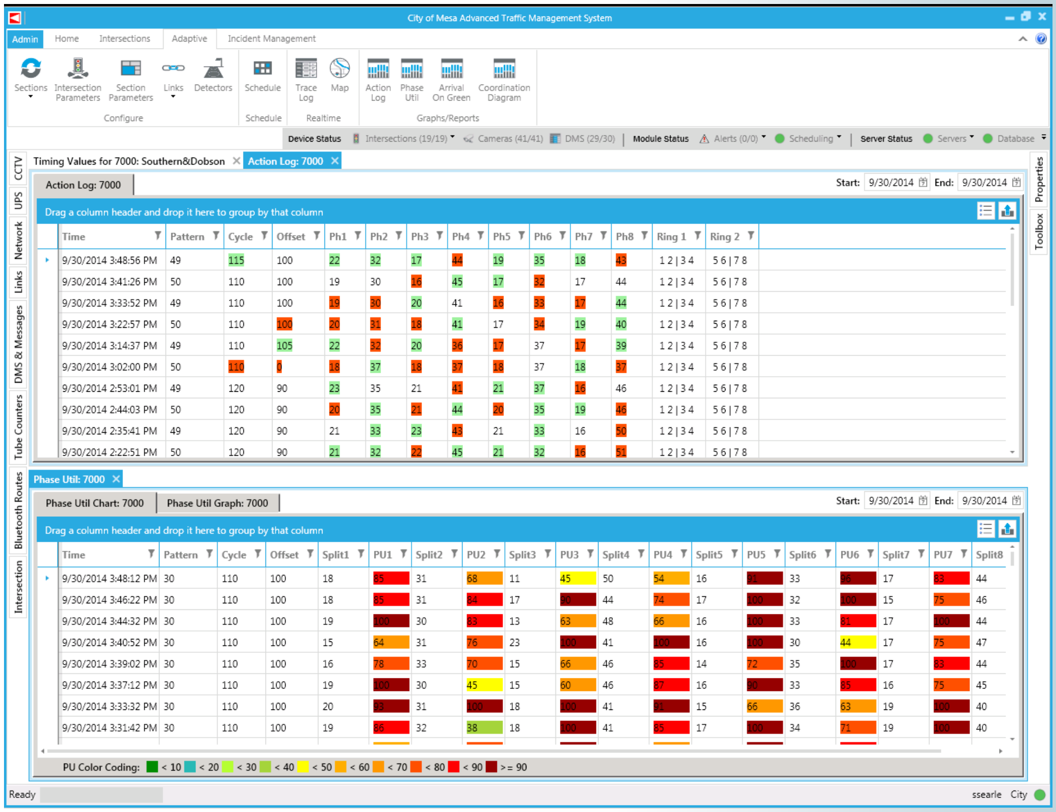


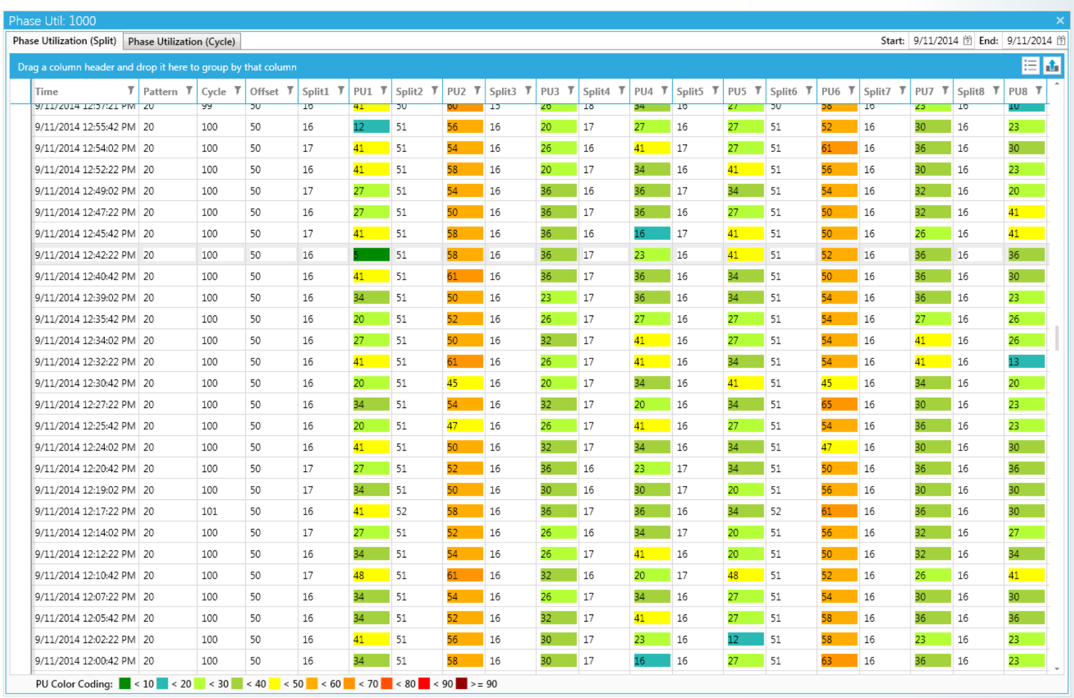
Flexible aggregation of percent arrivals on green by TOD and DOW



