# Active Traffic Management Through Adaptive Signal Control in Midtown Manhattan – Status Report


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## EXECUTIVE SUMMARY

The New York City Department of Transportation (NYCDOT) has Instituted the "Midtown in Motion" (MIM) project to enhance multimodal mobility in the Midtown Core of Manhattan, a 110 square block area or "box" from 2nd to 6th Avenues, 42nd to 57th Streets. MIM was announced by Mayor Michael R. Bloomberg on July 18, 2011. The MIM Project utilizes "active traffic management (ATM)" and the full capabilities of the NYCDOT Intelligent Transportation System (ITS) infrastructure -- advanced solid-state traffic controllers, network of sensors (video, microwave, electronic toll collection readers), wireless communication system, and the New York City Traffic Control System software system that manages the enterprise. The signal-timing measures applied by MIM complement other efforts by the City to improve traffic operations.

This technical memorandum addresses the overall ATM for the "Midtown in Motion" project, and the preparation that led to its implementation.

With respect to mobility of people and goods in vehicles (bus, taxi, truck, passenger car), the primary focus is on the north-south arterials, with some attention to key crosstown streets (e.g., 57th and 42nd Streets) and designated *THRU* Streets (45th, 46th, 49th, 50th, 53rd, and 54th Streets)

The extensive data now available confirm a basic principle ---- *significant variation in traffic conditions within the zone is the norm, and while there are clear aggregate patterns, the daily fluctuations require active traffic management that anticipates that reality, and is designed for it.*

The signal plan changes occur on two levels: Level 1 is strategic and implemented by arterial, to rebalance the traffic being delivered to the zone by changing the signal plan on the avenue approach to the zone. Level 2 is more tactical, in that it is designed to look at shorter–term fluctuations of "severity" on competing approaches (avenues and crosstown streets) at certain key intersections, and fine tune the allocation of traffic signal green time to alleviate a localized problem that is developing.

The ATM software has been installed in the NYCDOT Traffic Management Center (TMC), refined based upon discussions with NYCDOT personnel, and is available for use. Training has been done, and related materials provided. The results of the field tests prior to formal start of the project for the candidate plans are promising, and the basic rebalancing plan (NBP) has been made the default signal timing plan for weekdays, 8am to 8pm. A comprehensive evaluation of the project will be made after its initial six months of operation.

The intent is to implement the system 24 hours a day, weekends as well as weekdays, and improve operations based on qualitative and quantitative results.

# 1 OVERVIEW

This technical memorandum addresses the overall signal control concept for the "Midtown in Motion" project, and the preparation that led to its implementation. An earlier technical memorandum [1] addressed some of the early-stage data analysis.

## 1.1 Project Area and Project Objectives

The "Midtown in Motion" (MIM) project area is a 110 square block zone or "box" in Midtown Manhattan from 2nd to 6th Avenues, from 42nd to 57th Streets, inclusive.

The objective of MIM is to enhance multimodal mobility in the project area by a set of signal-based measures that build upon other non-signal-timing measures taken by the New York City Department of Transportation (NYCDOT). Prior to installing advanced solid-state traffic controllers (ASTC), traffic control was managed in Manhattan by Vehicular Traffic Control System (VTCS). VTCS only allowed with reliability "time of day" signal patterns. This limited the ability of the NYCDOT to respond to incidents, special events, fluctuating traffic demand and to address "oversaturated" traffic conditions.

The coordinated approach taken by the New York City Department of Transportation (NYCDOT) includes active traffic management (ATM) using the full capabilities of the ITS infrastructure enhancements that have been underway --- the advanced solid-state traffic controllers (ASTC), the network of sensors (video, microwave sensor detection, electronic toll collection (ETC) segment travel times), the wireless communication system, and the New York City Traffic Control System (NYCTCS) software that manages the enterprise.

This technical memorandum addresses the active traffic management component of the overall *Midtown in Motion (MIM)* undertaking.

## 1.2 Active Traffic Management

The active traffic management component of the MIM Project focuses on using the sensor network to (1) detect developing conditions and (2) present the information to the NYCDOT operator, and (3) recommended signal plan changes to the operator. The operator then consults with the Traffic Management Center (TMC) supervisor, who decides upon an action – implement the recommended plan, or not.

The extensive sensor network is enabling a rich data archive to be built. Combined with the record of actions taken and experience gained, the active traffic management will move to the plateau of a *learning traffic adaptive control* environment, in which new plans can be developed based upon the data archive and the experience gained.

With respect to mobility of people and goods in vehicles (bus, taxi, truck, passenger car), the primary focus is on the north-south arterials, with some attention to key cross streets (e.g., 57$^{th}$ and 42$^{nd}$ Streets) and the designated *THRU* Streets within the Midtown Core (45$^{th}$, 46$^{th}$, 49$^{th}$, 50$^{th}$, 53$^{rd}$, and 54$^{th}$ Streets) [2].

The extensive data now available due to the City's ITS sensor network, suitably analyzed and combined with operational experience and the wisdom it imparts, confirm a basic principle ---- *significant variation in the zone is the norm, and while there are clear aggregate patterns, the daily fluctuations require active traffic management that anticipates that reality, and is designed for it.*

The signal plan changes occur on two levels, by design:

Level 1, "Areawide Control", is strategic and implemented by arterial (i.e., avenues), based upon metrics to be described. The method is to rebalance the traffic approaching the Midtown Core by changing the signal timing plan. The purpose of this is to ameliorate developing levels of congestion in the core, which affects mobility both in the core and upstream of it, as congestion spreads.

Indeed, should congestion spread in certain ways, it can affect the key cross streets and even parallel arterials, because excessive queues and vehicle spillback at intersections can impede their performance.

Therefore, the strategic objective is to rebalance traffic being delivered, so as (1) to enhance travel times and mitigate the number of stops along the arterials, with beneficial effects on queues along the arterials, while (2) avoiding congestion that can spread beyond the zone, upstream along the arterials and/or onto the bridge and tunnel approaches and even crosstown streets to affect other arterials.

There are several degrees of rebalancing that are done, depending upon the observed traffic conditions. This is addressed later in this technical memo.

Level 2, "Intersection Control", is more tactical, in that it is designed to look at shorter–term fluctuations of "severity" on competing approaches at certain key intersections, and fine tune the allocation of green to alleviate a localized problem that is developing. Twelve intersections are designated for Level 2 control.

The focus to date has been on:

1) Developing the logic for both levels (based upon experience with an initial adaptive control deployment in a section of roadways near the College of Staten Island [3], [4], and [5]),

2) Developing and testing several rebalancing plans in the field (designated NBP, AC1, and AC2 herein),
3) Refining the logic and metrics as information and new sensors became available, and
4) Implementing the software and displays needed for the TMC personnel to be informed, so that they can make better decisions.

The system is now installed in the TMC, and the cycle of active traffic management, learning, and refinement is ready.

Concurrent with the above focus, there has also been an intensive effort in which the sensors were deployed, calibrated, tested, and integrated into the control logic.

At the time this project began, the primary tools for sensing the condition of the network was to be an extensive network of microwave sensors that would characterize individual links of the roadway network and be displayed so that clusters and patterns of vehicle behavior could be observed. These were to be supplemented by video monitoring where available. An early task was to locate the sensor network to best serve the ATM.

It became clear that the ETC reader network was going to be installed on part of the zone's network, and the questions that immediately logically arose were (1) how can the additional information be best used, and (2) should the sensor deployment be revised, to make best use of both data sources? As the work progressed, additional ETC readers were planned (and now implemented) and the sensor deployment was indeed revised (and now implemented).

Figure 1-1 shows the sensors currently deployed in the field. The control plans were developed with awareness of this deployment. Indeed, the needs of the ATM shaped the deployment plan.

## 1.3 System Design and Metrics

The traffic literature is replete with discussions of the most suitable measures and metrics, and well as those used in level of service/quality of flow analyses and in signal optimization work. This section focuses on the measures and metrics decided upon for the present undertaking. Section 3 provides the more detailed justification and rationale.

Part of the system design consideration (with illustrations of the issues) has to be:

- <u>How much data needs to be sent where, for effective decision-making</u>?

    While the microwave sensor detectors *can* transmit data for actuations of individual vehicles, it was decided to transmit the observed spot-specific <u>flow</u> and <u>occupancy</u> by travel lane, every 30 seconds. In this way, the communications channels are not overburdened with detail and the key information is available and can even be aggregated at the receiving end, if deemed appropriate. This experience was gained on Staten Island.

The ETC tag readers are a cost-effective means of detecting segment travel times via matching reader observations at the ends of the segments, sending the raw data back to actually do the matches, and to generate the travel time observations. Lessons being learned include identifying discrete travel times by "through" as compared to "right turning" traffic in such segments as E 49th to E 57th Streets on 3rd Avenue.

- How does one address the truly random fluctuations, as well as intermittent information gaps?

Experience has been that aggregating the sensor data over 2 to 3 signal cycles and then smoothing the flow and occupancy data allow underlying trends to be detected, without the "bounce" that comes with the very short-term observations.

Analysis has led to the conclusion that the ETC travel time data can be most effectively used *for control decision purposes* if the 50th percentile (that is, the median) travel time over the most recent 15 minutes is used, with updates every 6 minutes. Thus, it is a moving average, in effect. In addition, the use of the 50th percentile to a large extent renders moot the concern over the large "outliers" that can distort the mean, while needing a rationale and justification for dropping them.

The intermittent information gaps (e.g., communication disruptions) are mitigated by the use of smoothing for the sensor data and the 15-minute aggregation for the ETC data.

- How does one build a robust system that is not overly dependent upon continual, perfect communications?

The issue of communications is not just in *receiving* information at a central location (e.g., the TMC) but also of *sending* information to the field controllers. To add robustness to the control system, the actual Level 1 plans are downloaded in detail to the controllers in advance, and are resident in the controllers. Thus, the command that is sent is as terse as "Implement Plan X" rather than providing its detail each time, to each controller. And the terse command is repeated, for redundancy.

Should communications drop, there is a concern that a "special plan" may have outlived its usefulness and actually be disruptive. For this reason, an extended communication drop would lead to the controllers reverting to a default plan.

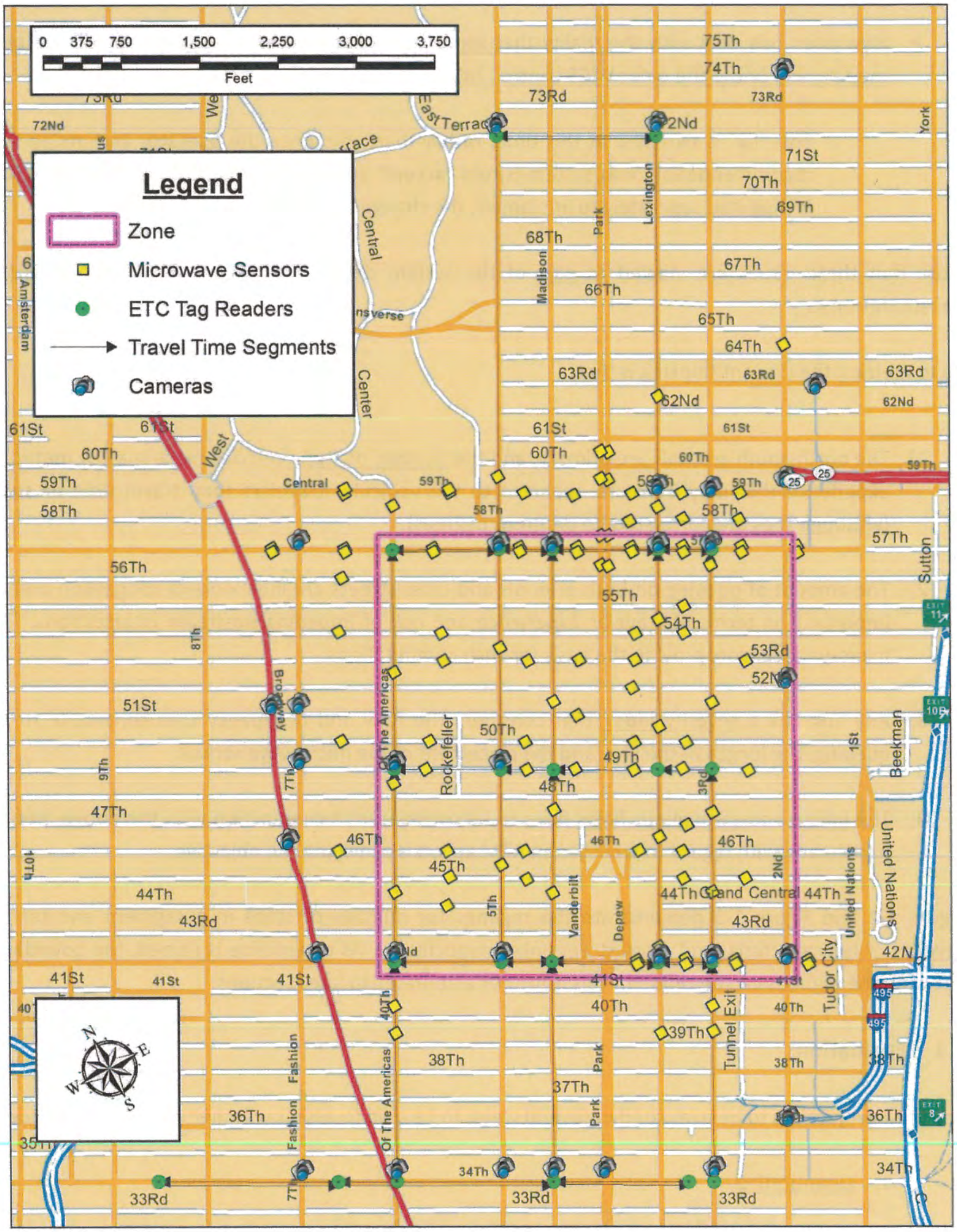



Figure 1-1 – The Microwave Sensor and ETC Tag Reader Deployment for the MIM Zone

- How does one deal with the reality that some controllers outside the zone are still the older models, and under the older VTCS control, rather than NYCTCS?

  The "fix" is two-step at this time, rather than one: once the operator accepts an ATM recommendation, that system is told "accept" so that it can log it, and the VTCS system is triggered separately to implement the change.

Note that these issues are viewed as part of the system design challenge, and not inhibitions or constraints on it.

As to metrics, the present thinking is that:

1) The north-south arterials are primary, and the number of stops vehicles make is a key metric, an experience that may be more apparent to the vehicular travelers than travel time or speed (although they are correlated, to different degrees).

2) The amount of queuing on both arterials and cross streets are indicators of congestion and are important, in terms of traveler experience and risk of impeding upstream intersections. The microwave sensors provide the basis for such computations.

3) Any link has a severity index that considers the flow and occupancy that contribute to the queuing, the length of the link, and the placement of the microwave sensor.

4) The inflow and throughput flows have to be considered in conjunction with the above metrics, particularly with regard to whether an ATM action is achieving the objective.

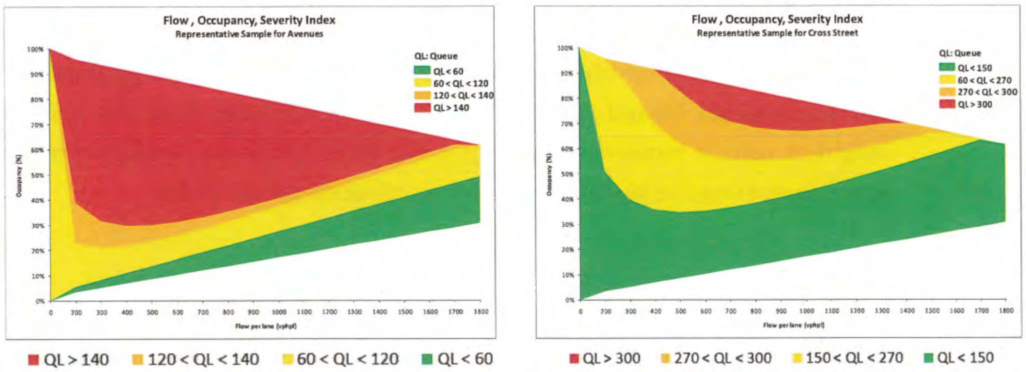
Figure 1-2 and Figure 1-3 demonstrate the regimes for number of stops in a segment and for the severity of typical arterial and cross street links, respectively. As experience is gained, the boundaries between the regimes can be refined. This is further elaborated in later sections.

## 1.4 Evaluation

The MIM project has to be evaluated in several ways, to be able to assess whether it has been a success:

1. Quantitative

   The primary sources of direct data are the microwave and ETC sensors, which provide the measures already cited. The data is classified by comparable days and/or periods within days, and statistical analysis is to be done. Some of the preliminary analysis done to date prior to the formal start of the project is reported in this technical memo.




QL = Queue Length (feet)

a. Illustrative Arterial Link    b. Illustrative Cross Street Link

Figure 1-2 – Displays of Regimes of "Severity" from Microwave Sensors

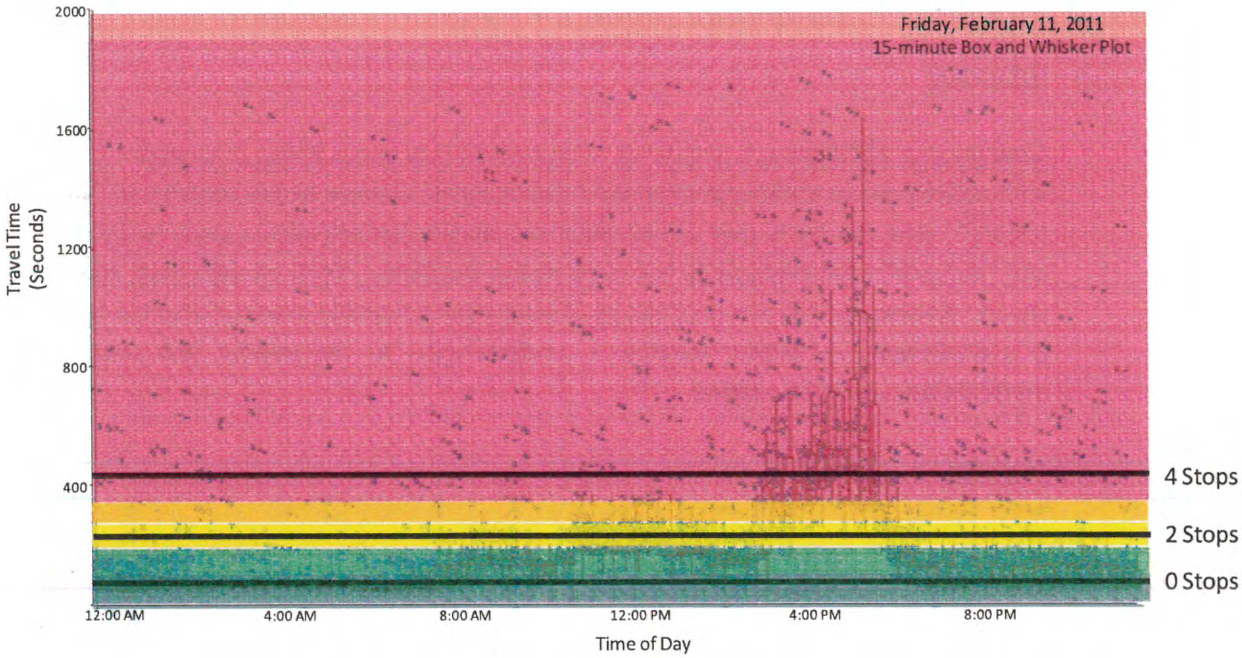



Figure 1-3 – Display of Regimes of ETC Tag Reader Based Travel Times and Estimated Stops

Both the microwave and ETC sensors provide rather large sample sizes, with the microwave sensors tending to be link specific and the ETC being an aggregate over 7 or 8 links (that is, a multi-block segment). Each has its purpose.

