COORDINATED INTELLIGENT TRANSPORTATION SYSTEMS DEPLOYMENT IN NEW YORK CITY (CIDNY)

FINAL REPORT

TASK 5

DEVELOP A COMPREHENSIVE GUIDE TO TRAFFIC SIGNAL TIMING, NEW DETECTION TECHNOLOGIES AND ADVANCED SIGNAL TIMING CONCEPTS APPLICABLE IN NEW YORK CITY

Performed by: New York University

U.S. Department of Transportation
Federal Highway Administration

NEW YORK STATE OF OPPORTUNITY. Department of Transportation

NEW YORK CITY DOT

University Transportation Research Center - Region 2

ABOUT THE PROGRAM

The FHWA, through its New York Division/New York City Metropolitan office is promoting programs pertaining to urban Intelligent Transportation Systems (ITS) in the region. The NYCDOT and NYSDOT-Region 11 Planning have taken the initiative in working with FHWA to take advantage of this FHWA program. NYCDOT and NYSDOT have developed the Training Courses and Research and Development Programs for the NYCDOT and NYSDOT Coordinated Intelligent Transportation Systems Deployment in New York City (CIDNY) which is a set of multi studies (task assignments) toward the fulfillment of the objectives of these programs.

The 2013 studies are being performed by institutions of the Region 2 University Transportation Research Center (UTRC). The studies focused on the following program areas: Construction Management, Traffic Demand Management, Dynamic Data Collection, Traffic Incident Management, Traffic Signal Timing and Detection Technologies, Strategic ITS Deployment Plan, Pedestrians and Cyclists Safety, Data Storage and Access Platform for MTA Bus Time Data.

The following tasks have been completed under this program.

- *Task 2 – Develop a multi-agency/multi modal construction management tool to enhance coordination of construction projects citywide during planning and operation phases to improve highway mobility and drivers experience*
- ***Task 5 –Develop a comprehensive guide to traffic signal timing, new detection technologies and advanced signal timing concepts applicable in New York City***
- *Task 6 – Strategic ITS Deployment Plan For New York City*
- *Task 7 – Research on Pedestrians and Cyclists Safety Using ITS Technology in NYC*
- *Task 8 – Develop Data Storage and Access Platform for MTA Bus Time Data.*

TASK 5 FINAL REPORT

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16. Abstract

The purpose of this guide is to provide some elementary guidance to beginning traffic engineers in the NYCDOT Signal Timing Division on the standards of signal timing in NYC. The guide is intended to provide an understanding of the influence of traffic signal design on traffic operations, and is a primer on traffic signal timing, phasing, and coordination. The guide provides an introduction to the types of traffic signal designs available, but it cannot take the place of the extensive knowledge, field experience, and engineering judgement required to become proficient in signal timing design. Additionally, an introduction to alternative priorities in signal timing is covered, such as transit signal priority (TSP) and the use of real-time data for adjusting signal timing plans.

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January 2017

Region 2
University Transportation Research Center

NEW YORK CITY
DEPARTMENT OF TRANSPORTATION

TRAFFIC SIGNAL MANUAL

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Chapter 1 INTRODUCTION

1.1 History of the Signal System in NYC

Until 1920, traffic signals did not exist in NYC. Police officers were stationed at a few of the busiest intersections to facilitate the flow of traffic, but as the number of automobiles increased, the need for a more consistent type of controller became apparent. In 1920, the first installations of tall box-type towers were placed down the middle of 5th Avenue. A police officer stood in the tower and manually changed the traffic signal. A simple coordination of traffic flow was performed by the officer by looking upstream at the previous signal. It was not until 1927 that automatic traffic signals were designed to be placed on the corners rather than in the middle of the street [1, 2].

Although the first traffic signals were three-head signals with green, yellow, and red indications, in 1929 the three head signals were abandoned for two-head signals (two-color only - red and green), since motorists did not fully understand the meaning of the yellow phase and either sped up to rush through the intersection or stopped too early, leading to crashes. In the first two-color traffic signals, a black-out period was shown to warn vehicles that the signal would be changing to red. Later, the black-out period was replaced by both the red and green indication being displayed together [3]. The two-color system was introduced throughout the City and by the 1940's they were the standard control type at signalized intersections.

It was not until the 1950's that the yellow change interval in a three-head traffic signal was re-introduced. Over the next 20 years, most of the two-head signals had been upgraded to three-head traffic signals.

In the 1930's, experiments with various types of pedestrian signals began, and in 1952, the first red "Don't Walk," and green "Walk" pedestrian signal was installed in Manhattan [3].

Traffic signals mounted on poles and placed on the corners had problems with visibility. In 1954, the first mast-arm/guy wire set up was installed, suspending traffic signals 20-feet high. By 1970, the majority of traffic signals in NYC were suspended [3].

1.2 History of Controllers Used in NYC

Early traffic signals were controlled by electro-mechanical controllers, consisting of cams, dials, and shafts. These had a fixed timing plan controlled by dial timers, with small gears within the timer that set the cycle length. NYC used such controllers into the late 1990s (there are still a few in existence to this day).

These controllers worked fairly well in the one-way grid system of Manhattan, but were limited by their ability to only have one timing plan programmed for the entire day. This meant that the timing plan could not be changed to accommodate various traffic patterns throughout the day. If a change in coordination plan was desired, engineers had to go to each intersection and manually change the dials.

In 1995, vehicular traffic control systems (VTCS) were installed on certain arterials in Manhattan. The VTCS system allowed for programming different timing plans for various times during the day, without interconnection being required. VTCS systems cannot respond to incidents or special events that cause changing traffic demand and possible oversaturation, but are set as fixed time signals, based on history of traffic demand for AM, Midday, and PM patterns.

Most controllers are now computerized. Computerized controllers allow for more traffic timing plans to be saved and implemented at various times during the day. However, there is no traffic responsive component that can adjust the timing plan based on real-time changes in traffic flow. The next level of controllers is now being installed, however.

In 2011, NYCDOT installed the first Advanced Solid State Traffic Controllers (ASTC). ASTC controllers can be controlled wirelessly, allowing for quickly adjusting signal timings in real-time. These were custom designed for NYC so that they could be installed in large scale. Signal timing settings can respond to changes in traffic due to increased demand and/or isolated incidents, such as, double-parked vehicles, a temporary lane closing, or crashes. The use of ASTC controllers will be discussed further in Chapter 3.

1.3 The Need for Timing and Retiming of the NYC Network

The timing and coordination of traffic signals in NYC must be continuously monitored in order to keep vehicular traffic moving as efficiently as possible. There are close to 13,000 signalized intersections in NYC, and approximately 98% of them are part of a coordinated network. Networks that are not timed to be well coordinated increase traffic delays, pollution, and fuel consumption. Planning is needed to develop and revise signal timing plans, to evaluate them (most often using software), and then to refine, fine tune, and install the new timing plan. After installation, the engineer will go into the field to observe the new timing plan and possibly refine some more.

The following situations that may require the retiming of the signal include:

- Change in traffic conditions, including demand changes, saturation, spillback
- Change in land use
- Requests from the public

- Crash history
- Geometric improvements

1.4 Scope and Purpose of this Guide

The purpose of this guide is to provide some elementary guidance to beginning traffic engineers in the NYCDOT Signal Timing Division on the standards of signal timing in NYC. The guide is intended to provide an understanding of the influence of traffic signal design on traffic operations, and is a primer on traffic signal timing, phasing, and coordination.

The guide provides an introduction to the types of traffic signal designs available, but it cannot take the place of the extensive knowledge, field experience, and engineering judgement required to become proficient in signal timing design.

Additionally, an introduction to alternative priorities in signal timing is covered, such as transit signal priority (TSP) and the use of real-time data for adjusting signal timing plans.

1.5 Organization of the Guide

Chapter 2 discusses the workflow of the signal timing division. The chapter gives an overall summary of the steps involved in placing a new signal or making changes to an existing signal in the NYC network. There are four units in the signal timing department. They are:

- The Intersection Control Unit, which collects and analyzes all of the data
- The Design Unit, which plans the layout of the intersection, including placement of the signals, controllers, and other hardware, as well as the geometric features, such as turn bays and bike lanes.
- The Signal Timing Unit, which develops all the timing plans for the vehicle, pedestrian, and bicycle signals, as well as all of the coordination plans.
- The Construction and Maintenance Unit, which oversees all of the construction and maintenance contractors.

Chapter 3 covers the details of the signal timing process, including determining the best phase plan, calculating the pedestrian signal timing, the vehicular signal timing, and coordination plans.

Chapter 4 discusses two reference manuals that are used by each of the units in the signal timing division. The two manuals are:

- The Manual on Uniform Traffic Control Devices (MUTCD), which contains the federal standards for placement of all traffic control devices.

- The Highway Capacity Manual (HCM), which is a collection of deterministic methodologies for estimating capacity and other measures of effectiveness of both interrupted and uninterrupted facilities.

Chapter 5 discusses the software programs that are used by the signal timing division, including Tru-Traffic, Synchro, SIDRA, and Aimsun.

Chapter 6 is a glossary of terms that are used throughout the guide.

References

[1] "History of the New York Traffic Lights," NY Times, May 16, 2014 http://www.nytimes.com/2014/05/18/realestate/a-history-of-new-york-traffic-lights.html

[2] New York City and the History of Traffic Lights on Fifth Avenue, 2012 http://stuffnobodycaresabout.com/2012/06/27/old-new-york-in-photos-19/

[3] "New York City Intersections," http://highwaydivides.com/wiki/index.php?title=New_York_City_Intersection

Chapter 2 OVERVIEW OF SIGNAL INSTALLMENT PROCESS

There are four units that oversee adding and/or changing a traffic signal control in NYC. The initial analysis begins in the Intersection Control Unit and then flows through the Design Unit, Timing Unit, and the Construction/Maintenance Unit. Figure 2.1 is a flowchart of the methodology for performing an intersection control analysis. The following sections in this chapter describe the responsibilities of each unit.

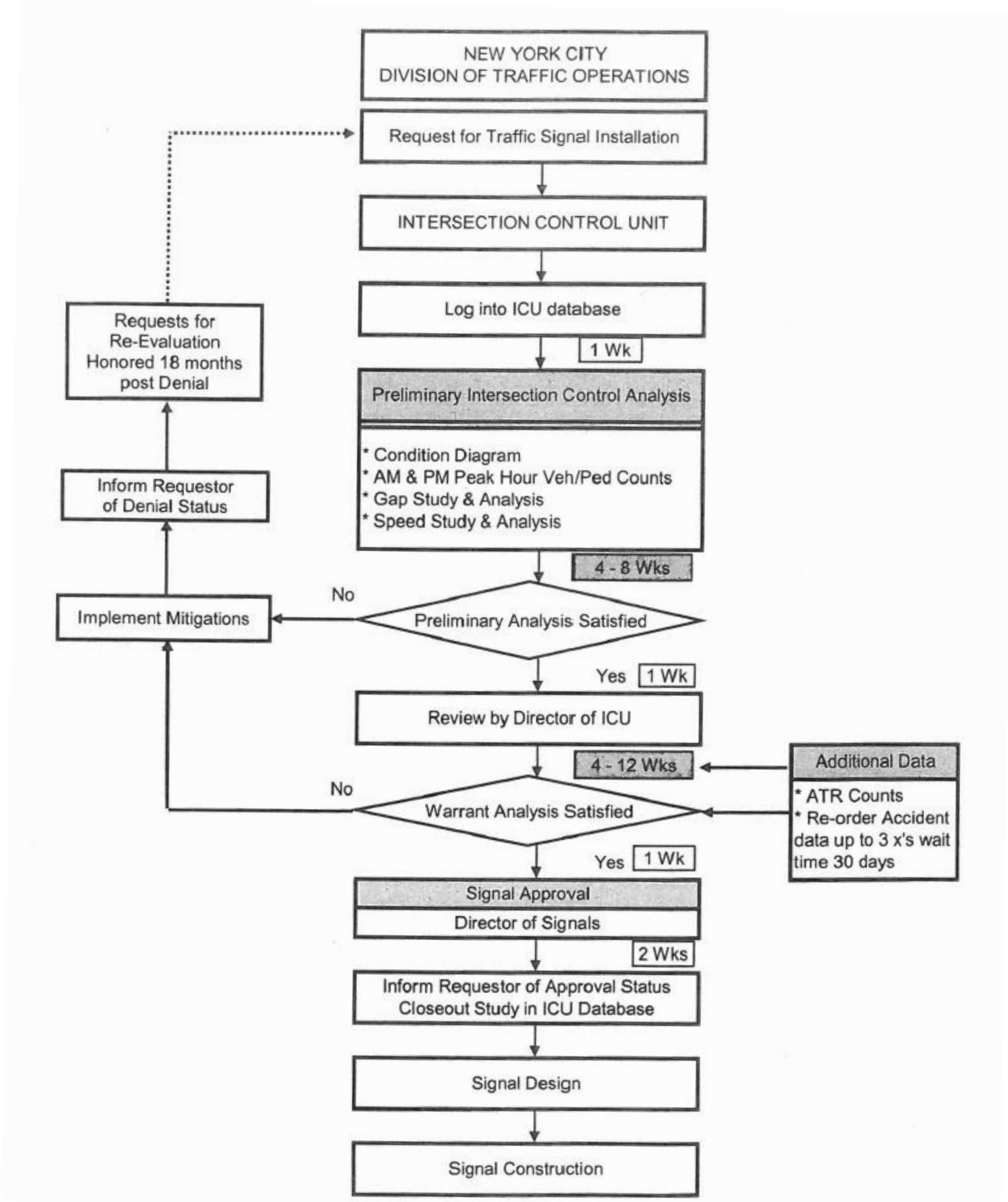


Figure 2.1 Flowchart of the Intersection Control Decision, Design & Placement Process

2.1 Intersection Control Unit

The Intersection Control Unit (ICU) determines where (at what location), when, and why a new traffic signal and/or other traffic control devices should be placed. The ICU is in charge of collecting all the relevant data and performing the required analyses needed to make the decision for a new traffic signal and/or for recommending other treatments. Additionally, the ICU collects the necessary data in response to complaints/concerns regarding existing intersections, such as a request for an exclusive left-turn phase.

When considering a new signal, the following steps are taken in the ICU in order to make the determination as to whether a new signal should be installed or not.

1. *Request for New Signal Received.*
   New signal requests can come from many different sources. All requests are fully considered and responded to by letter or email, with an explanation of the reasons for the decision. Requests can come from the following sources:

   a. The general public can make a request by writing a letter, sending an email, or calling 311
   b. Other city or state agencies such as NYCT, DDC, FDNY, NYPD etc.
   c. Elected Officials (Senators, Council, Assembly and Congress members, and Borough Presidents)
   d. Community Boards
   e. Observation in the field of a safety concern by an agency personnel
   f. Consultants that are doing studies for Developers can submit a request (this request is handled differently from the previous sources and will be discussed later in the chapter)

2. *Location Review*.
   After a request has been made, the first step is to determine if a traffic signal study will be opened or not. If there is no previous study at the given location, or if the study is more than 18 months old, a new signal study is always initiated. A new signal study will always be opened when there is a change of land use, such as a new school or mall nearby.

   At a location which has undergone a previous traffic signal study within the past 18 months, the location and data are reevaluated. A new accident summary is generated from the NYPD's Accident Index Summary System. If, since the previous study, five or more crashes have occurred, then new accident reports (MV-104) from the NYPD are requested. The prior study file, the new accident summary and all correspondence are given to the ICU Chief, Ben Eliya, P.E., for review.

   If a new traffic signal study will not be initiated, a letter or email explaining the decision is sent to the original requestor.

3. *Initiate New Study.*

A new study requires collecting the following field data:

a. Vehicular and Pedestrian Volumes. Turning Movement Counts (TMCs) are collected for the A.M and P.M peak periods. Should the location have high pedestrian volume such as at a hospital, park, or school, then midday counts are required. For a school location, counts are collected at dismissal time as well.
   i. When vehicular volumes observed exceed the volume threshold, Automatic Traffic Recorders (ATRs) are installed at appropriate locations in the study area for two consecutive weeks.
b. Speed data. Data is collected manually using a radar gun. Data is collected for 100 vehicles or 30 minutes, whichever condition is met first.
c. Available gaps for pedestrians are measured.
d. Accident Data for the past 12 months are gathered from NYPD accident reports and the NYSDOT accident data base.

A complete Intersection Control Analysis booklet is always created as the final document of a new intersection study. This booklet summarizes all of the data needed for making a final decision. (Appendix 2A contains a copy of the Intersection Control Analysis booklet). The Intersection Control Analysis booklet includes the following documents.

a. Spatial Data Warehouse Map. This map is obtained from NYCDOT's SharePoint collaboration tool and shows all of the signal locations and stop sign locations in NYC.
b. School Map (if required). A print out of the area around the location under study with the study location and any nearby schools clearly marked. (See Figure 2.2).
c. Condition Diagram. A condition diagram shows all physical features at the intersection. This includes geometric conditions (street and sidewalk widths, number of lanes, street directions, location of any signs and markings, land use, and street furniture). Figure 2.3 shows a completed condition diagram.
d. Block Front Survey (if required). A block front survey shows the location and type of parking on the block, where any driveways are located, and reports the area type as residential, commercial, industrial, or other. A block front survey is not required when daylighting is not recommended based on the field observations. Daylighting clears the sight lines for pedestrians by removing parking spaces in front of the crosswalk. Improving pedestrian visibility improves pedestrian safety.
e. Field Observation Report. The field observation report asks a series of questions about other factors that might influence the decision. (See Appendix 2A).

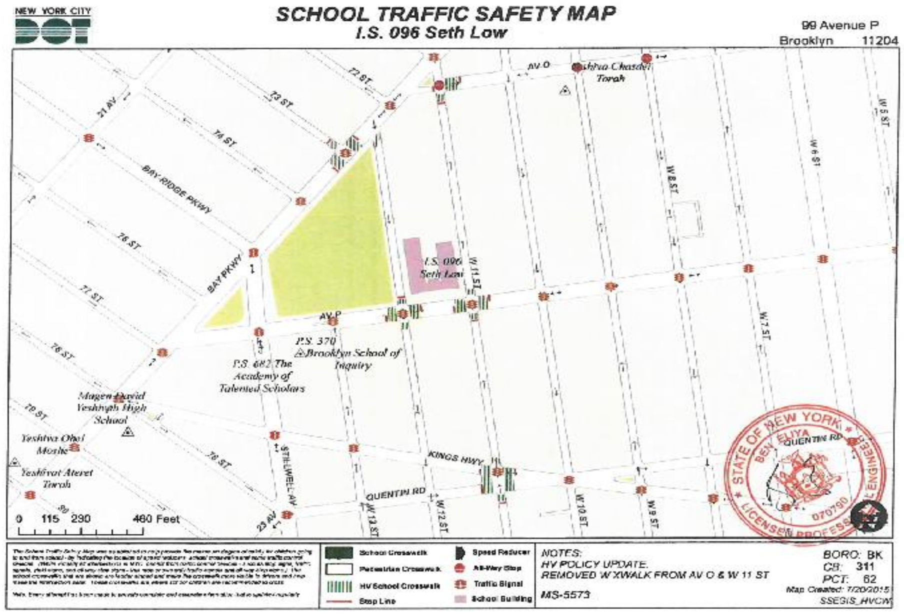


Figure 2.2 Example School Map added to ICU book, when required

f. Vehicle Classification and Turning Count Sheet. This sheet summarizes all vehicle counts, separated by vehicle type and movement, as well as pedestrian counts separated by the number of senior citizens, children, and people in wheel chairs. (See Appendix 2A).
g. Intersection Control Data Collection Analysis (Factor) Sheet. This sheet summarizes all of the data used for each warrant. (See Appendix 2A).

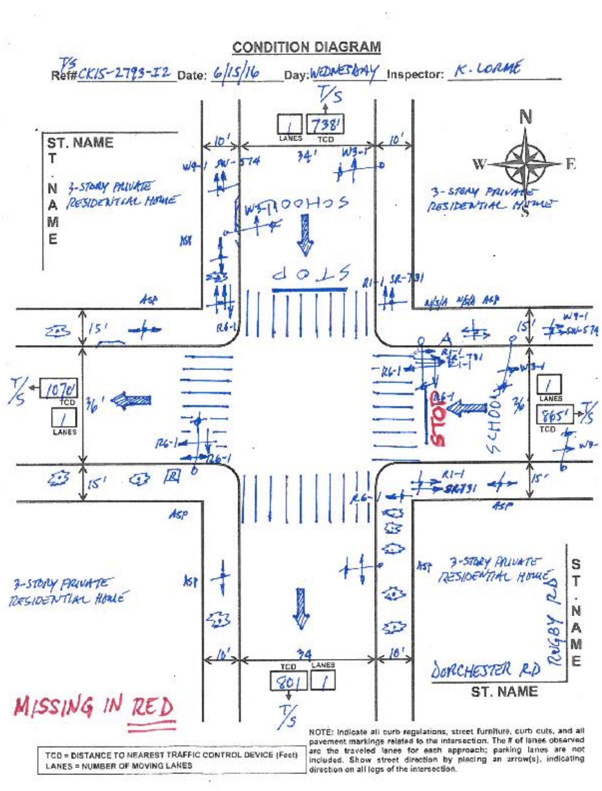


Figure 2.3 Example Condition Diagram

h. MUTCD Warrant Sheets. All nine warrant sheets are included, with a place to enter if the warrant is met or not. (See Appendix 2A.) The warrants are:
   i. Warrant #1. Eight-Hour Vehicular Volume
   ii. Warrant #2. Four-Hour Vehicular Volume
   iii. Warrant #3. Peak Hour Vehicular Volume and Intersection Delay Study
   iv. Warrant #4. Pedestrian Volumes
   v. Warrant #5. School Crossings
   vi. Warrant #6. Coordinated Signal System
   vii. Warrant #7. Crash Experience.
   viii. Warrant #8. Roadway Network Warrant
   ix. Warrant #9. At-grade Railroad Crossing Warrant

The first seven warrants are always used. Warrant #8, the roadway network warrant, and Warrant #9, the at-grade railroad crossing warrant, are rarely used.

Only one of the warrants needs to be met to recommend the installation of a traffic signal. Chapter 4 will describe the warrants and how they are used.

All relevant crash reports and summaries are attached at the end of the Intersection Control Report. Relevant crashes are those that might be preventable with the addition of a signal, such as pedestrians hit by vehicles crossing the major street, right-angle crashes, and left-turn vehicles crashing with opposing through traffic. Rear-end crashes are not included.

4. *Engineering Evaluation*.

   The engineer reviews the Intersection Control Analysis book, as well as the proximity of the study intersection to existing traffic control devices. Visibility for the drivers is checked. The geometry and number of lanes are considered. The number of senior citizens and children are also taken into consideration. Engineering judgment is used to make the final decision, and recommendations based on the engineering study, are documented.

5. *Senior Review.*

   The study must be signed off by three people.

   1) Chief of the ICU, Ben Eliya, P.E.
   2) Director of Signals and ITS Engineering, Ernest Athanailos, P.E.
   3) Director of Signals Operations and Street Lighting, Alan Borock, P.E.

6. *Notify Requestor.*

   A response letter is always written to the original requestor detailing the final decision and explaining why that decision was made.

7. *Signal Implementation.*

   If a signal is to be installed, the entire report is then sent to both the Design Unit and to the Timing Unit. When a signal is denied by ICU, the location is then analyzed for an enhanced crosswalk study. The policy for considering an enhanced crosswalk is described in Appendix 2C.

8. *Data Storage.*

   All of the data and applicable reports are scanned and uploaded into the Signal Work Orders Tracking System (SWOTS), an internet based data network. All decisions are documented in SWOTS, with a section for any comments to document recommendations, such as refurbishing markings, speed enforcement, etc. Hard copies of the studies are kept for three years and then sent for storage. All data is additionally uploaded to the NYCDOT Traffic Information Management System (TIMS).

Additional Studies. For existing signalized intersections, based on the nature of the request, the ICU collects data for:

- Leading Pedestrian Interval (LPI)
- Left-turn studies.

- Accessible Pedestrian Signal (APS) studies, which consider the number of lanes being crossed, whether there are pedestrian ramps or other pedestrian amenities, as well as what facilities for blind and visually-impaired people are nearby. If a recommendation is made to install APS, based on the intersection ranking, the APS is designed and installed.
- Other types of controls, such as multi-stop signage.

There are two exceptions to the above process:

1. The process described above is somewhat different when the request comes from a consultant. The consultant creates the entire Intersection Control Analysis book and sends the book to the Signals Engineering and ITS Unit senior engineers, Emad Makarious, P.E. and Jenny Baez, P.E. After it is reviewed and a decision is made, it is sent to the senior staff of Step 5.

2. Regardless of how the request comes in, if the request is at a T intersection with a minor street or a mid-block location, then the request is sent to the pedestrian group. The pedestrian group has their own warrants for installing crosswalks at uncontrolled locations.

Note: At the time of this document's completion, ICU is updating several of its standard operating procedures and protocols. Once complete, ICU will update the sections of this chapter accordingly.

2.2 Design Unit

The Intersection Design Unit determines where all above ground hardware will be placed at the intersection. This includes signs, signal posts, signal heads, pedestrian signals, APS units, control cabinets, and street lighting.

After a new signal is approved by the ICU and senior staff, the Intersection Control Analysis book is sent to the Design Unit. The Design Unit takes the book and begins to design the layout of the intersection as follows.

1. *Inspect the Intersection*. The condition diagram is examined to determine what is out there, such as how many legs there are and what issues there are to deal with. Engineers go out and take photos of the intersection and make notes on any special conditions that might be encountered, such as an underground vault, power line or sewer line running below that may affect the design. This information will then be added to the drawing. During this fieldwork, the engineer will look at the layout of the nearest upstream and downstream intersections, because when the new intersection is planned, the Design Unit tries to have consistency in the layouts.

2. *Prepare First Draft*. A design drawing is created using AutoCAD that lays out the placement of the hardware from the rough information gathered. In this first draft, lanes are not included. Guidelines used for creating the intersection design are from the NYCDOT Traffic Signal Standard Drawings (shown in Figure 2.4), NYCDOT Specifications manual, and the MUTCD Specs Guide.

