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Developing a Traffic Signal System Optimization Plan for New Jersey, USA


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The New Jersey Department of Transportation (NJDOT) owns, operates, and maintains approximately 2,500 traffic signals along its state highways. With New Jersey being the most densely populated state in the United States, the arterial roadway system operated by NJDOT routinely experiences high volumes and congested conditions. The performance of these roadway systems, in particular the traffic signal systems, is critical to the mobility of people and goods throughout the state. Improvements to traffic signal systems could reduce travel times, provide safer roadway conditions, and improve commerce.

Traffic signal related technology has been rapidly advancing in recent years. NJDOT has fully embraced some of these technologies, such as Computerized Traffic Signal Systems and Adaptive Traffic Signal Systems, and deployment of such systems has already begun. However, the existing NJDOT traffic signal systems currently utilize diverse equipment types and varying levels of technology statewide making it increasingly difficult to operate, maintain, and even upgrade the various systems.

With these advancements in traffic signal technologies, the NJDOT sought out to create a plan to systematically identify and upgrade traffic signal systems throughout the State of New Jersey. This plan infuses various degrees of "intelligent" traffic signal features to maximize system performance and better manage traffic operations statewide. The overall goal of the "Traffic Signal System Optimization Plan" was to analytically provide some form of signal improvement at each of the NJDOT traffic signals over a ten year period. These improvements can range from traffic signal timing optimization to high level intelligent signal systems, such as adaptive signal control. This deployment plan helps to assess and rank corridors which would most highly benefit from advanced technologies.

Tier Classifications

In order to designate each system with the appropriate measure of improvement, the project team worked with NJDOT to refine a concept in which each signal system would be classified into a tier corresponding to the traffic signal system's optimal proposed design characteristics. The various degrees of technology were identified along with their respective incremental implementation benefits. While it may seem that the highest technology should be deployed for every traffic signal system in the state, it is important to consider cost/benefit implications of implementation. Deployment of each one of the tiers on their own has clear operational benefits that can be realized.

Based on this information, six proposed signal system classification tiers were developed from T6 (being the least intelligent) to T1 (having the most intelligent features). Parameters for each system were developed that included some of the technology features desired and typical equipment attributes needed to deploy such a system. The following discusses these proposed tiers in more detail, along with some of their incremental benefits.

T1: Adaptive Traffic Signal Systems collect and communicate current traffic data to a central computer or local processor in real-time. Proprietary algorithms are utilized to make timing adjustments in real time based on the current traffic data and traffic demand. While each manufacturer has different features, these T1 systems can typically change cycle lengths (or period lengths), splits, offsets, and phasing. These parameters are constantly modified to best meet the real time needs of the system.

One of the most important aspects of an Adaptive Traffic Signal System is that once deployed and calibrated, there is likely no need to collect future traffic data and develop new traffic signal timing directives. This cuts down significantly on future investments in the system and inherently improves signal performance over time as the system does not rely on typical re-timing or optimization efforts. While the system still experiences costs associated with periodic parameter modifications and system maintenance, the overall future investment will be significantly less than other tiers by eliminating the need to manually re-time and optimize the system.

T2: Traffic Responsive Systems still utilize centralized computers and traffic data information to adjust signal timings but typically must run through several cycles before selecting from a number of predetermined timing plan options. These systems are obviously much more efficient, less labor dependent, and likely more responsive than some of the other lower tier systems, but the delayed response is not reacting to the real time demand like the T1 systems can.

Most T2 systems still rely on a bank of "Time of Day" style plans. The centralized computer applies the most appropriate timing plan considering the traffic demand. It is important to note that since the T2 systems rely on a bank of Time of Day plans, traditional traffic signal re-timing and optimization efforts must still be periodically conducted making future investments more than a T1 system. These systems also require a lot of the same system parameter modifications and maintenance upkeep that T1 systems do.

By introducing a T2 system, Time of Day plans deployed are based on current traffic conditions providing better response to traffic demand. The centralized software reviews current traffic information and selects the appropriate plan based on the conditions rather than blindly pushing out plans based on the time of day. Even though the plans are often implemented over the course of several cycles, they still are far more responsive to the actual conditions than the T5-T3 systems. This results in a much more efficient use of the timing.