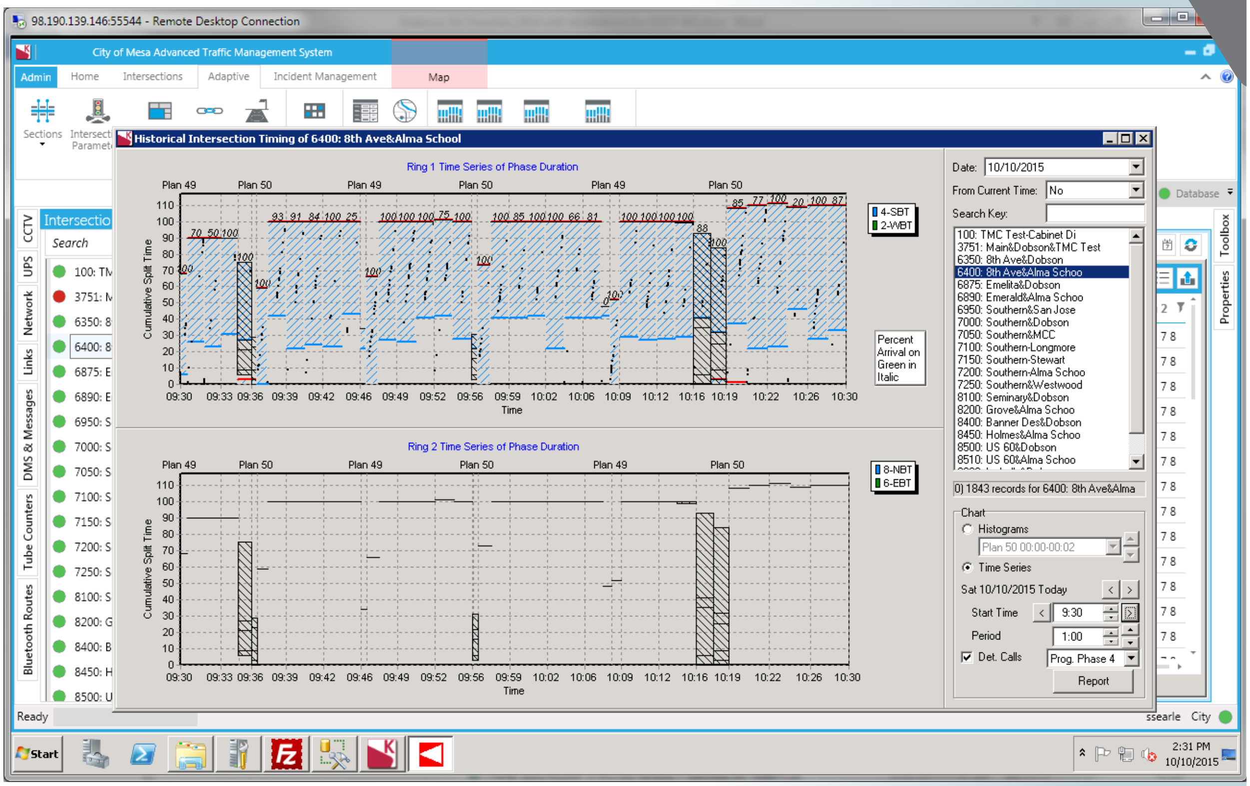
Purdue coordination diagrams showing percent arrivals on green for each cycle