The data is inspected by graphical displays on such renderings as Figure 1-2 and Figure 1-3 and in histograms, and by one-sided t-tests and related "p" values (standard statistical analysis).

Another source of quantitative data is travel time runs by GPS-equipped test vehicles that provide detailed trajectories, including stops, areas of slower speeds, and a complete "bread crumb" history of their trip, visually displayed. For comparative purposes, small number of observations has limited applicability. While the GPS data from the test vehicles provides insight in vehicle movements at a granular level, ETC data provides a more robust source when comparing the performance of the proposed control plans.

2. Qualitative

   Engineers and managers associated with this effort travelled the arterials and the cross streets regularly, observing conditions when the different test plans were in effect. Observations were also made from the TMC, using the video feeds and the sensors.

   There is also feedback from the public, notably by calls to 311 that flow to the NYCDOT managers. These are another source of information.

3. Simulation

   Simulation of MIM impacts is difficult to address in that one is trying to compare conditions with active control to those that would have occurred without active control, an "alternate history". One can try to pair comparable days and/or periods within days, to get a "with" and "without" characterization, for comparative purposes. With enough data, this can be sound. However, it has already been established that variability characterizes the zone, so it is a challenging --- and/or lengthy --- undertaking. In the interim less sophisticated methodology would be applied.

4. Taxi Data

   There is another important source of information that has already proven useful on NYCDOT projects (e.g., *Greenlight for Midtown*, the Maintenance & Protection of Traffic modeling near the Ed Koch Queensboro Bridge (QBB), related to the Third Water Tunnel construction), namely the use of the taxi travel time data available to NYCDOT from the Taxi and Limousine Commission (TLC). It is a rich data base, updated monthly. NYCDOT is currently providing support and assistance in this undertaking.

With regard to statistical tests, it must be noted that the convention is to set up a hypothesis such as "no change" in a key metric (travel time, for instance) and check if this hypothesis is rejected, thereby leading one to the finding that there must have been a change (the desired direction of change – a decrease of travel time, in this case – is taken into account in the computation). That is, rejecting a hypothesis of "no change" the desired outcome. Somewhat contrary thinking, but the standard way of expressing results in statistical analysis.

In this technical memo, the statistical results are reported with the usual level of significance of $\alpha = 0.05$[1] commonly used, and in the more current "p" value, which is generally much smaller --- and indicates the how improbable it is to reject a true hypothesis[2].

Finally, with regard to all statistical analysis done in this technical memo, it must be remembered that the test between candidate signal plans (Existing, NBP, AC1, AC2) is comparing their implementation over a series of days in which they were in force *whether needed or not*. This was done to test whether they worked without notable adverse impacts elsewhere. In real application, *the intent is to invoke them only as needed,* when needed.

## 1.5 Results

As of the writing of this technical memo, the active traffic management software has been installed in the TMC, refined based upon discussions with TMC and other personnel, and is available for use. Training has been done and related materials provided.

The results of the field tests for the candidate plans are promising, and the network balancing plan (NBP) has been made the default plan for weekdays, 8am to 8pm.

## 1.6 Next Steps

The intent is to implement the system 24/7 and improve operations based on qualitative and quantitative results.

As additional ASTC controllers are installed outside the Midtown in Motion zone, the operator's actions in implementing a recommended plan will be more direct.

After the initial learning and refinement, the system will be monitored and maintained, with future enhancements done as directed by NYCDOT.

Results will be reported on a regular basis.

## 1.7 Acknowledgements

The system exists in the operational mode because of the smooth and cooperative work by JHK/TransCore and the feedback and guidance received from NYCDOT management. It has truly been a team effort.

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[1] In the jargon of statistics, the chance that the hypothesis (e.g. no change) is true and one rejects it anyway. $\alpha = 0.05$ implies a one in twenty change of rejecting a true hypothesis

[2] For instance, a $p = 0.001$ means that there is only a one in a thousand chance that the hypothesis was true (that is, no change in travel time) and was rejected erroneously.

The report is structured as follows: Section 2 presents the framework for the active traffic management, Section 3 discusses the data analysis and Section 4 presents the signal timing plans developed with a comparative analysis. Section 5 and 6 present the decision support system and the implementation, followed by the next steps in Section 7. The references are listed in section 8. There are 6 appendices (A through F) presenting the control plans developed, statistical analysis of microwave sensor and ETC tag reader data, the operator manual, the analysis of the GPS travel time runs, and the comparison of ATR and ETC tag reader data, respectively.

## 2 ACTIVE TRAFFIC MANAGEMENT BUILT ON ACDSS FRAMEWORK

### 2.1 Overview

The traffic environment in Midtown Manhattan can be characterized by a grid network composed of,

- Short blocks (approx. 250 ft) along the avenues carrying heavy traffic, and
- Long blocks (approx. 500 ft to 1,000 ft) along the cross streets with crosstown traffic and different midblock activities such as loading/unloading and entering/exiting at parking garages.

And this is further characterized by,

- QBB and Queens Midtown Tunnel (QMT) producing/attracting a significant amount of traffic,
- Pedestrian activities caused by a number of attractions, in particular causing,
    - Heavy pedestrian flows conflicting vehicle turning,
- Heavy bus transit throughout the areas, many on designated lanes,
- Many on-street parking spaces for commercial vehicles, parking lots and garages,
- Gridlock conditions occur often,
- Short term incidents such as taxi drop off, double parking, and
- Street or lane closures due to construction, utility repairs or other causes.

All these create a unique and dynamic traffic condition over time with traffic heavily concentrated along the avenues and most cross streets. To improve mobility and minimize delays under such conditions is very challenging. The key is not only to control capacity but to manage space in order to avoid any further problems such as gridlock. Therefore, it is essential to rebalance traffic around the study area to alleviate congestion caused by the concentration of traffic on a network level. It is also essential to make local adjustment to accommodate a short term variation in demand at the intersection level depending on the nature of the variation. To meet the needs under this environment, two levels of strategic control concepts were recommended.

Level 1 control or termed otherwise, "Areawide Control" uses a library of timing plans, built up from earlier data analysis. These timing plans are specifically designed such that each plan will rebalance network flows at different scales by controlling traffic entering the Midtown study area. Depending on the severity of the traffic flow conditions in the study area, a different level of rebalancing plans will be applied to alleviate congestions.

Complementing Level 1 control is Level 2 control. Level 2 control, or termed otherwise, "Intersection Control" is a granular level of fine tuning at critical intersections. Under Level 2 control, only traffic signal splits are adjusted on a real-time basis at critical intersections. This will rebalance operations at the intersection level being sensitive of the volume to capacity ratios (v/c) of competing approaches. It will also be responsive to the level of severity, in which an index will be used to indicate the level of congestion. Initially, twelve intersections will be subject to Level 2 control. This is discussed later in this section.

Active traffic management will be achieved by combining these two levels of controls in real-time. The following sections present the framework of this new ATM and detail the strategies.

## 2.2 Framework

Figure 2-1 illustrates the context of the new Integrated Adaptive Control System (IACS). As depicted, the IACS is part of the traffic control system (TCS), which is comprised of real world infrastructure (A, B, C and D), communication layers (E and G), control room servers (F), as well as operator terminals (I). The cameras (A) provide real-time streaming traffic video that can be shown on a video wall in the TMC control room. Microwave wireless sensors and Spider™ networks (B) constitute the detection infrastructure that provides a continuous data stream of traffic counts and occupancy every 30 seconds.

The wireless sensors are deployed strategically for optimal estimation and prediction of traffic demands in real-time, subject to existing field constraints. This required field visits for each subject arterial to observe and understand behaviors (bus influences, turning vehicles affecting thru lanes). Based on field visits and a historical database of manual counts, detectors are deployed and detection zones are set up so that the information about critical turning movements can be maximized while non-critical turning movements can be inferred reliably through conservation and/or by a historical database. Detections zones are also positioned so that queue impedance can be effectively detected and traffic demand reliably estimated/adjusted in oversaturated conditions.

ASTCs (C) are deployed in the field for intersection control. These controllers are a special CBD (Central Business District) version customized for New York City, and communicate with NYCTCS servers at the TMC via NTCIP. The ETC Tag Readers (D) is deployed in the field for sampling travel time. The detection data from microwave sensors and ETC tag readers are first stored locally in the ASTC controllers then transmitted to NYCTCS servers together with signal timing data. NYCTCS servers retrieve the real-time data (detection and signal timing), and publish these data through a dedicated Adaptive Control Web Service (H). As shown in part H of Figure 2-1, the integrated adaptive control system includes several modules each dedicated to a different real-time task. These modules cover different hierarchies of the control strategies.

## 2.3 Level 1 Strategy

### Control Concept

Level 1 control, "Areawide Control", starts from a pre-stored library of timing plans. These timing plans are designed offline and are relevant to arterials inside the Midtown study area. It is the combination of these timing plans that are made of "strategies" to be applied in real-time to a specified array or grid of intersections. As a result of applying these specially designed timing plans, desired traffic progression patterns is adjusted and serves the overall purpose of regulating traffic into the Midtown study area, thereby enhancing mobility inside the area.

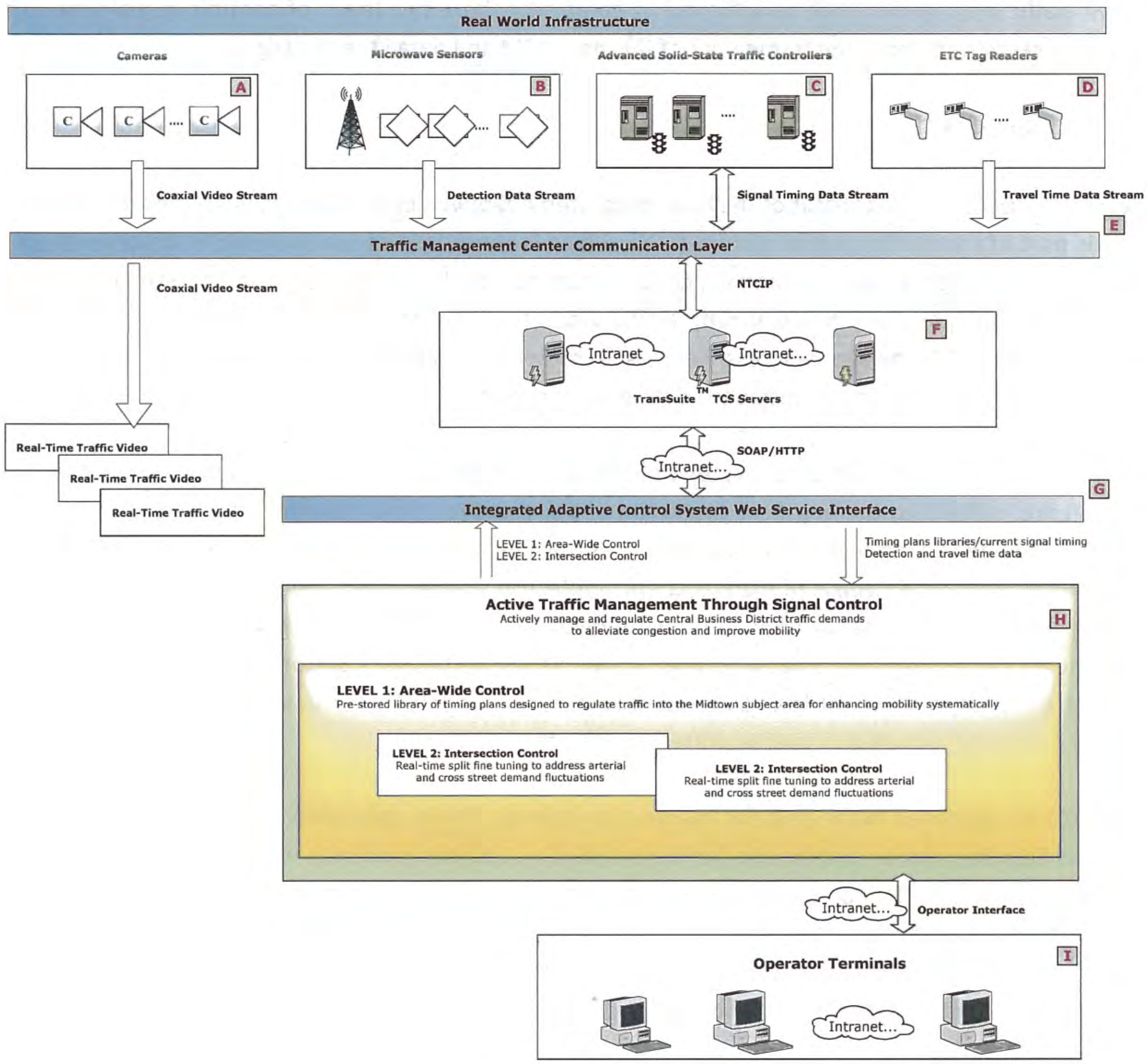



Figure 2-1 – The New Integrated Adaptive Control System (IACS)

The library of Level 1 timing plans are prepared offline based on NYCDOT archived traffic data (volume and occupancy) and the categorization of different reference patterns. Activation of a certain combination of timing plans (i.e., "strategy") is triggered by real-time travel time data; in this implementation, ETC transponder readers are employed to provide high resolution individual-vehicle-trip based travel time data.

When in real-time operation, individual-vehicle-trip based travel time data are aggregated into a vector of indexes. Level 1 control uses the indexes to determine the best strategy (i.e., combination of timing plans) then relevant sequence of timing plans are extracted from the library and implemented in the field so that the target reference pattern can be established.

Once a new strategy is determined, it is uploaded to the central NYCTCS system via the new Signal Control Web Service Interface and the corresponding timing plans are implemented to individual field controllers. A successfully uploaded strategy will persist until overwritten by a different strategy later.

**Signal Timing Plan Development**

Three additional signal timing plans for each avenue were developed and tested for Level 1 control depending on the level of rebalancing efforts. On top of CTOD (Central Time of Day control), the three additional timing plans are:

- Network Balancing Plan (NBP) – Simultaneous offset on approach to the zone with minimal green window tapering.
- Advanced Control (AC) 1 – Simultaneous offset on approach to the zone with increased green window tapering.
- AC2 – Reverse offset on approach to the zone with increased green window tapering.

These are further discussed in detail in Section 4.

**Decision Making Algorithm**

As described earlier, as part of Level 1 control, a selection is made from a library of plans by examining the flow conditions. Some of the critical issues are what metrics to use to make this choice, how often to make this choice, and how long the selected plans last. These metrics are discussed in detail in Section 3.

In order to build responsive traffic control, the decision-making interval of 6 minutes was selected, with the 50$^{th}$ percentile of the last 15-minute data as the key indicator. Using this approach, the control can avoid short term fluctuations/variations on traffic demand and be quick enough to catch up with varying conditions.

The 50$^{th}$ percentile is displayed in terms of color coding, into four regimes. Concurrent with this, the microwave sensor smoothed data is likewise classified, but using a "Severity Index" (SI) to be described in Section 3.1. Because the microwave sensor data is link-specific whereas the ETC provides an overall segment metric, it is expected that the microwave sensor will provide early indicators of changing regimes.

Every 6 minutes, the traffic conditions are analyzed and new plans are recommended if needed. Once new plans are in place, there is a minimum of a 30 minute "hold time" to guarantee some stability.

## 2.4 Level 2 Strategy

Complementing Level 1 control is Level 2 control. Level 2 control, "Intersection Control", is a granular level fine tuning initially at twelve critical intersections. Under Level 2, intersection splits are adjusted in real-time. To test the control concept, the present Level 2 control algorithm was developed for isolated intersections. Ultimately, it will be replaced with a systematic control algorithm.

When the system is running in operator-in-the-loop mode, operators in the TMC control room interact with the adaptive control system kernel via operator terminals (See Part I of Figure 2-1). These terminals allow the operator to intercept and review Level 2 signal timing plans. Upon approval from the operator, these plans are sent to TCS servers through the web service interface and implemented by field controllers.

The control objective of Level 2 is to balance severity between competing approaches. A Severity Index (SI) is the derived Measure of Effectiveness (MOE) described in Section 3.1, which is based on queue length thresholds expressed as 1: Not significant, 2: Warning, and 3: Significant (for Level 2 decisions, three levels are used).

As long as both competing approaches experience the same level of severity, there will be no adjustment in the "split" of signal green time among the approaches. However, if there is any difference, limited amounts of split adjustment will be recommended.

The amount of split adjustment will range from 2 to 3 seconds. And this control will be implemented with a three-cycle-interval. Because this level is more about queue/space control, three signal cycles are expected to be effective.

This concept of using the Severity Index is being implemented in two stages: Generation 1 Control is currently under testing at a single intersection level, and Generation 2 Control that is being developed to address a systematic approach taking into account split adjustments to adjacent intersections.

1. Current Plan for Level 2 Control

The basic action is to adjust green time by $\Delta G$ (2 or 3 seconds) for the approach with the higher Severity Index under the constraint that meets the minimum phase duration requirement. This is repeated whenever needed. Figure 2-2 shows the theoretical application of this algorithm over four days. The first row of charts shows the Severity Index for the arterial approach over time and the second row shows the Severity Index for the cross street approach over time. The third row shows the difference between the first and second rows. If the difference is positive, it indicates that the arterial approach needs attention and vice versa. The difference determines the intensity of treatment.

The following is an example of this algorithm, with step-by-step calculations, at an intersection using a typical two-phase signal.

Step 1: Aggregate flow and occupancy from the microwave sensor over 3 signal cycles for competing approaches.
Step 2: Calculate SI for artery and cross street approach and get the difference, $\Delta SI = SI(artery) - SI(Cross)$
Step 3: Set the amount of split adjustment as $\Delta G = \{0, 2, -2, 3, -3\}$ for $\Delta SI = (0, 1, -1, 2, -2)$
Step 4: Calculate the new split for artery such that $G_{a,new} = Min\{C - G_{c,min}, Max(G_{a,min}, G_{a,cur} + \Delta G)\}$

where $G_{a,new}$ = new arterial split recommended,
$G_{c,min}$ = minimum cross street split,
$G_{a,cur}$ = current arterial split
$C$ = Cycle length

2. Future Plan for Level 2 Control

Under this systematic approach, each intersection can have its own treatment. However, when these are put together, there can be systematic impact on adjacent intersections. For example, if upstream green expands while downstream green reduces, the downstream approach may experience an increase in queue length, potentially leading to significant problems. Therefore, systematic control is being developed to address these issues. The systematic control will evaluate these impacts and readjust/redistribute adjustments throughout the system.

## 2.5 Summary

The new Integrated Adaptive Control System (IACS) was discussed as well as control concepts of Level 1 and Level 2. Considering the unique traffic environment, more stable and reliable control actions are necessary. Level 1 control is used to effectively rebalance traffic around the study area, ultimately improving mobility while Level 2 is used to balance traffic operations at intersection level. The incremental adjustments in split will avoid any abrupt problems and will slowly adjust conditions.