T3: Computerized Traffic Signal Systems (CTSS) is the terminology used by NJDOT, which describes its Advanced Traffic Management Systems (ATMS). CTSS is utilized to view and manage current traffic conditions, diagnose signal system problems, and modify/implement traffic signal timing directives remotely through the Arterial Management Center (AMC). T3 systems do not have adaptive or traffic responsive features, so the corridors are coordinated through traditional optimization by maximizing green time bandwidths. An AMC operator has the ability to remotely implement and deploy timing modifications to the signal system in response to real time traffic conditions or incidents.

Creating a T3 system requires communication capabilities in place both system-wide (locally) and back to the AMC (centrally). CTSS provides the ability to remotely monitor systems in real time. AMC operators can view cameras to assess conditions and can be alerted to system malfunctions and issues by alarms and even text message and email communications. These capabilities have many operational benefits and can assist in incident management and response. Also, since CTSS has the ability to closely monitor traffic information and remotely deploy traffic signal timing directive modifications system-wide, most of the existing NJDOT T3 systems tend to have a more extensive bank of Time of Day plans than a traditional corridor, therefore having better operational performance.

T4: Coordinated Systems, Local Communication are similar to T3 as the traffic signal controllers still communicate locally with one another across the system. However, these signals are not communicating centrally with the AMC. Therefore, there is no monitoring capabilities or remote deployment functions associated with this system. However, T4 systems still generate various operational benefits.

T4 systems have a master controller that has local two-way communication with each signal on the system. Depending on the type of master controller, timing decisions as well as response to equipment failure can be accomplished by the master. The master controller also provides a single point to deploy system-wide traffic signal timing modifications, lowering timing deployment costs. The interconnection of controllers ensures synchronization and eliminates the possibility of "clock drift." Additionally, T4 systems have the infrastructure in place for future upgrades to a higher tier, and to provide centralized communication.

T5: Coordinated Systems, Time Based include time-based traffic signal coordination along corridors. NJDOT has a robust signal optimization program that has been in place for many years, and most of the state's signalized corridors have some sort of time based coordination. The timings along T5 corridors are optimized based on time of day (TOD) plans and are synchronized through time-based offset timing. A properly optimized corridor can yield many operational benefits including dramatically decreasing delay and travel time along the corridor. It is also important to note that traditional optimization efforts are low-cost and do not usually require construction efforts. They are an easy way to provide improved operation along a signal corridor.

T6: Isolated Signals, No Coordination are state owned and operated signals that do not need or receive any benefit from communicating or being coordinated with other signals and therefore do not function in a system. Most of these signals are isolated geographically and located in areas where no near-term development is planned on the roadway. These intersections are classified as isolated signals and should be reviewed separately to determine if signal improvements are beneficial.

Performance Evaluation Development

With the proposed tier structure defined, the project team developed an evaluation and scoring process that would assign the signal systems to the appropriate tier. The first step was gaining an understanding of the NJDOT's existing traffic signal conditions and features.The project team coordinated with various individuals at NJDOT to collect data from numerous sources. Each of these data sets were then reviewed and compiled to develop a master inventory of NJDOT owned and maintained traffic signals. The team utilized the traffic signal attribute information obtained through these data collection efforts to establish baseline existing traffic signal classifications.

Next, the project team needed to identify a way to implement traffic and roadway data and characteristics into our plan. Coordinating with the NJDOT Planning Department, we used their Statewide Intersection Analysis Process (SIAP) software package for capacity analysis of individual NJDOT signalized intersections. SIAP integrates and refines data from the New Jersey Congestion Management System (NJCMS) and NJ Straight Line Diagram (SLD) databases to better reflect the characteristics of individual signalized intersections, such as number of lanes on each approach, allowable movements, the presence of turning lanes, and traffic volumes. SIAP then utilizes the Highway Capacity Software (HCS) for the intersection analysis, and exports results into a database.