3. The draft is sent to the timing unit where the phasing sequence and timing is determined and then embedded into the AutoCAD drawing. Figure 2.5 shows a sample intersection design drawing before phasing and timing plans are determined. This drawing is sent to the timing unit, which adds the phasing plan.

Figure 2.4 NYCDOT Traffic Signal Standard Drawings

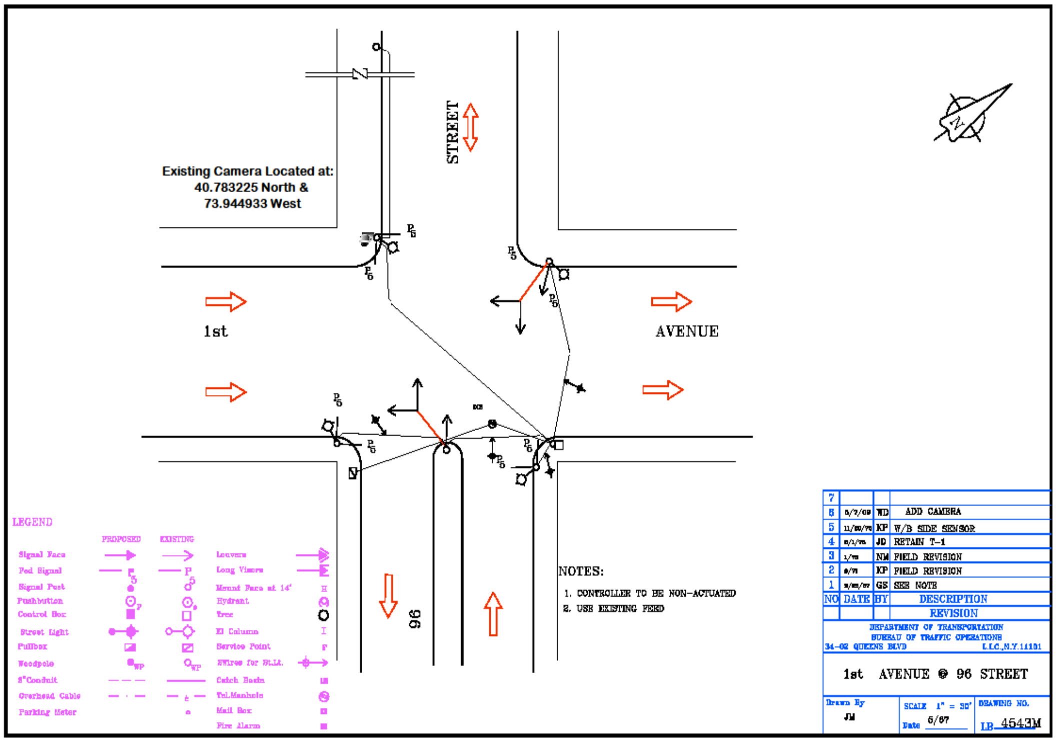


Figure 2.5 Example Initial Intersection Design Drawing, 1st Avenue @ 96th Street

4. *Drawing Returned to Design Unit*. After the phasing and timing plan is added to the drawing, the intersection design drawing is then returned to the Design Unit for review. If countdown signals or APS units, etc. are going to be placed based on decisions in the timing and ICU units, these are added to the design drawing.

5. *Coordinate with Highway Design Unit*. The Design Unit then coordinates with the Highway Design Unit to determine the number and type of lanes and specific geometric design. These details are then added to the intersection design drawing. Hardware may also need to be changed due to special geometric designs. Figure 2.6 shows a completed intersection design drawing for the same intersection.

6. *Review*. The completed drawing is checked again by the Director of the Design Unit before final approval.

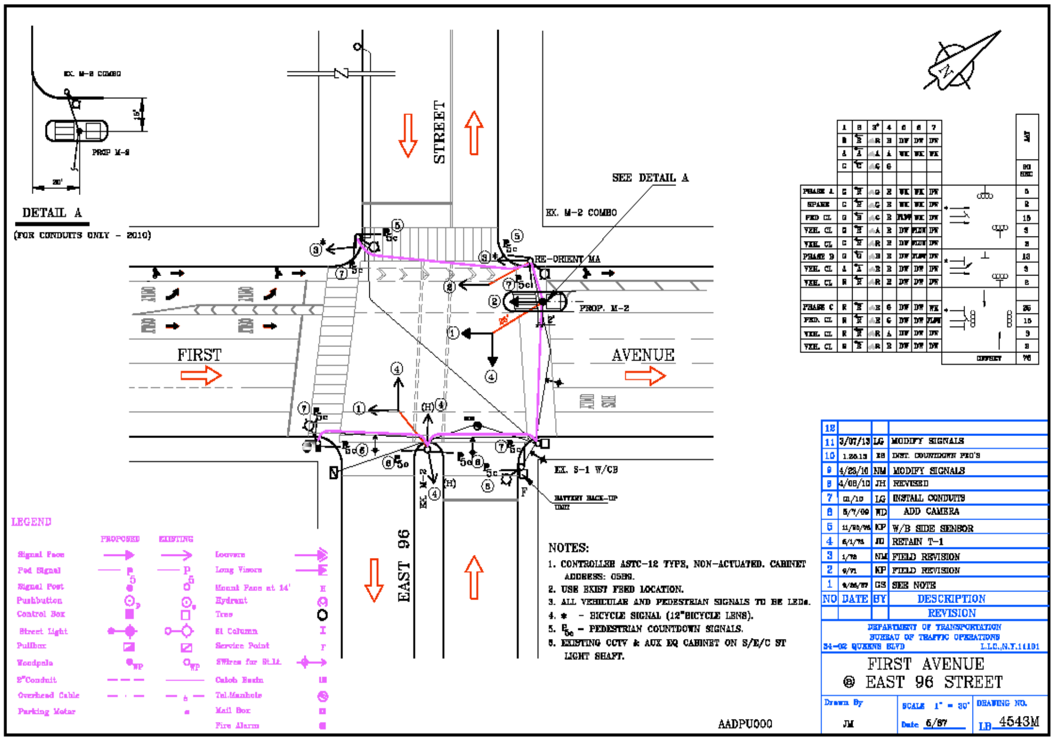


Figure 2.6 Completed Intersection Design Drawing after Phasing and Timing Plan Added, 1st Avenue at 96th Street

7. *Senior Review.* The design drawing has to be signed off by three people.
   a. Director Signal Design, James C. Huey
   b. Director of Signals and ITS Engineering, Ernest Athanailos, P.E.
   c. Director of Signals Operations and Street Lighting, Alan Borock, P.E.

8. *Storage*. Store intersection design drawings. The design maps are stored in CAD files and filed by the Borough Engineer. The Design Unit keeps a hard copy of all drawings.

9. *Send to Construction Unit*. After being signed off by the Senior staff in step 7, the Design Unit chief releases a work order for the contractor. The traffic contractor has approximately 45 days to implement the installation. The final design drawing goes to the Construction Unit, the Highway Design Unit, and to the Borough Engineer.

2.3 Timing Unit

The timing unit determines the cycle length, phasing and phase times for every signal in NYC. This includes signals for vehicles, pedestrians, and bicycles, at all intersections and mid-block crossings.

The timing unit works closely with the other units to complete the intersection layout drawing so that it can then be sent to construction. The completed Intersection Analysis Control book from the ICU unit is used to make the determination as to what phases and timings are needed. Once a decision is made for phasing and timing, the phase diagram is added into the intersection layout drawing received from the design unit. There are checks and double checks between the Timing and Design Unit before sending the drawing to the Construction Unit. Chapter 3 is dedicated solely to the responsibilities of Timing Unit and goes into detail of the phasing and timing process.

2.4 Construction and Maintenance Inspection Unit

The Construction and Maintenance Inspection Unit, also known as the Electrical Inspection Unit (E.I.U), oversees the day-to-day operations of the outside contractors who construct, modernize and maintain intersections throughout NYC. The E.I.U. is overseen by the Director of E.I.U. The Deputy Director reports directly to the Director. There are eight managers that report to the Deputy Director. The eight managers include one manager for each of the five boroughs, one for night operations, one for construction related issues, and one for special operations and events. Each borough is divided into many subareas, and each subarea is assigned to an inspector, whose main responsibility is to inspect all construction and maintenance work taking place in the assigned subarea. The inspectors report to their borough manager.

2.4.1 Construction

The construction process begins when the Design Unit gives the finished drawing to the E.I.U. and the contractor. The contractor foreman and the borough manager then meet on site to layout the job together. Once construction begins, the contractor must submit progress report when they have completed a work phase. There are three phases of work: the digging/underground phase which includes conduit and pole foundation installations, the wiring phase is the erection of posts and installation of signals, and the restoration phase is the permanent restoration of the roadway and sidewalk. The area inspector is responsible for overseeing all construction activities.

The inspector will keep track of the work schedule and know when each step of construction occurs. For example, when the foundation is being dug or when posts are installed, or wiring is done, the inspector must monitors that the work is proceeding on schedule and check that it is being done correctly.

Contractors are out working every day at various locations. The contractors are required to notify their inspectors exactly where they are working each day. Many different sites are being worked on every day in each subarea and the inspector tries to go to each site once per day. If they are not able to go to a site, it will definitely be visited the next day. Each day a Daily Work Report is filled out and sent to the borough manager. Appendix 2B includes forms used by the E.I.U. Figures 2B1 and 2B2 show the daily work report forms.

In general, it takes approximately two weeks to complete construction of a new intersection. When a job is complete, the inspector writes up an Operations Order, which is sent to Con Edison and to the maintenance contractor. The inspector is also responsible for filling out a Final Inspection Checklist to make sure that nothing was missed (See Figure 2B3).

Additionally, a written inventory of all materials that are used for construction is kept. Whatever materials are not used, the contractor leaves in the inventory kept by the E.I.U. (See Figure 2B4). At the end of the contract, any unused materials issued to the contractor or purchased by him as detailed in the contract, shall be returned to the Department.

When the work is complete, a release form needs to be signed by the inspector, the borough manager, and the Director of the E.I.U.

All documents related to a job are stored in a hard copy file. This file is kept from the day construction begins to the present, and includes all documentation related to the location, such as drawings, maintenance sheets, documents of any changes, and bills. The documents are also scanned for additional backup.

2.4.2 *Maintenance*

The subarea inspectors and borough manager oversee all maintenance work done in their area of responsibility in order to ensure that the maintenance contractors are performing their required duties on time and correctly.

Maintenance contractors are required to make annual visits to every intersection in the five boroughs. During an annual visit, they are required to do a thorough check of the controller, its wiring and communication, as well as cleaning dust and checking air filters. Annual cleaning of every lens on every traffic and pedestrian signal is required. Every five years, the maintenance contractor must repaint the intersection and check brackets and swinging equipment. A stray voltage test must be performed at least once per year.

For reported issues, which are often called in to 311 by the public, the maintenance contractors are required to respond within a certain timeframe, depending upon the severity of the issue. Table 2.1 shows the response time by severity.

Table 2.1 Mandatory Response Times by Contractor

Issue	**Response Time**
Intersection all out; Timing issues	2 hours
Base Cover Missing	12 hours
One Vehicle signal lamp is out	48 hours

A log is run at various times to check for intersections that have repeated failures. The inspector will want to know what is going on at that intersection that is causing it to show up repeatedly in the log. The daily work report, shown in Figures 2B1 and 2B2, includes both maintenance and construction activities done by the inspector each day. Monthly progress meetings are held with both the construction contractors and the maintenance contractors to discuss the progress of work, the schedule, and any issues that are interfering with their responsibilities.

Appendix 2A
Intersection Control Analysis Book

New York City
Department of Transportation

INTERSECTION
CONTROL ANALYSIS

LOCATION

NEW YORK CITY DOT

I.C.U.

Rev: 03-04-2015/mot.

Loc: G:\ICU Documents\ICU\Study Book

ELECTED OFFICIAL ACKNOWLEDGEMENTS

Location____

Borough______________ Reference #__________________ CB #______

DOT Case # ______________________________________

Date notification was sent out ______________________________

BOROUGH PRESIDENT ________________________________

CONGRESS MEMBER ________________________________

STATE SENATOR __________________________________

ASSEMBLY MEMBER ________________________________

COUNCIL MEMBER _________________________________

C.B. MANAGER ___________________________________

REQUESTOR ____________________________________

Signal Approval

____
Location

☐ APPROVAL

☐ DENIAL

________________________ ________________________
BEN ELIYA, P.E. Date
Chief, Intersection Control Unit/ Count Shop

☐ APPROVAL

☐ DENIAL

________________________ ________________________
ERNEST ATHANAILOS, P.E. Date
Director of Signals and ITS Engineering

☐ APPROVAL

☐ DENIAL

________________________ ________________________
ALAN BOROCK, P.E. Date
Director of Signals Operations & Street Lighting

Intersection Control Unit

Location: ______________________________

File#: ______________________________

DOT Case #: ______________________________

Request: ______________________________

Requestor: ______________________________

Determination Date: ______________________________

Determination: ______________________________

Comments: Based upon our evaluation of data collected, it is our judgment that a traffic signal be approved under Warrant ______________________________

____

BEN ELIYA, P.E.
Chief, Intersection Control Unit/Count Shop

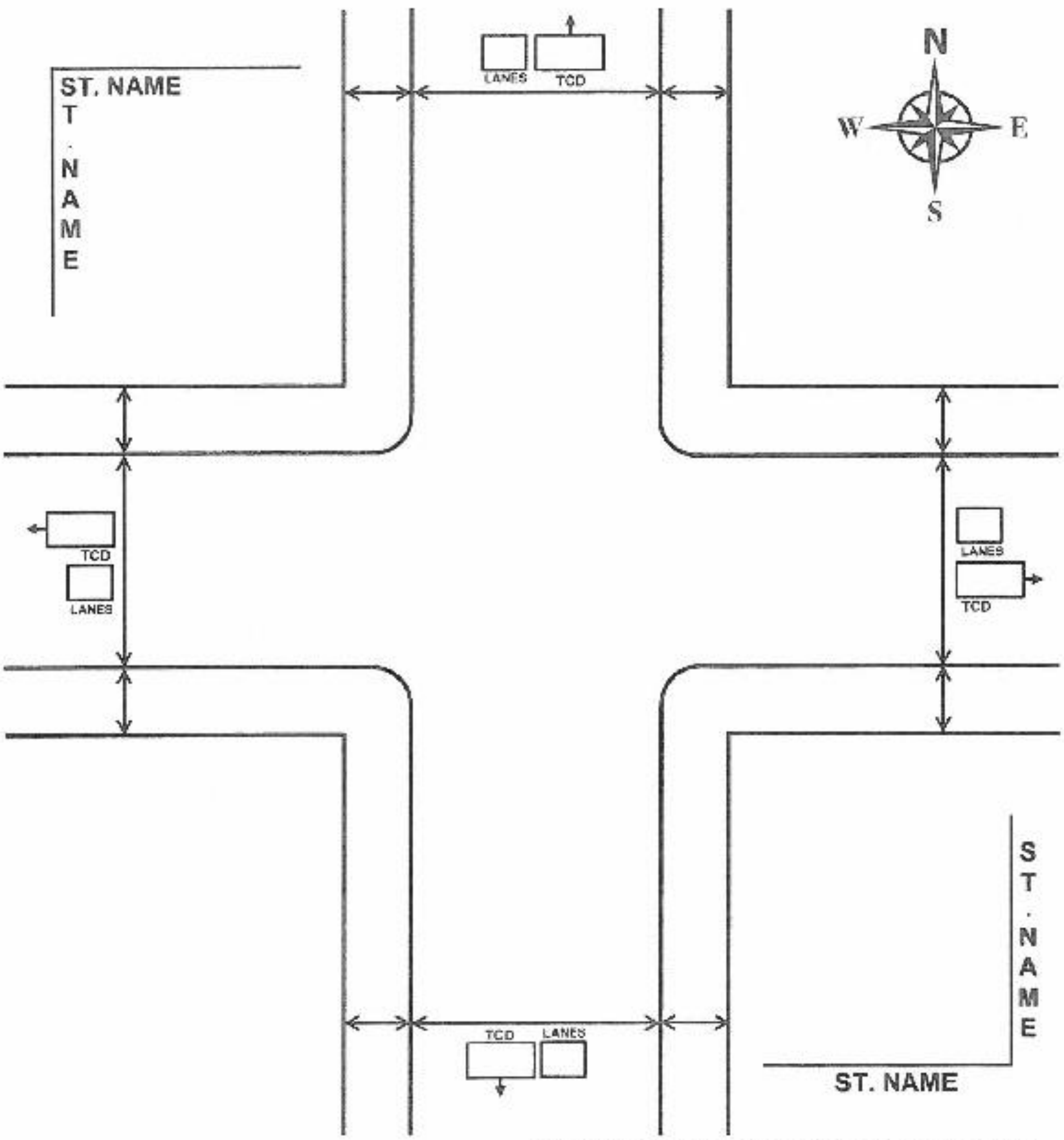
THE STUDY SHOULD INCLUDE THE FOLLOWING:

CHECK LIST

- ☐ **Data Warehouse map with legend & measurements**
  (Location of required Traffic Control Device to be highlighted with a red circle.)
- ☐ **School Map (if required)**
  (Location of required Traffic Control Device is to be highlighted with a red circle.)
- ☐ **Condition diagram** *(and proposed mitigations, markings, etc.)*
- ☐ **Block Front Survey (if required)**
- ☐ **Field Observation Report**
- ☐ **Volume counts**
- ☐ **Gaps (if required)**
- ☐ **Speeds** *(and memorandums on speed enforcement - if required)*
- ☐ **Analysis Factor Sheet**
- ☐ **Memorandums** *(on proposed mitigations, pavement markings etc.)*

CONDITION DIAGRAM

Ref#______________ Date: __________ Day: __________ Inspector: ______________

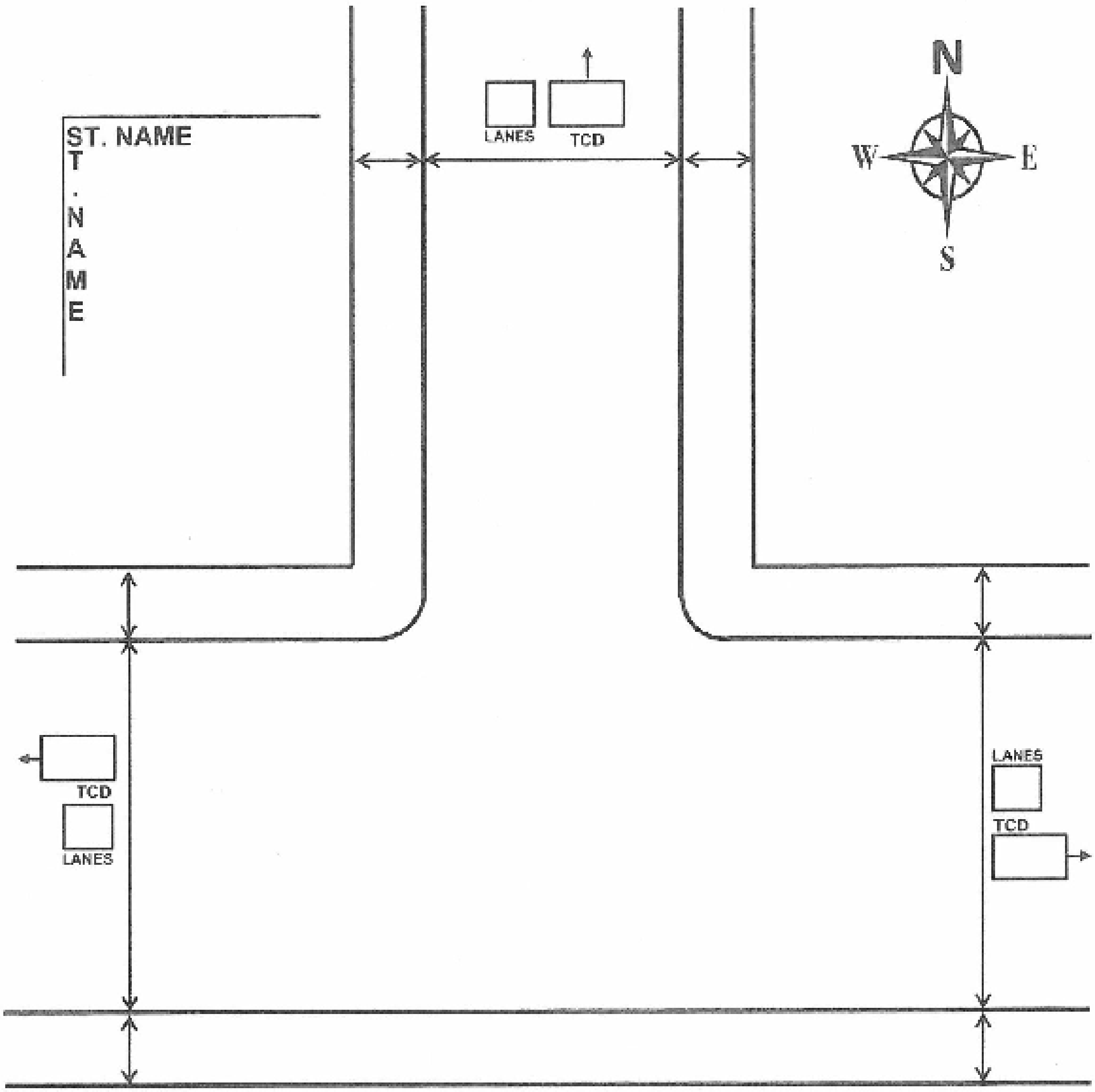


TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet)
LANES = NUMBER OF MOVING LANES

NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

CONDITION DIAGRAM

Ref#______________ Date: ___________ Day: ____________ Inspector: ________________

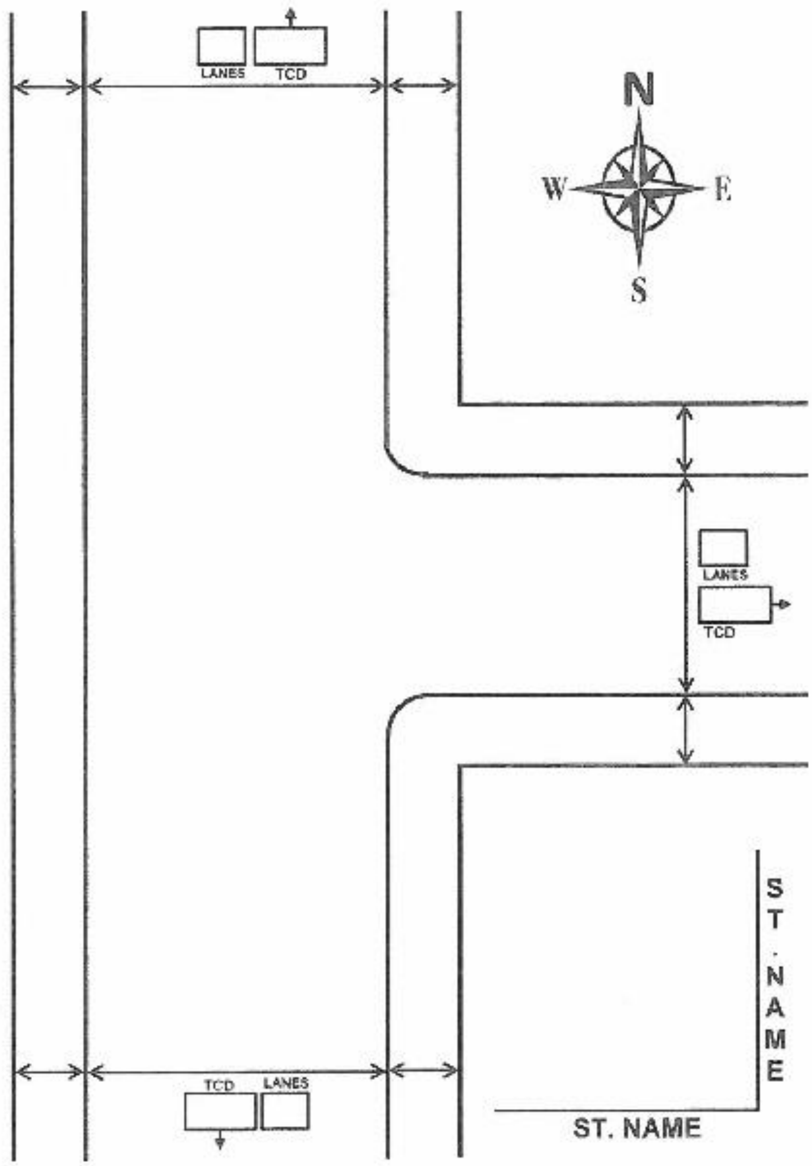


TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet)
LANES = NUMBER OF MOVING LANES

NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

CONDITION DIAGRAM

Ref#______________ Date: ___________ Day: ___________ Inspector: ________________