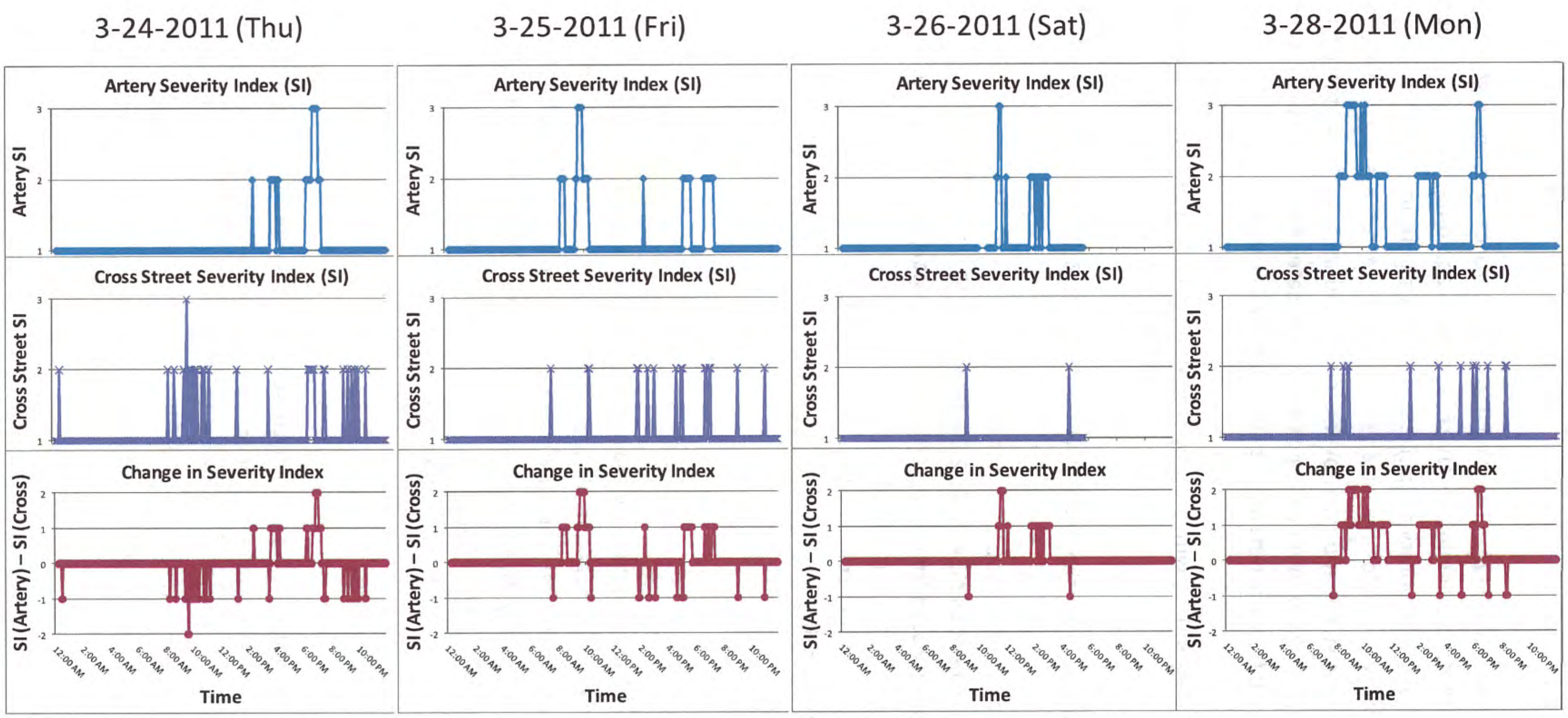



Figure 2-2 – Intersection Control using Severity Index, Lexington Avenue and E. 54th Street

## 3 DATA ANALYIS: METRICS

### 3.1 Microwave Sensor Data

#### Interpretation of Sensor Data

Currently the smallest aggregation interval for microwave sensor data is 30 seconds. For each interval, flow and occupancy are calculated for all detectors on a real-time basis and are being archived in the data management server at the TMC. In order to represent cyclic traffic operation at signalized approaches, this data must be aggregated over a multiple number of signal cycles.

Since microwave sensor data is a point measure, care must be taken in its use. For example, the volume to capacity ratio based on the flow measure alone can represent different flow conditions. The same flow rate with different occupancy means different flow levels as shown in Figure 3-1. The same flow can be observed for different occupancies, representing "smooth flow" and "congested flow" conditions. Therefore, flow and occupancy should be considered together.

Also as shown in Figure 3-1, if these two measures are identical for the competing approaches, it doesn't necessarily mean that both approaches are in identical flow conditions. This is because the competing approaches most likely will have different link lengths. In other words, similar level of congestion causing some queuing will result in different impacts depending on the available storage of the link.

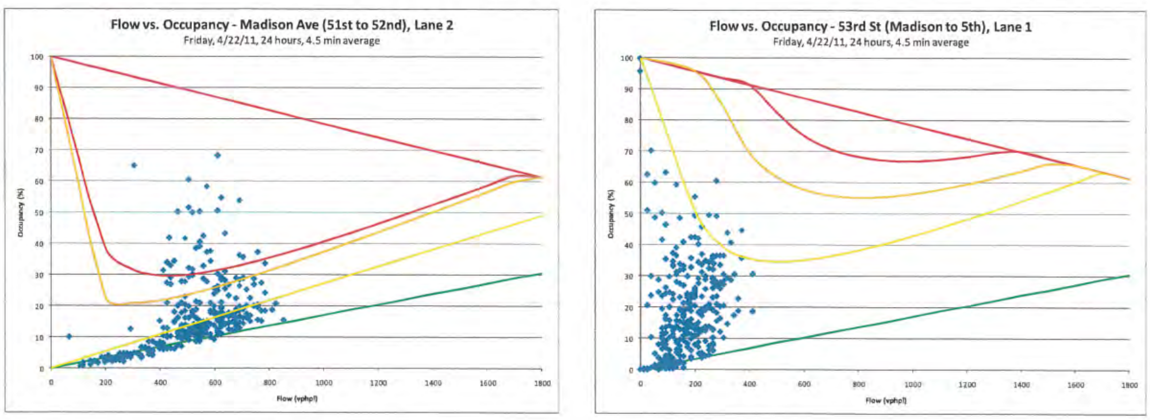



Figure 3-1 – Scatter Plot of Microwave Sensor Data (Flow versus Occupancy)

To address aforementioned issues, these two measures were translated into a link measure. Thus, a new MOE, called, SI was developed to describe how severe the flow condition is based on an estimated queue length for a given link.

**Severity Index**

As described, Severity Index is an index based on queue length for a given approach. In order to define Severity Index, the first step is to estimate queue length. A new queue length estimation algorithm based on a point detector measure has been developed as part of this effort and is presented in this section. The glossary is at the end of this section.

Two assumptions are used in this algorithm.

1. If all vehicles during a specified interval such as one cycle or two cycles cross the detector with a free-flow speed (approximately 30 mph), there is no queue.
2. If there are vehicles that cross the detector within the specified threshold, for example, moving at less than 15 mph, queue length is increasing within the vicinity of detector location.

Based on the first assumption, "Base Occupancy 1" is formulated as below.

$$OCC_{base,1} = \frac{\left\{\left(\frac{L_d+L_v}{v1}\right)\times flow_{obs}\right\}}{3600} \tag{3.1}$$

Here $v_1$ is the free-flow speed. As seen, the term $\left(\frac{L_d+L_v}{v1}\right)$ is elapsed time for a vehicle to cross the detector and ($flow_{obs}$/3600) is the reciprocal of arrival headway. Therefore, "Base Occupancy 1" is the occupancy when a vehicle crosses the detector with a speed of $v_1$. If the observed occupancy is greater than the "Base occupancy 1", it implies queuing on the subject link. Applying the same equation after replacing the speed $v_1$ with $v_2$, "Base Occupancy 2" can be calculated.

$$OCC_{base,2} = \frac{\left\{\left(\frac{L_d+L_v}{v2}\right)\times flow_{obs}\right\}}{3600} \tag{3.2}$$

Here, $v_2$ is the mean speed of platoon when the queue starts forming in the vicinity of the detector. It is dependent on the detector's setback that is the greater the detector setback is the smaller $v_2$ is. Since the detector is set back from the stop line, the mean speed of platoon when the platoon starts forming a queue is usually faster than at the stop line. With this, $v_2$ must be calibrated carefully for each location. Based on this concept, the queue estimation algorithm is developed using the following steps:

Step 1: Calculate "Base Occupancy 1 and 2" using equations (3.1) and (3.2) where the only dynamic input is observed flow rate.

Step 2: Calculate queue length as follows.

If $OCC_{obs}$ >= $OCC_{base2}$, then

$$Q = D_s + f_q * (OCC_{obs} - OCC_{base2}) * C * Lq / h \tag{3.3}$$

Elseif $OCC_{obs} > OCC_{base1}$, then

$$Q = (OCC_{obs} - OCC_{base1}) / (OCC_{base2} - OCC_{base1}) * D_s \tag{3.4}$$

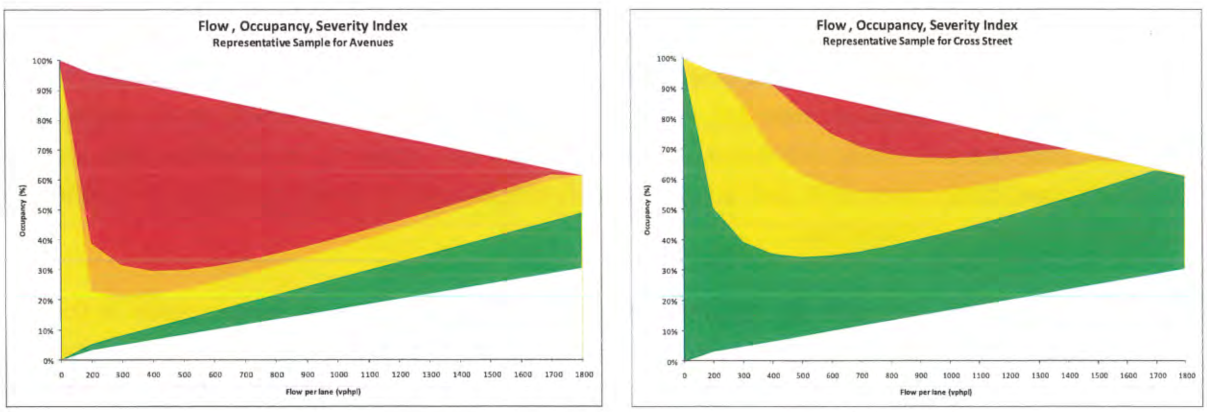
Endif

Equation (3.3) is used when queue grows in the vicinity of the detector. Equation (3.4) is used when queue grows downstream of the detector.

Once queue length is estimated, the Severity Index can be set as follows, for Level 2 Control:

- SI = 1: Queue length is within one third of the block, indicating no significant congestion
- SI = 2: Queue length is between one-third and two-thirds of the block, indicating advent of imminent congestion
- SI = 3: Queue length is greater than two-thirds of the block, indicating significant congestion

The theoretical Severity Index regime based on flow and occupancy measure can be calculated using the above equations and the predefined queue length thresholds. As illustrated in Figure 3-2, the bottom line of the curve is based on Equation (3.1), which represents the flow/occupancy with free flowing conditions. The border lines between the green and yellow regime is based on queue length equal to approximately one-third of the block length. The border line between orange and red is based on queue length equal to approximately two-thirds of the block length. The border line between the yellow and orange zone is based on queue length near around two-thirds of the block. The top line is derived based on the assumption that the detector is occupied for the remaining time after moving vehicles. In other words, a queue always exists at or beyond the detector.




**Avenue** **Cross Street**

Figure 3-2 – Severity Index Regimes

Glossary

$L_d$ = Longitudinal length of detection zone (ft) = 10 ft
$L_v$ = Average vehicle length (ft) = 17 ft
$v$ = Mean free flow speed (fps)
$D_s$ = Detector setback (ft)
$Q$ = Queue Length (ft)
$C$ = Cycle length (sec)
$OCC_{obs}$ = Observed occupancy (%)
$flow_{obs}$ = Observed flow (pcphpl) – passenger car per hour per lane

$h$ = Arrival headway (sec/veh) = 3600 / $flow_{obs}$

$L_q$ = Average vehicle space in queue (ft) = 20 ft

$f_q$ = Queue growth adjustment factor = 1.25

Using this MOE, split control at the intersection level can be achieved as discussed in Section 2.4. Also, by looking at a group of detectors along avenues, arterial performance could be evaluated.

## 3.2 ETC Tag Reader Data

### Underlying Pattern with Raw Data

The raw ETC tag reader data is shown in Figure 3-4 as blue dots in a scatter chart to show each individual trip's travel time over the day. As seen in this figure, there are clusters representing average travel time condition with some samples with sparse and significantly higher travel time, indicating outliers. Trips with longer travel times that are far from the average cluster represent outliers, where there is additional trip time in addition to travel time. The question is whether/how to exclude these outliers to address the average flowing condition.

### Mean or Median

If average travel times were to be used as a decision variable, outliers would have to be removed. The typical way to remove outliers is to use mean and standard deviation and to remove data points that are one or two standard deviations from the mean and repeat this process iteratively until convergence. However, since the underlying distribution of the data does not appear to be a normal "bell shaped" distribution and data is skewed in such a way that only longer travel time belongs to outliers, removing outliers in this way can create bias.

Another approach to determine the "representative" travel time is to use a median value or the 50$^{th}$ percentile. As seen in Figure 3-4, a box and whisker [6] chart[3] is overlaid on the travel time data. The middle line in the box represents the 50$^{th}$ percentile. The median is calculated including outliers for each 15-minute period over 24 hours. As seen, the median values cut through the center of the clusters consistently. Since the points are clustered and form a band, the median values are quite insensitive to the existence of outliers. Figure 3-5 presents a comparison of the median estimated with and without the outliers. As seen in the plot on the right side of Figure 3-5, the median is insensitive to the outliers.

[3] The box and whisker chart was derived using the tool Arc (http://www.stat.umn.edu/arc/software.html). The box presents the middle 50% of the data points (25$^{th}$ percentile to 75$^{th}$ percentile) and the whiskers are 1.5 times the size of the box. All other points are outliers.

**Usage of Median**

The following section describes the steps to map travel time to number of stops per trip. This is to convert travel time into a more practical metric such as a number of stops. Travel time increases with a number of stops. By looking at the clusters in the travel time data, insights were gained regarding sample groups by a number of stops. The "No Stop" travel time samples were almost one-cycle (90 seconds) apart from "One Stop" travel time samples. Similarly, the "Two Stop" travel time samples are about cycle away from "One Stop" samples.

The median travel time can be theoretically estimated by the following arithmetic. See Figure 3-3.

- The ETC travel time for each segment is either 8 blocks (E 57th Street to E 49th Street) or 7 blocks (E 49th Street to E 42nd Street).
- First calculate the possible minimum travel time with no stops over the 8 blocks using a block travel time of 6 seconds[4]. The minimum 8-block travel time is around 48 (6 × 8) seconds.
- Next, calculate the possible maximum travel time with no stops. The maximum 8-block travel time is the minimum travel time plus green time (approximately 50 seconds). This means a trip starts at the beginning of green window upstream and ends at the end of green window downstream. Then, it becomes 98 seconds.
- Then, the estimate of the median is average of these two values which is (½) × (48 + 98) = 73 seconds expecting that median will most likely reside midway of these two values.
- Startup loss time and acceleration/deceleration are not considered in these calculations.

The similar type of calculation can be done for a multi-stop flow scenario too. Table 3-1 shows the theoretical estimate of the median for different flow conditions using actual block lengths and signal timing information for the segment along 3rd Avenue from E 42nd Street to E 49th Street. Since each segment along the avenues is similar in terms of signal coordination, the theoretical median travel time estimates for a different number of stop conditions for all those segments are comparable. Therefore, the same thresholds were set for all segments for Level 1 control.

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[4] Based on average travel time for a block length of 250 feet at 30 mph (44.1 feet/sec): 250/44.1 = 5.66 seconds

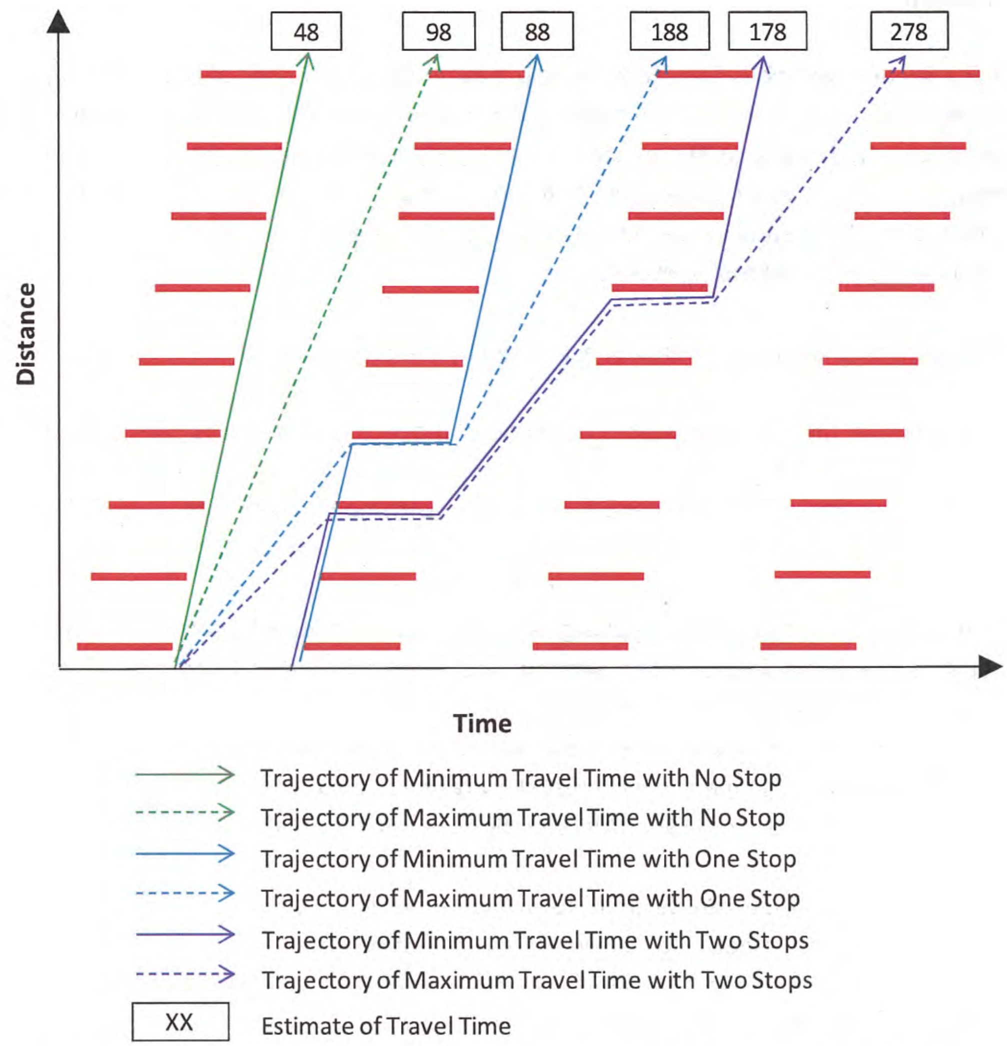



Figure 3-3 – Theoretical Trajectories of Minimum and Maximum Travel Times

Table 3-1 – Median Travel Time Estimate between E 49 St and E 57 St (Seconds)

| Stops | Min | Max | Median |
|---|---|---|---|
| 0 | 54 | 94 | 74 |
| 1 | 85 | 184 | 135 |
| 2 | 175 | 274 | 225 |
| 3 | 265 | 364 | 315 |
| 4 | 355 | 454 | 405 |
| 5 | 445 | 544 | 495 |
| 6 | 535 | 634 | 585 |
| 7 | 625 | 724 | 675 |
| 8 | 715 | 814 | 765 |