Color-coded phase utilization display and configurable docking

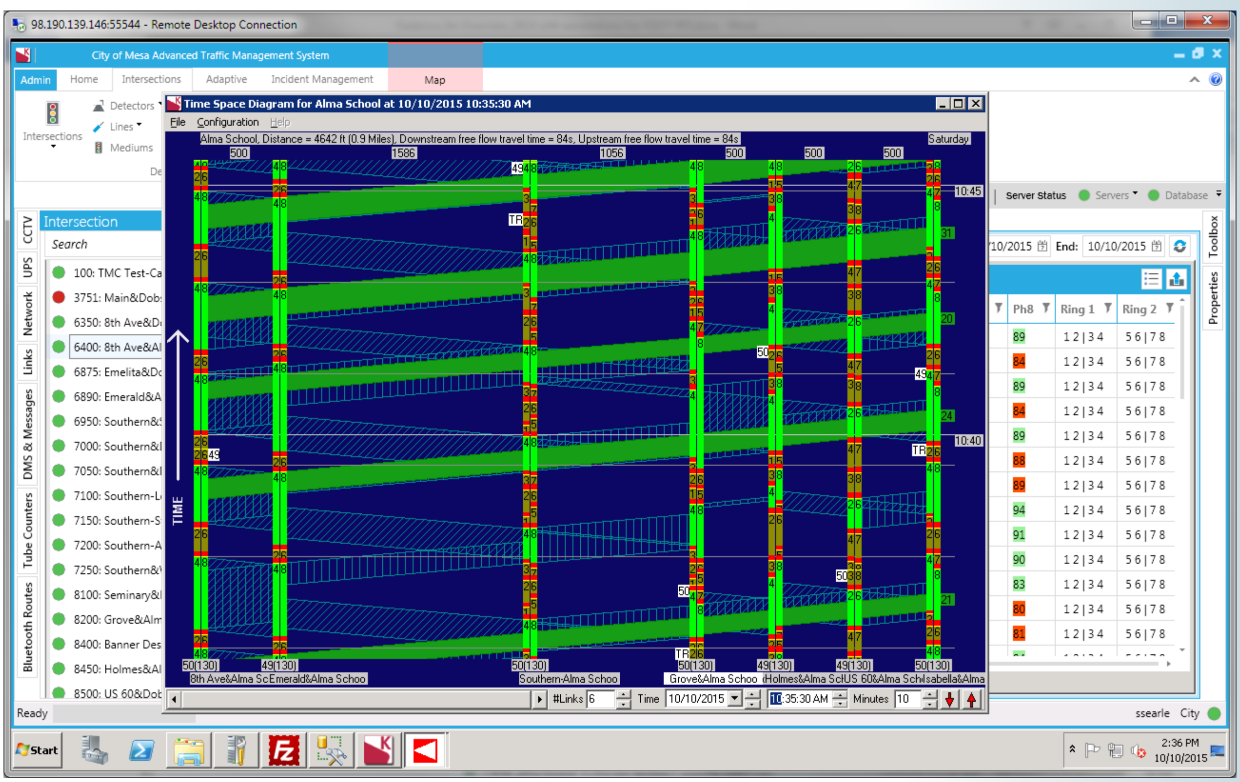




Color-coded phase utilization display with served splits



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