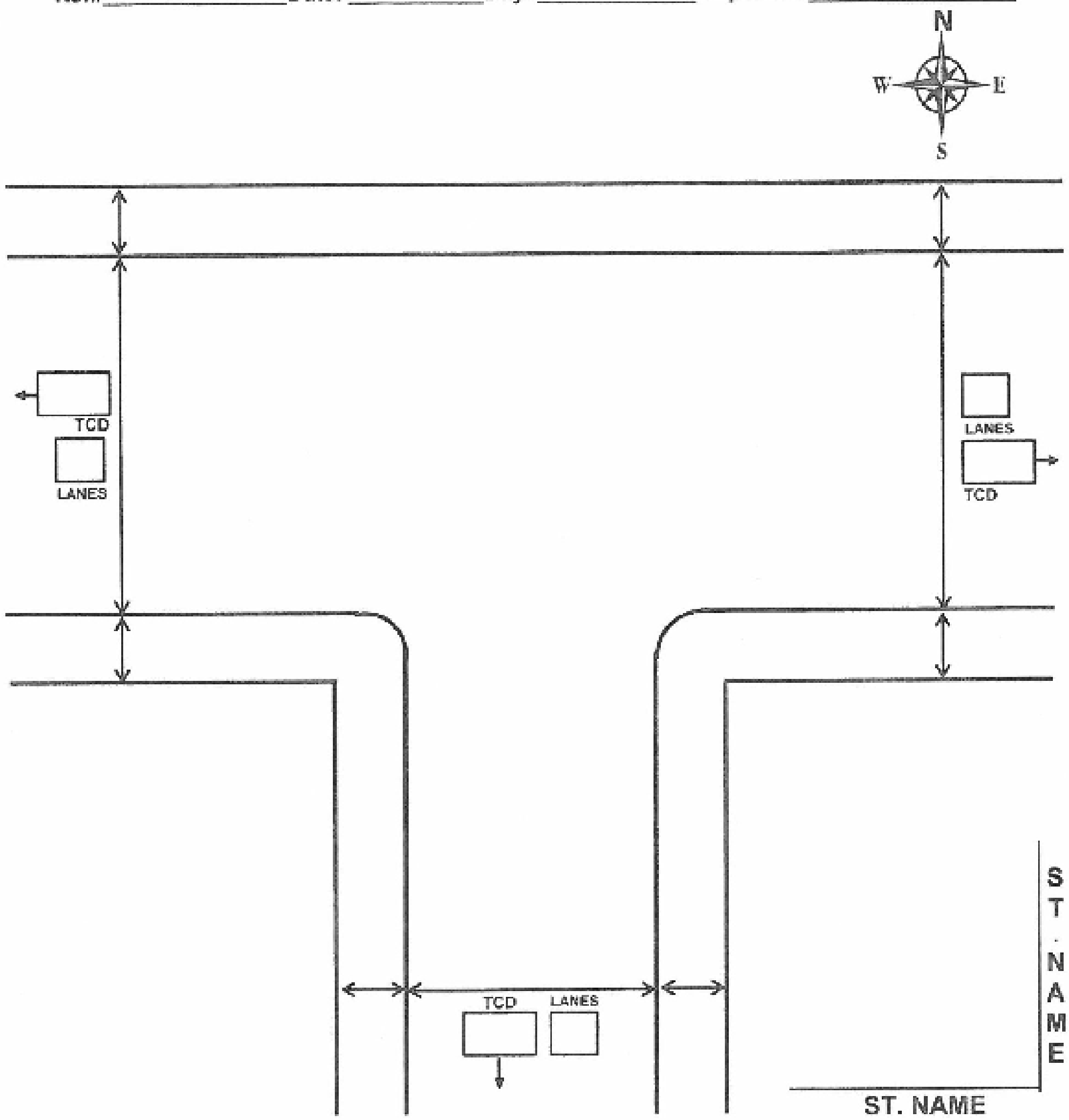


NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet)
LANES = NUMBER OF MOVING LANES

CONDITION DIAGRAM

Ref#______________ Date: __________ Day: ____________ Inspector: ________________

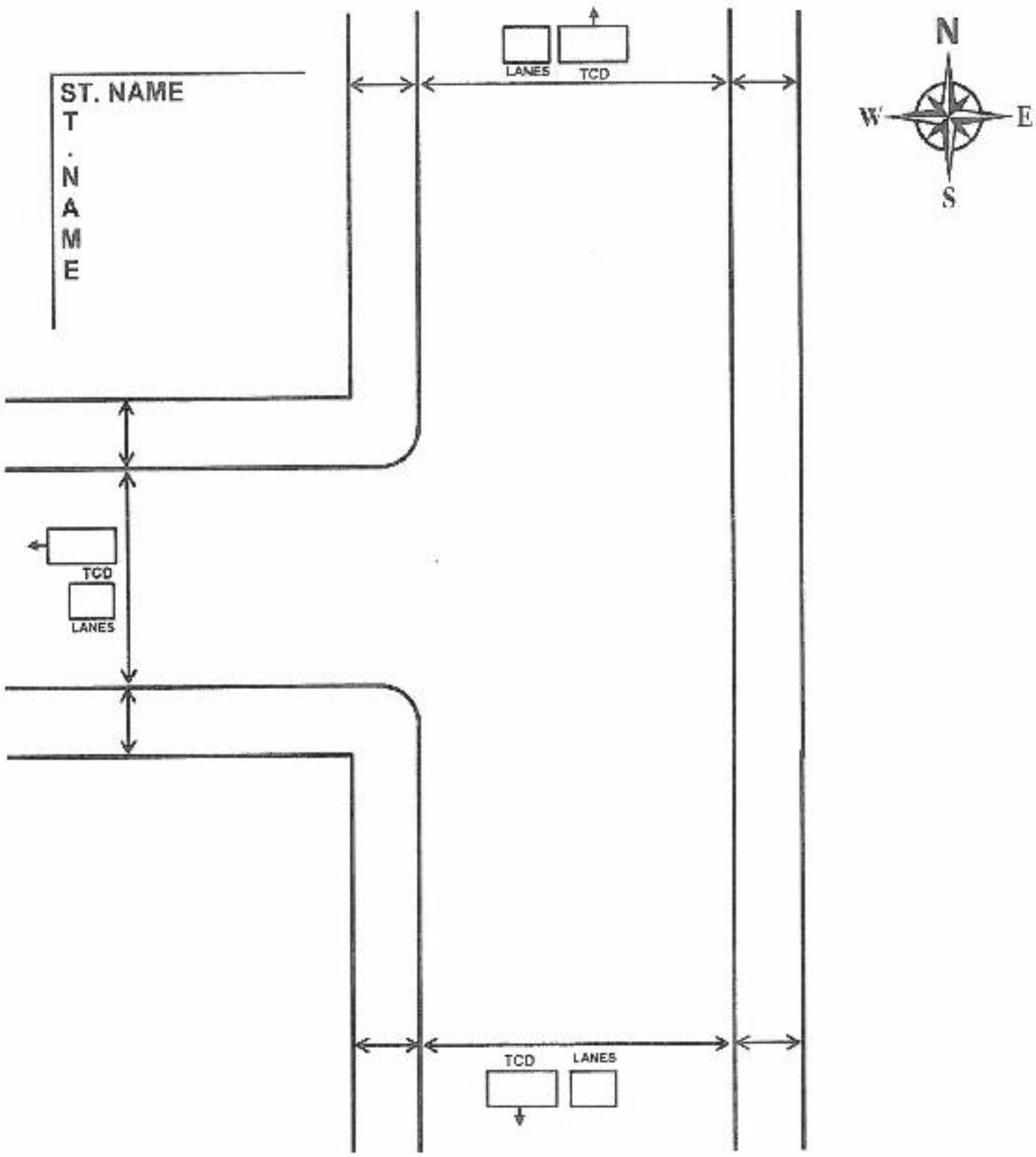


TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet) LANES = NUMBER OF MOVING LANES

NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

CONDITION DIAGRAM

Ref#_______________Date: ____________Day: ___________Inspector: _________________



TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet)
LANES = NUMBER OF MOVING LANES

NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

CONDITION DIAGRAM

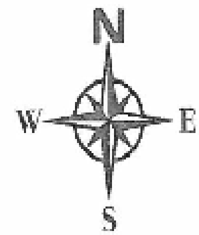
Ref#_______________ Date: ____________ Day: ____________ Inspector: __________________

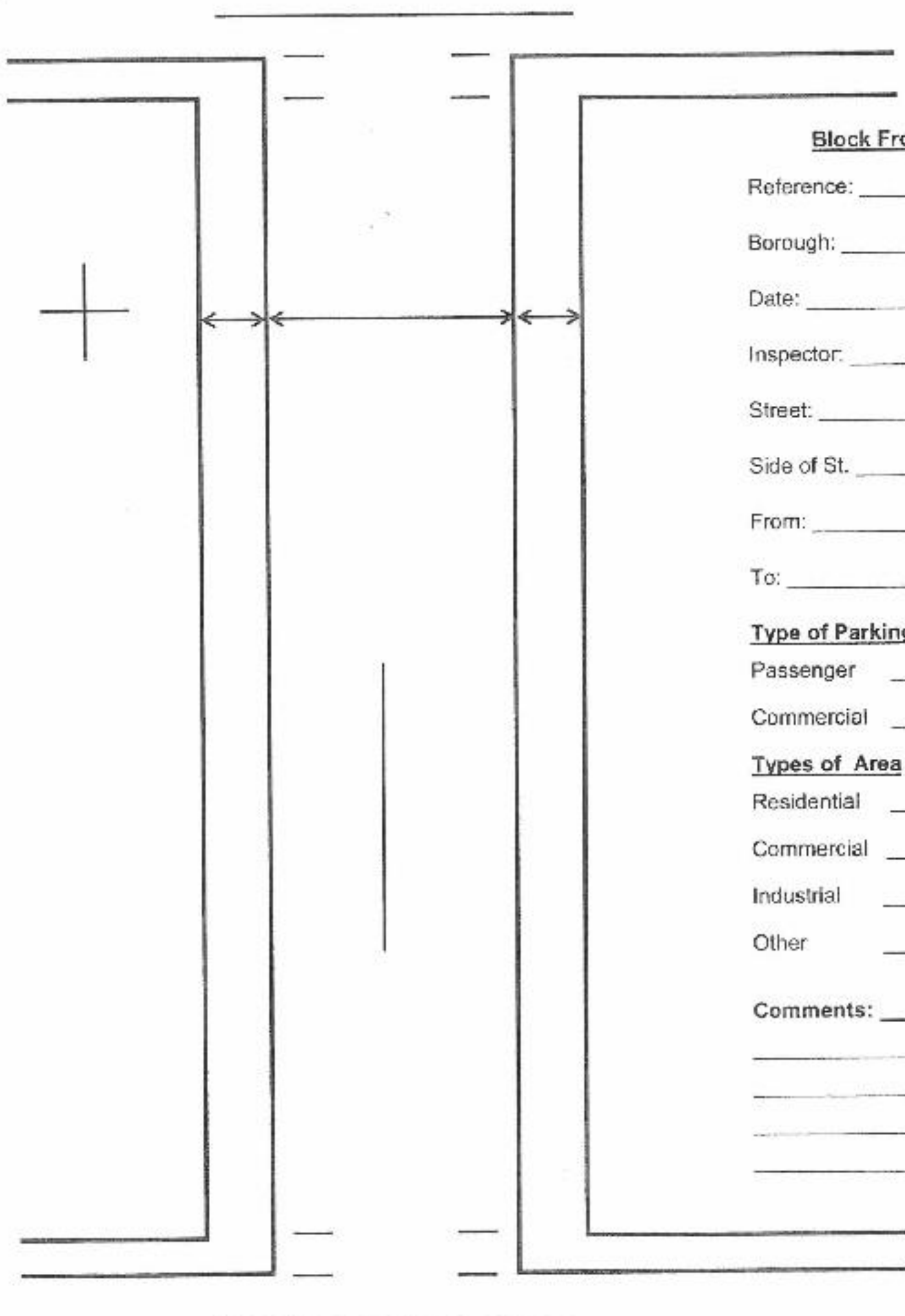
TCD = DISTANCE TO NEAREST TRAFFIC CONTROL DEVICE (Feet)
LANES = NUMBER OF MOVING LANES

NOTE: Indicate all curb regulations, street furniture, curb cuts, and all pavement markings related to the intersection. The # of lanes observed are the traveled lanes for each approach; parking lanes are not included. Show street direction by placing an arrow(s), indicating direction on all legs of the intersection.

CONDITION DIAGRAM

Ref#______________Date: __________Day: __________Inspector: ________________





Block Front Survey

Reference: ____________

Borough: ______________

Date: ________________

Inspector: _____________

Street: ________________

Side of St. _____________

From: _________________

To: ___________________

Type of Parking

Passenger ________%

Commercial ________%

Types of Area

Residential ________%

Commercial ________%

Industrial ________%

Other ________%

Comments: ___________

____

____

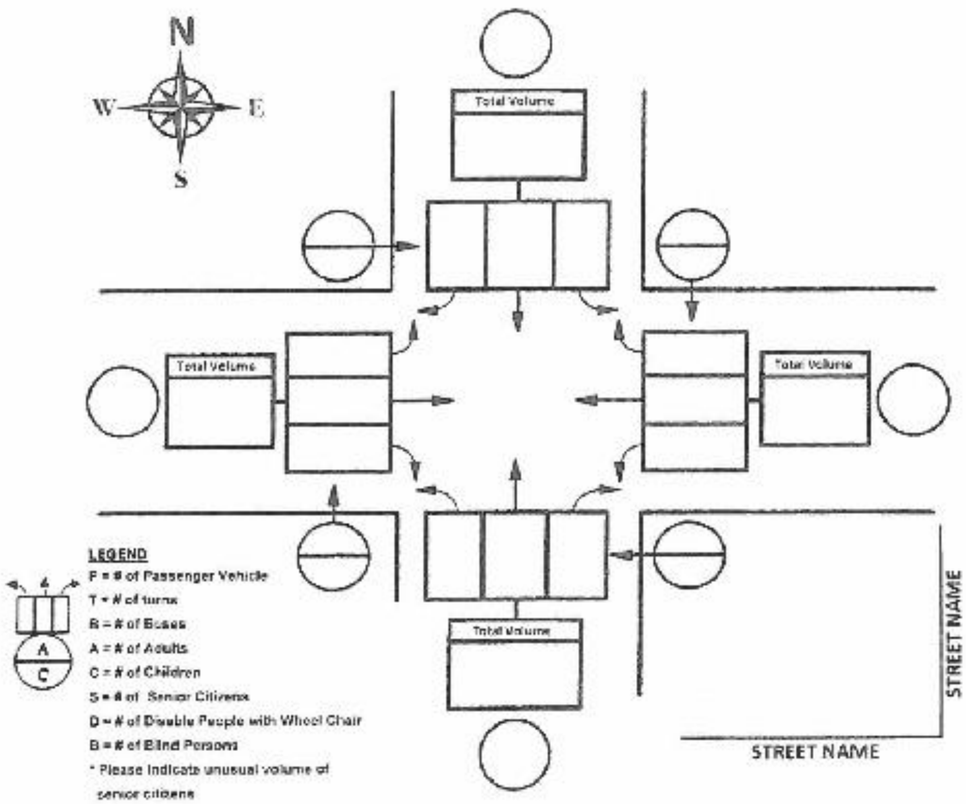
____

____

VOLUME CLASSIFICATION AND TURNING COUNTS

DATE: ______________________ TIME: ______________________

DAY : ______________________ INSPECTOR: ______________________



COMMENTS:

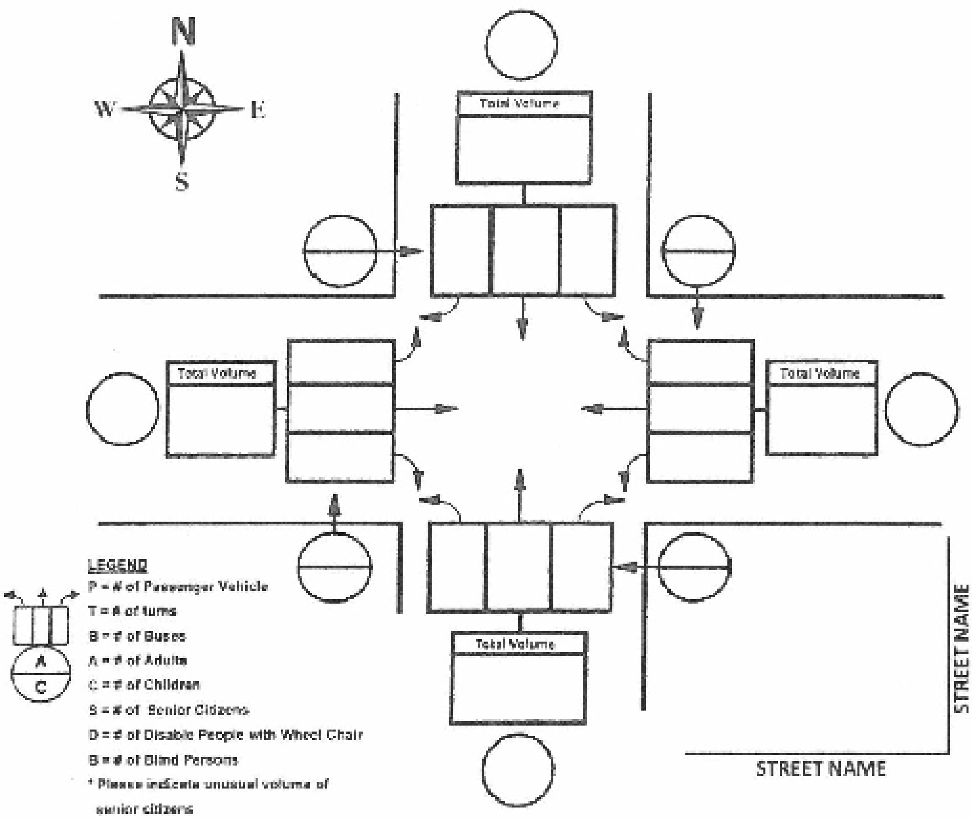
MAJOR	
MINOR	
PEDS	
SC	
Other	

Note: *Bikes in Crosswalks are assumed as pedestrians, While Bikes in roads and in bike-lanes are assumed as Vehicles*

VOLUME CLASSIFICATION AND TURNING COUNTS

DATE: ______________________ TIME: ______________________

DAY : ______________________ INSPECTOR: ______________________



COMMENTS:

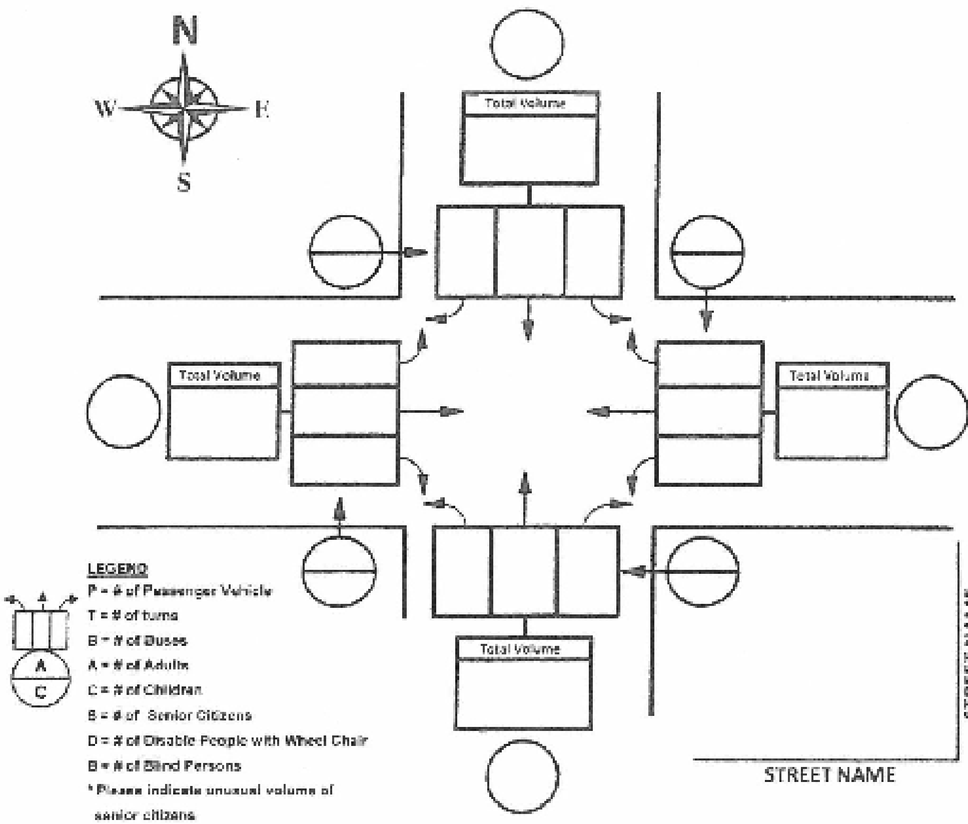
MAJOR	
MINOR	
PEDS	
SC	
Other	

Note: *Bikes in Crosswalks are assumed as pedestrians, While Bikes in roads and in bike-lanes are assumed as Vehicles*

VOLUME CLASSIFICATION AND TURNING COUNTS

DATE: ______________________ TIME: ______________________

DAY : ______________________ INSPECTOR: ______________________



COMMENTS:

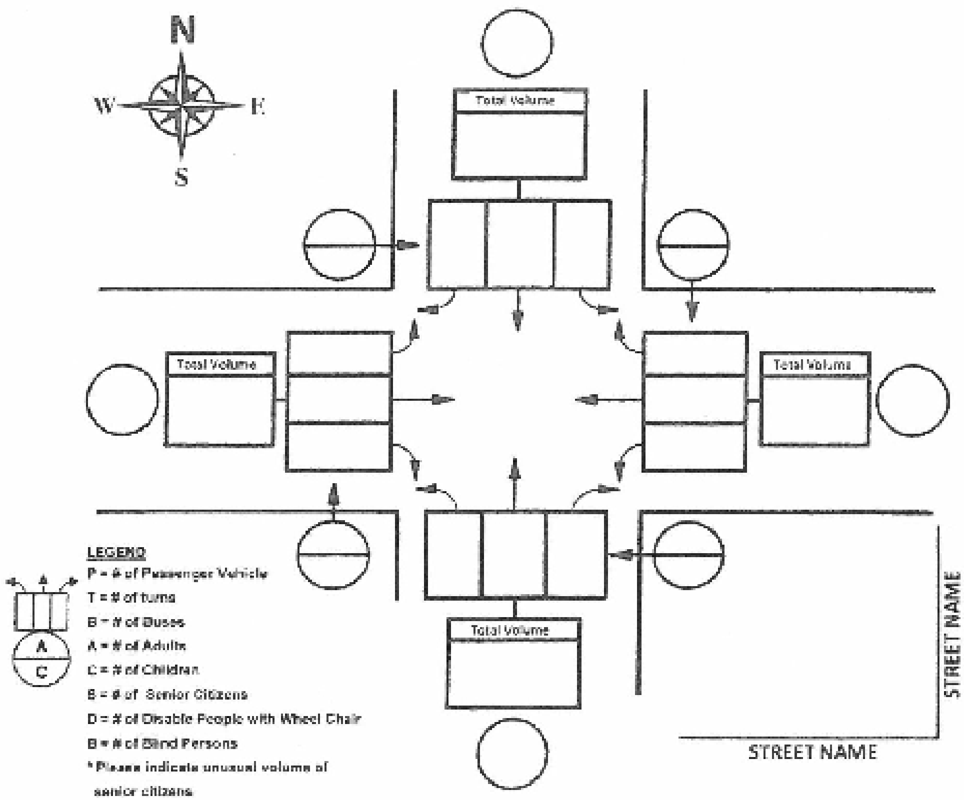
MAJOR	
MINOR	
PEDS	
SC	
Other	

Note: *Bikes in Crosswalks are assumed as pedestrians, While Bikes in roads and in bike-lanes are assumed as Vehicles*

VOLUME CLASSIFICATION AND TURNING COUNTS

DATE: ____________________ TIME: ____________________

DAY : ____________________ INSPECTOR: ____________________



COMMENTS:

MAJOR	
MINOR	
PEDS	
SC	
Other	

Note: *Bikes in Crosswalks are assumed as pedestrians, While Bikes in roads and in bike-lanes are assumed as Vehicles*

REF# __________ START: __________ END: __________

WEATHER: __________ DIRECTION: __________

MPH SPEED LIMIT: _____ POSTED: __________

(MAJOR)

DATE: __________ START: __________ END: __________

DAY: __________ DIRECTION: __________

UNPOSTED: __________

WARRANT ANALYSIS

Warrant 1, Eight-Hour Vehicular Volume

Condition A – Minimum Vehicular Volume

Number of Lanes for moving traffic on each approach		MAJOR STREET VOLUMES: Vehicles per hour on major street (total of both approaches)				MINOR STREET VOLUMES: Vehicles per hour on higher volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour
1..............	1..............	500	400	350		150	120	105	
2 or more....	1..............	600	480	420		150	120	105	
2 or more....	2 or more....	600	480	420		200	160	140	
1..............	2 or more....	500	400	350		200	160	140	

Condition B – Interruption of Continuous Traffic

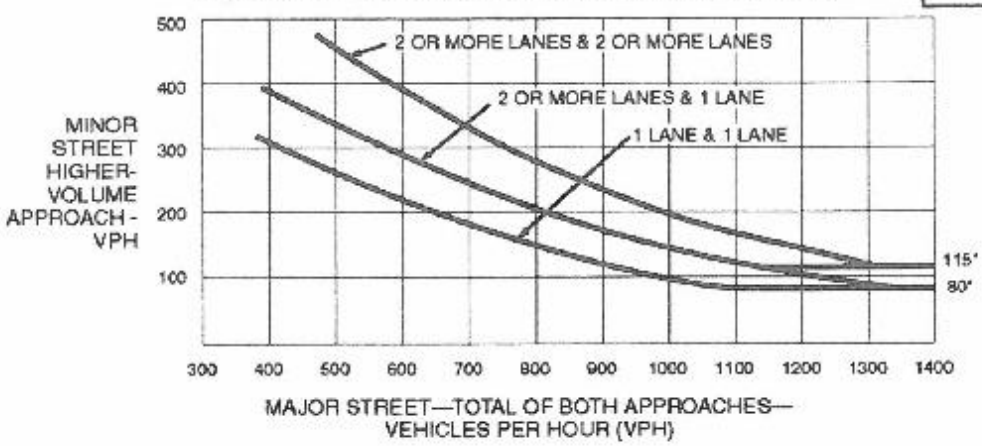
Number of Lanes for moving traffic on each approach		MAJOR STREET VOLUMES: Vehicles per hour on major street (total of both approaches)				MINOR STREET VOLUMES: Vehicles per hour on higher volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour
1..............	1..............	750	600	525		75	60	53	
2 or more....	1..............	900	720	630		75	60	53	
2 or more....	2 or more....	900	720	630		100	80	70	
1..............	2 or more....	750	600	525		100	80	70	

[a] Basic minimum hourly volume

[b] Used for combination of Condition A and B after adequate trial of other remedial measures.

[c] May be used when the major street speed exceeds 40 mph(70km/h) or in an isolated community with a population of less than 10,000.