**Note:** For this formulation a symmetric distribution was used

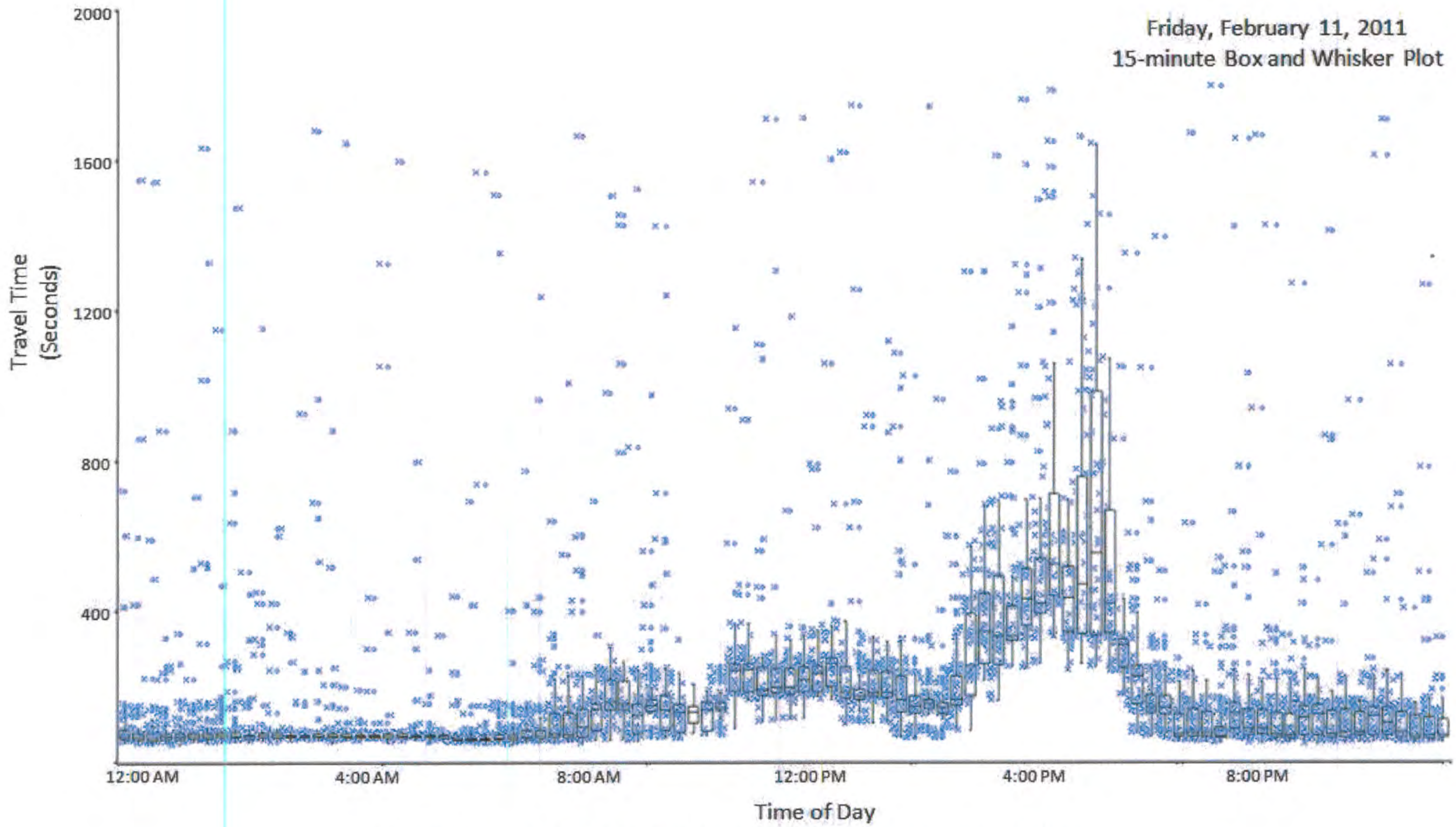
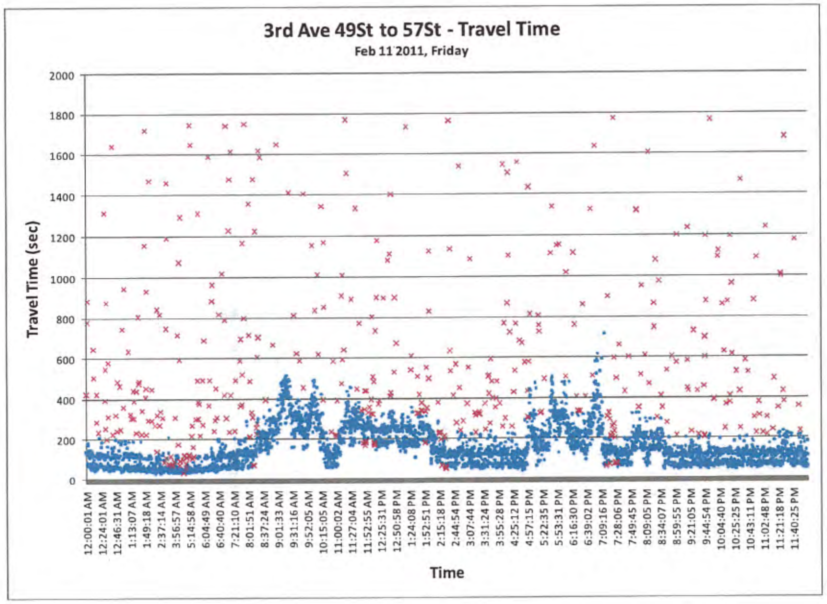
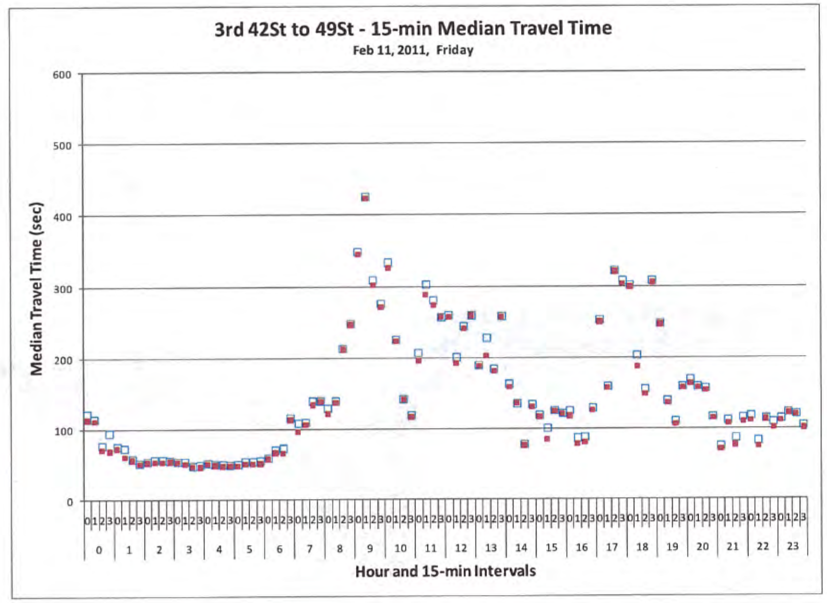



Figure 3-4 – Box and Whisker chart (black) of Travel Time data (blue)




Raw Data (Blue Line) with Outliers (Red Mark)




Comparison of Median with Outliers (Blue Box) and without Outliers (Red Box)

Figure 3-5 – Outlier Analysis

**Define Regimes by a Number of Stops**

Since there is a mechanism to translate the raw data into a median value and then into a number of stop flow condition, new thresholds to implement Level 1 control can be set as follows. The thresholds to separate regimes are based on the midpoint of two medians values. For example, If median value of one stop condition is 140 seconds and that of two stop condition is 220 seconds, then the threshold is most likely the midpoint of these two values, (140 + 220) / 2 = 180 seconds.

- Four regimes are defined with a corresponding control plan.
-
    - Less than a 2 stop condition will be the **green** regime representing no significant congestion which needs CTOD,
    - A two stop condition will be the **yellow** regime representing warning for advent of imminent congestion which needs NBP,
    - A three stop condition will be the **orange** regime representing more significant congestion which needs AC1, and
    - A four stop or more condition will be the **red** regime indicating very significant congestion which needs AC2.

The usage of the ETC travel time and the thresholds will be further discussed in Section 5 describing the decision support system.

**ETC Tag Reader Data and ATR Counts**

Traffic counts Automatic Traffic Recorders (ATR) were collected in and around the Midtown Zone in April 2011. NYCDOT selected two intersections along 34th Street at 3rd Avenue and 6th Avenue, with overlapping ATR counts and ETC tag reader data. There was one tag reader at 3rd/34St and two tag readers 6th/34St. The ATR data from all movements was aggregated for each intersection and compared to the number of tags registered by these ETC tag readers. The data suggests that approximately 4% and 18% of the total traffic using the intersection is recorded by the ETC tag readers at 3rd/34St and 6th/34St, respectively. The data is presented in Appendix F.

## 3.3 Summary

There are three different types of real-time data at the TMC, which are microwave sensors, ETC travel time, and closed-circuit televisions (CCTV). For the control, the first two data were intensively examined.

The new derived MOE, Severity Index, based on microwave sensor data was presented. This Severity Index is a link measure that represents the level of congestion. Using this measure, intersection split control can be implemented and arterial performance can also be evaluated.

ETC travel time data was analyzed in different ways. Using a median value is a very reliable measure to understand underlying flow conditions along each segment. Matching travel time data to a corresponding number of stops is an intuitive way to understand the raw data and develop thresholds for traffic signal control.

# 4 DEVELOP PLANS FOR DIFFERENT LEVELS OF REBALANCING

In this section, the control plans developed for different levels of rebalancing are presented. First the concept of rebalancing is discussed, followed by a summary of the developed plans as well as the evaluation.

## 4.1 Framework

As indicated earlier, Level 1 control is based on pre-defined signal timing plans which are designed to rebalance traffic on approach to the Midtown in Motion study area (zone). Rebalancing can be achieved by:

- Regulating traffic arrival into the zone
- Managing queue growth
- Increasing capacity leaving the zone

Given the conditions in the zone, the first two treatments are used in developing plans. First, sections along each avenue that will be used for regulating traffic while not bringing any significant disruption to adjacent areas are identified. This was done using insight obtained from a multiple number of field visits and by examining the existing signal timing plans.

Secondly, effort was taken to study what would be the effective treatment to regulate traffic with minimal disruption on these sections. A simulation study was preformed to gain insights on the difference between different signal settings. Based upon this, it was determined that simultaneous or reverse offsets with tapering green windows was an effective way to regulate traffic arrival with minimal disruptions. Hence, the following plans were proposed and are now being tested. In general, the plans are:

- NBP – Simultaneous offset on approach to the zone with minimal green window tapering.
- AC1 – Simultaneous offset on approach to the zone with increased green window tapering.
- AC2 – Reverse offset on approach to the zone with more green window tapering.

As an illustration, Figure 4-1 and Figure 4-2 demonstrate the change in the green window along Madison Avenue for the developed NBP and AC1 control plans. Figure 4-2 shows the reduced green time under AC1 as compared to the NBP in Figure 4-1. The green window represents the trajectories that vehicles can experience given the signal timings. In particular, the sequence of green times and offsets along the arterial are displayed relative to the direction of travel.

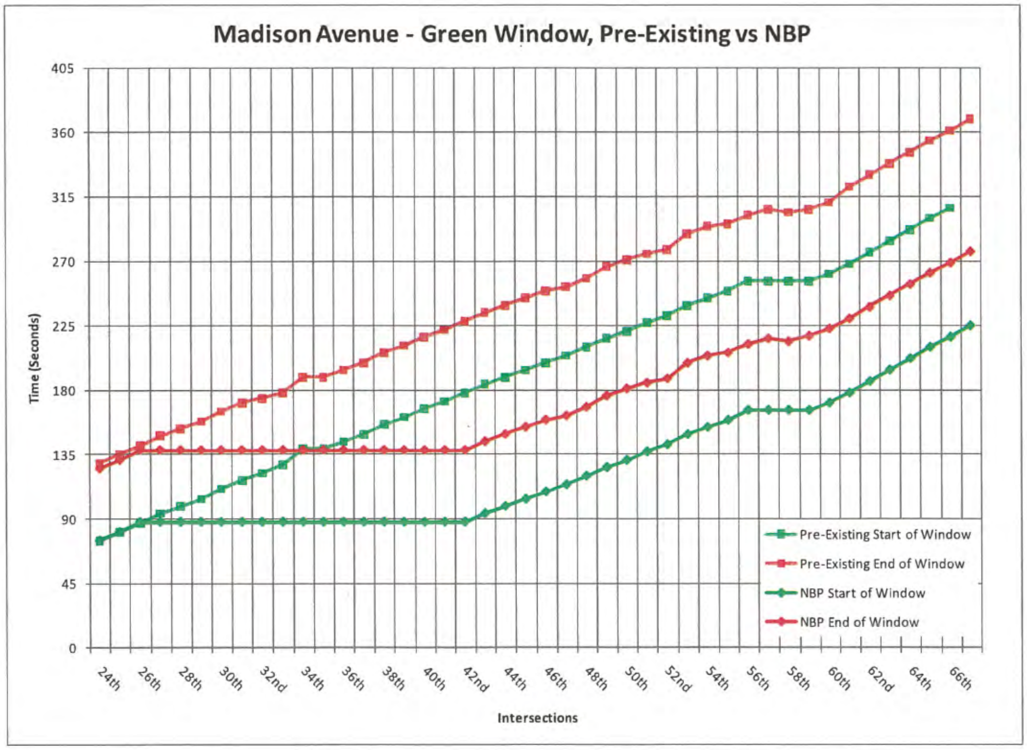



Figure 4-1 – Madison Avenue, Green Window, Pre-Existing vs. NBP

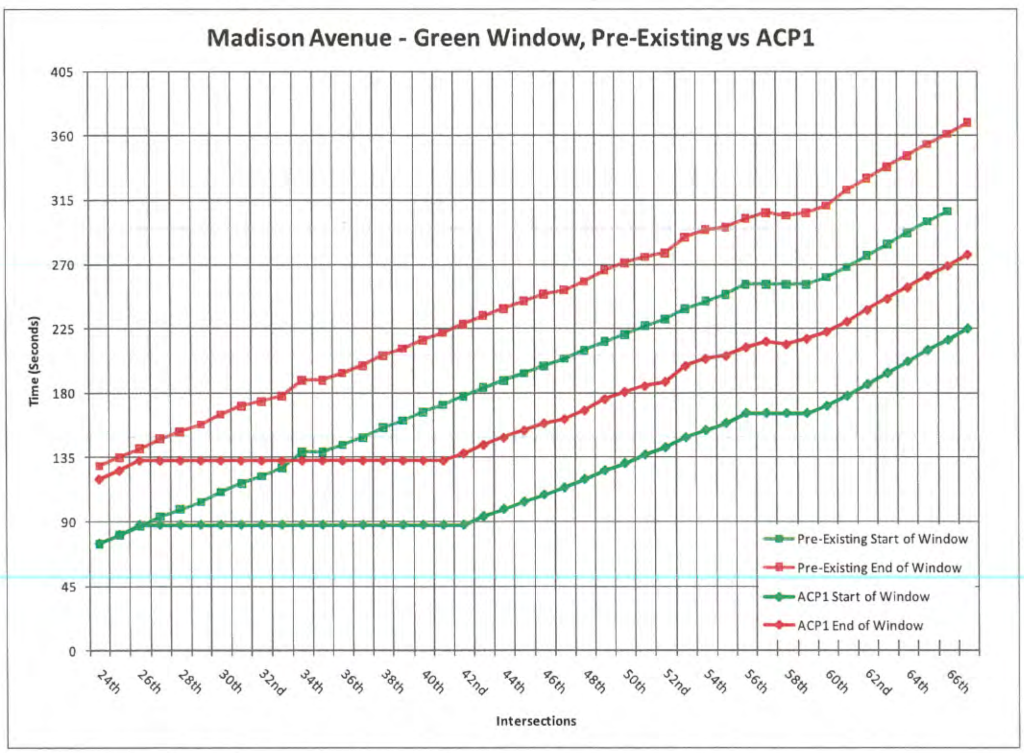



Figure 4-2 – Madison Avenue – Green Window, Pre-Existing vs. AC1

## 4.2 Plans Developed

Table 4-2 briefly summarizes the different rebalancing plans developed. Details of the individual control plans can be found in Appendix A.

Table 4-1 – Summary of Plans Developed

<table>
<tr><th>Avenue</th><th>Segment</th><th>NBP</th><th>AC1</th><th>AC2</th></tr>
<tr><td>Broadway</td><td>25St to 42St</td><td colspan="3">The signal offsets were adjusted to accommodate the proposed control plans along 5th and 6th Avenues.</td></tr>
<tr><td>6 Ave</td><td>25St to 41St</td><td rowspan="5">The existing forward offset is changed to a simultaneous offset along with a tapering of the arterial green window by four seconds</td><td rowspan="5">The existing forward offset is changed to a simultaneous offset along with a tapering of the arterial green window by nine seconds</td><td rowspan="3">The existing forward offset is changed to a simultaneous offset along with a tapering of the arterial green window by twelve seconds</td></tr>
<tr><td>5 Ave</td><td>62St to 78St</td></tr>
<tr><td>Madison Ave</td><td>26St to 41St</td></tr>
<tr><td>Lexington Ave</td><td>63St to 81St</td><td rowspan="2">The existing forward offset is changed to a reverse offset along with a tapering of the arterial green window by nine seconds</td></tr>
<tr><td>3 Ave</td><td>28St to 41St</td></tr>
<tr><td>QMT</td><td>34St & 35St</td><td colspan="3">The signal offsets were adjusted to accommodate the proposed control plans along 3rd Avenue.</td></tr>
<tr><td>2 Ave</td><td>64St to 78St</td><td>The existing forward offset is changed to a simultaneous offset along with a tapering of the arterial green window by four seconds</td><td></td><td></td></tr>
</table>

Note: required ped crossing times at individual intersections are considered in setting the tapering. Above numbers are generally applied.

## 4.3 Evaluation of Plans Implemented

After the above mentioned plans were developed, they were implemented and tested in the field. Table 4-2 contains a summary of the start dates when the control plans were implemented for preliminary testing.

Table 4-2 – Implementation/Testing of Proposed Control Plans – Start Dates

| Avenue / Control Plan | 6th Ave | 5th Ave | Madison Ave | Lexington Ave | 3rd Ave | 2nd Ave |
|---|---|---|---|---|---|---|
| NBP | 4/18/2011 | 4/18/2011 | 3/21/2011 | 2/18/2011 | 2/18/2011 | 3/14/2011 |
| AC1 | Being Implemented | Being Implemented | 4/18/2011 | 3/21/2011 | 3/21/2011 | Not Applicable |
| AC2 | Being Implemented | Being Implemented | Being Implemented | 4/18/2011 | Being Implemented | Not Applicable |

The proposed plans were tested on weekdays from 8:00 AM to 8:00 PM. It is important to emphasize that the plans were tested, regardless of whether traffic conditions warranted them or not. A comparison of the plans indicated an improvement, however sometimes brief and not necessarily detected.

In order to evaluate the potential effectiveness of the proposed control plans, a comparison was performed using microwave sensor data and ETC travel time data. Based on available data, five microwave sensor locations were chosen along with six ETC segments and are listed in Table 4-3 and Table 4-4 respectively. At each microwave sensor location selected, the through lane was used for the analysis. Table 4-5 presents the days for which data was available for analysis by control plan.

The data used in the comparison was grouped by control plan and by time of day, AM (8 AM to 10 AM), Midday (11 AM to 1 PM) and PM (4 PM to 6 PM). Only Tuesdays, Wednesday and Thursdays were considered for the analysis. Days with inclement weather, holidays, special events or data was incomplete were not considered for the analysis. Also, travel time samples greater than 720 seconds were considered outliers and removed from consideration.