Once all of the data were gathered, the team developed a methodology for taking the individual intersections, breaking them into appropriate systems, and applying a scoring system to be used to determine the optimal design classification. A four-step iterative process was developed to make this evaluation and the separate steps are illustrated in Figure 1 and discussed in more detail below.

SIAP was used to assign an individual score to each of the intersections in our list. This ***Intersection SIAP Scoring*** was determined based around 5 categories including Importance (Roadway Functional Classification including Urban/Rural Designation), Magnitude (Total Traffic Volume for all approaches), Intensity (Level of Congestion based on volume-to-capacity (V/C) ratio), Speed (Speed limit), and Density (Number of NJDOT signalized intersections within a 5 mile radius). These categories are described in more detail below.

- **Functional classification**—indicates the role of streets in the overall roadway network. It categorizes streets according to their ability to move traffic and to provide access to abutting streets and properties. Implicit in functional class is the general number and width of travel lanes—major and minor arterials generally having a wider cartway than collectors and local streets. Other roadway design characteristics such as horizontal and vertical alignment, speed limits, curbside activity and signalization are also implicit in the functional classification. Because of their importance in the overall roadway system, roadways with higher classifications such as major and minor arterials are more likely to benefit from traffic signal coordination than would collectors and local streets, and therefore are scored higher.
- **Urban/Rural Designation**—Urban intersections generally feature more constrained operations than rural intersections, resulting from such elements as higher peak-hour traffic volumes, a larger number of turning vehicles, auxiliary lanes, curb parking, pedestrian and bicyclist traffic and the presence of public transit vehicles and stops. Traffic signals in urban areas are typically more closely spaced, with a larger number of cross streets and driveways. By contrast, rural intersections are typically less constrained, with longer intersection spacing, fewer driveways and cross streets, fewer turning movements and special signal phasing, and often a higher percentage of heavy vehicles. Urban intersections are more likely to benefit from signal coordination than rural highways and therefore are scored higher.
- **Traffic Volume**—The total traffic volume on intersection approaches indicates the level of activity, and thus affects intersection layout, the number of movements and traffic signal design, in particular the number of phases and cycle length. At intersections with higher traffic volumes, more motorists will benefit from signal timing improvements and therefore are scored higher.
- **Volume-to-Capacity Ratio (V/C)**—is a good indicator of capacity sufficiency, congestion, and the need for intersection improvements. Intersections that are more congested can typically benefit from signal timing improvements. Intersections with higher V/C ratios are generally scored higher.
- **Speed**—is the main variable used to estimate travel time between signalized intersections, to coordinate traffic signals along arterials, and to determine stopping distance and clearance requirements. High-speed arterials may benefit from better coordination to provide non-stop travel along the corridor, to achieve speed harmonization, and to thereby increase both safety and convenience for motorists. Higher speed roadways are generally scored higher.
- **Density**—Establishing signal coordination is easiest to justify when intersections are close to each other and when traffic

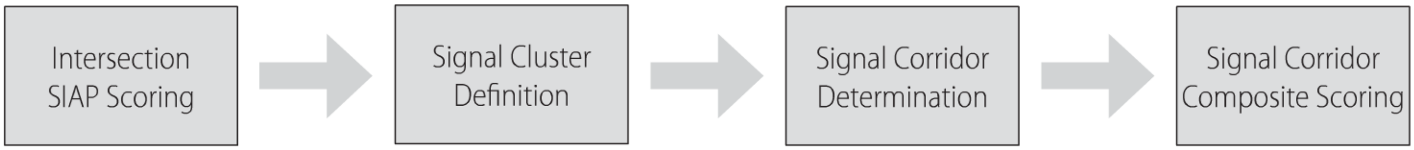

Figure 1. The Four Step Performance Evaluation Process

volumes between the adjacent intersections are large. When intersections are close together, traffic typically arrives in platoons that have been formed by the release of vehicles from upstream intersections. Higher signal densities generally received higher scores.

Once the individual SIAP scores were obtained for all of the intersections, a method to combine intersections into signal systems was developed. The first step was to meet with the NJDOT Planning Department to determine their current procedures for defining corridors associated with the NJDOT Signal Optimization Program. With this information in mind, the *Signal Cluster Definition* process was utilized for grouping signals along state routes into signal clusters.