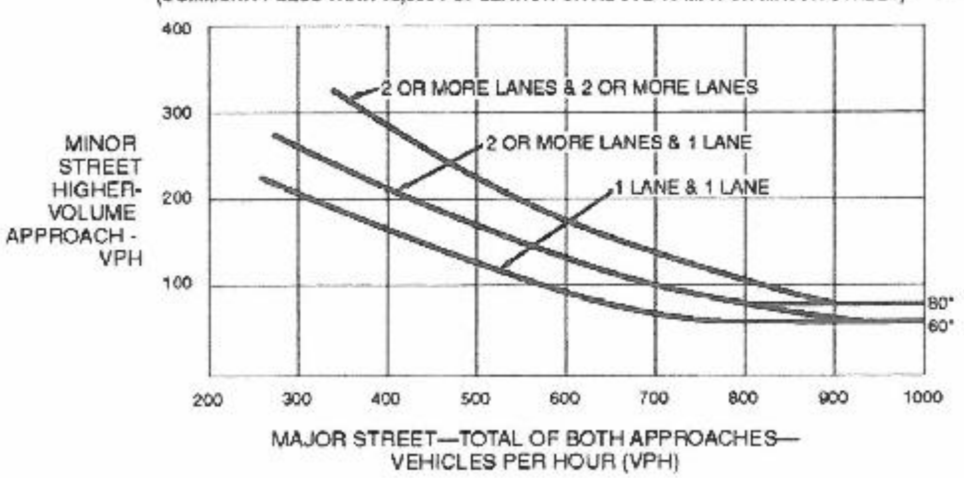
Figure 4C-1. Warrant 2, Four-Hour Vehicular Volume



*Note: 115 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 80 vph applies as the lower threshold volume for a minor-street approach with one lane.

Figure 4C-2. Warrant 2, Four-Hour Vehicular Volume (70% Factor)

(COMMUNITY LESS THAN 10,000 POPULATION OR ABOVE 40 MPH ON MAJOR STREET)



*Note: 80 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 60 vph applies as the lower threshold volume for a minor-street approach with one lane.

WARRANT 3, PEAK HOUR: [ ]

WARRANT # 3 condition A

Total volume for intersection W/3 Approaches = 650 or more VPH (   )
Total volume for intersection W/4 Approaches = 800 or more VPH (   )
Higher Minor Approach W/1 Lane = 100 or more VPH (   )
Higher Minor Approach W/2 Lane = 150 or more VPH (   )

INTERSECTION DELAY STUDY

TOTAL DELAY = TOTAL VEHICLES STOPPED X SAMPLING INTERVAL

= ____________ X 15 = ________________Veh. Sec.

AVERAGE DELAY PER APPROACH VEHICLE = $\frac{\text{TOTAL DELAY}}{\text{APPROACH VOLUME}}$ = ______________

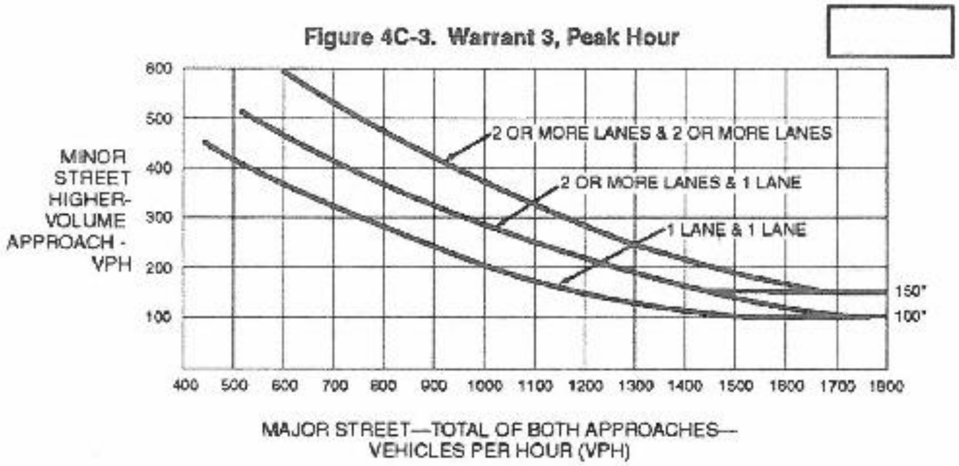
= ___________________ Sec.

AVERAGE DELAY FOR WARRANT 3 = AVERAGE DELAY X PEAK HOUR VOLUME FROM MACHINE COUNTS

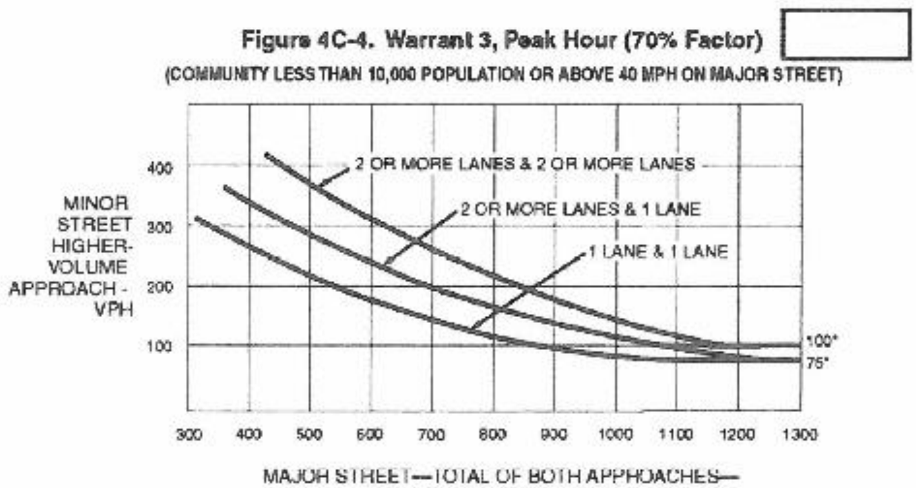
= ________________ X __________________

= ________________ Veh. -Sec.

NOTE:
The above information will be used for Warrant 3 – Peak Hour analysis.

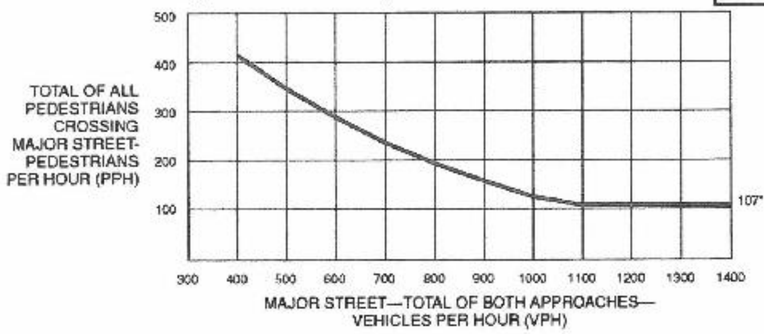


*Note: 150 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 100 vph applies as the lower threshold volume for a minor-street approach with one lane.



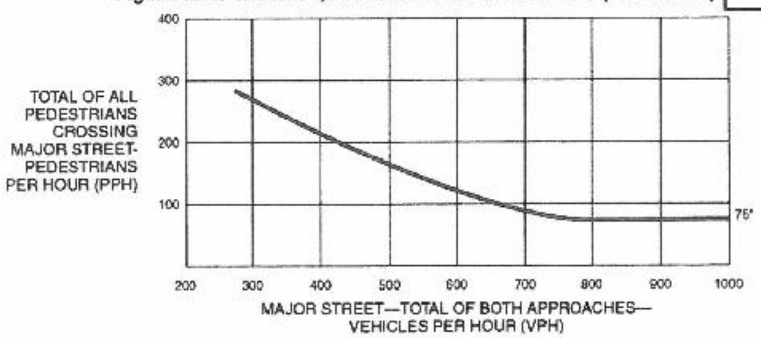
*Note: 100 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 75 vph applies as the lower threshold volume for a minor-street approach with one lane.

Figure 4C-5. Warrant 4, Pedestrian Four-Hour Volume



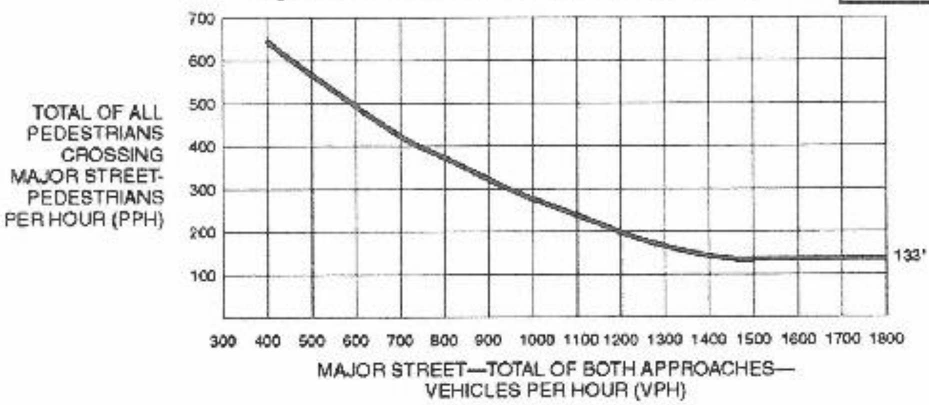
*Note: 107 pph applies as the lower threshold volume.

Figure 4C-6. Warrant 4, Pedestrian Four-Hour Volume (70% Factor)



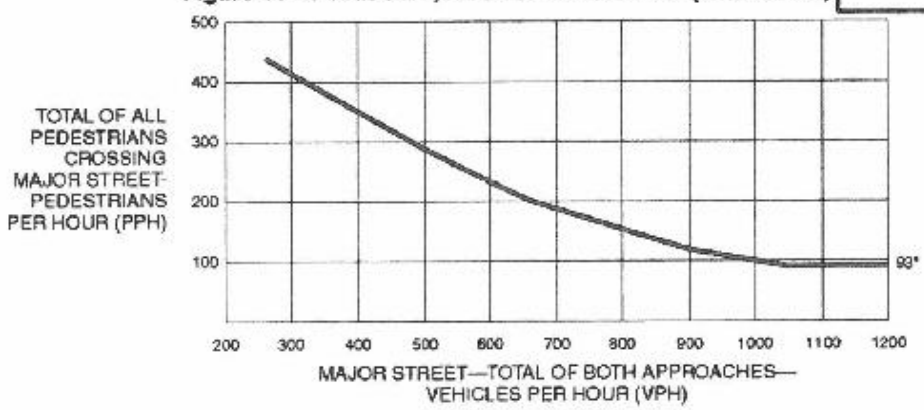
*Note: 75 pph applies as the lower threshold volume.

Figure 4C-7. Warrant 4, Pedestrian Peak Hour



*Note: 133 pph applies as the lower threshold volume.

Figure 4C-8. Warrant 4, Pedestrian Peak Hour (70% Factor)



*Note: 93 pph applies as the lower threshold volume.

WARRANT 4, PEDESTRIAN VOLUME:

Section 4C.05 Warrant 4, Pedestrian Volume

The pedestrian Volume signal warrant is intended for application where the traffic volume on Major Street is so heavy that pedestrians experience excessive delay in crossing the major street.

The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that one of the following criteria are met:

A. For each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) all fall above the curve in Figure 4C-5; or

B. For 1 hour (any four consecutive 15-minute periods) of an average day, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding pedestrians per hour crossing the major street (total of all crossings) falls above the curve in Figure 4C-7.

Option:

07 The criterion for the pedestrian volume crossing the major street may be reduced as much as 50 percent if the 15th-percentile crossing speed of pedestrians is less than 3.5 feet per second.

08 A traffic control signal may not be needed at the study location if adjacent coordinated traffic control signals consistently provide gaps of adequate length for pedestrians to cross the street.

WARRANT 5, SCHOOL CROSSING:

Section 4C.06 Warrant 5, School Crossing

The School Crossing signal warrant is intended for applications where the fact that Schoolchildren cross the major street is the principal reason to consider installing a traffic control signal.

The word "Schoolchildren" includes elementary through High School students

The need for a traffic control signal shall be considered when an engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at an established school crossing across the major street shows that the number of adequate gaps in the traffic stream during the period when the school children are using the crossing is less than the number of minutes in the same period and there are a minimum of 20 Schoolchildren during the highest crossing hour.

School Crossing Warrant (California Warrant):

The School Crossing Warrant (Warrant# 5) as contained in the federal Manual on Uniform Traffic Control Devices (MUTCD) is dependent on the frequency and adequacy of gaps in the traffic stream. At certain intersections with designated school crosswalks, gaps cannot be measured due to the presence of a school crossing guard, all way stop control, or other field conditions.

In such cases, if no other warrant contained in the MUTCD is satisfied, the engineer, upon review of the traffic conditions and physical characteristics of the intersection, can use guidelines outlined in the California Department of Transportation (CALTRANS) Traffic Manual. These guidelines are based on satisfying minimum vehicular and schoolchildren volume requirements. In an urban area, 500 vehicles (total in both directions on the major street) and 100 schoolchildren for each of any two hours (not necessarily consecutive) are required.

California Warrant = A School Crossing with All-Way stop or School Crossing Guard present and 500 vehicles on major street and 100 schoolchildren crossing major street for each of any two hours.

WARRANT 6, COORDINATED SIGNAL SYSTEM:

The need for a traffic control signal shall be considered if an engineering study finds that one of the following criteria is met:

A. On a one-way street or a street that has traffic predominantly in one direction, the adjacent traffic control signals are so far apart that they do not provide the necessary degree of vehicular platooning.

B. On a two-way street, adjacent traffic control signals do not provide the necessary degree of platooning and the proposed and adjacent traffic control signals will collectively provide a progressive operation.

Note: *The Coordinated Signal System signal warrant should not be applied where the resultant spacing of traffic control signals would be less than 300 m (1000 ft).*

WARRANT 7, CRASH EXPERIENCE:

The crash experience signal warrant conditions are intended for applications where the severity and frequency of crashes are the principal reason to consider installing a traffic signal.

The need for a traffic control signal shall be considered if an engineering study finds that all of the following criteria are met:

A. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency; and

B. Five or more reported crashes, of types susceptible to correction by a traffic control signal, have occurred within a 12-month period, each crash involving personal injury or property damage apparently exceeding the applicable requirements for a reportable crash; and

C. For each of any 8 hours of an average day, the vehicles per hour (VPH) given in both of the 80 percent columns of Condition A or the VPH in both of the 80 percent columns of Condition B exists on the major-street and the higher-volume minor-street approach, respectively, to the intersection, or the volume of pedestrian traffic is not less than 80 percent of the requirements specified in the Pedestrian Volume warrant. These major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Section 4C.09 Warrant 8, Roadway Network:

01 Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a roadway network.

Standard:

02 **The need for a traffic control signal shall be considered if an engineering study finds that the common intersection of two or more major routes meets one or both of the following criteria:**

A. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 vehicles per hour during the peak hour of a typical weekday and has 5-year projected traffic volumes, based on an engineering study, that meet one or more of Warrants 1, 2, and 3 during an average weekday; or

B. The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a non-normal business day (Saturday or Sunday).

03 **A major route as used in this signal warrant shall have at least one of the following characteristics:**

A. It is part of the street or highway system that serves as the principal roadway network for through traffic flow.

B. It includes rural or suburban highways outside, entering, or traversing a city.

C. It appears as a major route on an official plan, such as a major street plan in an urban area traffic and transportation study.

Section 4C.10 Warrant 9, Intersection Near a Grade Crossing:

Support:

01 The Intersection near a Grade Crossing signal warrant is intended for use at a location where none of the conditions described in the other eight traffic signal warrants are met, but the proximity to the intersection of a grade crossing on an intersection approach controlled by a STOP or YIELD sign is the principal reason to consider installing a traffic control signal.

Guidance:

02 *This signal warrant should be applied only after adequate consideration has been given to other alternatives or after a trial of an alternative has failed to alleviate the safety concerns associated with the grade crossing. Among the alternatives that should be considered or tried are:*

A. Providing additional pavement that would enable vehicles to clear the track or that would provide space for an evasive maneuver, or

B. Reassigning the stop controls at the intersection to make the approach across the track a non-stopping approach.

Standard:

03 **The need for a traffic control signal shall be considered if an engineering study finds that both of the following criteria are met:**

A. A grade crossing exists on an approach controlled by a STOP or YIELD sign and the center of the track nearest to the intersection is within 140 feet of the stop line or yield line on the approach; and

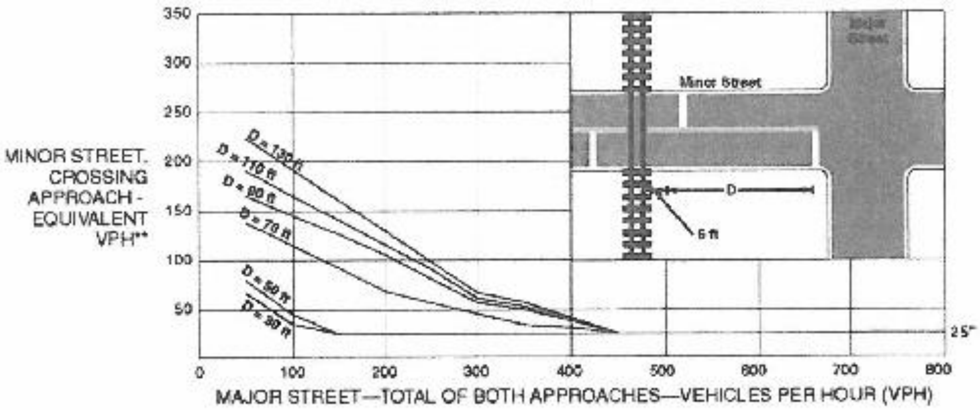
B. During the highest traffic volume hour during which rail traffic uses the crossing, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the minor-street approach that crosses the track (one direction only, approaching the intersection) falls above the applicable curve in Figure 4C-9 or 4C-10 for the existing combination of approach lanes over the track and the distance D, which is the clear storage distance as defined in Section 1A.13.

Guidance:

04 *The following considerations apply when plotting the traffic volume data on Figure 4C-9 or 4C-10:*

A. Figure 4C-9 should be used if there is only one lane approaching the intersection at the track crossing location and Figure 4C-10 should be used if there are two or more lanes approaching the intersection at the track crossing location.

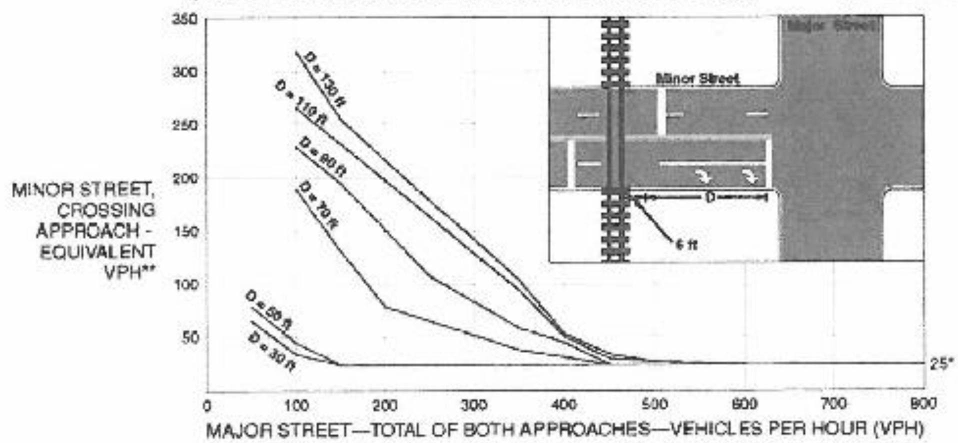
Figure 4C-9. Warrant 9, Intersection Near a Grade Crossing (One Approach Lane at the Track Crossing)



* 25 vph applies as the lower threshold volume

** VPH after applying the adjustment factors in Tables 4C-2, 4C-3, and/or 4C-4, if appropriate

Figure 4C-10. Warrant 9, Intersection Near a Grade Crossing (Two or More Approach Lanes at the Track Crossing)



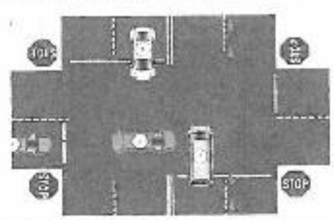
* 25 vph applies as the lower threshold volume

** VPH after applying the adjustment factors in Tables 4C-2, 4C-3, and/or 4C-4, if appropriate

Attach all relevant Accident reports and summaries

(Pedestrians hit by Vehicles crossing Major, Right Angle, and Left-Turn Accidents)

FOR A SAFER NYC
SPEED LIMIT 25
VISION ZERO



Prepared by: M. Rahman - 03/04/2015

Appendix 2B
Forms Used By Construction and Maintenance Unit

BUREAU OF TRAFFIC OPERATIONS
ELECTRICAL INSPECTIONS
DAILY WORK REPORT

Inspector: ____________________ **Vehicle** ________ ____________

Borough ____________________ **Area** ________ **Date** ________

Maintenance Inspections

		8500				Traff.P.M.			Streetlighting Orders					Stlt P.M.		Routine Patrol			
	Time of Day	Excavations	Post/Cable/Signals	8500 Check		Lens Cleaning	Controller Cleaning	Painting	Excavations	Cable/Panel	Luminare Bracket/Post	S L O Check		Highway Survey	Zip Survey	Streetlight Defects	Traffic Repairs	CE Equip Insp	Recheck
Traffic Repair Calls																			
Streetlight Defects																			

Figure 2B1. Daily Work Report: Maintenance Inspections Form

Construction Inspections

Location		Type Activity: Excavations	Wiring Post/Heads	Repaving	Job Number: Traffic Requirement	Public Works	Streetlight Requirement
TOTAL INSPECTIONS							TOTAL HRS.

	IN	OUT					
OFFICE			OFFICE HRS. MAINT.		OFFICE HRS. CONST.		
			FIELD HRS. MAINT.		FIELD HRS. CONST.		
RADIO			TOTAL HRS. MAINT.		TOTAL HRS. CONST.		
			TOTAL INSPECT. TRAFFIC MAINT.		TOTAL INSP. TRAFFIC CONST.		
			TOTAL INSPECT. STRLT MAINT.		TOTAL INSPECT. STRLT CONST.		

I hereby certify that I have made the inspection described above at the dates and times mentioned, and that the findings reported are an accurate description of the conditions found during the inspection.

Inspector's Signature ______________________ Date ______________

Reviewed By ______________________ Title Borough Chief

9/19/2014

Figure 2B2. Daily Work Report: Construction Inspections Form

New/Modified Signal Check List

Location: College Point BlVD @ 40th Rd

E. Order Number: Z-84

Contract Number: 2012 SH

New (Modified) Temporary

Date Entered in Book: 6-15-15

Laid Out with Contractor: LAY OUT NOT NEEDED

Date Excavation Started: NO EXCAVATION

Date Signal Turned On: 9-10-1951

Date Final Restoration: NO EXCAVATION DONE

Upon completion of Final Restoration, Signs & Markings Must be Notified, ~~*718-433-3160*~~ 646-892-1123

Date Roadway Markings/Lane Paint Restoration Sent: 6-16-15

FINAL INSPECTION CHECKLIST

- ✓ All as-built drawings must be received and accurate to reflect what was installed in field.
- ✓ All cables to be tagged at pole base and sidewalk boxes. Pole bases must be bonded correctly
- ✓ In-line fuses only. No Edison base fuses!
- ✓ All required hardware must be in place, vehicle signals, pedestrian signals, streetlight fixtures, detector/sensors, controllers, etc....
- ✓ Cables in boxes must be properly racked & secured.
- ✓ Cables in bases must be properly taped. Silicone filled wire nuts only. Base doors must be hinged
- ✓ Control box must be close properly. BIU cable must be properly secured inside CB so as not to cause a flashing condition. Timing sheet must be left inside plastic enclosure within CB. Signal and communication cable entry must be sealed. Modem must be communicating with TMC.
- ✓ Confirm proper operation of signal controllers and it's equipment, (sensors, detectors, push buttons, etc.).
- ✓ Check for tripping hazards around base of pole or around boxes. Check for proper alignment of mat. Check that all construction debris has been removed.
- ✓ Check that all furnished equipment matches catalogue cuts submitted by contractor.
- ✓ Any conduit installed for future use must be ball and brushed and witnessed by an Inspector from NYCDOT, EIU. A 3/8 inch drag line must be tied off and left for future cable pull.

Figure 2B3. Signal Check List

Contract: ______________________ Date: ______________________

"E" NO.: ____________ Hylan Electric

Borough: ______________________

Location: ______________________ Page: OF ______________

Type of Work ______________________

Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	Item Description goes here	
item # here	item # here	item # here	item # here	item # here	item # here	item # here	item # here	item # here	item # here	Date
										TOTALS

Material Used

QTY	ITEM #	QTY	ITEM #	QTY	ITEM #

Material Reused in Field

QTY	ITEM #	QTY	ITEM #	QTY	ITEM #

Figure 2B4. Form for List of all supplies Obtained and Supplies Used at a given Location

BOROUGH	ADDRESS	CONTRACT #	E #
CODE:			
DESCRIPTION:			

LAYOUT	
TIMING	
CHECKED	
APPROVED	

REQUESTED BY:	TYPED:	APPROVED:	COMPLETED:
RECOMMENDED BY:	PUBLISHED:		
BUREAU OF TRAFFIC OPERATIONS		COMMISIONER:	PAGE #

Figure 2B5. Order Release Form

Appendix 2C

Policy for Enhanced Crosswalks

Policy for Implementing New Crosswalk

The following policy governs the process for evaluating locations for new crosswalks.