Table 4-3 – Selected Microwave Sensor Locations for Plan Evaluation

| |
|---|
| Lexington (59th to 58th) Lane 2 |
| Lexington (63rd to 62nd) Lane 2 |
| 3rd (44th to 45th) Lane 2 |
| 3rd (47th to 48th) Lane 2 |
| Lexington (51st to 50th) Lane 3 |

Table 4-4 – Selected ETC Travel Time Segments for Plan Evaluation

| |
|---|
| Lexington (49th to 42nd) |
| Lexington (57th to 49th) |
| 3rd (42nd to 49th) |
| 3rd (49th to 57th) |
| Madison (42nd to 49th) |
| Madison (49th to 57th) |

Table 4-5 – Selected Dates for Plan Evaluation

| Date | Madison | 3rd and Lex |
|---|---|---|
| 2/9/2011 | Pre-Existing | Pre-Existing |
| 2/10/2011 | Pre-Existing | Pre-Existing |
| 2/15/2011 | Pre-Existing | Pre-Existing |
| 2/16/2011 | Pre-Existing | Pre-Existing |
| 2/17/2011 | Pre-Existing | Pre-Existing |
| 3/1/2011 | Pre-Existing | NBP |
| 3/2/2011 | Pre-Existing | NBP |
| 3/3/2011 | Pre-Existing | NBP |
| 3/8/2011 | Pre-Existing | NBP |
| 3/15/2011 | Pre-Existing | NBP |
| 3/22/2011 | NBP | AC1 |
| 3/30/2011 | NBP | AC1 |

## 4.4 Results

Two analyses were performed to obtain a preliminary evaluation of the effectiveness of the proposed timing plans. The first included the creation of a histogram and the second used the "t-test".

For the microwave sensor data, the histogram dealt with occupancies grouped in bins and for the ETC data, the histogram dealt with number of stops derived from the reported travel time. The t-test was used to test the hypothesis that the change in the control plans resulted in a change in the average occupancy or average travel time.

Figure 4-3 presents the histograms of the travel time data as number of stops for the different set of plans during the weekday AM period (8 AM to 10 AM). It can be inferred from this figure, that the average travel time has decreased from the pre-existing control plan to the NBP and AC1 control plans due to the shift in distribution toward lower number of stops. An identical interpretation can be performed on the microwave sensor histogram. As can be seen in Figure 4-4, a greater percentage of occupancies are in the 20% to 30% range with the NBP and AC1 control plans as compared to pre-existing control plan. This is further supported by Figure 4-5, which presents average flow versus occupancy for the different control plans. As can be seen with the NBP and AC1 plans, there is a decrease in the observed occupancy and an increase in flow.

In addition a comparison of AC2 versus AC1 was performed. Figure 4-6 shows that the number of stops experienced is similar. Continued analysis of AC2 will be performed as more data become available and the control plan will be fine tuned using the results of that analysis.

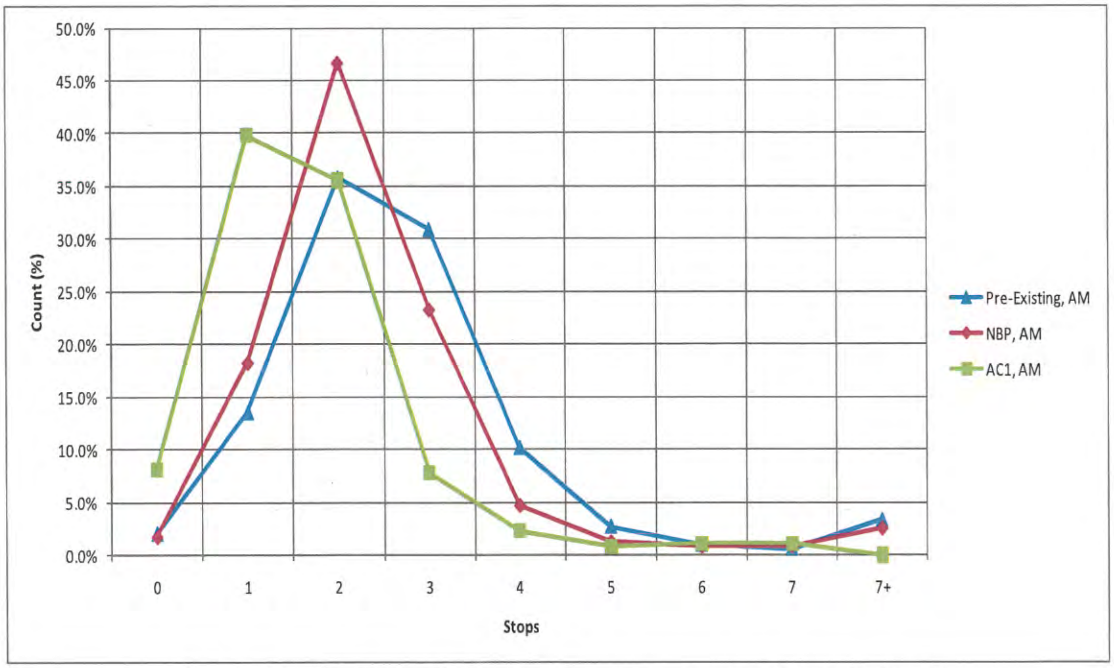



Figure 4-3 – AM Stops Histogram, Lexington Ave (E. 49th to E. 42nd)

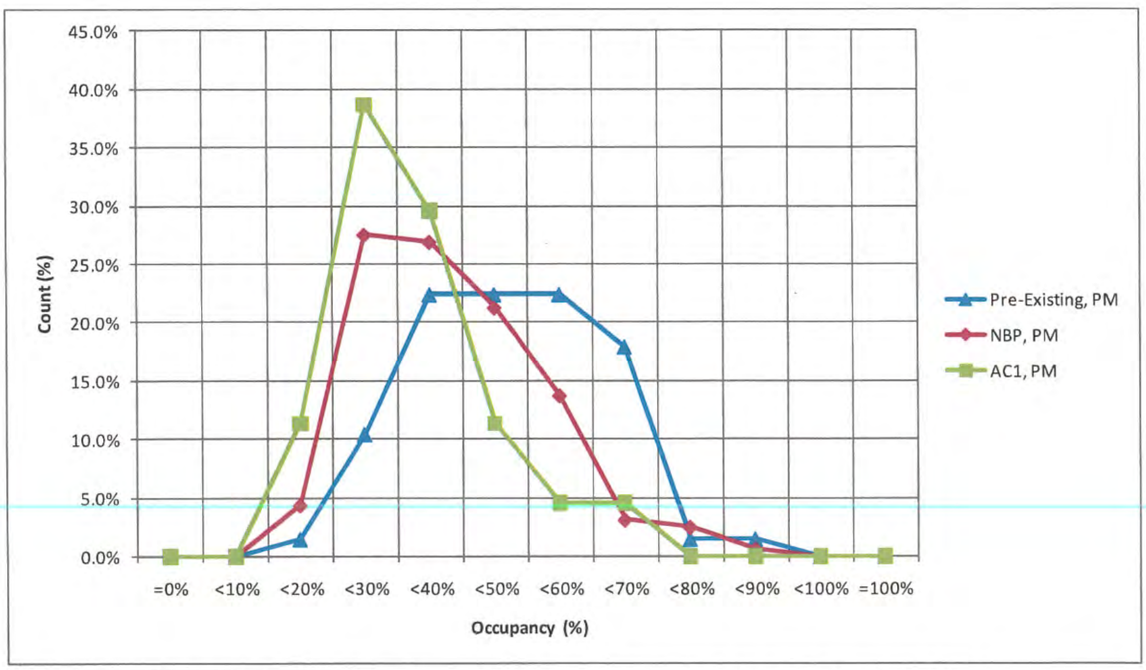



Figure 4-4 – PM Occupancy Histogram, Lexington Ave (E. 63rd to E. 62nd)

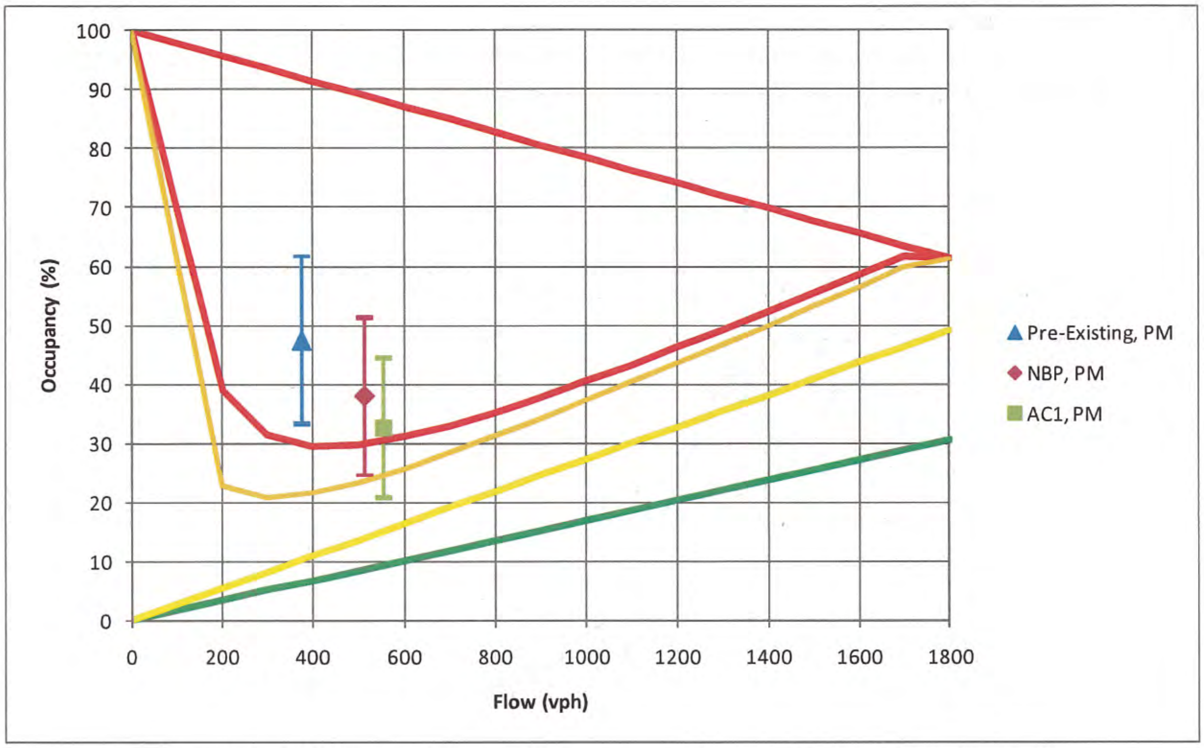



Figure 4-5 – PM Average Flow vs. Occupancy, Lexington Ave (E. 63rd to E. 62nd)

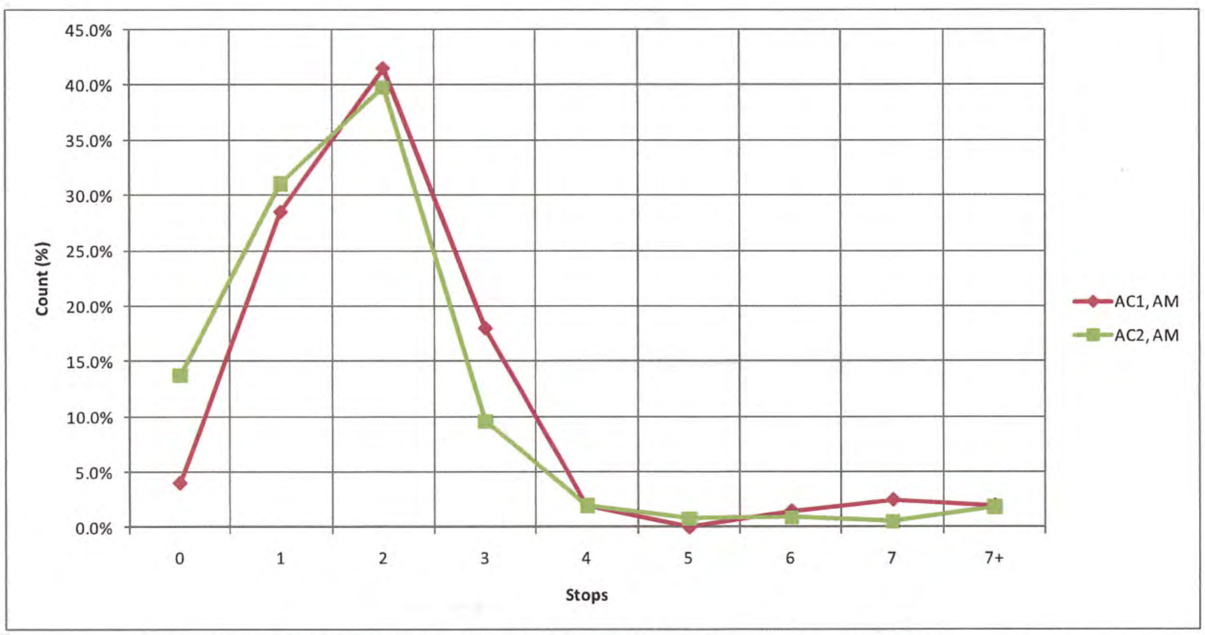



Figure 4-6 – AM Stops Histogram (AC1 vs. AC2), Lexington Ave (E. 49th to E. 42nd)

Table 4-6 contains a summary of the t-test using ETC travel time data from the segment on Lexington Avenue (E. 49th to E. 42nd Streets). Based on the t-statistic, the hypothesis that the means of the two populations of observed travel times (pre-existing vs. NBP and NBP vs. AC1) are statistically similar, is rejected. Furthermore, the NBP and AC1 have lower average travel times compared to the pre-existing control plan, suggesting an improvement in mobility.

Table 4-6 – Statistical t-test, Travel Time, Lexington Ave (E. 49th to E. 42nd Streets)

| Control | Pre-Existing, AM | NBP, AM | ACP, AM |
|---|---|---|---|
| Number of Observations | 2790 | 2798 | 731 |
| Average TT (sec) | 266 | 241 | 196 |
| Standard Deviation (sec) | 96 | 88 | 95 |
| t Stat | | 10.2 | 12 |
| t Critical (one tail) | | 1.6 | 1.6 |
| p Value (one tail) | | 1.01E-24 | 4.89E-33 |
| Mean Same? | | Reject | Reject |
| Improvement? | | Yes | Yes |

As discussed in Section 1, with regard to statistical tests, it must be noted that the convention is to set up a hypothesis such as "no change" in a key metric (travel time, for instance) and check that that this hypothesis is rejected, thereby leading one to the finding that there must have been a change (the desired direction of change – a decrease of travel time, in this case – is taken into account in the computation). That is, rejecting a hypothesis of "no change" is desired. While this may be contrary thinking, it is the standard way of expressing results in statistical analysis.

Table 4-7 contains a summary of the t-test using the ETC data for all locations. Tables similar to Table 4-6 and 4-7 for other microwave sensor locations and ETC travel time data segments are included in Appendix B and Appendix C, respectively.

As presented in Table 4-7, a total of 6 segments along three avenues were analyzed for three peak periods, AM, Midday, and PM. There were three comparisons viz. Pre-existing vs. NBP, Pre-existing vs. AC1, and NBP vs. AC1. Therefore, a maximum of 54 paired statistical tests (6 segments * 3 periods * 3 comparisons) could be performed. However, based on data available 42 tests were performed.

The cells in Table 4-7 are color coded such that that green represents improvements with statistical significance and yellow implies that the means are different with statistical significance for the paired comparison. Based on the results in Table 4-7

- 36 of 42 t-test shows there are changes in travel time with statistical importance.
- Among these 36 cases, 23 cases show improvement meaning the reduction in travel time ranging from 3% to 46%.
- There are instances where the average travel time increased in the comparisons, especially along 3rd Avenue in the AM and PM peak periods. These instances need further investigation.

Table 4-7 – Summary of t-test using ETC Data comparing Travel Time

| Block | Comparison | AM | | | MD | | | PM | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre Existing vs NBP | Pre Existing vs AC1 | NBP vs AC1 | Pre Existing vs NBP | Pre Existing vs AC1 | NBP vs AC1 | Pre Existing vs NBP | Pre Existing vs AC1 | NBP vs AC1 |
| Madison (E 42nd to E 49th) | Mean Same? | Reject | | | Reject | | | Reject | | |
| | Improvement? | No | | | Yes | | | Yes | | |
| | % Difference | 17% | | | -17% | | | -20% | | |
| Madison (E 49th to E 57th) | Mean Same? | Not Reject | | | Reject | | | Reject | | |
| | Improvement? | No | | | Yes | | | Yes | | |
| | % Difference | -2% | | | -23% | | | -17% | | |
| 3rd (E 42nd to E 49th) | Mean Same? | Not Reject | Not Reject | Not Reject | Reject | Reject | Reject | Reject | Reject | Not Reject |
| | Improvement? | No | No | No | No | Yes | Yes | No | No | No |
| | % Difference | 6% | 5% | -1% | 46% | -17% | -43% | 12% | 17% | 4% |
| 3rd (E 49th to E 57th) | Mean Same? | Reject | Reject | Reject | Reject | Reject | Reject | Not Reject | Reject | Reject |
| | Improvement? | No | No | No | No | Yes | Yes | No | No | No |
| | % Difference | 61% | 77% | 10% | 76% | -23% | -56% | 2% | 10% | 8% |
| Lex (E 57th to E 49th) | Mean Same? | Reject | Reject | Reject | Reject | Reject | Reject | Reject | Reject | Reject |
| | Improvement? | Yes | No | No | Yes | Yes | Yes | Yes | Yes | No |
| | % Difference | -5% | 10% | 16% | -8% | -43% | -38% | -21% | -14% | 9% |
| Lex (E 49th to E 42nd) | Mean Same? | Reject | Reject | Reject | Reject | Reject | Reject | Reject | Reject | Reject |
| | Improvement? | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | % Difference | -9% | -26% | -19% | -7% | -25% | -19% | -3% | -6% | -3% |

**Note: "Rejecting" a hypothesis of "no difference" is desired in terms of concluding that an improvement exists.**

The microwave sensor data was analyzed using the histograms of occupancy, using the flow vs occupancy regime plots. This combined analysis is required to evaluate the performance, as opposed to using only flow or occupancy. Table 4-8 presents the average flow and occupancy to facilitate such a comparison. The cells in this table are color coded as Green, Yellow, Orange and Red based on the discussion of Figure 3-2. In addition to comparing the flow/occupancy the cell colors indicate if the traffic conditions shifted towards lesser congested conditions (lower Severity Index). The data in this table is presented graphically in Appendix B.

Table 4-8 – Summary of Microwave Sensor Data comparing Flow and Occupancy

| Location | AM | | |
|---|---|---|---|
| | Pre-Existing | NBP | AC1 |
| Lex (63rd to 62nd), Lane 2 | 490/42 | 625/30 | 581/27 |
| Lex (59th to 58th), Lane 2 | 608/18 | 632/19 | 550/16 |
| Lex (51st to 50th), Lane 3 | 331/64 | 141/85 | 98/70 |
| 3rd (44th to 45th), Lane 2 | 547/18 | 557/22 | 541/18 |
| 3rd (47th to 48th), Lane 2 | 299/9 | 184/8 | 273/8 |
| Location | MD | | |
| | Pre-Existing | NBP | AC1 |
| Lex (63rd to 62nd), Lane 2 | 400/43 | 534/31 | 498/31 |
| Lex (59th to 58th), Lane 2 | 561/16 | 565/14 | 582/11 |
| Lex (51st to 50th), Lane 3 | 317/67 | 148/78 | 295/45 |
| 3rd (44th to 45th), Lane 2 | 569/22 | 535/29 | 561/20 |
| 3rd (47th to 48th), Lane 2 | 283/16 | 230/14 | 331/17 |
| Location | PM | | |
| | Pre-Existing | NBP | AC1 |
| Lex (63rd to 62nd), Lane 2 | 376/47 | 512/38 | 555/33 |
| Lex (59th to 58th), Lane 2 | 639/19 | 679/19 | 659/16 |
| Lex (51st to 50th), Lane 3 | 334/60 | 227/73 | 409/24 |
| 3rd (44th to 45th), Lane 2 | 494/10 | 505/12 | 510/13 |
| 3rd (47th to 48th), Lane 2 | 294/9 | 257/21 | 337/15 |

**Note**: Flow is measured as (vehicles/hour/lane) and occupancy as percentage. The cells are color coded based on the regime definition as discussed in Figure 3-2.