For each State Route, signal spacing was determined by calculating the distance between the two nearest signalized intersections in either direction along a State Route. A *signal cluster* was developed based upon a signal spacing less than or equal to 1 mile. This 1 mile value was based on the recommended spacing of traffic signals as defined by the *New Jersey State Route Access Code, Section 16:47-3.4(b).*

Applying this methodology, if two or more consecutive intersections along a State Route had a calculated signal spacing of 1 mile or less, the intersections were grouped into a signal cluster. Any intersections with signal spacing greater than 1 mile in both directions on a State Route were categorized as individual intersections. This is illustrated in Figure 2.

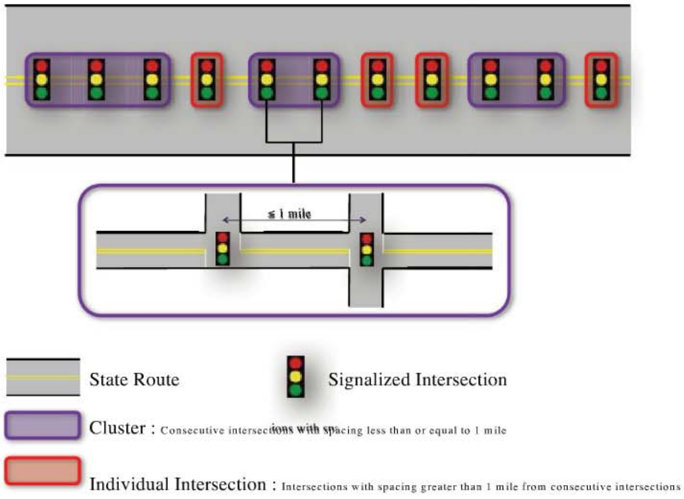

Figure 2. The Signal Cluster Definition Process

This process was repeated for each State Route with the clusters assigned numerical designations. This step took the 2,562 total intersections and returned 301 defined signal clusters and 188 individual intersections.

While using the signal spacing to combine signals into clusters is an important step in creating systems, it is also important to determine if adjacent clusters and individual intersections should be combined based on similar operational characteristics. The Signal Corridor Determination process utilized the SIAP operations score, in conjunction with the signal spacing evaluation, to determine if clusters and individual intersections should be combined into signal corridors.

The SIAP performance evaluation methodology produced an operations score for each signalized intersection under NJDOT jurisdiction. For each signal cluster within the State Route, the SIAP score for each intersection included in the cluster was averaged. To determine if adjacent signal clusters should be grouped into signal corridors, the average cluster scores were compared to the Mean Route Score of the State Route. If the average cluster score of a cluster or individual intersection score of adjacent clusters/intersections are within one standard deviation of the mean route score, these clusters and individual intersections were combined.

The mean route score was utilized to create a uniform baseline for comparing multiple clusters along the same State Route. The standard deviation is utilized to determine the variability between the cluster and the roadway data sets. The proximity of one standard deviation from the mean was considered the optimal distance for determining similarity between clusters.

Any intersections with no adjacent signals located within 1 mile in either direction on a State Route, and not within one standard deviation of the mean route score were designated as individual intersections. This is illustrated in Figure 3.

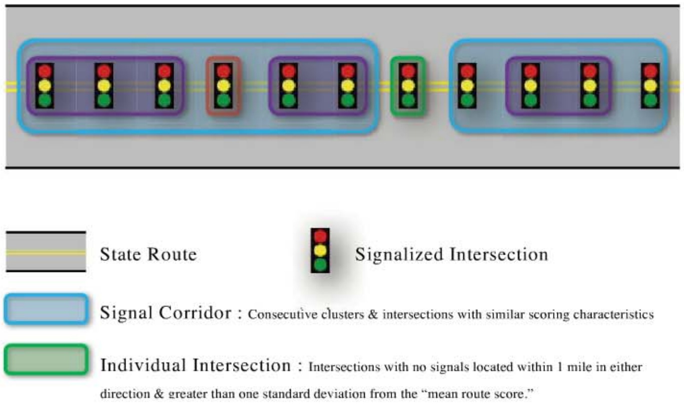

Figure 3. The Signal Corridor Determination Process

This step further refined the 301 signal clusters and 188 individual intersections into a total of 297 signal corridors and 101 individual intersections.