Detailed Steps:

1. Determine if the location has previously been studied for traffic controls
    a. Intersection Control Unit (ICU)
        i. Through intersections, T-in intersections, midblock or T-away intersections
            1. If ICU has never studied the location, request a study be opened where they can test for various control warrants
                a. If meets warrant, create proposal and share with Geometric Design (GD), Borough Commissioner's Office (BC) and SIM for ped ramp review
                b. Once approved, implement
            2. If location was previously studied, or ICU denies controls following your study request, ask for all data collected
                a. If more than 18 months have passed since the study, the data is considered old and cannot be shared. If significant change in area since previous study, have ICU open new study
                b. If a midblock or T-away intersection and peak hour pedestrians outnumber peak hour vehicle volumes, pass to BE for stop control review
        ii. ICU Contacts: Ben Eliya and Kamal Zaki, Anthony Mack for opening new study
    b. Borough Engineering
        i. Elbow location or midblock/T-away intersection where peak hour pedestrians outnumber peak hour vehicle volumes (determined in ICU study)
            1. Give BE pedestrian and vehicle volumes, any relevant crash data
            2. BE reviews for stop control
                a. If stop control approved, create proposal and share with GD, BC and SIM for ped ramp review
                b. Once approved, implement

2. Data to be collected for Enhanced Crossings if no control is approved
    a. Location
        i. Must be only one travel lane per direction with maximum 25mph speed limit
        ii. 500 ft. or more between marked crosswalks
        iii. Are the adjacent land uses significant pedestrian generators?
        iv. Within 700' of a school?
            1. Pass to School Safety to evaluate for school crossing
                a. If school crossing denied, continue with Enhanced Crossing analysis
    b. Review ICU Data, or collect your own data

i. ATRs
    1. Is there less than 8,000 ADT (generally under 400 vehicles in the peak hours)?
    2. If a two-way street with refuge island, is there less than 12,000 ADT?

ii. Traffic calming – can an additional traffic calming device be included with the uncontrolled marked crossing?
    1. Speed study to see if speeding above is an issue
        a. If speeding is an issue, determine if speed humps are feasible
            i. Checking for Speed Humps: Check in SRTS (Speed Reducer Tracking System) to see if there are any recent requests for speed humps at the intersection (http://dotdw/speedreducer/login.asp - login as guest). If not, and speeding is an issue, request a study be opened for the feasibility of speed humps (if location is not a truck or bus route)
            ii. If there is an open study, follow-up to see when the speed humps will be installed
            iii. Contacts: Jeannette Saunds and William Padron
    2. If speeding is an issue and location is not feasible for speed humps or other traffic calming, the crosswalks will not be approved

c. Complete Enhanced Crossing Approval Form and send to Merisa Gilman in PPG for review and approval of Enhanced Crossing

d. If Enhanced Crossing approved, create proposal and share with PPG, GD, BC and SIM for ped ramp review

e. Once approved, implement
    i. Markings (GD), Pedestrian Warning Signs (BE), Pedestrian Ramps (SIM), and any additional traffic calming where feasible

Project Manager ______________________

Unit ______________________

Street ______________________

Cross Street ______________________

Borough ______________________

SIP Name ______________________ N/A

ICU REVIEW

ICU Study/Denial Date ______________________

Traffic Control Denied by ICU ______________________

LOCATION ANALYSIS

Intersection Type — THROUGH T-IN T-AWAY MIDBLOCK ELBOW ***if Elbow Pass to BE for review***

Travel Lanes Per Direction ______________________

Distance to Nearest Marked Crosswalk (for each direction) ______________________

Does Distance between Existing Marked Crosswalks Sum to 500' or More? Yes No

Adjacent Lane Use with Significant Pedestrian Generator ______________________

Within 700' of School Yes No ***If yes, pass to School Safety for Review***

DATA COLLECTION

Average Daily Travel (ADT) ______________________

Date ATR Collected ______________________

If no ATR, Peak Hour Vehicle Volumes (include bikes) ______________________

Date Peak Hour Volumes Collected ______________________

Peak Hour Pedestrian Volume ______________________

Date Pedestrian Volume Collected ______________________

For Midblock or T-Away Intersection, is Peak Hour Pedestrian Volume Higher than Peak Hour Vehicle Volume? Yes No ***If yes, pass to BE for review***

Is Traffic Calming Feasible Yes No

Type of Traffic Calming ______________________

Speed Analysis ***Please include field sheet for review***

Date Speed Data Collected ______________________

SIM REVIEW

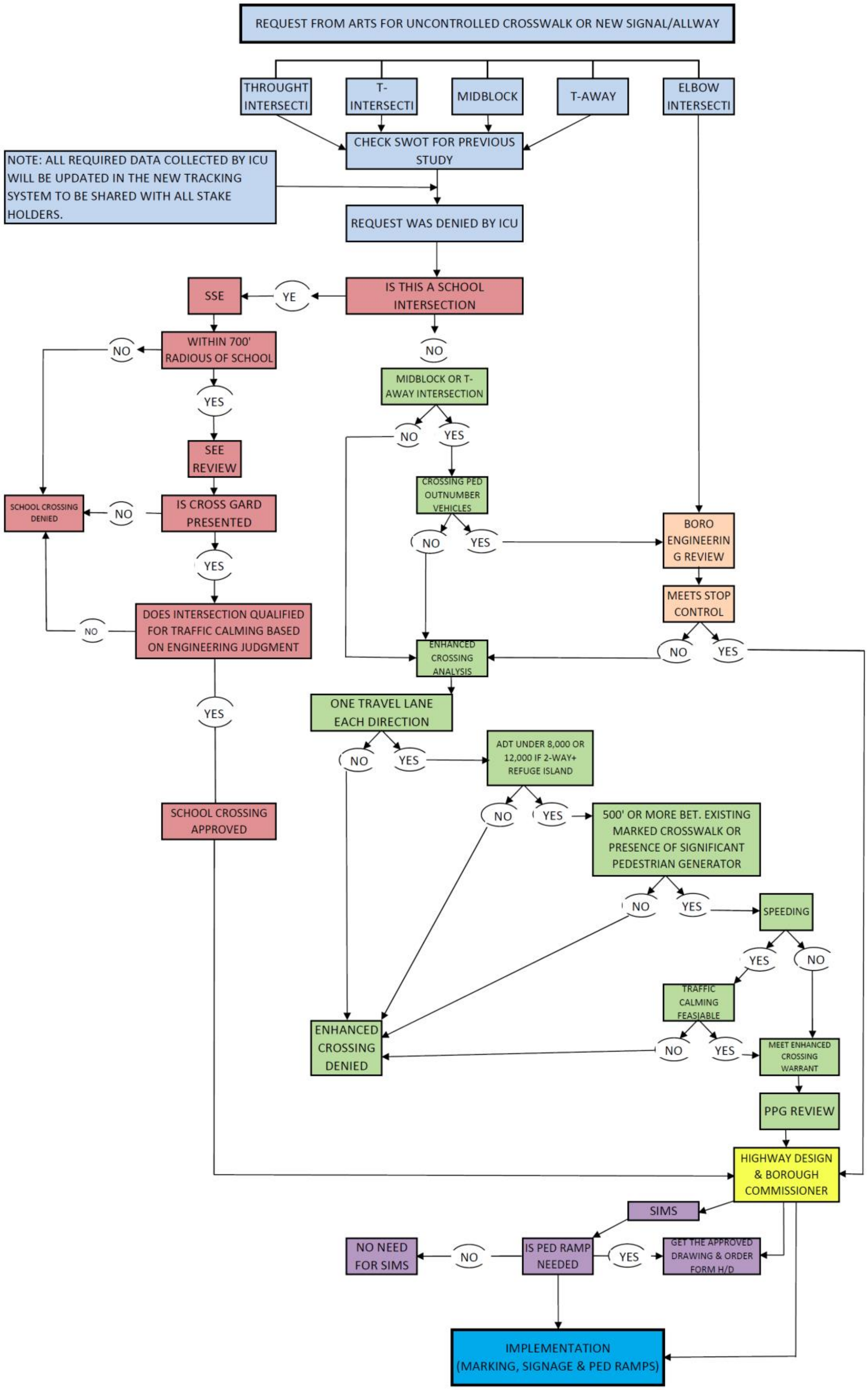
Ped Ramps Feasible Yes No

PPG APPROVAL

Enhanced Crossing Feasible Yes No

Merisa Gilman Approval ______________________

Approval Date ______________________


REQUEST FROM ARTS FOR UNCONTROLLED CROSSWALK OR NEW SIGNAL/ALLWAY
THROUGHT INTERSECTI
T-INTERSECTI
MIDBLOCK
T-AWAY
ELBOW INTERSECTI
CHECK SWOT FOR PREVIOUS STUDY
NOTE: ALL REQUIRED DATA COLLECTED BY ICU WILL BE UPDATED IN THE NEW TRACKING SYSTEM TO BE SHARED WITH ALL STAKE HOLDERS.
REQUEST WAS DENIED BY ICU
IS THIS A SCHOOL INTERSECTION
YE
SSE
WITHIN 700' RADIOUS OF SCHOOL
NO
YES
SEE REVIEW
IS CROSS GARD PRESENTED
SCHOOL CROSSING DENIED
DOES INTERSECTION QUALIFIED FOR TRAFFIC CALMING BASED ON ENGINEERING JUDGMENT
SCHOOL CROSSING APPROVED
MIDBLOCK OR T-AWAY INTERSECTION
CROSSING PED OUTNUMBER VEHICLES
BORO ENGINEERIN G REVIEW
MEETS STOP CONTROL
ENHANCED CROSSING ANALYSIS
ONE TRAVEL LANE EACH DIRECTION
ADT UNDER 8,000 OR 12,000 IF 2-WAY+ REFUGE ISLAND
500' OR MORE BET. EXISTING MARKED CROSSWALK OR PRESENCE OF SIGNIFICANT PEDESTRIAN GENERATOR
SPEEDING
TRAFFIC CALMING FEASIABLE
MEET ENHANCED CROSSING WARRANT
ENHANCED CROSSING DENIED
PPG REVIEW
HIGHWAY DESIGN & BOROUGH COMMISSIONER
SIMS
IS PED RAMP NEEDED
NO NEED FOR SIMS
GET THE APPROVED DRAWING & ORDER FORM H/D
IMPLEMENTATION (MARKING, SIGNAGE & PED RAMPS)

Chapter 3 SIGNAL TIMING UNIT

Chapter 3 discusses the responsibilities of the Signal Timing Unit. The Signal Timing Unit develops the operational plans of the signalized intersection system in NYC. There are approximately 12,900 signalized intersections in all five boroughs of NYC, and every one of their timing plans goes through the Signal Timing Unit.

Developing an operational plan for a signalized intersection entails deciding on a phasing and timing plan to safely accommodate the vehicular, pedestrian, and bicycle needs at the location. Safety is the first priority in signal timing design. Operations at signalized intersections range from the simplest two-phase operation to more complicated phase plans at non-typical intersections. To minimize stops and delays along a corridor, the operational plan also takes into consideration signal coordination between adjacent signals to promote smooth progression of traffic, when possible.

The Signal Timing Unit is responsible for:

- Reviewing, developing and implementing timing plans and patterns to meet Vision Zero goals
- Making changes in timing plans due to street improvement projects and temporary construction projects
- Reviewing timing plans for Transit Signal Priority corridors.

3.1 Signal Phasing

A phasing plan is chosen to allow the traffic signal to accommodate all of the intersection's users in a safe and efficient manner. Phase plans must be implemented according to the MUTCD [1] guidelines, and must be consistent with the intersection's geometry and lane channelization. Delay and capacity are affected by the phasing and timing plan and it is necessary to understand these relationships.

A phase is defined as a traffic signal display that gives the right of way to a movement or group of movements, including its yellow change and red clearance interval. A vehicular phase consists of three intervals: the green, yellow-change, and all-red intervals. A pedestrian phase also consists of three intervals: the steady walk, flashing don't walk, and solid don't walk. The timing of these intervals will be discussed in the following section. The vehicle and pedestrian phases are generally related as follows: the through movement green interval occurs concurrently with the pedestrian walk and flashing don't walk intervals.

Adding phases will increase delay due to lost time at the beginning and end of each phase. Lost time is the amount of time during each cycle that is not able to be used by vehicles. There are two types of lost time, one at the beginning and another at the end of a phase. Lost time at the beginning of a phase is called start-up lost time.

It is the time during which the first three or four vehicles react to the signal turning green and accelerate into the intersection. The lost time at the end of the phase is called the clearance lost time. It is the time between the end of green for the subject phase and the initiation of green for the next phase that is not used by any mode. This generally includes some portion of the yellow plus all-red time.

Because it is desirable to have the least amount of lost time, two-phase signals are installed whenever possible. However, depending on the volume of vehicles and pedestrians, there are times and locations when more phases are needed to service a specific movement. Such phases are called protected phases, because the movement is being protected from conflicting movements, that is, the movement is separated in time from other movements that hinder the subject movement. Protecting movements can reduce crashes by separating conflicting movements from each other. Movements that may need protection are left turns, pedestrians, or bicycles. Thus the safety benefits and improved efficiency of protecting movements must be weighed against the increase in delay. Movements that are not protected are said to operate in permissive mode.

Permissive mode for left-turning vehicles requires the vehicle to yield to opposing through traffic as well as to pedestrians and bicycles in the crosswalk adjacent to opposing through traffic. Permissive mode for right-turning vehicles requires the vehicle to yield to pedestrians and bicycles in its adjacent crosswalk. Permissive mode, particularly for left-turning vehicles, has more risk for crashes because navigating a left-turn requires finding gaps through both opposing vehicles and pedestrians.

3.1.1 Two-phase Operation

Two-phase signals are installed at approximately 98% of new signals added in NYC and operate at approximately 85% of existing signals. In a two-phase signal plan, all movements for a given roadway (vehicles, pedestrians, and bicycles) are allowed to proceed at the same time. Figure 3.1 shows a 2-phase diagram. In the phasing diagram, the through arrow also represents any left-turn and/or right-turn movements that exist at the intersection.

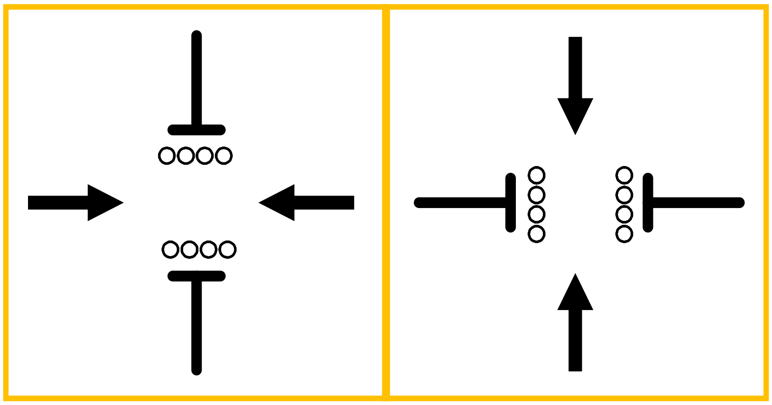


Figure 3.1 Phase Diagram of a two-phase signal

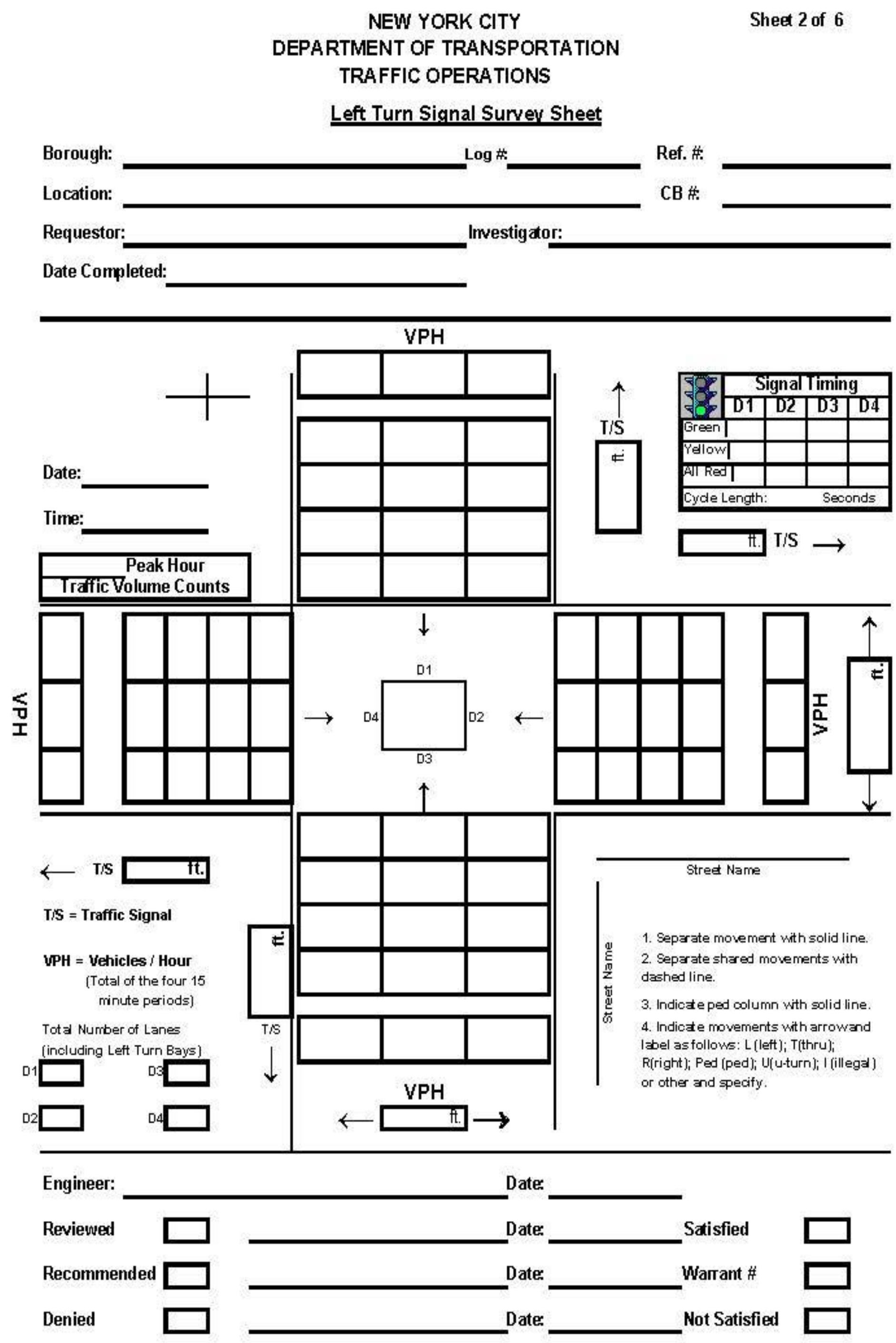
Circles represent the pedestrian movements that are serviced during the phase. During Phase A, all movements eastbound and westbound are permitted to proceed. During Phase B, all movements northbound and southbound are permitted to proceed.

3.1.2 *Protected Left-turn Phasing*

Protected left-turn phasing is recommended when the permissive mode is not capable of providing enough gaps for the volume of left-turn vehicles present. In NYC, when a protected left-turn phase is given, an exclusive left-turn lane or left-turn bay must exist or be added, which has sufficient length to provide for the expected queue of left-turn vehicles.

Figure 3.2 shows the NYC left-turn survey sheet, which includes all the necessary intersection data to be gathered. Additionally, accident data for the intersection will be gathered. For each approach the following intersection data is entered into the survey sheet of Figure 3.2

- Peak-hour traffic counts by fifteen minutes
- Number of lanes, including turn bays
- Width
- Current signal timing
- Type of lanes and movements allowed in the lane
- Street names


NEW YORK CITY
DEPARTMENT OF TRANSPORTATION
TRAFFIC OPERATIONS

Sheet 2 of 6

Left Turn Signal Survey Sheet

Borough: ______ Log #: ______ Ref. #: ______

Location: ______ CB #: ______

Requestor: ______ Investigator: ______

Date Completed: ______

VPH

Date: ______

Time: ______

Peak Hour
Traffic Volume Counts

T/S ft.

Signal Timing	D1	D2	D3	D4
Green				
Yellow				
All Red				
Cycle Length: Seconds				

ft. T/S

VPH

D1
D4 D2
D3

VPH ft.

T/S ft.

T/S = Traffic Signal

VPH = Vehicles / Hour
(Total of the four 15 minute periods)

ft.

Total Number of Lanes
(including Left Turn Bays)

D1 D3
D2 D4

T/S

VPH

ft.

Street Name

Street Name

1. Separate movement with solid line.
2. Separate shared movements with dashed line.
3. Indicate ped column with solid line.
4. Indicate movements with arrow and label as follows: L (left); T(thru); R(right); Ped (ped); U(u-turn); I (illegal) or other and specify.

Engineer: ______ Date: ______

Reviewed ☐ ______ Date: ______ Satisfied ☐

Recommended ☐ ______ Date: ______ Warrant # ☐

Denied ☐ ______ Date: ______ Not Satisfied ☐

Figure 3.2 Left-turn Signal Survey Sheet

NYCDOT considers the need a protected left-turn phasing using two warrants.

a. Warrant 1. Crash Experience
   The crash warrant is satisfied when there are five or more left-turn related crashes in the previous twelve months. Left-turn related crashes include crashes between
   - left-turn vehicle and an opposing through vehicle
   - left-turn vehicle and crossing pedestrians

b. Warrant 2. Left-turn Capacity
   The capacity warrant is satisfied when the left-turn flow rate is greater than the left-turn capacity of the permitted phase.

Worksheets for performing both warrants are shown in Figures 3.3(a) - 3.3(d).

Sheet 3 of 6

NEW YORK CITY
DEPARTMENT OF TRANSPORTATION
TRAFFIC OPERATIONS

Left Turn Signal Warrant Sheet

WARRANT 1 (Accident Experience)

Satisfied ☐
Not Satisfied ☐

This Warrant is satisfied when a minimum of 5 related left turn accidents exist in the latest 12 month period in which accident records are available.

Year	Total Accidents	Left Turn Accidents

Accident sheets must be attached.

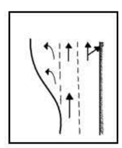
WARRANT 2 (Left Turn Capacity)

Satisfied ☐
Not Satisfied ☐

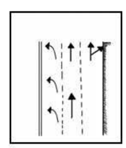
This Warrant is satisfied when for the analyzed direction the Left-Turn flow rate exceeds the left-turn capacity.
The left-turn capacity is the maximum flow rate that may be assigned to the designated phase.

– On approaches with exclusive left-turn bays / lanes, the left-turn capacity is computed by using the following equations:

(1A) $C_{ELT} = (1{,}400 - V_O)\,(g/c)_{LT}$



Exclusive Left-Turn Bay



Exclusive Left –Turn Lane

Or

(2) C_{ELT} = 2 vehicles per signal cycle

where:

C_{ELT} = capacity of the left-turn protected / permitted phase, in vph;

V_O = opposing thru plus right-turn service flow rate*, in vph, and

$(g/c)_{LT}$ = effective green** ratio for the protected / permitted phase, in seconds.

Figure 3.3(a) Left-Turn Warrant Sheet, Page 1

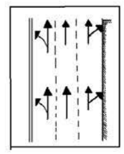
*Service flow rate is the equivalent hourly rate at which vehicles pass a roadway during a given time interval less than one hour, usually 15 minutes.

Service flow rate = (highest 15 minute count) x 4.

**Effective green time is the time during a given phase that is effectively available to the permitted movements: this is generally taken to be the green time (G) plus the change interval (Y + AR) minus the lost time (3.0 seconds) for the designated phase.

On approaches with shared left-turn and thru vehicles, the left-turn capacity is computed by using the following equations:

(1B) $C_{SLT} = [\,(1{,}400 - V_O)\,(g/c)_{LT}\,]\,f_{SLT}$



Shared Lanes

Or

(2) C_{SLT} = 2 vehicles per signal cycle

where:

C_{SLT} = capacity of the left-turn in the shared lane, in vph:

f_{SLT} = adjustment factor for left-turn vehicles

The adjustment factor basically accounts for the fact that the left-turn movements cannot be made at the same saturation flow rates as thru movements. They consume more of the available green time, and consequently, more of the intersection's available capacity.

The adjustment factor is computed as the ratio of the left-turn flow rate (which is converted to an approximate equivalent flow of thru vehicles) to the thru vehicles that share the same lane.

The following TABLE 1 may be used to convert the left-turn vehicles to equivalent thru vehicles.

TABLE 1			
TOTAL OPPOSING FLOW RATE (V_O)	CONVERSION FACTOR (f_{pce})	TOTAL OPPOSING FLOW RATE (V_O)	CONVERSION FACTOR (f_{pce})
0 – 200	1.50	1001 – 1050	5.00
201 - 500	2.00	1051 – 1075	5.50
501 – 700	2.50	1076 – 1100	6.00
701 – 800	3.00	1101 – 1125	6.50
801 – 900	3.50	1126 – 1145	7.00
901 – 950	4.00	> 1146*	
951 - 1000	4.50		

*Use exclusive Left-Turn lane procedure.

Comments:____

Figure 3.3(b) Left-Turn Warrant Sheet, Page 1

COMPUTATIONS
EXCLUSIVE LEFT-TURN LANE

Opposing Thru Plus Right Turn Service Flow Rate

V_O = (highest 15 minute count) x 4

V_O = [ ] x 4 = [ ] vph

Left Turn Service Flow Rate (Direction analyzed for Left-Turn Phase)

V_{LT} = (highest 15 minute count) x 4

V_{LT} = [ ] x 4 = [ ] vph

Left Turn Capacity

$C_{ELT} = (1{,}400 - V_O)\,(g/c)_{LT}$

where:

g = [G + Y + AR – 3.0] x f_q* = [ ] x [ ] = [ ] seconds

* Adjustment factor used to calculate the portion of the green phase that is not blocked by an opposing queue of vehicles. The fq factor is given for each case in TABLE 2.

c = cycle length = [ ] seconds

thus, $(g/c)_{LT}$ = [ ]

TABLE 2

OPPOSING THRU LANES	f_q
1	.85
2	.90
≥ 3	.95

and

C_{ELT} = (1400 - [ ]) ([ ])$_{LT}$ = [ ] vph

or

C_{ELT} = 2 vehicles per signal cycle

C_{ELT} = 2 x (3600÷C) = [ ] vph

V_{LT}= vph [>] or [<] C_{ELT}** = vph

**Select the highest left turn capacity

- If V_{LT} (Left turn service flow rate) is greater than (>) the C_{ELT} (left turn capacity), the Warrant is satisfied and a left turn phase is needed.
- If V_{LT} is less then (<) the C_{ELT} the Warrant is not satisfied because the signal and geometric design can accommodate the left turn volume at the intersection.