Based on Table 4-8, the following observations can be made:

a) Lexington Avenue between 63rd St and 62nd St.
   - The average occupancy is lower, and average flow is higher under NBP and AC1 compared to Pre-existing. However, based on the combination of flow and occupancy, the traffic conditions represent a lower Severity Index only in the am peak period, with comparable conditions for midday and pm conditions.

b) Lexington Avenue between 59$^{st}$ St and 58$^{th}$ St.

- The average occupancy is comparable for all peak periods under the different control plans. However, average flow is better during the midday and pm conditions. The combination of flow and occupancy suggests that the traffic conditions are comparable for all peak periods under all control plans.

c) Lexington Avenue between 51$^{st}$ St and 50$^{th}$ St.

- The average occupancy is generally high at this location compared to other locations and caution needs to be applied when using the flow measurement. However, the combination of flow and occupancy, suggests that traffic conditions under AC1 have a lower severity index compared to Pre-existing during the am and pm conditions.

d) 3$^{rd}$ Avenue between 44$^{th}$ St and 45$^{th}$ St.

- During all three peak periods, the traffic conditions are comparable under Pre-existing, NBP and AC1.

e) 3$^{rd}$ Avenue between 47$^{th}$ St and 48$^{th}$ St.

- During all three peak periods, the traffic conditions are comparable (same Severity Index) under Pre-existing, NBP and AC1, with AC1 having higher average flow compared to Pre-existing in the midday and pm peak periods.

**Summary of Results**

The following observations can be made based on the analysis of the travel time data:

- For Lexington Avenue
  - In general, travel time was lower under NBP and AC1 compared to the pre-existing
  - For the section from E 49St to E 42St
    - Travel times are lower under NBP and AC1 compared to pre-existing in all peak periods
    - Travel times are always lower under AC1 compared to NBP
  - For the section from E 57St to E 49St
    - Travel times are lower under NBP and AC1 compared to pre-existing only in the midday peak period
    - Travel times are lower under AC1 compared to NBP only in the midday peak period
- For 3rd Avenue
  - Travel time was lower under AC1 compared to the NBP and pre-existing only in the midday peak period and this can be attributed to the change of signal progression from simultaneous to smooth operation (forward progression) in the zone
  - The two individual sections between E 42St to E 49St, and E 49St to E 57St showed similar performance under the different plans in the different peak periods
- For Madison Avenue
  - Travel time was lower under NBP compared to the pre-existing in the midday and pm peak period for both sections between E 42St to E 49St, and E 49St to E 57St

Travel time was also sampled using GPS probe vehicles by NYCDOT along Madison Avenue, Lexington Avenue, and 3rd Avenue under the Pre Existing, NBP, AC1 and AC2 control plans. Appendix E provides the travel time and the vehicle trajectories of this data.

## 4.5 Throughput Analysis

Analysis to assess the change in throughput relative to the proposed control plans was preformed. The primary data source for this analysis was the microwave sensors. Table 4-9 contains a summary of the dates where data was available for the analysis along with the active control plan(s) for the specified arterial. Due to the installation schedule of the microwave sensors, data availability was limited on some arterials. As with the previously discussed analysis, the data used in the comparison was grouped by control plan and by time of day, AM (8 AM to 10 AM), Midday (11 AM to 1 PM) and PM (4 PM to 6 PM). Only Tuesdays, Wednesday and Thursdays were considered for the analysis. Days with inclement weather, holidays or special events were not considered for the analysis.

Table 4-9 – Summary of Data Available for Throughput Analysis

| ***Date*** | ***2nd Avenue*** | ***3rd Avenue*** | ***Lexington Avenue*** | ***Madison Avenue*** | ***5th Avenue*** | ***6th Avenue*** |
|---|---|---|---|---|---|---|
| 2/9/2011 | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing |
| 2/10/2011 | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing |
| 2/15/2011 | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing |
| 2/16/2011 | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing |
| 2/17/2011 | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing | Pre Existing |
| 3/1/2011 | Pre Existing | NBP | NBP | Pre Existing | Pre Existing | Pre Existing |
| 3/2/2011 | Pre Existing | NBP | NBP | Pre Existing | Pre Existing | Pre Existing |
| 3/3/2011 | Pre Existing | NBP | NBP | Pre Existing | Pre Existing | Pre Existing |
| 3/8/2011 | Pre Existing | NBP | NBP | Pre Existing | Pre Existing | Pre Existing |
| 3/15/2011 | NBP | NBP | NBP | Pre Existing | Pre Existing | Pre Existing |
| 3/22/2011 | NBP | AC1 NBP | AC1 NBP | NBP | Pre Existing | Pre Existing |
| 3/30/2011 | NBP | AC1 | AC1 | NBP | Pre Existing | Pre Existing |
| 4/7/2011 | NBP | AC1 | AC1 | NBP | Pre Existing | Pre Existing |
| 4/12/2011 | NBP | AC1 | AC1 | NBP | Pre Existing | Pre Existing |
| 4/14/2011 | NBP | NBP | NBP | NBP | Pre Existing | Pre Existing |
| 4/26/2011 | NBP | AC1 | AC1 NBP* | AC1 | NBP | NBP |
| 4/27/2011 | NBP | AC1 | AC2 NBP | AC1 | NBP | NBP |
| 4/28/2011 | NBP | AC1 | AC2 NBP | AC1 | NBP | NBP |
| 5/3/2011 | NBP | NBP | AC2 NBP | AC1 | NBP | NBP |
| 5/5/2011 | NBP | NBP | AC1 AC2 NBP | AC1 | NBP | NBP |
| *Note: "AC1 NBP" indicates that both AC1 and NBP were both activated on the given day. | | | | | | |

Table 4-10 to Table 4-12 contain the summary of the throughput analysis. One arterial, Lexington Avenue had data available exiting and entering the study area (box). 5th Avenue only has data available entering the study area (box) and 6th Avenue only has data available exiting the study area (box). Pre Existing was compared with NBP, NBP with AC1 and AC1 with AC2. The average of two representative lanes, typically lanes 2 and 3 or the inner most lanes with predominately through traffic was used. The outer most lanes were removed from consideration due to the potential interference from turning traffic.

With a few exceptions, it can be observed that flows decreased modestly for the available comparison. *This indicates that the implemented control plans are operating as expected, namely balancing the flow into the zone.*

Table 4-10 – Lexington Avenue Throughput Comparison

| Lexington Avenue | | Entering (vphpl) | Exiting (vphpl) |
|---|---|---|---|
| AM | Pre-Existing | 579 | - |
| | NBP | 564 (-3%) | 475 |
| | AC1 | 520 (-8%) | 460 (-3%) |
| | AC2 | 531 (+2%) | 437 (-5%) |
| MD | Pre-Existing | 487 | - |
| | NBP | 495 (+2%) | 436 |
| | AC1 | 472 (-5%) | 399 (-8%) |
| | AC2 | - | - |
| PM | Pre-Existing | 564 | - |
| | NBP | 566 (0%) | 462 |
| | AC1 | 565 (0%) | 457 (-1%) |
| | AC2 | - | - |
| Entering Location | | Lex Ave (E. 59thSt to E. 58thSt), Lanes 2 and 3 (Average Flow) | |
| Exiting Location | | Lex Ave (E. 40thSt to E. 39thSt), Lanes 2 and 3 | |

Table 4-11 – 5th Avenue Throughput Comparison

| 5th Avenue | | Entering (vphpl) | Exiting (vphpl) |
|---|---|---|---|
| AM | Pre-Existing | 557 | - |
| | NBP | 514 (-8%) | - |
| | AC1 | - | - |
| | AC2 | - | - |
| MD | Pre-Existing | 532 | - |
| | NBP | 485 (-9%) | - |
| | AC1 | - | - |
| | AC2 | - | - |
| PM | Pre-Existing | 494 | - |
| | NBP | 458 (-7%) | - |
| | AC1 | - | - |
| | AC2 | - | - |
| Entering Location | | 5th Ave (E. 60thSt to E. 59thSt), Lanes 2 and 3 (Average Flow) | |
| Exiting Location | | Not Available | |

Table 4-12 – 6th Avenue Throughput Comparison

| 6th Avenue | | Entering (vphpl) | Exiting (vphpl) |
|---|---|---|---|
| AM | Pre-Existing | - | 256 |
| | NBP | - | 240 (-6%)* |
| | AC1 | - | - |
| | AC2 | - | - |
| MD | Pre-Existing | - | 257 |
| | NBP | - | 237 (-8%) |
| | AC1 | - | - |
| | AC2 | - | - |
| PM | Pre-Existing | - | 298 |
| | NBP | - | 275 (-8%) |
| | AC1 | - | - |
| | AC2 | - | - |
| Entering Location | | Not Available | |
| Exiting Location | | 6th Ave (E. 58thSt to E. 59thSt), Lanes 2 and 3 (Average Flow) | |

## 4.6 Summary

As can be seen in Table 4-7 and Table 4-8, as well as Table 4-10 through Table 4-12 the comparisons in general, showed a favorable improvement. Learning through use is beginning, and will lead to the appropriate implementation of the developed control plans for a given network state. And when ready, the system can "go live" and implement the developed control plans.

# 5 DECISION SUPPORT TOOL AND IMPLEMENTATION

This section describes the tool that was developed to assist in the decision making process as discussed in Sections 2 and 3. The first section is an overview of the tool and the features, and the second section is the description of the operating procedure.

## 5.1 Decision Support System

Figure 5-1 and Figure 5-2 present screens of the tool. This tool is currently installed in the TMC. This tool has a hierarchical structure to support different levels of interaction from the operator and supervisor. Figure 5-3 shows the decision making process. The parameters illustrated in Figure 5-3 are user defined and will be refined as part of the learning process of running the system in the coming months. The current set of parameters is based on the discussion in Sections 2 and 3.

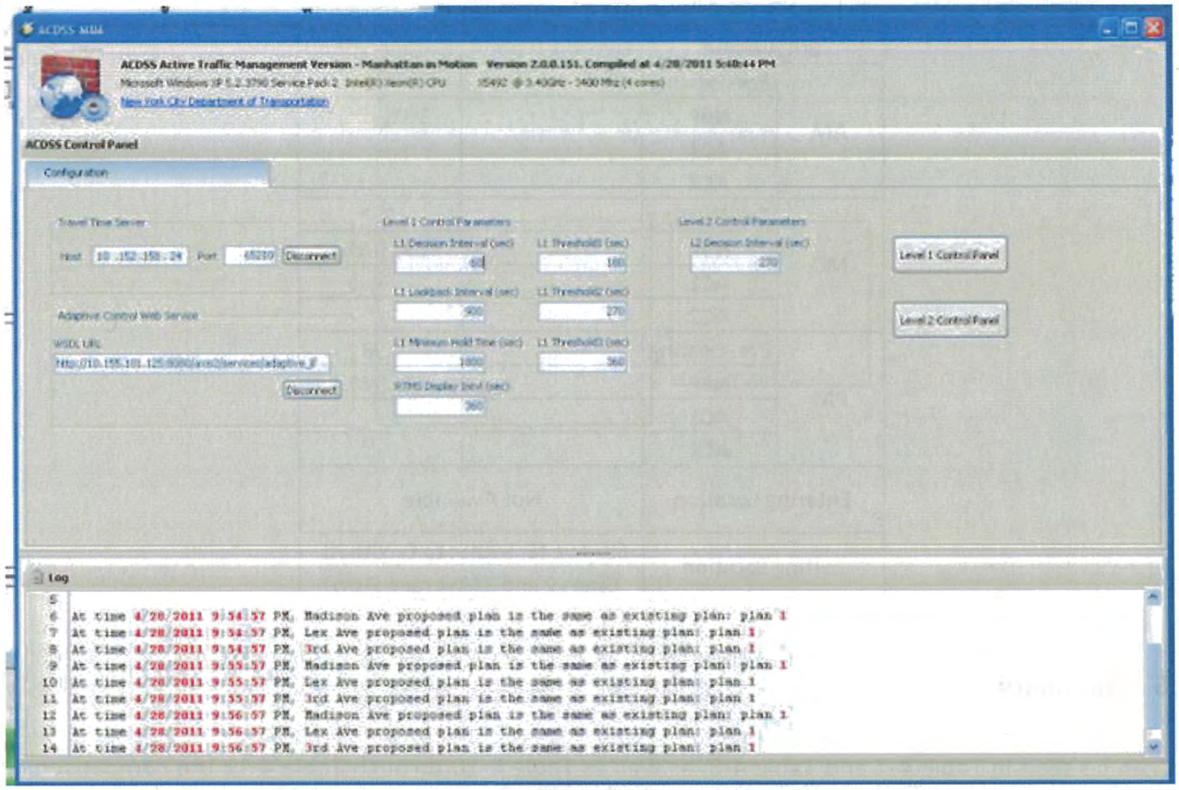



Figure 5-1 – Decision Support System – Main Console Display

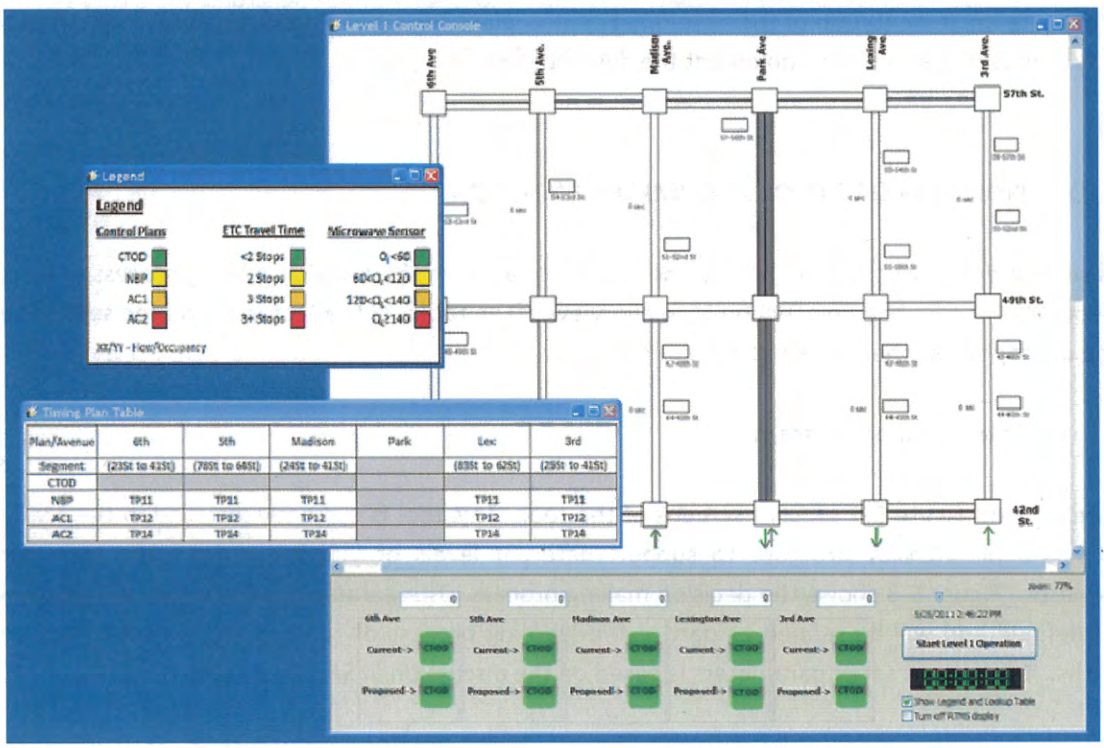



Figure 5-2 – Decision Support System – Level 1 Control Display

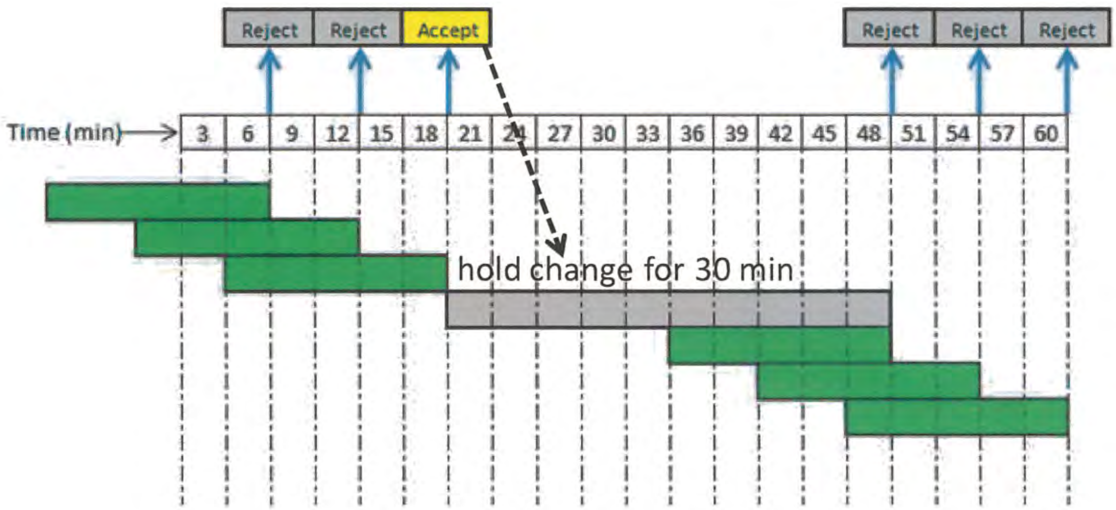



Figure 5-3 – Decision Support Process

The display in the tool is tailored to support control decision making for the arterials (5th, 6th, Madison, Lexington and 3rd Avenues). The full spectrum of data – microwave sensor and travel time data – will be presented in a companion GIS display as shown in Figure 5-4. This display will present the real-time data.

## 5.2 Operating Procedure

This section outlines the steps to use the tool as part of day to day operations. As discussed earlier there are two levels of control that are facilitated using a combination of real-time data from microwave sensors and ETC tag readers:

- Level 1 or *Area-wide Control* that starts from a pre-stored library of timing plans (CTOD, NBP, AC1 and AC2). These timing plans are specifically designed, such that they facilitate formation of specific traffic patterns to serve the overall purpose of metering traffic into the CBD area, enhancing mobility inside the area, or favoring designated *THRU* streets. As discussed in Section 4, these have been implemented and field tested.
- Level 2 or *Intersection Control* is a granular level fine tuning of critical intersections. Under Level 2 control, only splits are adjusted on a real-time basis.