The SIAP Analysis provides a method for initially screening individual intersections. However, the goal when developing the performance evaluation methodology was to develop scoring that considered the entire corridor. Both quantitative and qualitative factors were considered to develop this *Signal Corridor Composite (SCC) Scoring* system. This final step of the performance evaluation process was used to help determine the optimal design characterization and final system recommendations.

The SCC score was developed around six categories including mean corridor SIAP score, route ADT, arterial signal spacing, truck volume, variable traffic generators, and kurtosis of ADT. These categories are described in more detail below.

- **Mean Corridor SIAP Score**—The mean corridor SIAP score is an important indication of traffic characteristics along a corridor. It is an average of the individual scores along the corridor and includes the various factors discussed previously.
- **Route ADT**—The previous SIAP score only considered intersection volumes and peak hours. The route ADT data was included to consider the overall route traffic volumes for a 24-hour period. Route ADT helps measure the magnitude of benefit in the cost/benefit criteria, by quantifying the amount of users affected by the improvement.
- **Arterial Signal Spacing**—Signal density has been considered in previous steps, but the density in the SIAP analysis is based on a radial area. The arterial signal spacing is the linear distance between signals on the same route. The team felt it was important to consider this factor in this scoring step as signal technology advancements are more beneficial along corridors where the traffic signals are closely spaced.
- **Truck Volume**—The characteristics of truck operation impact capacity along a corridor, due to longer start-up times and acceleration. Improving the movement of goods, by increasing corridor operation, results in economic benefits.
- **Variable Traffic Characteristics**—"Smart" traffic signals can better adapt to variable traffic conditions. Signal corridors in areas with large traffic generators, including seasonal routes or regional destinations, benefit more from advanced control than those with constant traffic conditions, due to the fact that they experience high variability in traffic volumes. This includes shore routes and routes near regional malls, amusement parks and sports venues.
- **Kurtosis of ADT**—Kurtosis is a statistical measure that describes the shape of distribution curve of a particular variable (in this case average daily traffic). A high kurtosis represents an even ADT distribution whereas a low kurtosis depicts an ADT distribution concentrated around the mean. The ratio of deviation of kurtosis for a particular corridor was determined by comparing the kurtosis of a corridor to the most extreme leptokurtic distribution (higher probability of extreme values) of all corridors in the state. This was a key factor which was presented in the NJDOT Adaptive Signal Control Feasibility Study.

Optimal Design Characterization and Final System Determinations

The Performance Evaluation process produced a list of 297 total SCC scores. The higher the SCC score, the more intelligent features (higher tier) are needed and warranted along those corridors. To define the points in which we transition from one tier designation to the next we reviewed a scatter plot of the scores to determine some natural break points in the data. Natural breaks in the data were used to define "demark" points for tier classification when possible. Also, preliminary budgetary constraints were reviewed and factored in when developing these demarcation points. From this effort, each of the 297 signal corridors received a preliminary tier classification based on the optimal design.

The preliminary tier classifications for each signal corridor were then compared with adjacent signal corridor classifications along each route to determine if they could be combined into systems. Corridors with similar tier designations were combined to ensure consistent control features throughout the roadway. We felt that this was an optimal way to conduct future Concept of Operations Phases. Figure 4 further illustrates this process.