Figure 3.3(c) Left-Turn Warrant Sheet, Page 1

COMPUTATIONS
SHARED LEFT-TURN / THRU LANE

Adjustment Factor for Left-Turn Vehicles
(Opposing Thru Plus Right Turn Service Flow Rate)

V_O = (highest 15 minute count) x 4

V_O = [ ] x 4 = [ ] vph

Using TABLE 1, f_{PCE} = [ ]

V_{TV} = [ ] x 4 = [ ] vph

where: V_{TV} = Thru vehicles in the shared lane.

Left Turn Service Flow Rate
(Direction analyzed for Left-Turn Phase)

V_{LT} = (highest 15 minute count) x 4

V_{LT} = [ ] x 4 = [ ] vph

$V_{PCE} = V_{LT} \times f_{PCE}$ = [ ] x [ ] = [ ] vph

$f_{SLT} = V_{PCE} \div (V_{TV} + V_{PCE})$ = [ ] ÷ ([ ] + [ ]) = [ ]

TABLE 2	
OPPOSING THRU LANES	f_q
1	.85
2	.90
≥ 3	.95

Left Turn Capacity

$C_{SLT} = [(1,400 - V_O) (g/c)_{LT}] f_{SLT}$

where:

g = [G + Y + AR – 3.0] x f_q = [ ] x [ ] = [ ] seconds

c = cycle length = [ ] seconds   thus, $(g/c)_{LT}$ = [ ]

and C_{SLT} = [(1400 - [ ]) ([ ])$_{LT}$] x [ ] = [ ] vph

or

C_{SLT} = 2 vehicles per signal cycle

C_{SLT} = 2 x (3600 ÷ C) = [ ] vph

V_{LT}= vph [>] or [<] C_{SLT}* = vph

*Select the highest left turn capacity

-If V_{LT} (Left turn service flow rate) is greater than (>) the C_{SLT} (left turn capacity), the Warrant is satisfied and a left turn phase is needed.
-If V_{LT} is less then (<) the C_{SLT}, the Warrant is not satisfied because the signal and geometric design can accommodate the left turn volume at the intersection.

Figure 3.3(d) Left-Turn Warrant Sheet, Page 1

3.1.1 Types of Protected Left-turn Phasing

Protected left-turn operation occurs as either a lead or lag phase. These terms refer to the order in which the phase is displayed relative to the opposing through movement. In NYC, all protected left-turn phases require an exclusive left-turn lane or bay.

3.1.1.1 Lag/Lag or Lead/Lead Dual Left-turn Phasing

Dual left-turn phasing is used when both opposing left turns require a protected phase. With lead/lead left-turn phasing both opposing left turns start at the same time before the opposing through traffic is released. With lag/lag left-turn phasing, both opposing left turns are serviced after the opposing through traffic is stopped. Figures 3.4 and 3.5 show the phase diagram for lag/lag and lead/lead left-turn phasing, respectively. (Note that in the phase diagrams that follow, only the east/west phasing is shown.)

In Phase A of Figure 3.4 (lag/lag), the eastbound and westbound through and right-turn vehicles will see a green ball and the eastbound and westbound left-turning vehicles will see a red left-turn arrow. In phase B, the eastbound and westbound left-turning vehicles will see a green left-turn arrow and the through and right-turning vehicles will see a red ball. Pedestrians will be permitted only in Phase A.

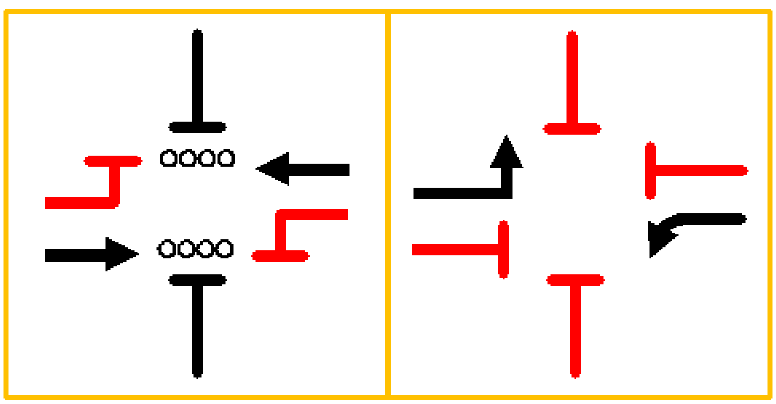


Figure 3.4 Lag/Lag Phasing

In Figure 3.5 (lead/lead), Phase A displays a green arrow to the eastbound and westbound left-turning vehicles, all other vehicular movements will see a red ball, and pedestrians will see solid Don't Walk. In Phase B, a green ball is displayed to the eastbound and westbound through and right-turning vehicles. The eastbound and westbound left-turning vehicles see a red left-turn arrow. Pedestrians are permitted only in Phase B.

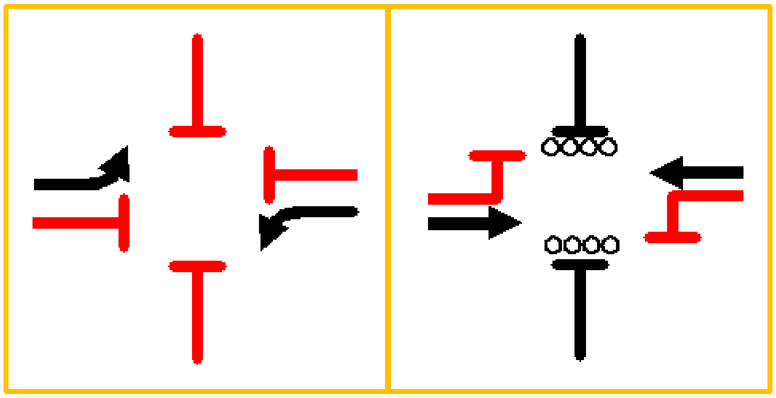


Figure 3.5 Lead/Lead Phasing

Because of the large number of pedestrians in NYC, the NYCDOT prefers lag/lag phasing when possible, for the safety of the pedestrians. Pedestrians in NYC tend to move out into the intersection and begin their crossing as soon as the cars moving perpendicular to them stop, expecting their "WALK" signal, which would not be displayed till phase B in lead/lead phasing.

In neither Figure 3.4 nor Figure 3.5 are left turns allowed in permissive mode during the through phase. Only at locations where lead/lead phasing is used are left turns sometimes allowed in permissive mode during Phase B, as shown in Figure 3.6. This is called protected/permissive left-turn (PPLT) phasing. The dotted line for the left-turn movement in Phase B represents left turns operating in permissive mode. Although the through arrow alone implies permitted left turns, the dotted lines are added here for emphasis.

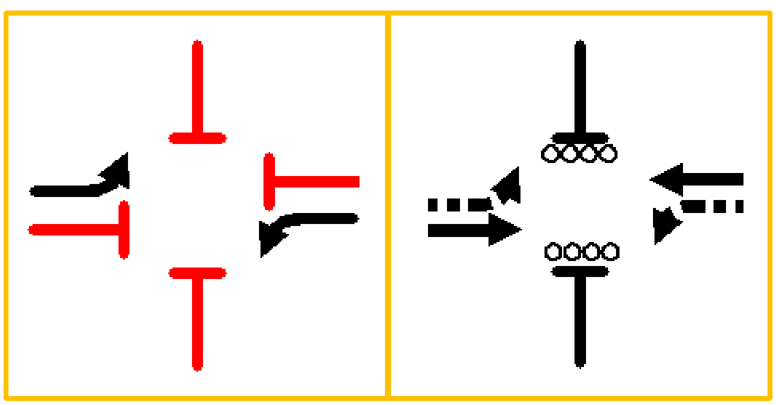


Figure 3.6 Protected-Permitted Dual Leading Left-turn Phasing

In general, PPLT phasing is only allowed when there are no more than two opposing traffic lanes. There are some exceptions to this rule when, for example, there are service roads that are stopped controlled, such as on Ocean Parkway in Brooklyn, shown in Figure 3.7. In phase A of Figure 3.7, the left, through, and right turning vehicles are allowed to enter the intersection. Right-turning vehicles are always assumed to operate at the same time with the through vehicles unless specifically prohibited on the phase diagram. In Phase B, the through and right-turn vehicles are not permitted, giving the left-turn vehicles protected time.

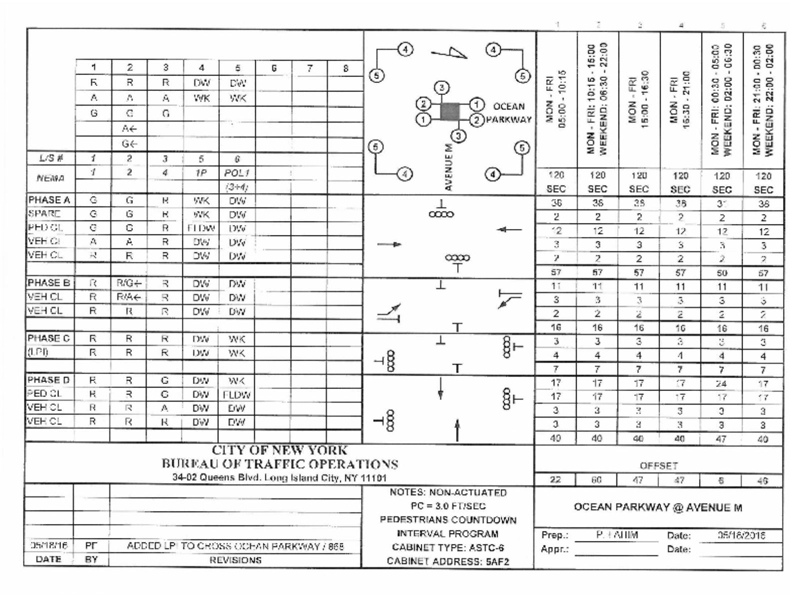


Figure 3.7 Example permissive/protected left-turn phasing (Phase A/Phase B)

When there is dual lagging (lag/lag) protected left-turn phasing, NYCDOT does not allow left-turns to operate in permissive mode during Phase A.

3.1.1.2 One-direction Lead or One-direction Lag Phasing

One-direction lead or lag phasing is used when only one opposing left-turn movement requires a protected phase. Figure 3.8 shows one-direction lead phasing. In phase A, all eastbound movements are serviced, with the eastbound lefts being protected. In Phase B, all eastbound and westbound movements are serviced, with all left turns operating in permissive mode.

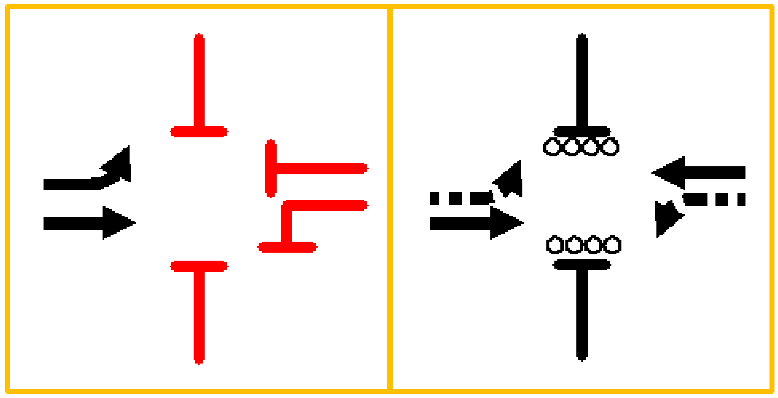


Figure 3.8 One-Direction Lead Phase

Figure 3.9 is a phase diagram of one-direction lag phasing. Such phasing is never used, however, due to the safety issue involved, called the left-turn trap or yellow trap.

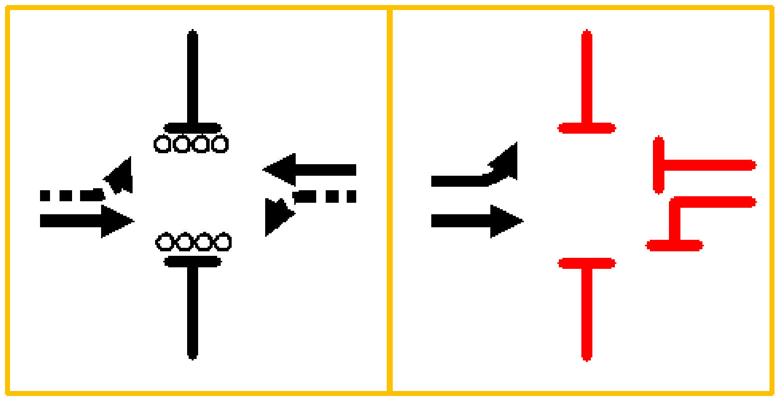


Figure 3.9 One-Direction Lag Phase

The yellow trap occurs when there is a lag phase for one direction after a permissive left-turn phase in the opposing direction, as shown in Figure 3.9. During Phase A, both opposing left-turning vehicles operate in permissive mode. Since at the end of Phase A, the westbound left turners see a yellow signal for themselves and also for the westbound through and right-turning vehicles, they may incorrectly assume that the eastbound vehicles are also receiving a yellow signal and are about to stop. Any westbound left-turning vehicles waiting for a gap to make the turn will either be trapped in the intersection with no way to turn, or complete the left turn assuming the eastbound through vehicles are stopping, producing a serious safety concern.

Because of the yellow-trap problem, one-direction lag phasing is only used when the opposing left-turn movement is banned, such as shown in Figure 3.10.

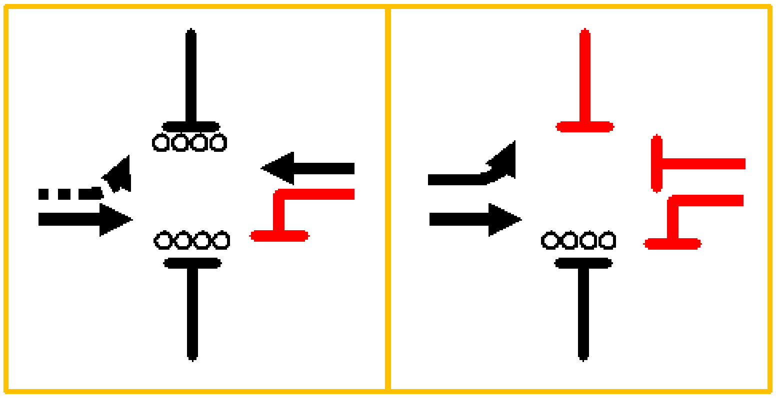


Figure 3.10 One-Direction Lag Phase with Opposing Left Turn Banned

If the opposing left-turn movement is not banned, a lead phase will always be used in order to avoid the yellow trap problem.

3.1.1.3 Lead/Lag Protected Left-turn Phasing

Lead/Lag left-turn phasing serves the opposing left turns at different times, one before its opposing through movement and one after its opposing through movement. Figure 3.11 shows a phase diagram of lead/lag left-turn phasing.

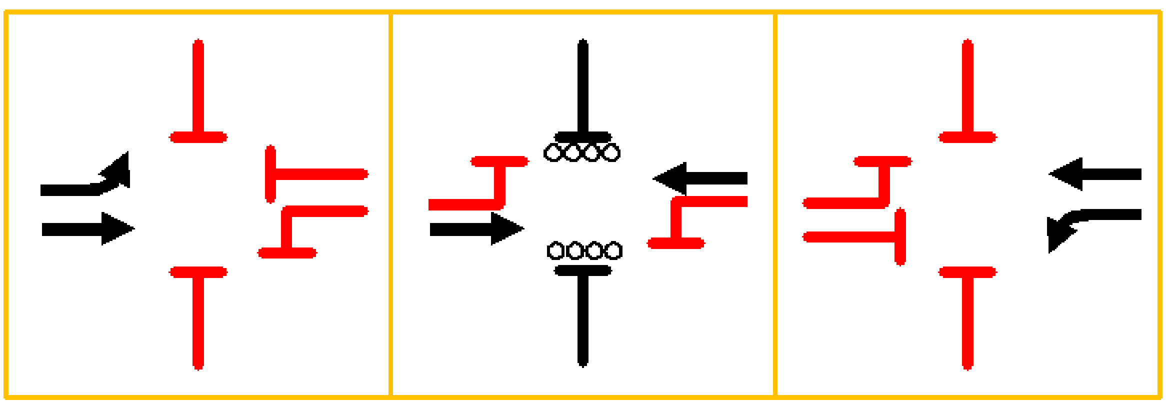
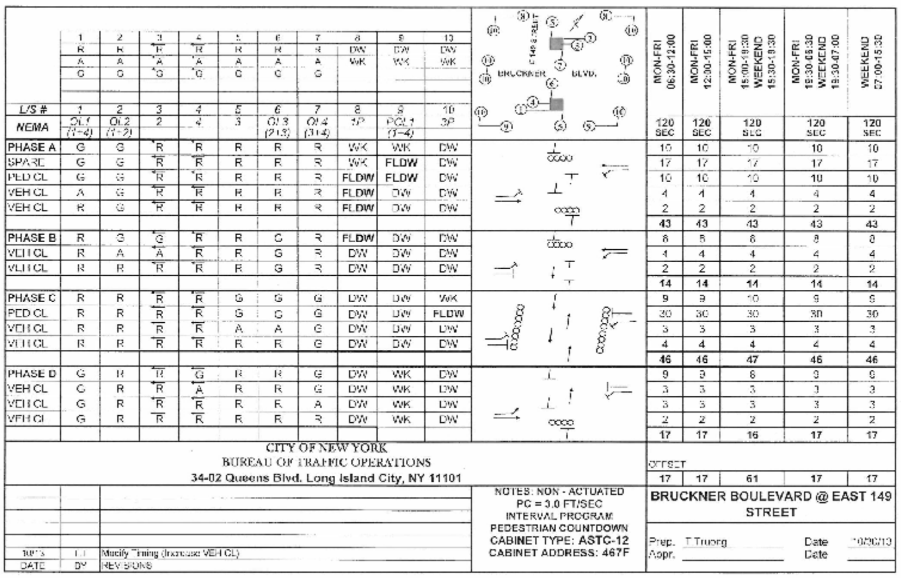


Figure 3.11 Lead/Lag Phases

In NYC, lead/lag phasing is only used when it is not possible to allow opposing left-turn movements at the same time. Most often this is due to turning radius issues, as seen in Figure 3.12 of the intersection of Bruckner Blvd and 149th Street, where the two streets do not intersect at 90 degrees. As for all protected left-turn phasing, exclusive left-turn lanes or bays are required. In NYC, protected/permissive phasing is never allowed with lead/lag left-turn phasing, i.e., left turns are never allowed to operate in the permissive mode during phase B.



	1	2	3	4	5	6	7	8	9	10	MON-FRI 06:30-12:00	MON-FRI 12:00-15:00	MON-FRI 15:00-19:30 WEEKEND 15:30-19:30	MON-FRI 19:30-06:30 WEEKEND 19:30-07:00	WEEKEND 07:00-15:30
	R	R	R	R	R	R	R	DW	DW	DW					
	A	A	A	A	A	A	A	WK	WK	WK					
	G	G	G	G	G	G	G								
L/S #	1	2	3	4	5	6	7	8	9	10					
NEMA	OL1 (1+4)	OL2 (1+2)	2	4	3	OL3 (2+3)	OL4 (3+4)	1P	POL1 (1-4)	3P	120 SEC	120 SEC	120 SEC	120 SEC	120 SEC
PHASE A	G	G	R	R	R	R	R	WK	WK	DW	10	10	10	10	10
SPARE	G	G	R	R	R	R	R	WK	FLDW	DW	17	17	17	17	17
PED CL	G	G	R	R	R	R	R	FLDW	FLDW	DW	10	10	10	10	10
VEH CL	A	G	R	R	R	R	R	FLDW	DW	DW	4	4	4	4	4
VEH CL	R	G	R	R	R	R	R	FLDW	DW	DW	2	2	2	2	2
											43	43	43	43	43
PHASE B	R	G	G	R	R	G	R	FLDW	DW	DW	8	8	8	8	8
VEH CL	R	A	A	R	R	G	R	DW	DW	DW	4	4	4	4	4
VEH CL	R	R	R	R	R	G	R	DW	DW	DW	2	2	2	2	2
											14	14	14	14	14
PHASE C	R	R	R	R	G	G	G	DW	DW	WK	9	9	10	9	9
PED CL	R	R	R	R	G	G	G	DW	DW	FLDW	30	30	30	30	30
VEH CL	R	R	R	R	A	A	G	DW	DW	DW	3	3	3	3	3
VEH CL	R	R	R	R	R	R	G	DW	DW	DW	4	4	4	4	4
											46	46	47	46	46
PHASE D	G	R	R	G	R	R	G	DW	WK	DW	9	9	8	9	9
VEH CL	G	R	R	A	R	R	G	DW	WK	DW	3	3	3	3	3
VEH CL	G	R	R	R	R	R	A	DW	WK	DW	3	3	3	3	3
VEH CL	G	R	R	R	R	R	R	DW	WK	DW	2	2	2	2	2
											17	17	16	17	17
OFFSET											17	17	61	17	17

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NOTES: NON - ACTUATED
PC = 3.0 FT/SEC
INTERVAL PROGRAM
PEDESTRIAN COUNTDOWN
CABINET TYPE: ASTC-12
CABINET ADDRESS: 467F

BRUCKNER BOULEVARD @ EAST 149 STREET

Prep. T.Truong Date 10/30/13
Appr. Date

DATE	BY	REVISIONS
10/13	T.T	Modify Timing (Increase VEH CL)

Figure 3.12 Example of lead/lag phasing (Phase D/Phase B)

3.1.2 Right-turn Phasing

Right-turn phases provide time when right-turning vehicles are allowed to enter the intersection. The type of right-turn phasing provided is dependent on the number and safety of the pedestrians in the adjacent crosswalk, as well as the volume of right-turning vehicles that must conflict with the pedestrians.

<u>3.1.2.1 Permissive-only Right-turn Phases</u>

Permissive-only right-turn phasing is the most common type of right-turn phasing used. Permissive right-turn phases allow concurrent moving of right-turning vehicles and conflicting pedestrians (pedestrians in the crosswalk adjacent to the right-turning vehicles). The standard two-phase signal phasing, as was shown in Figure 3.1 and repeated here in Figure 3.13 for easy reference, shows all movements in permissive mode.

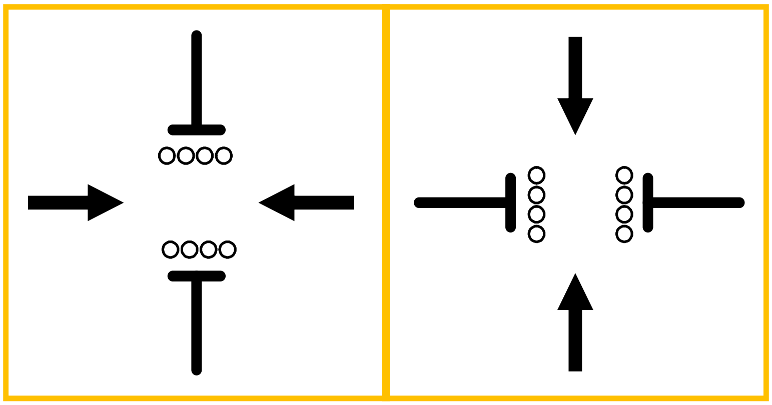


Figure 3.13 Permitted Right-Turn Phasing

3.1.2.2 Protected-only Right-turn Phases

A protected-only right-turn phase completely separates the time when pedestrians are allowed to cross the intersection and the time when turning vehicles are allowed to enter the intersection. Figure 3.14 shows a phase diagram of an intersection of two one-way streets, with protected-only right-turn phasing. An Exclusive right-turn lane or bay is required.

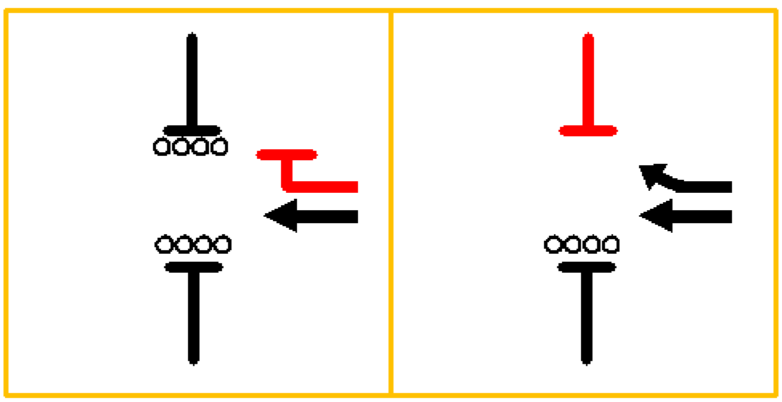


Figure 3.14 Protected-Only Right-Turn Phasing

3.1.2.3 Protected/Permissive Right Turns (PPRT)

The protected/permissive right-turn phasing only occurs when split lead pedestrian interval phasing is used, as discussed in the next section.

3.1.3 Lead Pedestrian Intervals (LPI)

Leading Pedestrian Intervals (LPI) are being used in NYC to improve pedestrian safety by increasing pedestrian visibility to turning vehicles. The LPI phase gives a "head start" to the pedestrians before the vehicles are released. This partially separates the pedestrians and vehicles in time, reducing conflicts. Figure 3.15 shows a phase diagram for an LPI phase.