As part of Level 1, recommendations to the operator with action (i.e. change of balancing plan – NBP, AC1, and AC2) will be made based upon:

- ETC display crossing into a different regime (based on median travel time);
- Microwave sensor display showing a shorter term pre-cursor problem (some operational experience needed, to fine-tune this);

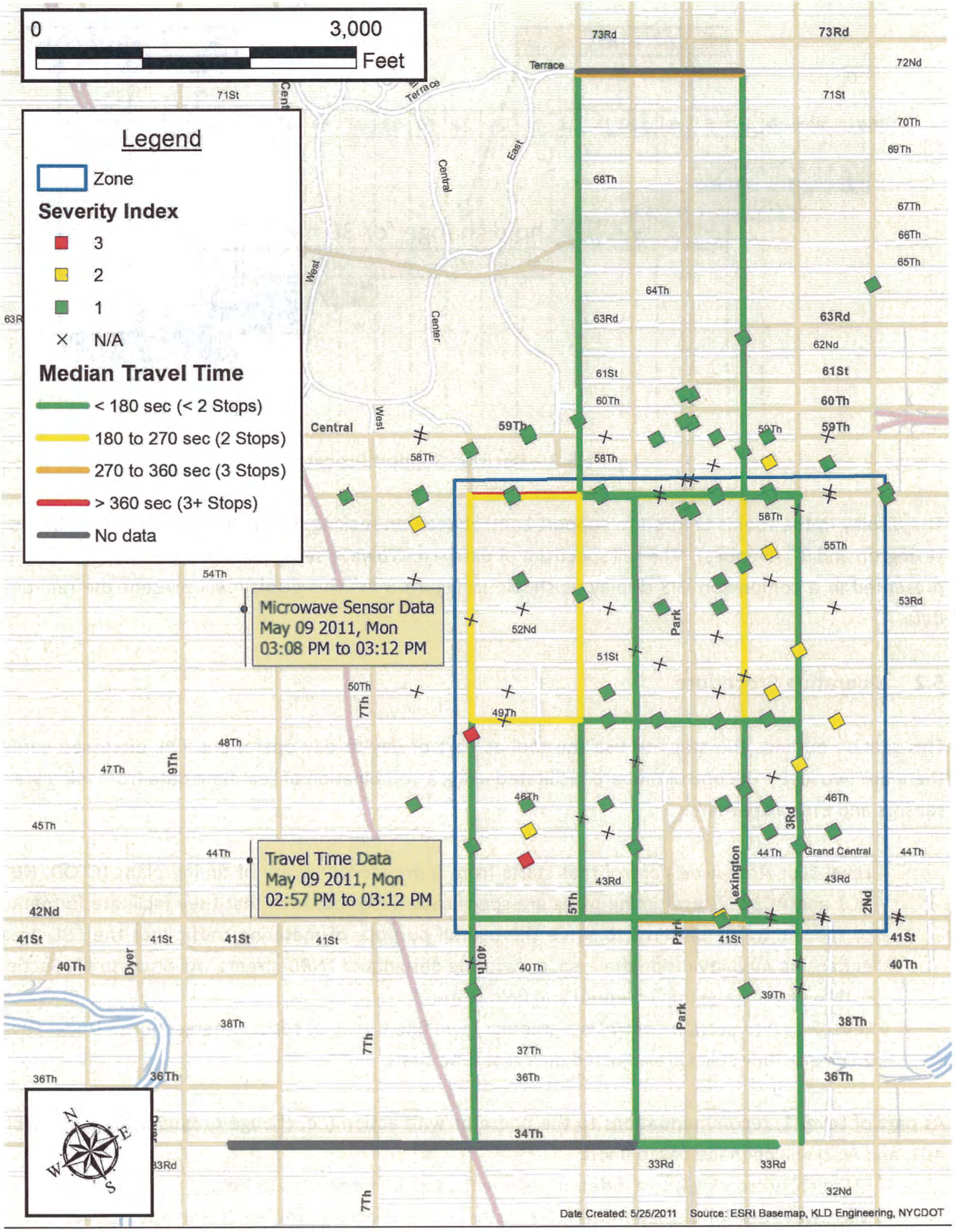



Figure 5-4 – GIS Display of Real-Time Data

Table 5-1 presents a set of decision making rules for the operator while using the system

Table 5-1 – Decision Making Rules

The guidance to the operator is:

- The microwave sensor detectors are early indicators of plan change – when the color codes go upscale, the operator should be attentive to upcoming travel time segment changes, and possibly tighter control;

- The same is true as the microwave sensor colors go downscale: the operator should be attentive to upcoming travel time segment changes, and possibly less tight control;

- The buttons at the bottom of the screen show recommended plan changes, based upon the underlying control rules;

- The recommendations are by arterial and the decisions are made for each one, individually;

- The operator needs to consider three things before implementing a control change:
    a. Existing operational issues that might be influencing the change recommendation, such as special events (Easter Sunday), accident reports, video inspection (if available);
    b. Experience, which will be developed over the days after following implementation, on the effects with and without implementing the recommendation;
    c. The preference to implement the recommendation during the test mode

- During the test mode, a TMC supervisor will be monitoring and confirming the initial test decisions, particularly in the 8am-8pm weekday periods.

- When the operator chooses to implement a recommendation, no further change of plan on that arterial is allowed for "N" minutes. The present setting is N = 30 minutes. It can be overridden (release / drop control) by the operator.

The system is set up to run continuously 24/7. In the initial set up, during the weekdays between 8AM and 8PM, the NBP will be in effect. During the period in the weekdays, Level 1 recommendations will have *three* possible recommendations including NBP, AC1 and AC2 and *four* possible recommendations including the CTOD (Central Time of Day base plan control) at all other times.

Figure 5-5 presents an example of the recommendations that would be made over the course of a single week day.

It is anticipated that as the system is operational, the intervals for recommendation, the "hold" period will be refined. Specifically, the decision to move from NBP → AC1 → AC2 will have a different "hold" period versus the move from AC2 → AC1 → NBP. This is to avoid the "hysteresis" effect. Appendix D includes a copy of the user documentation provided to the TMC operators and supervisors.

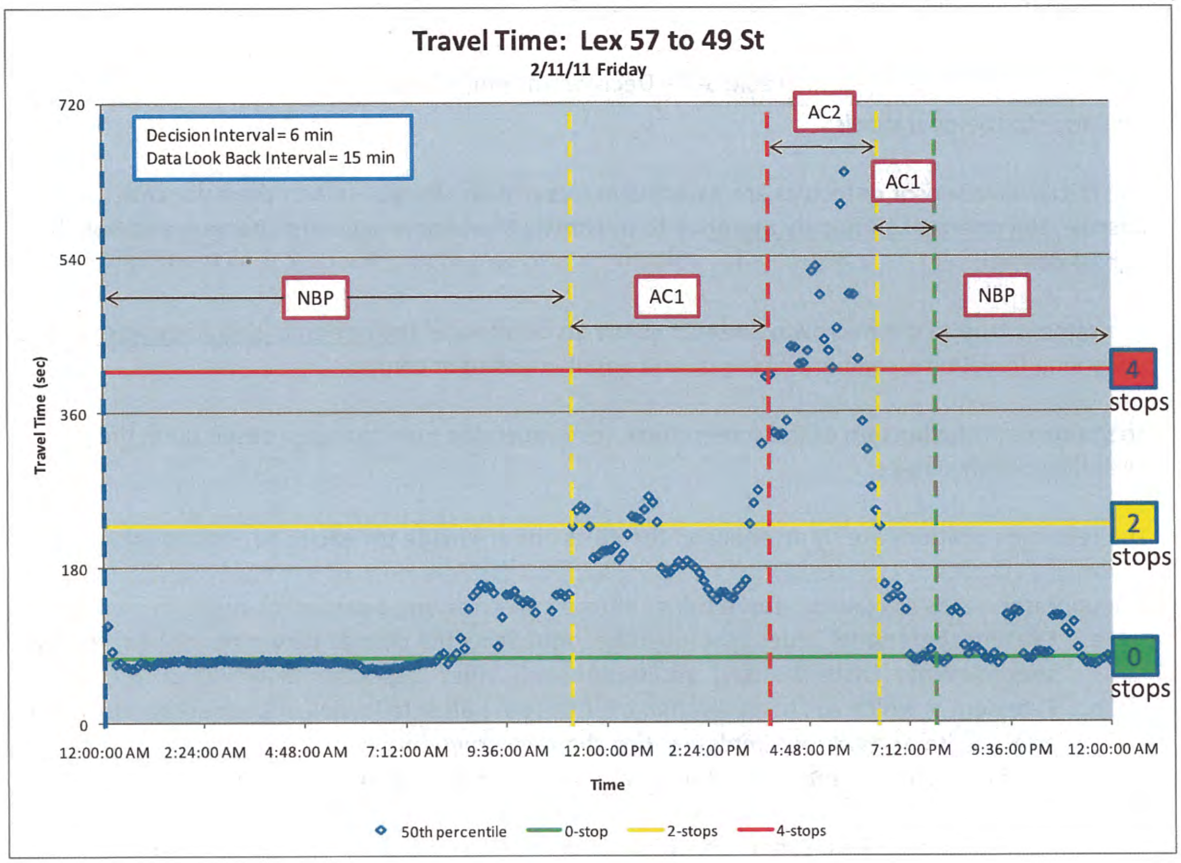



Figure 5-5 – Illustration – Recommendations for Level 1

With regard to Level 2 control, currently testing is ongoing with a "dummy" controller. This mode of operation is expected to be "autonomous" similar to the implementation in Staten Island for Victory Boulevard. Figure 5-6 shows a screen shot of the log from the Level 2 testing with the dummy controller and Figure 5-7 shows a sample of split adjustment being recommended using real-time data.

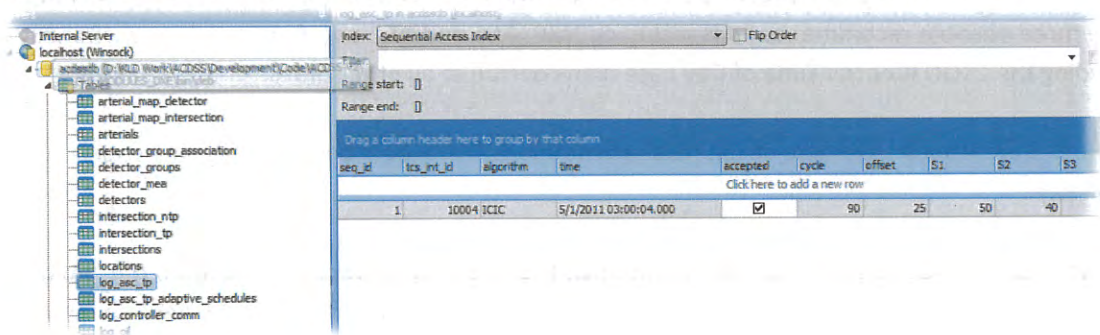



Figure 5-6 – Level 2 Control Log

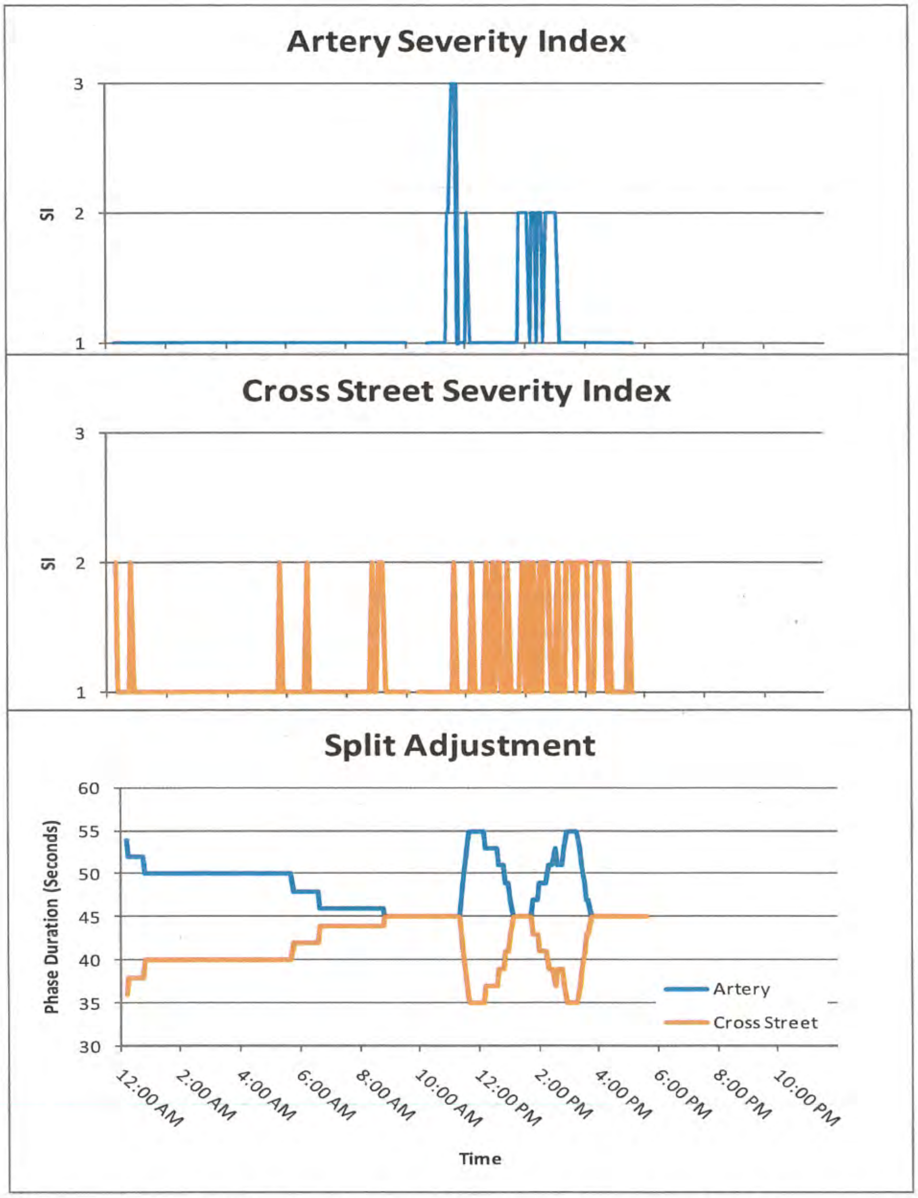



Figure 5-7 – Illustration – Recommendations for Level 2

# 6 GETTING THE SYSTEM READY

This section describes the set up in terms of hardware installed, configured, integrated and software developed to facilitate the real-time operation of the decision support tool.

As part of this effort, a total of 101 Microwave sensor providing data from 258 different travel lanes, and 23 intersections with tag readers providing travel time for 44 segments along five avenues and five streets have been installed, configured and integrated into the NYCTCS by NYCDOT and JHK/TransCore. Most of controllers at the intersections within zone have been upgraded to the next generation, advanced solid state traffic controller (ASTC) that support real-time traffic control. The intersections along the approaches to the zone are in the process of being upgraded. To access this data and process it in real-time, the existing web services interface that was developed under the ACDSS implementation for Victory Boulevard is being enhanced. Figure 6-1 shows the framework that was developed for that implementation and has been adapted as shown in Figure 2-1.

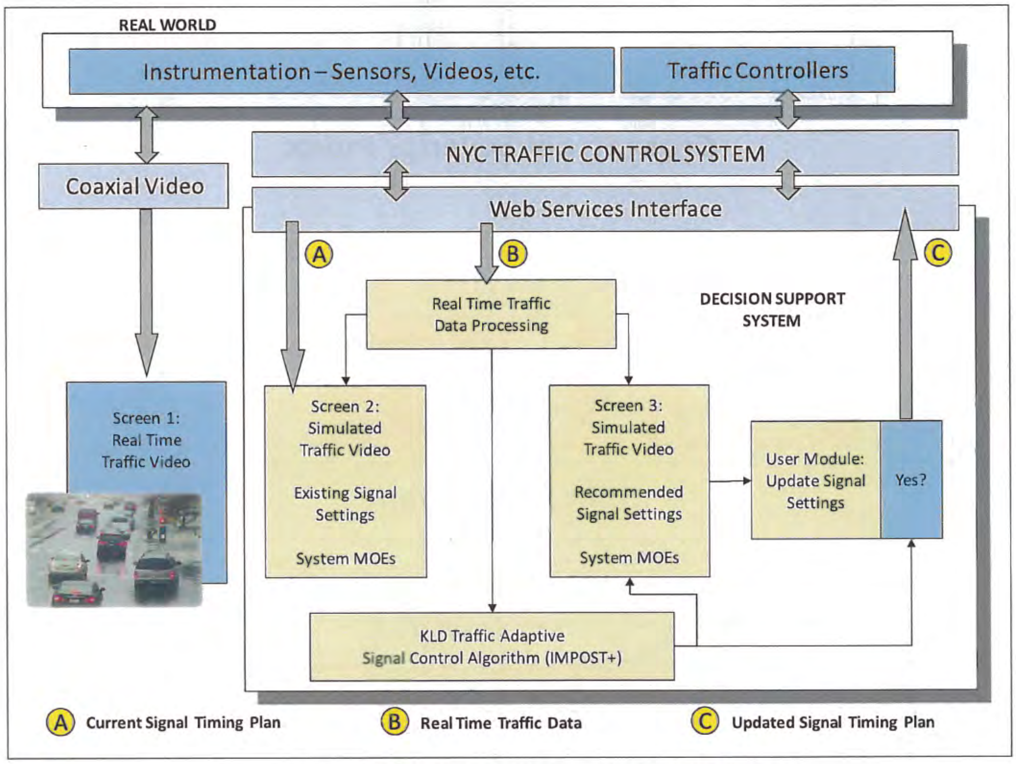



Figure 6-1 – ACDSS Framework – Victory Boulevard

This enhanced web services interface will be capable of handling additional data feeds from microwave sensors and ETC tag Readers that will be coming live in the near future. Also, based on discussion with NYCDOT P&S, it appears that additional data sources such as Taxi GPS data will be might be made available.

Working with TransCore/JHK and NYCDOT the tool was embedded in the control room in the TMC. The tool was set up on a terminal accessible to the operators such that it could be viewed on the video wall and run on the systems that had access to both TCS and VTCS systems. The recommendations for plan changes as part of Level 1 require access to the VTCS system under the current setup, with eventual transition to TCS after the controllers for the intersections outside the zone are upgraded.

A few interactive sessions have been completed with the TMC supervisors during the last couple of weeks in April 2011. These sessions provided valuable feedback for new features and modifications to the tool. These have been incorporated into the tool, and this process is expected to be ongoing in the coming months.

## 7 NEXT STEPS

A comprehensive evaluation of the MIM project will be conducted for the first six months of its implementation. This evaluation will include results for Level I and the early stage of Level II implementation. Following the installation, an intense period of "learning" is anticipated. During this period, based on running the system, refinements will be made to features, operating procedures and thresholds within the system. It is anticipated that the metrics identified will continue to be used for evaluation.

As upgrades to the field controllers are completed, and integration of newer microwave sensor installations and ETC tag readers are performed, the system will be updated to accommodate these data feeds.

The availability of the taxi GPS data from NYCDOT will facilitate evaluating impacts to sections (arterials/cross streets) that are not instrumented with either microwave sensor or ETC tag readers. This will supplement the analysis currently being performed. Figure 8-1, presents the sections that have estimated travel times using the taxi GPS data.