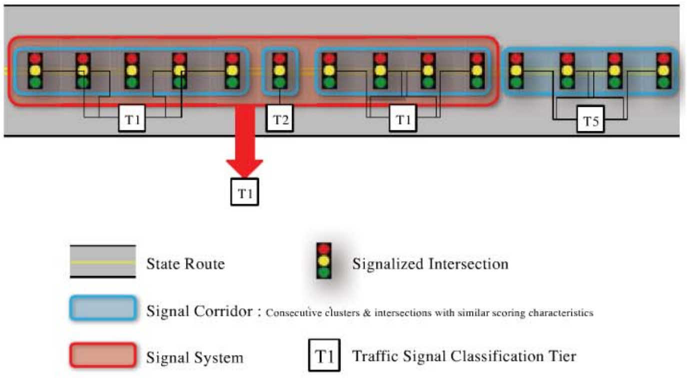

Figure 4. The Final Systems Determination Process

This Final Signal System Determination process resulted in a total 56 "T1-T4" signal systems and then another 207 systems designated for optimization (T5). A summary of the final traffic signal system list can be found in Table 1.

Optimal Tier	Number of Signals	Number of Systems
T1	309	17
T2	126	8
T3	413	19
T4	298	12
T5	1,407	207
T6	9	N/A
Total	**2,562**	**263**

Table 1.Proposed Tier Classification Summary

Project Prioritization and Pipeline Development

The primary purpose of this deployment plan was to provide NJDOT with a tool to help facilitate proposed signalization improvements. We needed to develop a strategy to take the systems defined in the previous steps, identify a prioritization amongst the projects, and develop a project pipeline to be used. First, we removed T5 and T6 signalized intersections with the intent that they would be addressed as part of the NJDOT Signal Optimization Program and/or individually through other projects. Next, we took the 56 "T1-T4" systems and removed the systems which were existing and would not require any upgrades or modifications based on the scoring.

After these initial steps, 44 systems remained and each of the systems was assigned an average system score based on the SCC scores. The system scores set up an initial prioritization list, with the higher scores requiring a higher priority. However, the team felt it was important to create a final Project Priority List and Pipeline that was made flexible so that it can account for various other factors down the line including more comprehensive cost-benefit analyses, results of Concept of Operations (ConOps) phase. Other factors could include safety implications, other ITS deployment strategies, regional equity, political factors, upcoming construction projects, realistic workload, and cost breakdown.

In addition to this flexibility, we understood that the design and planning efforts associated with each of these tiers can be considerably different. Based on discussions with NJDOT, we formulated a project priority list and pipeline that would stagger the various tasks so improvements could be implemented as soon as possible. This was primarily accomplished by breaking the plan into three (3) phases allowing for the various aspects of the projects and costs to be spread out and staggered over the entire ten year period. For example, most of the T1 systems are scored the highest priority but their complexity could cause a log-jam; so the T1 systems were broken into groups spread out over the three (3) phases. A corresponding capital plan was also developed based on preliminary estimates to help define budgetary expectations.

Project Conclusions and Overall Significance

NJDOT and the project team set out to develop a strategy and plan to help identify and select optimal traffic signal design characteristics along state-owned roadways. Knowing that traffic signal technologies are evolving, they wanted to create a way to systematically infuse the various degrees of "intelligence" into their signal systems to maximize system performance. More importantly, they set out to select the roadway corridors which would benefit most from these investments and not haphazardly deploy technologies throughout the state. In most instances, agencies of this size are reactionary and rarely have the foresight to develop a concept such as this.

This Traffic Signal System Optimization Plan is innovative in that it leverages agency planning tools typically used for other applications, combines it with a scoring approach that was specifically developed for this application, and provides a clear and concise approach to improving each of the 2,500+ state-owned traffic signals over a 10-year period. This was a challenging undertaking because the traditional method of determining the appropriate technology and identifying the applicable corridors is not typically done with high level planning tools. This is normally done through extensive data collection, traffic analysis and preliminary engineering, resulting in a large study that could take years to complete and implement. The extent of this has caused agencies to put off this type of effort, and deploy improvements based on a narrow focus on current projects, ignoring the overall needs of their roadway network. This can result in deployment of technology that may not be compatible throughout the system, or not the optimal solution for traffic operations as well as cost-benefit implications.

This Traffic Signal System Optimization Plan will allow the NJDOT to implement state-of-the-art design enhancements tactically throughout their entire roadway network, resulting in better use of funding resources and driving improvements in performance and operations along the roadways which need it most.

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