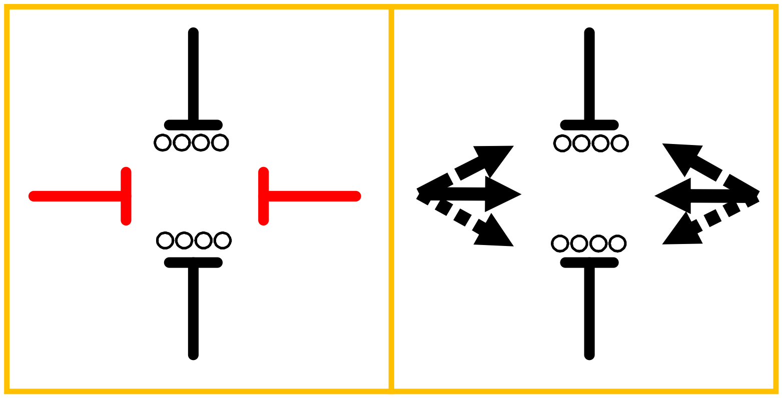


Figure 3.15 Lead Pedestrian Interval Phasing (LPI)

In NYC, there are basic rules of thumb for considering LPI phasing:

- In Manhattan, LPI signals are considered when there are ≥ 200 vph turning left and right through the crosswalk.
- In the outer boroughs, there would also have to be greater than 200 pedestrians going through the crosswalk.
- Locations where there are two or more pedestrian crashes due to left- or right-turning vehicles.
- School Crossings: 99% of LPIs requested for crossings near schools get the LPI phasing.
- The standard NYC LPI phase is seven seconds.

3.1.4 Split Phase

The term split phase refers to completely separating the pedestrian signal time from the conflicting turning-vehicle time. The split phase can either separate pedestrians from right-turning vehicles, as was shown in Figure 3.14, or the split phase can separate the pedestrians from the left-turn movement, or both. Exclusive-turn lanes are always required when split phasing is used.

Split phasing is often used at intersections of two one-way streets. In these cases, pedestrians are allowed to cross on one of the crosswalks during both phases, while the other crosswalk will split the time between pedestrians and turning vehicles, as shown in Figure 3.16.

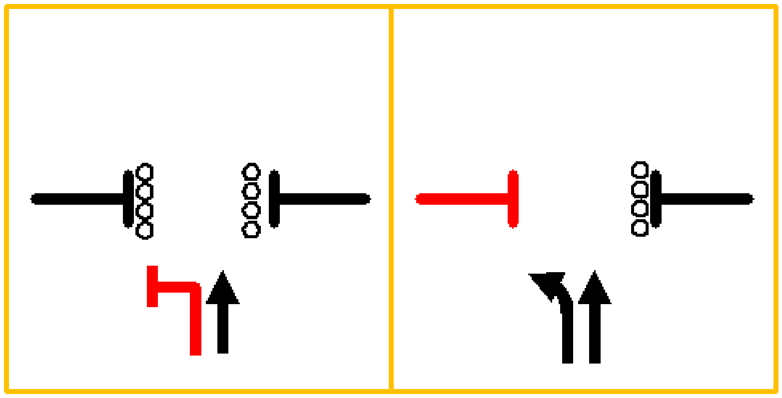


Figure 3.16 Split Phasing at Intersection with One-way Street Northbound

A disadvantage to split phasing is the limited amount of time available for pedestrians to cross safely. The advantage is that the turning movement never gets the signal at the same time as the pedestrians, thus there is never any conflict between the two.

Split LPI (Delaying Turns)

With split LPI phasing, both Phase A and Phase B allow pedestrians, which removes the problem of timing for pedestrians to cross safely. The first phase, Phase A, allows through vehicles and pedestrians, but not turning vehicles. This gives the LPI benefit of providing the "head start" time into the crosswalk. The second phase allows all the movements, with a flashing arrow in Phase B for the turning movement, as in Figure 3.17.

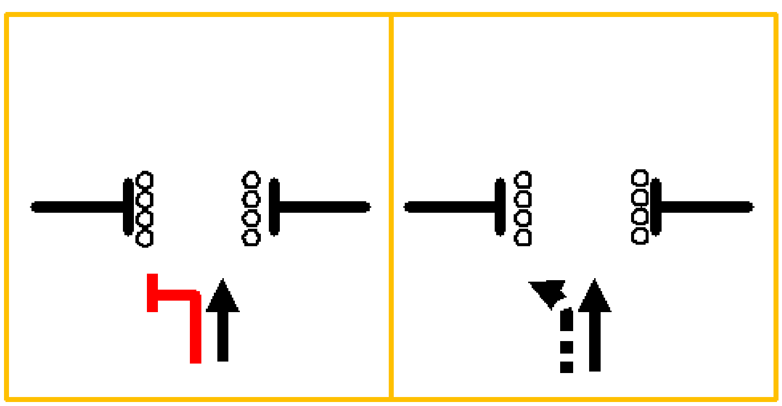
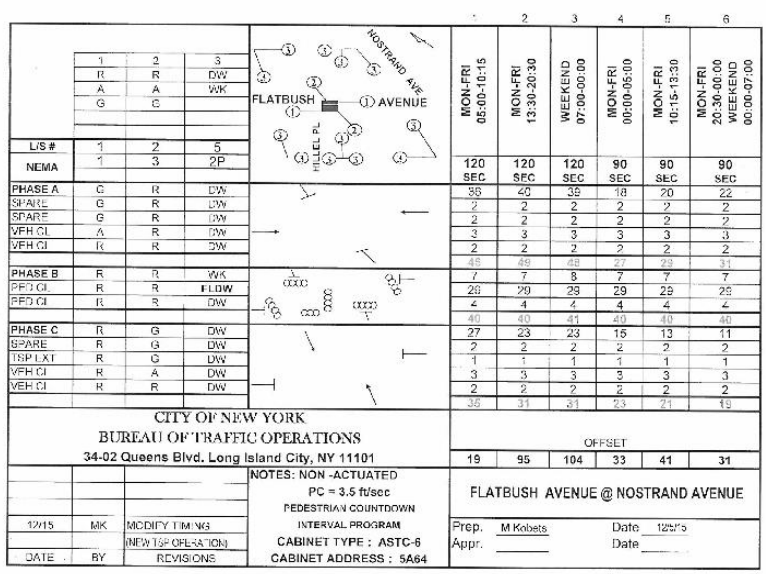


Figure 3.17 Split LPI Phasing on One-Way Street, Flashing Arrow in Phase B

With split LPI phasing, there are conflicts with vehicles, but pedestrians get the LPI benefit not provided in regular split phasing. There is no lost time for the through vehicles. Phase B uses a flashing yellow arrow for the turning movement to warn them to yield to pedestrians. The split LPI requires a turning lane or bay, which is not required for a standard LPI phase as was shown in Figure 3.15.

3.1.5 Exclusive Pedestrian Phase (Barnes Dance)

An exclusive pedestrian phase is considered only when there is unusual geometry or other situations that make it difficult for pedestrians to cross safely. Figure 3.18 shows an intersection drawing for a location with an exclusive pedestrian phase (Phase B).



				[illegible]	2	3	4	5	6
	1	2	3	MON-FRI 05:00-10:15	MON-FRI 13:30-20:30	WEEKEND 07:00-00:00	MON-FRI 00:00-05:00	MON-FRI 10:15-13:30	MON-FRI 20:30-00:00 WEEKEND 00:00-07:00
	R	R	DW						
	A	A	WK						
	G	G							
L/S #	1	2	5						
NEMA	1	3	2P	120 SEC	120 SEC	120 SEC	90 SEC	90 SEC	90 SEC
PHASE A	G	R	DW	36	40	39	18	20	22
SPARE	G	R	DW	2	2	2	2	2	2
SPARE	G	R	DW	2	2	2	2	2	2
VEH CL	A	R	DW	3	3	3	3	3	3
VEH CI	R	R	DW	2	2	2	2	2	2
				46	49	48	27	29	31
PHASE B	R	R	WK	7	7	8	7	7	7
PED CL	R	R	FLDW	29	29	29	29	29	29
PED CI	R	R	DW	4	4	4	4	4	4
				40	40	41	40	40	40
PHASE C	R	G	DW	27	23	23	15	13	11
SPARE	R	G	DW	2	2	2	2	2	2
TSP EXT	R	G	DW	1	1	1	1	1	1
VEH CI	R	A	DW	3	3	3	3	3	3
VEH CI	R	R	DW	2	2	2	2	2	2
				35	31	31	23	21	19
OFFSET				19	95	104	33	41	31

CITY OF NEW YORK
BUREAU OF TRAFFIC OPERATIONS
34-02 Queens Blvd. Long Island City, NY 11101

DATE	BY	REVISIONS
12/15	MK	MODIFY TIMING (NEW TSP OPERATION)

NOTES: NON -ACTUATED
PC = 3.5 ft/sec
PEDESTRIAN COUNTDOWN
INTERVAL PROGRAM
CABINET TYPE : ASTC-6
CABINET ADDRESS : 5A64

FLATBUSH AVENUE @ NOSTRAND AVENUE

Prep. M Kobets Date 12/5/15
Appr. Date

Figure 3.18 Exclusive Pedestrian Phase at Flatbush and Nostrand Avenues

Exclusive pedestrian phases add significant delay to the vehicles at the intersection. Therefore, If possible, the preference is not to install an exclusive pedestrian phase and other possibilities are considered first. For example, at an intersection with geometry as shown in Figure 3.19, there may be a request for an exclusive pedestrian phase because of the skewed geometry which causes the vehicles coming from the south to have a large distance to travel before reaching crosswalk *A*. Vehicles arriving at the intersection on green have limited visibility of the pedestrians and can be moving at considerable speed when reaching the crosswalk, causing unsafe conditions for the pedestrians.

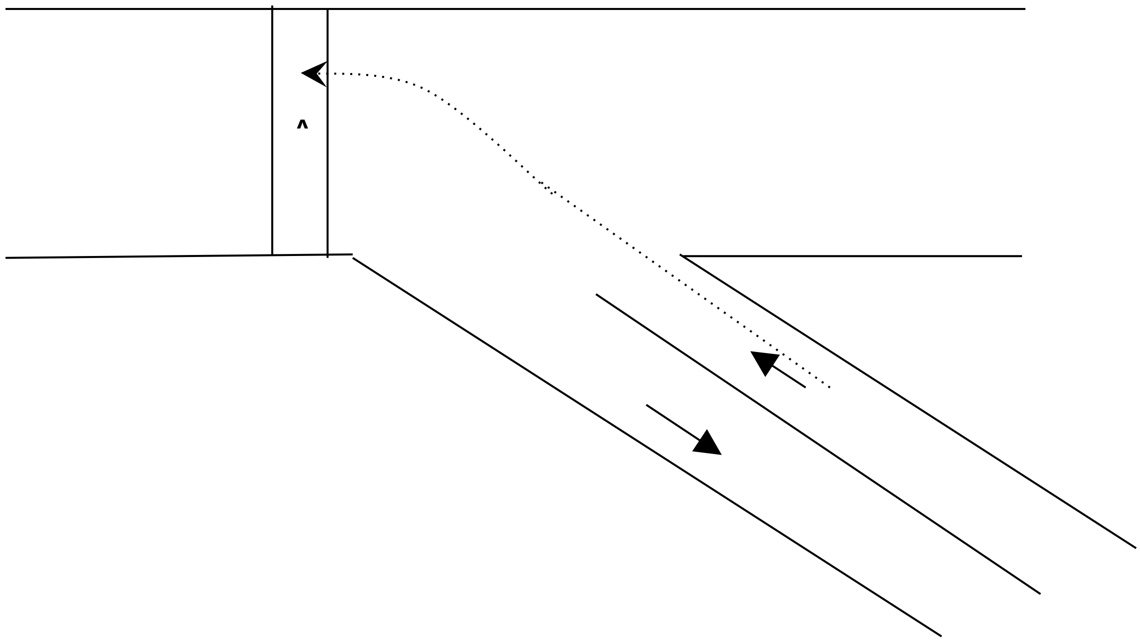


Figure 3.19 Example Location Requesting an Exclusive Pedestrian Phase

Before adding an exclusive pedestrian phase, however, it is preferable to determine if there is a way to normalize the geometry to make it safer for pedestrians crossing. Figure 3.20 shows a solution without having to add the extra time for the exclusive pedestrian phase by building a bulb-out and moving the crosswalk from A to B.

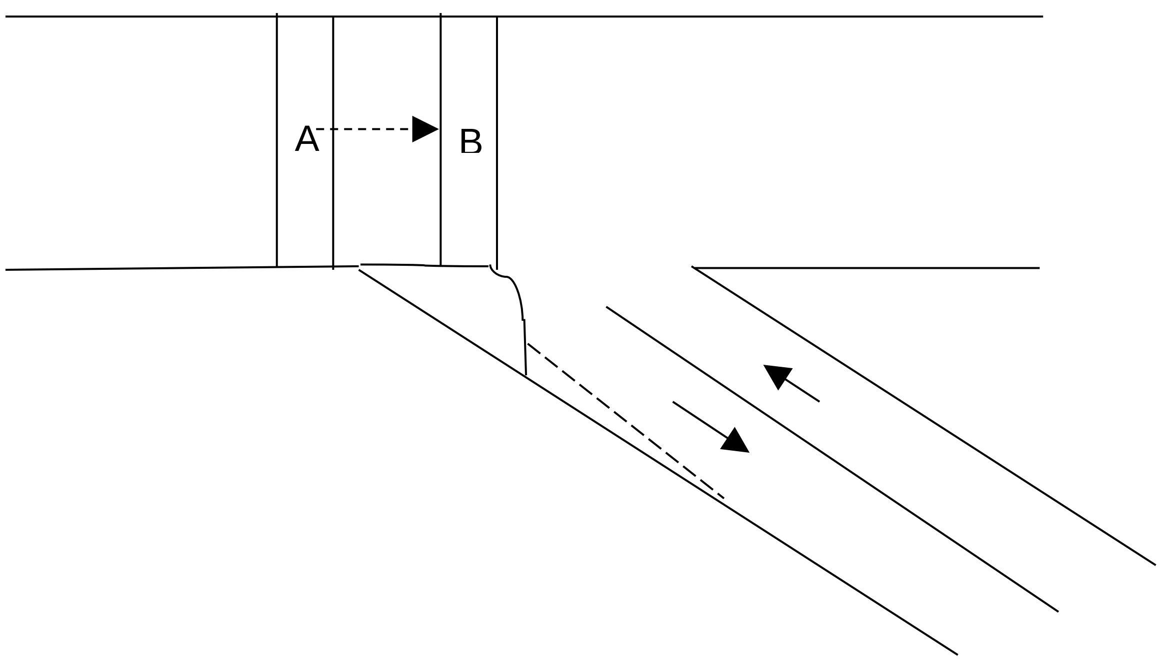


Figure 3.20 Intersection Solution without Barnes

T-away intersections, such as shown in Figure 3.21, always have an exclusive pedestrian phase, since there is never another need to stop the main street vehicles except for the pedestrians.

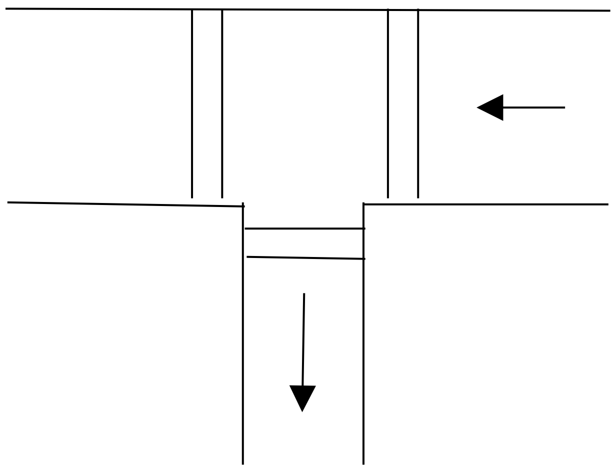


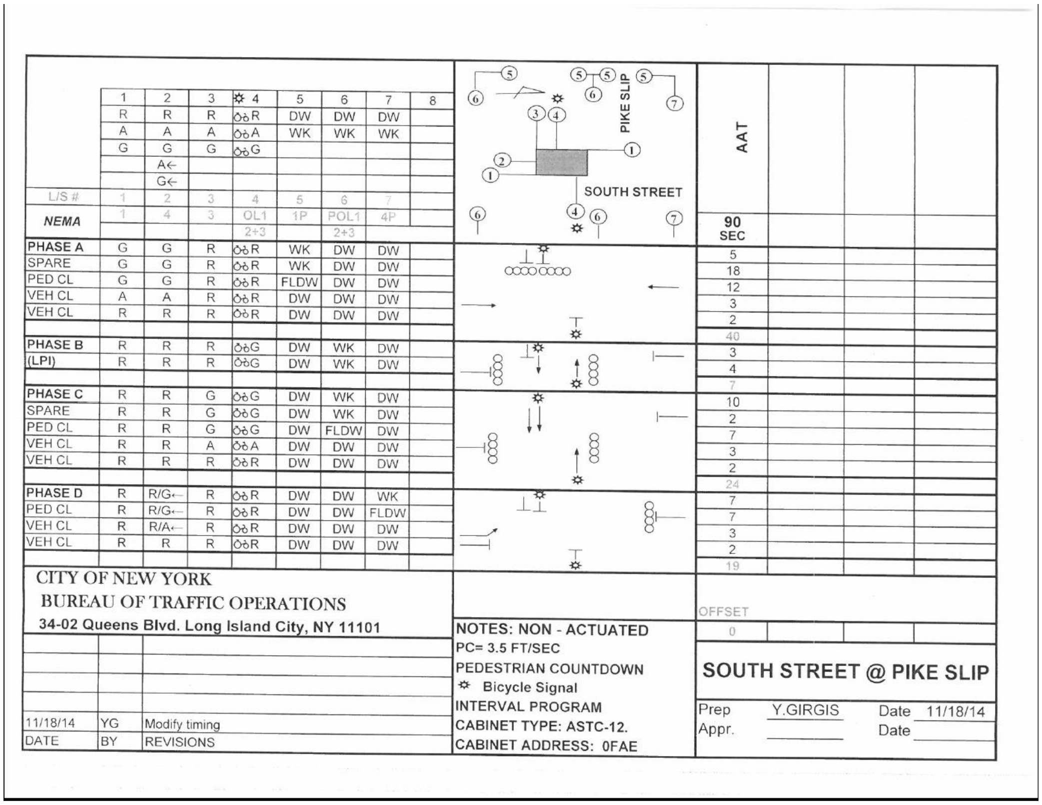
Figure 3.21 T-away intersection

3.1.6 Bicycle Phase

Signalized Intersections with bike lanes may have signal heads specifically for bicyclists. This can be a useful tool for improving the safety of bicyclists through the intersection by making it clear to the cyclist when and when not they may enter the intersection. In general, the bicycle signal follows the vehicle signal.

Leading Bicycle Interval (LBI)

In almost all cases, the decision to have an LBI phase is based on pedestrian considerations and not the bicycle. Whenever there is a bicycle LBI, a pedestrian LPI will always be displayed as well, for example, as shown in Figure 3.22.



	1	2	3	✲ 4	5	6	7	8	AAT
	R	R	R	ȯȯR	DW	DW	DW		
	A	A	A	ȯȯA	WK	WK	WK		
	G	G	G	ȯȯG					
		A←							
		G←							
L/S #	1	2	3	4	5	6	7		
NEMA	1	4	3	OL1 2+3	1P	POL1 2+3	4P		90 SEC
PHASE A	G	G	R	ȯȯR	WK	DW	DW		5
SPARE	G	G	R	ȯȯR	WK	DW	DW		18
PED CL	G	G	R	ȯȯR	FLDW	DW	DW		12
VEH CL	A	A	R	ȯȯR	DW	DW	DW		3
VEH CL	R	R	R	ȯȯR	DW	DW	DW		2
									40
PHASE B	R	R	R	ȯȯG	DW	WK	DW		3
(LPI)	R	R	R	ȯȯG	DW	WK	DW		4
									7
PHASE C	R	R	G	ȯȯG	DW	WK	DW		10
SPARE	R	R	G	ȯȯG	DW	WK	DW		2
PED CL	R	R	G	ȯȯG	DW	FLDW	DW		7
VEH CL	R	R	A	ȯȯA	DW	DW	DW		3
VEH CL	R	R	R	ȯȯR	DW	DW	DW		2
									24
PHASE D	R	R/G←	R	ȯȯR	DW	DW	WK		7
PED CL	R	R/G←	R	ȯȯR	DW	DW	FLDW		7
VEH CL	R	R/A←	R	ȯȯR	DW	DW	DW		3
VEH CL	R	R	R	ȯȯR	DW	DW	DW		2
									19

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34-02 Queens Blvd. Long Island City, NY 11101

DATE	BY	REVISIONS
11/18/14	YG	Modify timing

NOTES: NON - ACTUATED
PC= 3.5 FT/SEC
PEDESTRIAN COUNTDOWN
✲ Bicycle Signal
INTERVAL PROGRAM
CABINET TYPE: ASTC-12.
CABINET ADDRESS: 0FAE

OFFSET 0

SOUTH STREET @ PIKE SLIP

Prep Y.GIRGIS Date 11/18/14
Appr. Date

Figure 3.22 Example LBI phase (Phase D)

Bicycle Split Phase

A complete split phase for the bicycle is rarely used, but exists at a few locations along First Avenue, as shown in Figure 3.23.

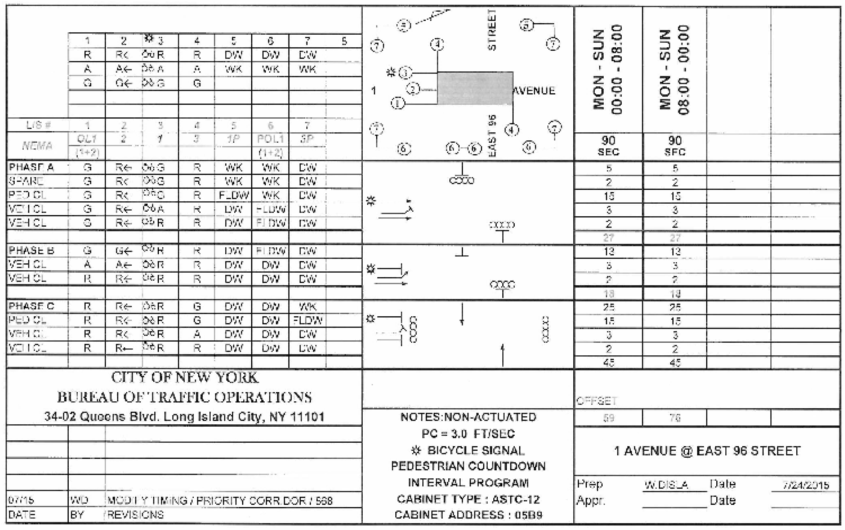


Figure 3.23 Example Split Bicycle Phase (Bicycles allowed only in Phase A)

3.1.1 Flashing Arrow (left and right)

Flashing arrows are <u>only</u> used with split phases or split LPI phases (pedestrians alone or pedestrians and bicycles) to alert turning vehicles to yield to the pedestrian and/or bicyclist. Flashing arrows always require an exclusive turning lane or bay. Thus the turning vehicle will first see a red arrow at the same time that the pedestrians and/or bicycles are permitted to proceed. Pedestrians and/or bicyclists continue to proceed, when the red arrow turns to a yellow flashing arrow.

3.1.2 Bus Queue Jumping

A bus queue jumping phase is a type of leading bus interval (LBI) that allows only the bus to move because the bus needs to move ahead of the queue onto the left moving lane. Figure 3.24 shows a phase diagram with a bus queue jumping phase.

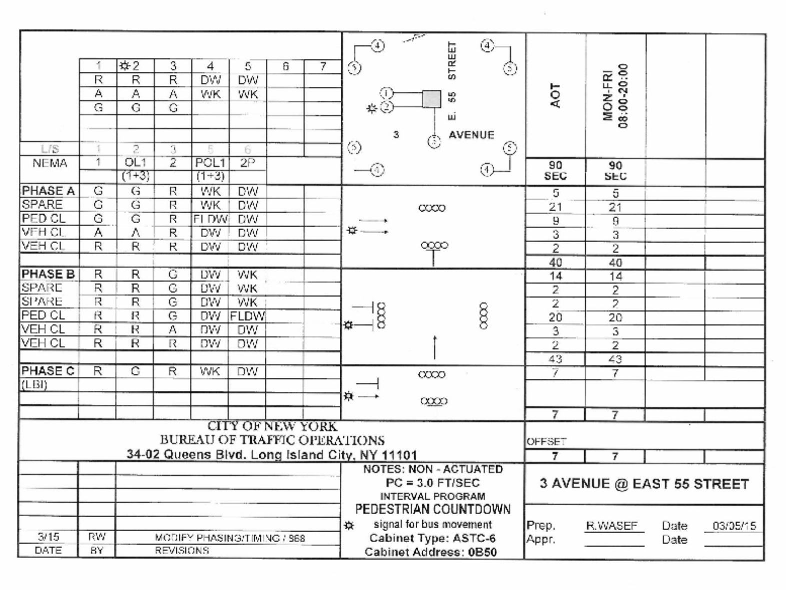


Figure 3.24 Bus Queue Jumping Phase

3.1.3 Experimental Signals

Midblock Crossings

Experimental signals are generally signals placed at midblock locations. At the crosswalk, a flashing amber is displayed until the pedestrian push button is activated. Four seconds after activation, the flashing amber changes to a steady amber for four seconds, and then red. After a two-second “all red” interval, the pedestrian phase begins.

T-Intersections of two one-way streets

At intersections of two one-way streets that do not meet any of the warrants for adding a signal, flashing arrows are used. This is usually at a school crossing. Figure 3.25 shows such a location.

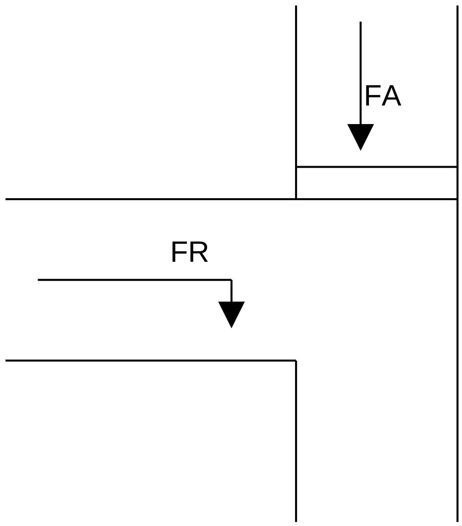


Figure 3.25 Experimental Signal

In Figure 3.25, FR is a flashing red signal. FA is a flashing amber signal, where a pedestrian push button would be installed at the curb of each end of the crosswalk. When the pedestrian button is pressed, after four seconds the flashing amber changes to a steady amber for four seconds, then turns red. After two seconds of all red, the pedestrian phase begins.