## 8 REFERENCES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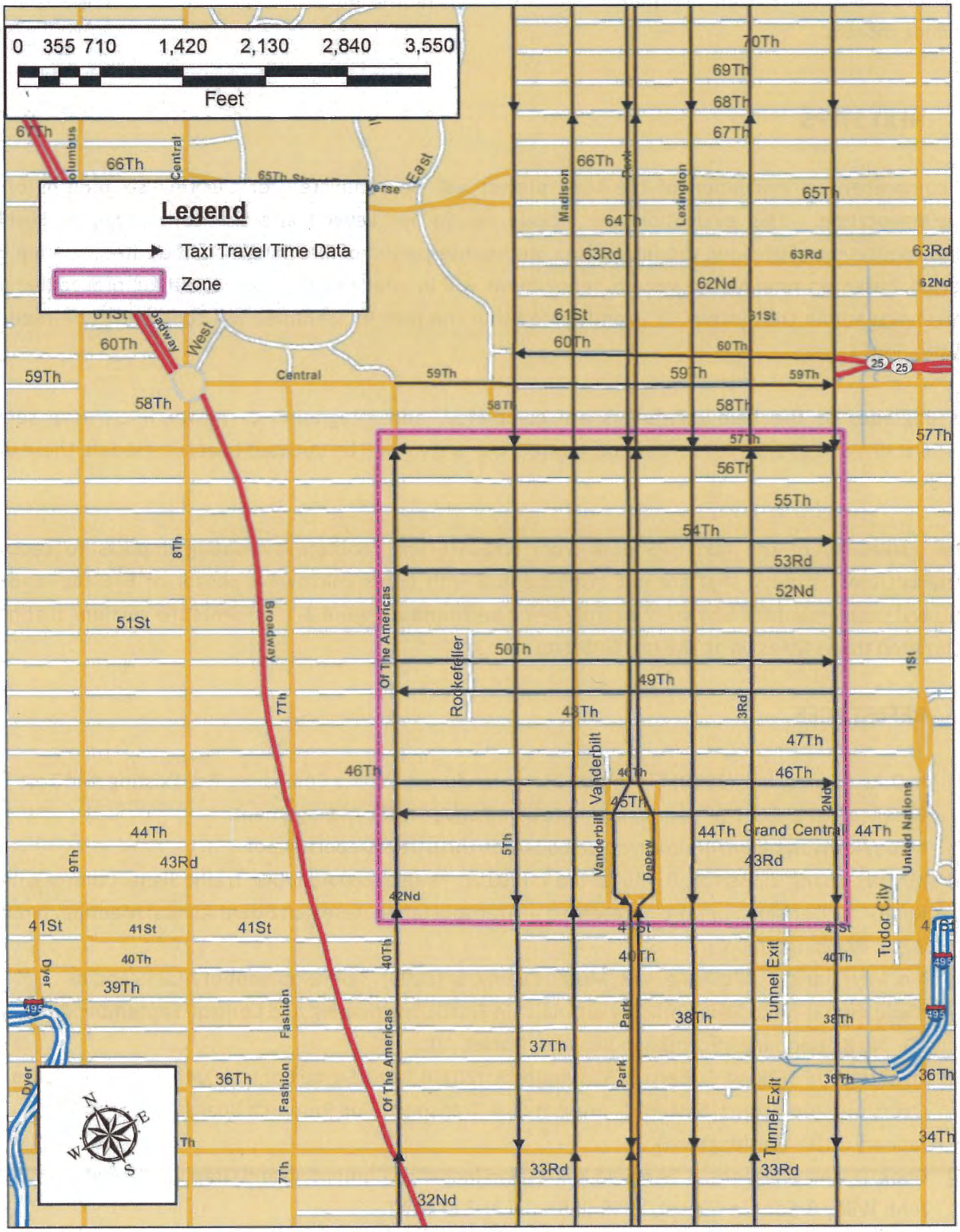


Figure 8-1 – Taxi GPS Travel Time Segments

## APPENDIX A – PROPOSED CONTROL PLANS

Included in this appendix is a summary of the implementation of the proposed control plans (Table A-1), along with a calendar summarizing available data, implemented control plans, holidays and weather (Figure A-1 and Figure A-2). Lastly, the proposed control plans are included (Table A-2 to Table A-9).

Table A-1 – Implementation of Proposed Control Plans

| Date | Street Segment | AC1 plan | Start Time | End Time | Comment |
|---|---|---|---|---|---|
| 3/21/2011 | 3 ave (25 - 41 Sts) | 12 | 8:07 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 8:12 | 20:00 | |
| 3/22/2011 | 3 ave (25 - 41 Sts) | 12 | 7:55 | 20:00 | communication issues until 9am |
| | Lex (83 - 62 Sts) | 12 | 7:55 | 20:00 | communication issues until 9am |
| 3/23/2011 | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 20:00 | |
| 3/24/2011 | 3 ave (25 - 41 Sts) | 12 | 8:19 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 8:19 | 20:00 | |
| 3/25/2011 | 3 ave (25 - 41 Sts) | 12 | 7:54 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 7:54 | 20:00 | |
| 3/28/2011 | 3 ave (25 - 41 Sts) | 12 | 14:39 | 20:00 | Late implementation |
| | Lex (83 - 62 Sts) | 12 | 14:50 | 20:00 | Late implementation |
| 3/29/2011 | 3 ave (25 - 41 Sts) | 12 | 8:03 | 20:00 | communication issues between 10:45 am- 14:00 |
| | Lex (83 - 62 Sts) | 12 | 8:03 | 20:00 | |
| 3/30/2011 | 3 ave (25 - 41 Sts) | 12 | 7:55 | 20:00 | communication issues between 11:40 -11:51am |
| | Lex (83 - 62 Sts) | 12 | 7:55 | 20:00 | |
| 3/31/2011 | 3 ave (25 - 41 Sts) | 12 | 7:55 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 7:55 | 20:00 | |
| 4/1/2011 | 3 ave (25 - 41 Sts) | 12 | 7:58 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 7:58 | 20:00 | |
| 4/4/2011 | 3 ave (25 - 41 Sts) | 12 | 15:43 | 20:00 | issues with communication- late implementation |
| | Lex (83 - 62 Sts) | 12 | 11:42 | 20:00 | issues with communication- late implementation |
| 4/5/2011 | 3 ave (25 - 41 Sts) | 12 | 8:52 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 8:54 | 20:00 | |
| 4/6/2011 | 3 ave (25 - 41 Sts) | 12 | 9:00 | 14:20 | AC problem - rebooted |
| | Lex (83 - 62 Sts) | 12 | 9:06 | 14:20 | AC problem - rebooted |
| 4/7/2011 | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:00 | |
| | Lex (81 - 62 Sts) | 12 | 7:54 | 20:00 | |
| 4/8/2011 | 3 ave (25 - 41 Sts) | 12 | 8:30 | 20:00 | VTCS down before 8:30 am |
| | Lex (81 - 62 Sts) | 12 | 8:30 | 20:00 | VTCS down before 8:30 am |
| 4/11/2011 | 3 ave (25 - 41 Sts) | 12 | 8:02 | 20:00 | |
| | Lex (81 - 62 Sts) | 12 | 8:02 | 20:00 | |
| 4/12/2011 | 3 ave (25 - 41 Sts) | 12 | 7:56 | 20:00 | |
| | Lex (83 - 62 Sts) | 12 | 7:55 | 20:00 | |
| 4/13/2011 | 3 ave (25 - 41 Sts) | | | | No implementation on 3rd ave due to offlines |
| | Lex (83 - 62 Sts) | 12 | 8:02 | 20:00 | |
| 4/14/2011 | 3 ave (25 - 41 Sts) | | | | No implementation |
| | Lex (83 - 62 Sts) | | | | |
| 4/15/2011 | 3 ave (25 - 41 Sts) | | | | No implementation on 3rd ave due to offlines |
| | Lex (83 - 62 Sts) | 14 | 8:40 | 10:00 | |
| 4/18/2011 | 3 ave (25 - 41 Sts) | | | | No implementation on 3rd ave due to offlines |
| | Lex (83 - 62 Sts) | 14 | 8:40 | 10:00 | |
| | Lex (83 - 62 Sts) | 12 | 10:00 | 20:00 | |
| 4/19/2011 | 3 ave (25 - 41 Sts) | 12 | 9:15 | 14:18 | AC2 problem started at 14:18 |
| | Lex (83 - 62 Sts) | 14 | 8:40 | 10:19 | |
| | Lex (83 - 62 Sts) | 12 | 10:19 | 14:18 | |
| 4/20/2011 | 3 ave (25 - 41 Sts) | | | | AC2 problem - no implementation |
| | Lex (83 - 62 Sts) | | | | |
| | Lex (83 - 62 Sts) | | | | |
| 4/21/2011 | 3 ave (25 - 41 Sts) | 12 | 9:36 | 20:00 | |
| | Lex (83 - 62 Sts) | 14 | 9:29 | 10:14 | |
| | Lex (83 - 62 Sts) | 12 | 10:14 | 20:00 | |
| 4/22/2011 | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:00 | |
| | Lex (83 - 62 Sts) | 14 | 8:40 | 10:00 | |
| | Lex (83 - 62 Sts) | 12 | 10:00 | 20:00 | |

Table A-1 – Implementation of Proposed Control Plans

| Date | Street Segment | AC1 plan | Start Time | End Time | Comment |
|---|---|---|---|---|---|
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| 4/25/2011 | Lex (83 - 62 Sts) | 14 | 8:40 | 10:00 | released to time of day operation schedule at 10:00 |
| | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:00 | |
| 4/26/2011 | Lex (83 - 62 Sts) | 12 | 8:40 | 20:00 | |
| | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:22 | |
| 4/27/2011 | Lex (83 - 62 Sts) | 14 | 8:00 | 10:00 | released to time of day operation schedule at 10:00 |
| | 3 ave (25 - 41 Sts) | 12 | 7:51 | 20:00 | |
| 4/28/2011 | Lex (83 - 62 Sts) | 14 | 7:53 | 10:00 | released to time of day operation schedule at 10:00 |
| | 3 ave (25 - 41 Sts) | 12 | 8:00 | 20:00 | |
| | Lex (83 - 62 Sts) | 14 | 8:40 | 10:00 | |
| 4/29/2011 | Lex (83 - 62 Sts) | 12 | 10:00 | 20:00 | |
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 9:15 | |
| 5/2/2011 | Lex (83 - 62 Sts) | 14 | 9:15 | 10:37 | released to operation schedule at 10:37 am |
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| 5/3/2011 | Lex (83 - 62 Sts) | 14 | 9:15 | 10:15 | released to operation schedule at 10:15 am |
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| 5/4/2011 | Lex (83 - 62 Sts) | 12 | 8:00 | 13:00 | due to communication issue no plan changes at 9:15 am |
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 9:24 | |
| 5/5/2011 | Lex (83 - 62 Sts) | 14 | 9:24 | 10:39 | released to operation schedule at 10:39 am |
| | 3 ave (25 - 41 Sts) | 12 | 7:57 | 9:15 | |
| | 3 ave (25 - 41 Sts) | 14 | 9:15 | 10:15 | released to operation schedule at 10:15 am |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 9:15 | |
| 5/6/2011 | Lex (83 - 62 Sts) | 14 | 9:15 | 10:15 | released to operation schedule at 10:15 am |
| | 3 ave (25 - 41 Sts) | | | | No plan change on 3rd ave |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 9:15 | |
| 5/9/2011 | Lex (83 - 62 Sts) | 14 | 9:15 | 10:27 | released to operation schedule at 10:27 am |
| | 3 ave (25 - 41 Sts) | 12 | 8:00 | 12:39 | |
| | 3 ave (25 - 41 Sts) | TOD (TP#11) | 12:39 | 13:24 | testing- KLD system (released to operation schedule) |
| | 3 ave (25 - 41 Sts) | 12 | 13:24 | 20:55 | testing- KLD system |
| | Lex (83 - 62 Sts) | 12 | 8:00 | 9:15 | |
| 5/10/2011 | Lex (83 - 62 Sts) | 14 | 9:15 | 10:15 | released to operation schedule at 10:15 am |

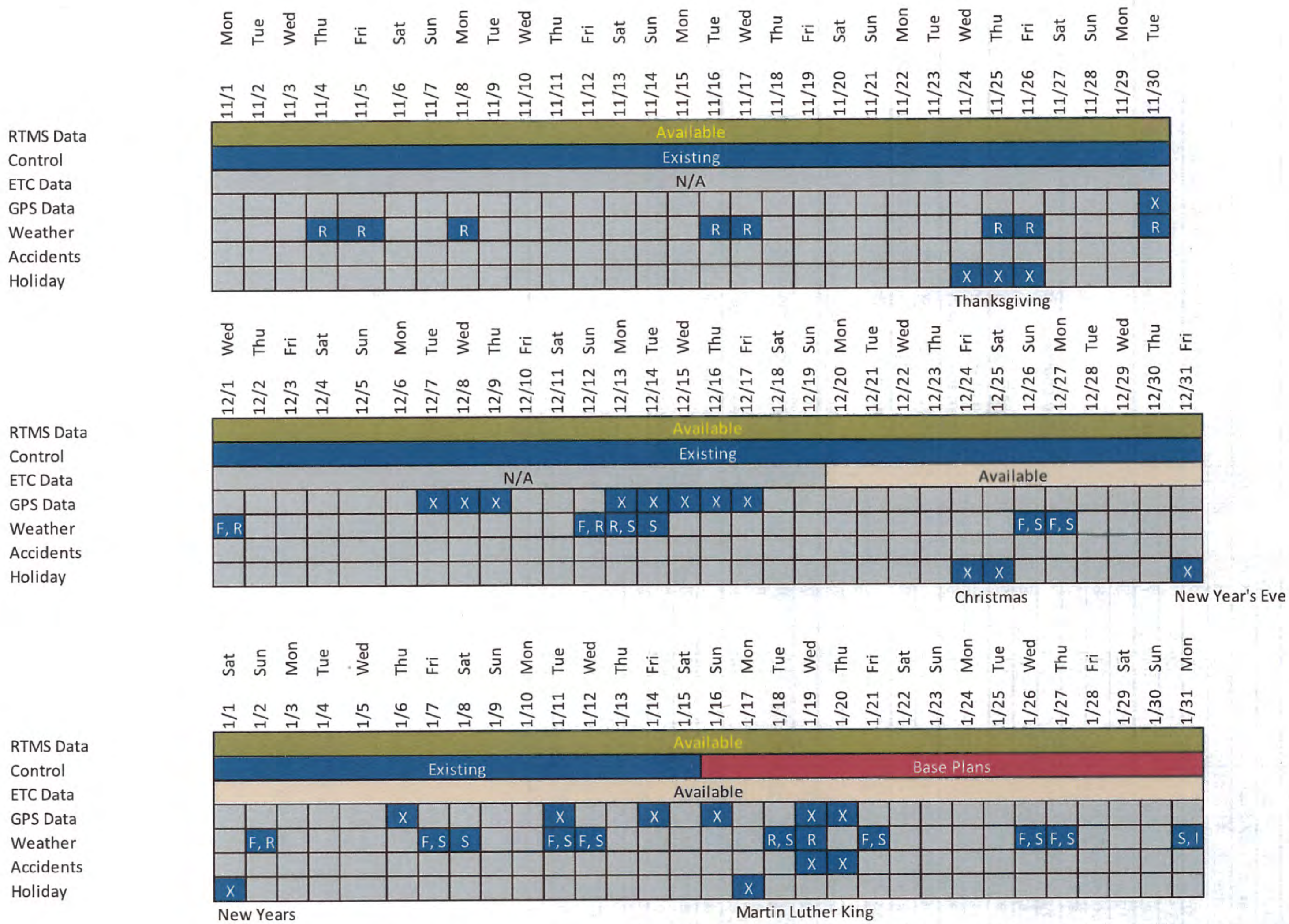


Figure A-1 – Calendar (November 2010 to January 2011)

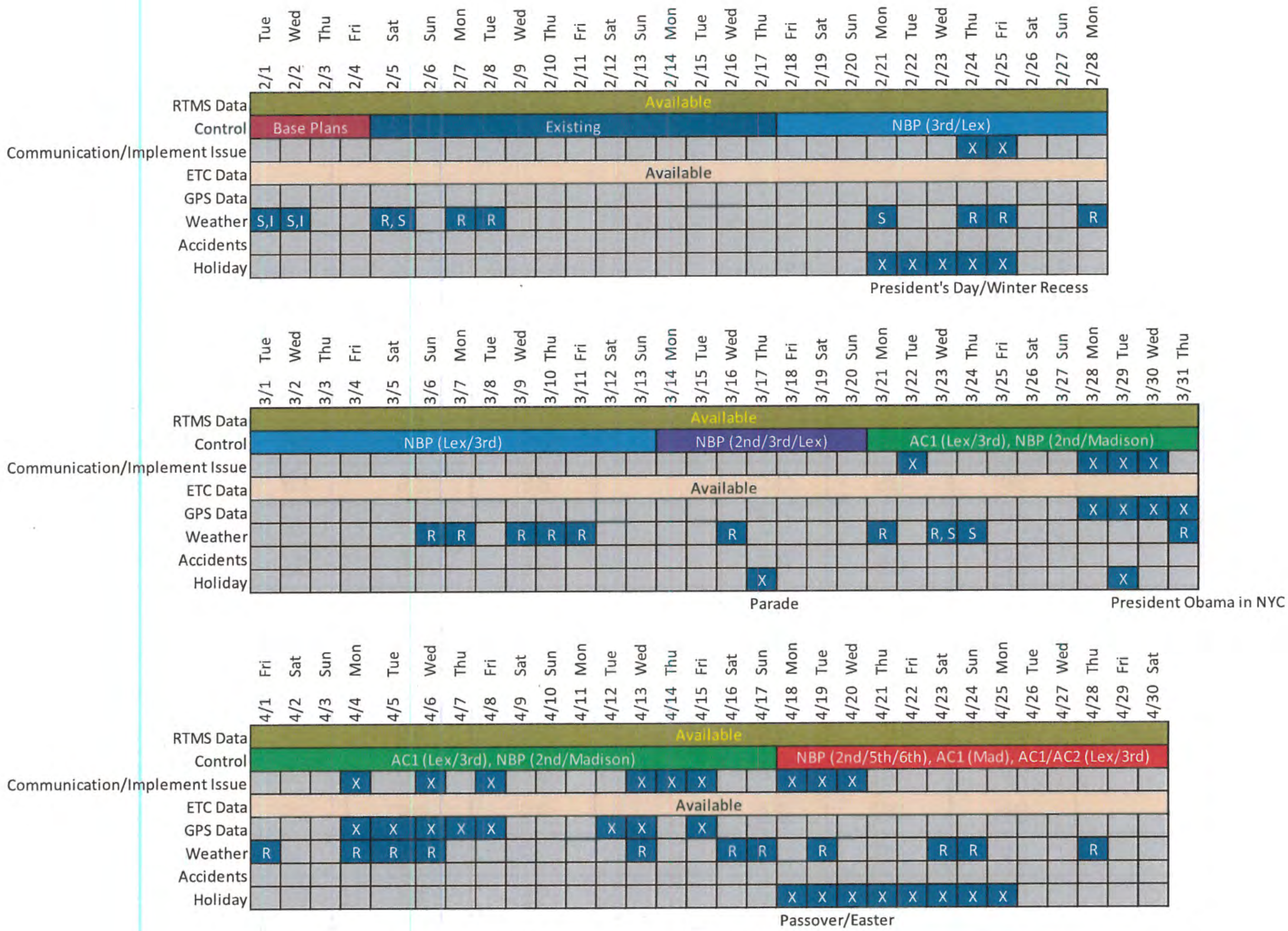


Figure A-2 – Calendar (February 2011 to April 2011)

Table A-2 – Proposed Signal Timings, 2nd Avenue

| Intersection | TP1 | | | | NBP | | | |
|---|---|---|---|---|---|---|---|---|
| | Offset | Phase 1 | Phase 2 | Phase 3 | Offset | Phase 1 | Phase 2 | Phase 3 |
| 2nd & 78th | 24 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 77th | 31 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 76th | 37 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 75th | 43 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 74th | 49 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 73rd | 54 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 72nd | 59 | 49 | 41 | | 20 | 50 | 40 | |
| 2nd & 71st | 65 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 70th | 70 | 54 | 36 | | 20 | 50 | 40 | |
| 2nd & 69th | 76 | 53 | 37 | | 20 | 50 | 40 | |
| 2nd & 68th | 81 | 52 | 38 | | 20 | 50 | 40 | |
| 2nd & 67th | 88 | 51 | 39 | | 20 | 50 | 40 | |
| 2nd & 66th | 4 | 50 | 40 | | 20 | 50 | 40 | |
| 2nd & 65th | 9 | 50 | 40 | | 20 | 50 | 40 | |
| 2nd & 64th | 14 | 50 | 40 | | 20 | 50 | 40 | |

**Note:** TP1 (Timing Plan 1) is the NYCDOT base plan labeled as Pre-existing plan in the analysis for this arterial section.