3.2 Optimization of Signal Timing

The previous section discussed the phasing plan, which assigns right-of-way to each of the various movements that use the intersection. This section discusses how time is divided among the phases.

The signal timing control can operate in one of two modes.

- Pretimed Control
- Actuated Control

In pretimed control mode, the amount of time given to each phase is fixed, regardless of changes in the traffic demand. The number and order of the phases does not change. The advantage of pretimed control is the ability to coordinate the signals in order to move vehicles smoothly through the signals with the least amount of stops and delay.

In actuated control mode, detectors at the intersection monitor traffic demand to adjust phase times based on that demand. If no demand exists for a given movement, the phase controlling that movement can be skipped.

Each phase is made up of intervals. An interval is a period of time during which the signal indication does not change. For both pretimed and actuated control phases, all phases must end with a change and clearance interval.

3.2.1 The Change and Clearance Intervals

The MUTCD [1] requires that all signal phases have a yellow change interval between the green interval and the red interval for a given movement, with an optional all-red interval. The ITE Manual on Traffic Signal Design [2], however, recommends that both a yellow change interval and an all-red clearance interval be used. NYCDOT follows the ITE recommendation and uses both the yellow change and all-red clearance intervals.

Yellow Change Interval

The yellow change interval serves the purpose of warning users that their phase is ending and allow vehicles to decide to either safely stop before the crosswalk or to safely proceed to enter the intersection on yellow.

In NYC, the yellow change interval is normally set as the speed limit divided by ten, rounding up if not an integer. The *minimum* yellow interval allowed in NYC is 3 seconds. With the vision zero speed limit being set at 25 mph, 98% of intersections in NYC have a 3-second yellow change interval.

All-red Clearance Interval

The all-red clearance interval is a period of time when all movements at the intersection have a red indication. For vehicles that entered the intersection on the yellow indication, the all-red phase should allow those vehicles to safely clear the intersection before green is initiated for the next phase. In NYC, this time is set using Equation 3-1.

$$ar = \frac{distance}{speed\ limit} \qquad [3\text{-}1]$$

Where *distance* is the curb-to-curb distance, not including parking lanes, if any.

The minimum all-red interval used in NYC is 2 seconds, and the maximum all-red interval is 8 seconds. Ninety-nine percent of signals in NYC have an all-red interval of 2 seconds. The all-red interval may be increased when left-turning vehicles are regularly getting trapped in the intersection.

3.2.2 Cycle Length

Cycle length is defined as the total time it takes to complete one full sequence of phases. In NYC, the cycle length is set based on adjacent signals. Example cycle lengths used are shown in Table 3.1

Table 3.1 Example Cycle Lengths on NYC Arterials

Arterial	**Cycle Length (seconds)**
York Avenue	120 all day
West Street	120 am peak; 150 pm peak; 135 other times
All intersections between York Avenue and West Street in Manhattan	90 all day
Queens Boulevard	150 am/pm peaks; 120 other times
Flatbush Avenue (between Tillary and GAP)	120 all day
Flatbush Avenue South of Grand Army Plaza	120 am/pm peaks; 90 other times

3.2.3 Splitting Available Time between Phases

The cycle length is split among the phases in proportion to the demand for the critical movement using each phase. The critical movement is the movement in each phase with the highest demand. For example, for a lead/lead left-turn phase, Phase A would be timed for the higher of the two opposing left-turn volumes. Phase times calculated based on volume must be checked against the pedestrian phase timing needed to ensure safe pedestrian crossing. The computer program SYNCHRO is used to calculate the phase times and splits. However, the split is also dependent upon the adjacent signals.

3.2.4 Pedestrian Signal Timing

The pedestrian phase consists of three intervals. The Walk interval allows the pedestrians to move off the curb and enter the crosswalk. The Flashing Don't Walk interval is calculated as a portion of the pedestrian clearance time, which allows pedestrians time to cross curb-to-curb, including any parking lanes at a walking speed of 3 or 3.5 fps. Slower pedestrian walking speeds are used at locations with significant numbers of seniors as well as near schools.

Walk Interval

The pedestrian walk phase is set to 7 seconds, except in areas with significant numbers of seniors, where it is then set to 10 seconds. At school crossings, it is sometimes set to 10 seconds as well, based on engineering judgement.

Flashing Don't Walk Interval

The Flashing Don't Walk (FDW), yellow-change, and all-red intervals together are the pedestrian clearance time (PC). The pedestrian clearance time is calculated using Equation 3-2.

$$PC = \frac{Distance}{Walking\ Speed} \qquad [3\text{-}2]$$

Where distance is measured curb-to-curb, including parking lanes.

The yellow-change and all-red clearance intervals are calculated first as described above. The FDW is then calculated using Equation 3-3.

$$FDW = PC - Y - AR \qquad [3\text{-}3]$$

Where
Y = yellow change interval, sec
AR = all-red clearance interval time, sec

Pedestrian Timing for Roadways with Medians

At intersections where raised medians exist, if the pedestrian phase can clear pedestrians safely curb-to-curb, without adding an unreasonable amount of delay to the vehicles, the pedestrian phase would be timed for curb-to-curb crossing. If that is not possible, then the pedestrian phase is timed to cross the pedestrians from curb to end of median. All intersections with raised medians also have countdown signals, with a minimum countdown of 12 seconds. The timing of a countdown signal is described in the next section.

Countdown Signals

Countdown signals are only placed at intersections that are wider than 45 feet. The countdown time interval replaces the Flashing Don't Walk interval and is generally calculated the same way. The countdown time begins at the end of the Walk signal and reaches zero when the vehicle green interval ends (start of yellow change interval).

The exception to the countdown signal being timed as the Flashing Don't Walk interval is when there is a raised median in the intersection, where the minimum countdown time is twelve seconds.

For example, at an intersection that is 45 feet wide, the Flashing Don't Walk interval would be calculated as follows:

$$PC = \frac{45}{3} = 15sec$$
$$FDW = 15 - 3 - 2 = 10sec$$

Where 3 = the yellow change interval and 2 = the all-red interval.

The same intersection with a raised median would have the countdown signal set at 12 seconds.

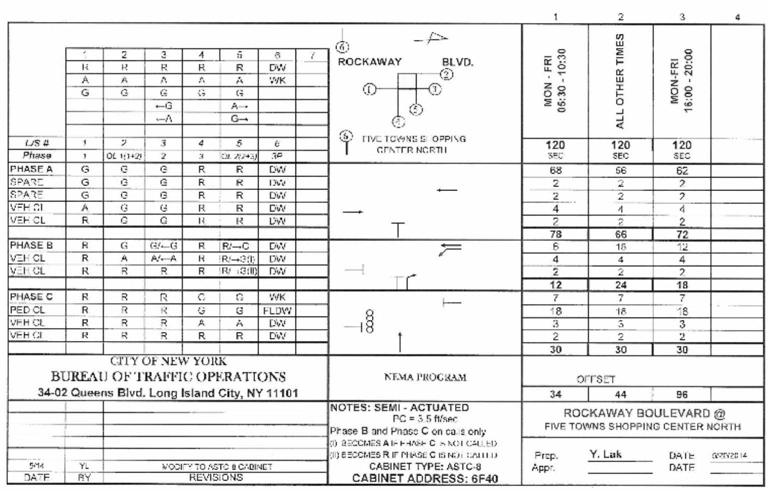
3.2.5 Actuated Signal Control

Actuated signal control uses information obtained from detectors that monitor demand on the approaches to the intersection to change phase times relative to the demand. The purpose is to avoid wasting green time on demand that does not exist. Phase times can change cycle-to-cycle.

There are two different types of actuated control: fully actuated and semi-actuated. Fully-actuated control has detectors on all approaches to the intersection. Semi-actuated control has detectors only on the side street or for the main street left-turn movement. In NYC, fully-actuated control is not used.

In general, in Manhattan there are no actuated-controlled phases for vehicle movements. In the next chapter, a special signal timing system that is used in midtown Manhattan will be discussed. It is called Midtown in Motion and does change phase times based on demand.

Semi-actuated control is sometimes used in the outer boroughs of NYC, in areas with low pedestrian volumes. For example, at the exit from the Rockaway shopping mall on Rockaway Blvd, as shown in Figure 3.26



	1	2	3	4	5	6	7	1 MON - FRI 05:30 - 10:30	2 ALL OTHER TIMES	3 MON-FRI 16:00 - 20:00	4
	R	R	R	R	R	DW					
	A	A	A	A	A	WK					
	G	G	G	G	G						
			←G		A→						
			←A		G→						
L/S #	1	2	3	4	5	6		120 SEC	120 SEC	120 SEC	
Phase	1	OL 1(1+2)	2	3	OL 2(2+3)	3P					
PHASE A	G	G	G	R	R	DW		68	56	62	
SPARE	G	G	G	R	R	DW		2	2	2	
SPARE	G	G	G	R	R	DW		2	2	2	
VEH CL	A	G	G	R	R	DW		4	4	4	
VEH CL	R	G	G	R	R	DW		2	2	2	
								78	66	72	
PHASE B	R	G	G/←G	R	R/→G	DW		6	18	12	
VEH CL	R	A	A/←A	R	R/→G(I)	DW		4	4	4	
VEH CL	R	R	R	R	R/→G(II)	DW		2	2	2	
								12	24	18	
PHASE C	R	R	R	G	G	WK		7	7	7	
PED CL	R	R	R	G	G	FLDW		18	18	18	
VEH CL	R	R	R	A	A	DW		3	3	3	
VEH CL	R	R	R	R	R	DW		2	2	2	
								30	30	30	
OFFSET								34	44	96	

ROCKAWAY BLVD.

FIVE TOWNS SHOPPING CENTER NORTH

CITY OF NEW YORK
BUREAU OF TRAFFIC OPERATIONS
34-02 Queens Blvd. Long Island City, NY 11101

NEMA PROGRAM

NOTES: SEMI - ACTUATED
PC = 3.5 ft/sec
Phase B and Phase C on calls only
(I) BECOMES A IF PHASE C IS NOT CALLED
(II) BECOMES R IF PHASE C IS NOT CALLED
CABINET TYPE: ASTC-8
CABINET ADDRESS: 6F40

ROCKAWAY BOULEVARD @
FIVE TOWNS SHOPPING CENTER NORTH

Prep. Y. Lak DATE
Appr. DATE

DATE	BY	REVISIONS
5/14	YL	MODIFY TO ASTC 8 CABINET

Figure 3.26 Intersection under semi-actuated control

Pedestrian-activated phases are used in all boroughs. A typical location where a pedestrian-activated phase would be used is near a school. For example, Figure 3.27 shows an intersection that works in fixed time mode until 4pm and then becomes pedestrian activated.

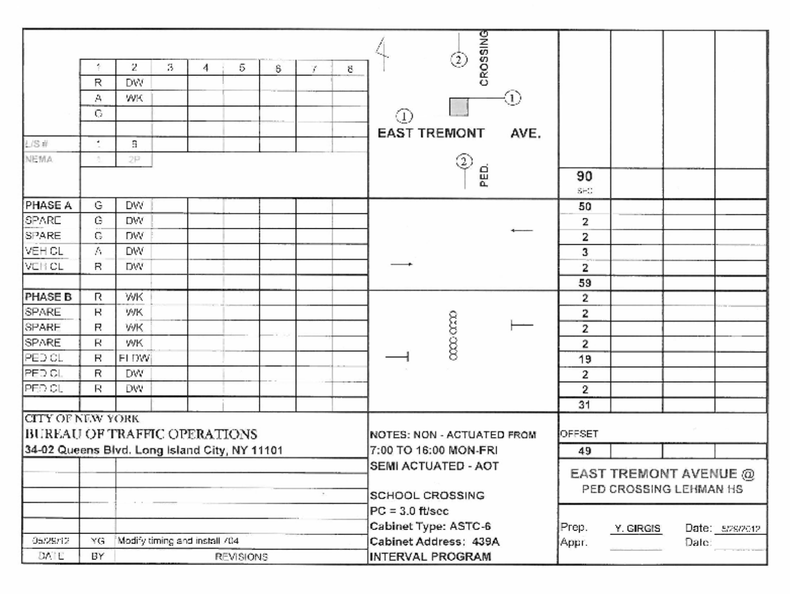


Figure 3.27 Pedestrian Actuated Crossing Phase

3.3 Coordination Concepts

3.3.1 Introduction

Coordination refers to the concept of synchronizing the signal timing of closely spaced intersections in order to progress platoons of vehicles efficiently through the signalized intersections of a corridor for a planned speed. The goal of coordination is for large percentage of vehicles departing the upstream intersection arriving during the green at the downstream intersection. All intersections on the arterial should have the same cycle length.

The advantages of coordinating traffic signals are:

- Keeping tight platoons minimizes the headway between vehicles, increasing capacity;
- Stops and delay are reduced;
- Vehicles in a platoon move at similar speeds, leading to reduced crashes;
- Reducing stops, reduces rear-end crashes;
- Reducing stops and delay leads to less air pollution and better fuel consumption.

3.3.2 Offset

Offset is the means by which signals are coordinated. Offset is the time relationship (in seconds) between a point in the cycle and a system reference point. The fixed point in the cycle is often the start of the through-movement green interval. Correct setting of the offset permits a platoon of vehicles to proceed, with minimal delay, through a series of intersections at a planned speed.

In general, NYCDOT has three timing plans for different periods of the day.

- AM Peak Period
- PM Peak Period
- All other times

Time-Space Diagrams

A time-space diagram is a chart that plots the signal phases for a series of intersections as a function of time. It is a useful device for visualizing the concept of coordination. A very simple time-space diagram is shown in Figure 3.28. On this figure, the y-axis is distance and the x-axis is time. (It should be noted that some programs reverse the axes.) The solid rectangles represents effective red time, the space between the rectangles represents effective green time. The start of green at the first intersection from the bottom is at T1 seconds and the start of green at the second intersection is at T2 seconds. The offset between these two intersections is (T2 - T1) seconds.

Crucial in setting the offset is the vehicle travel time. This is dependent upon:

- Desired through-traffic travel speed, *v*, and
- Distance between intersections, *L*

Given a desired speed for vehicles on the roadway, *v*, and a block length, *L*, the ideal offset would be the travel time from the upstream intersection to the downstream intersection, *L/v*.

In a well-progressed system, platoons of vehicles move through multiple intersections during the green signal. In a poorly progressed system, vehicles would experience unnecessary stops.

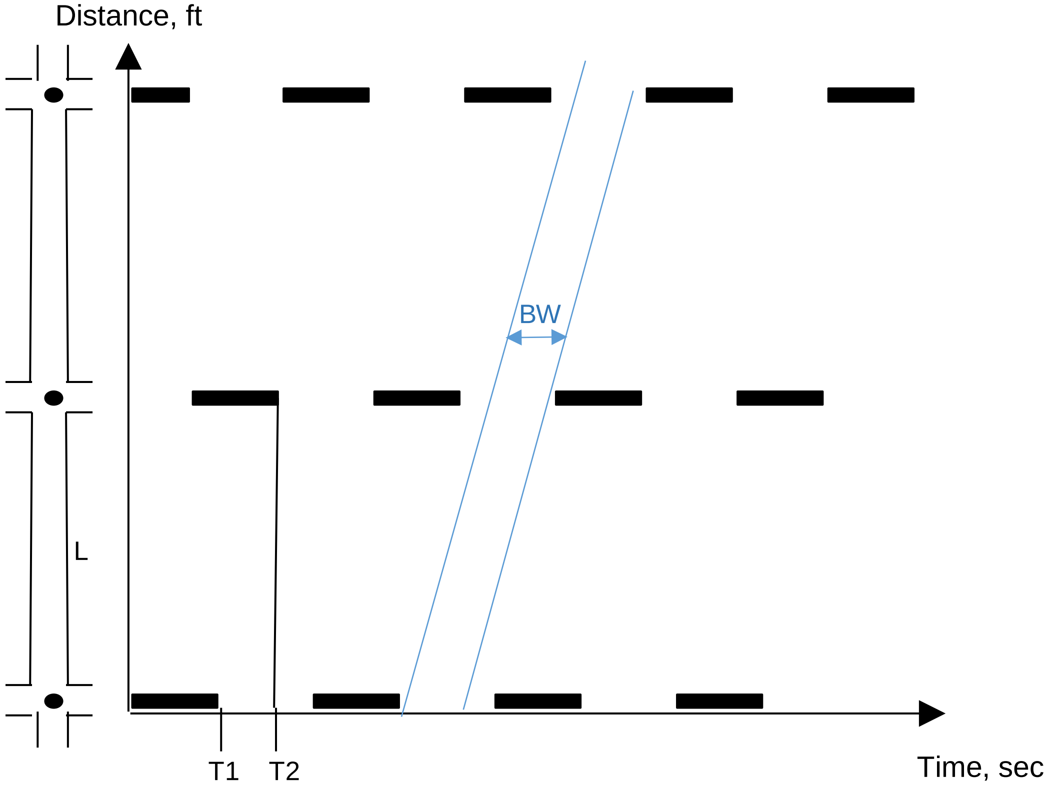


Figure 3.28 Example Time-Space Diagram

3.3.3 Bandwidth

Bandwidth is the time period between the passing of the first and last possible vehicle in a platoon of vehicles moving continuously through a series of intersections at the design speed. In Figure 3.28, the time (in seconds or percent of cycle) between the two parallel lines represents the bandwidth (BW). The slope of the line is the speed of the progression.

Optimizing bandwidth strives to create windows of green along the arterial. For long arterials, the bandwidth solutions can move the platoons through a group of signals, with breaks to stop, and then form a new platoon. Bandwidths can also be used to control traffic speed. Vehicles that travel faster than the progression speed will reach the downstream intersection early and be forced to stop.

3.4 Computer Tools Used for Signal Timing and Progression

Software programs are used by traffic engineers to compute the signal timing and offsets for best moving vehicles through the system of intersections. Two programs are regularly used in the signal timing division: Synchro and Tru-Traffic. Synchro optimizes the signal progression by minimizing stops and delay as the objective function. Tru-Traffic optimizes bandwidth. These programs will be discussed in more detail in Chapter 5.

3.5 Advanced Technologies

3.5.1 Transit Signal Priority

Transit signal priority (TSP) is a technique for prioritizing bus service over other modes using the arterial. The goals of TSP are to:

- Reduce bus travel time
- Improve the reliability and on-time performance of bus service
- Encourage the use of transit by improving bus operations
- Reduce delays and improve air quality overall
- Improve overall mobility

In NYC, in order to expedite bus service, the TSP controller uses three strategies:

1. Extension of Green Time (to Reduce Stops)

When a bus is approaching the intersection as the green interval is about to end, the green may be extended to allow the bus to proceed through the intersection without stopping.

2. Early Return to Green (to Reduce Delay)

When a bus is stopped at the intersection, the TSP controller may shorten the conflicting phase in order to return the green to the bus movement’s phase. A phase may not be shortened below the minimum requirements of the pedestrian phase.

3. Queue Jumps (to Reduce Delay)

Where a bus may be delayed by queued vehicles stopped at a signal in an adjacent lane (such as at a near-side bus stop where a lane change to the left is required to discharge) the bus may be given its own traffic signal and receive an advanced green before other traffic is allowed to proceed. This enables the bus to “jump” ahead of other traffic waiting to discharge rather than being delayed while they discharge first.

In order to maintain progression for the general traffic on a TSP corridor, the following guidance is given for designing TSP parameters:

- If the block length is 300 feet or less, the maximum truncation/extension cannot be more than 5 seconds.
- If the block length is 1000 feet or more, the maximum truncation/extension can be up to 18 seconds as long as the side street traffic is not impacted (thus, the higher truncation/extension time for long blocks could be recommended on a case-by-case basis depending upon the MOE results)
- Re-service time should be three (3) times the cycle length

Advanced Solid State Traffic Controllers (ASTC) have the necessary capabilities to provide TSP operations and these controllers can be controlled wirelessly. TSP currently relies on the NYC wireless communication system (NYCWiN) for communications between the bus, the MTA, the TMC, and the traffic controller. As shown in Figure 3.29, a GPS location device is placed in the bus. TSP requests from a bus are directed to the MTA, which performs the authentication, and then relays the request to the TMC for action.

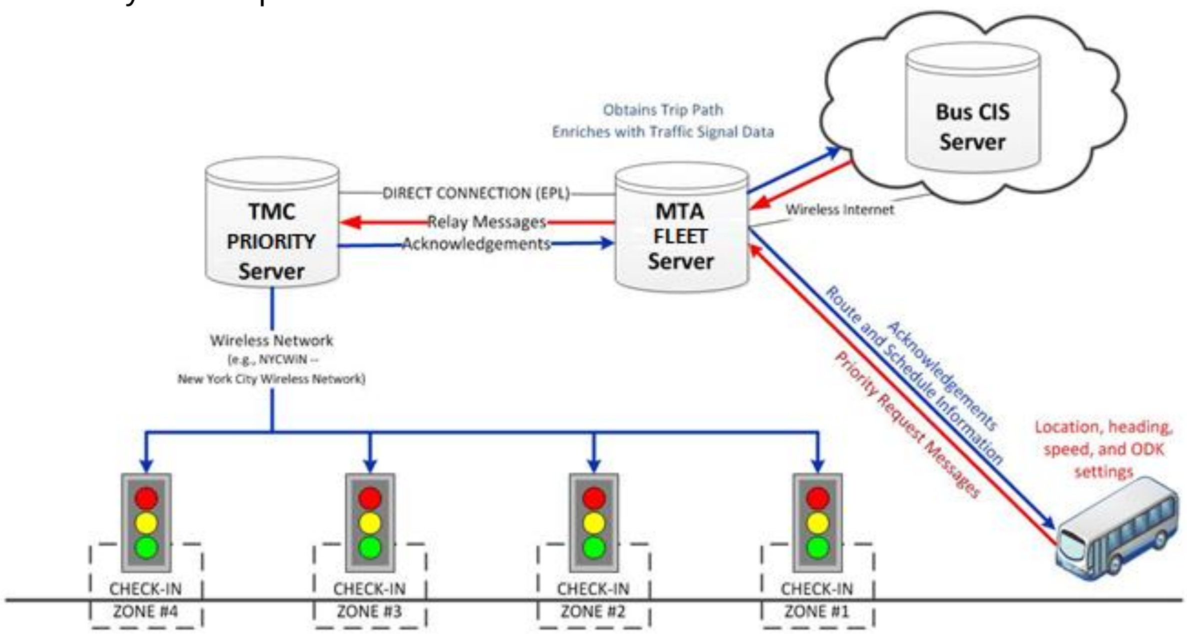


Figure 3.29 Communication between the bus, the MTA, the TMC, and the Traffic Controller

Over 1,200 intersections already have the infrastructure in place (ASTC controllers) to support TSP control. However, which arterials and intersections should get TSP must be considered very carefully.

Before optimizing for TSP, the first step is to optimize the current corridor without TSP. NYCDOT looks for modest improvements, such as changing the signal timing, adding striping, etc. Synchro is initially used to optimize the signal timing on the arterial and these results are manually reviewed. The arterial is then created in AIMSUN, a microscopic simulation model, which is validated for the existing conditions and later used for TSP simulation. A custom version of AIMSUN for NYC is used.

Once the corridor is set for optimal performance without TSP, the next step is to optimize the signal timing for the buses knowing that TSP will be implemented. The first consideration is the safety of the pedestrians. This means a minimum green time must be maintained on the side street.

After setting that minimum, a solution is searched for that gives the most benefit to the buses, while minimally affecting the side streets. This is accomplished by beginning an iterative process that optimizes the timing for buses to receive the maximum benefit, and then looking at the effect on the side street. If the delay to the side streets is unacceptable, trade-offs are set to balance an acceptable effect to the side streets with improving service for the buses.

TSP may sometime be only implemented in one direction at a time due to the need to keep coordination. The detailed microsimulation of Aimsun is essential to finding the best solution for maintaining coordination, maximizing benefits to the buses, and minimizing the delay to the side streets. It takes many trials and errors to get the final optimal signal timing plan.

Questions that must be answered include:

- When to act on the information of knowing where a bus is, for instance, where should the bus be in relation to the stop line when the decision to extend the green is made? Which phase to adjust and how much time the phases can be extended or shortened?
- How soon after implementing TSP for one bus should the next bus be allowed to get TSP?
- Which intersections are candidates for TSP? For example, some intersections have limited or no time available to give to TSP. Even if there is time to allocate in the subject direction, would it unacceptably affect the opposing direction? Intersections with police control cannot be given TSP. Intersections with LPIs have limited time to give, because the benefits are being given elsewhere (to the pedestrians).

TSP with NYCWiN was first implemented along a 2.2 mile portion of the M15 Select Bus Service (SBS) route in Lower Manhattan in the spring of 2013. An “After” Study was conducted in 2014 to assess the effectiveness of the system. Results suggest that bus travel times were reduced by 2.6 minutes (13.7%) during the morning and 3.5 (18.4%) minutes during the afternoon peak commuting periods. The study found that approximately 60% of these benefits came from optimized signal timings, splits, offsets, lane striping and other improvements with the remainder coming from the real-time signal timing adjustments of Active TSP.

Appendix 3A is an article written about this implementation of TSP in downtown Manhattan, from South Ferry to Houston Street that discusses the challenges and issues involved in the implementation.

3.5.2 Red Light Cameras

Red light cameras are placed at intersections to catch vehicles driving through a red light. Placement of red-light cameras are based on accident history and/or a request from a community group or school principal. If a request made, the accident history will be examined.

3.5.3 School zone Camera

School zone speed cameras photograph and ticket speeding vehicles in a school zone. The cameras are permitted to operate from an hour before the school day begins until an hour after it ends. They also may be operated nights, weekends, and vacations when there is a special activity happening at the school for 30 minutes before until 30 minutes after the activity.

3.5.4 Battery Back-up Systems for Black Outs

Every major intersection in NYC now has a 12-hour battery back-up system.

3.5.5 Accessible Pedestrian Signals (APS)

APS signals are installed in order to assist blind and visually-impaired pedestrians to safely cross an intersection. Figure 3.30 shows an APS controller used in NYC.

Figure 3.30 Accessible Pedestrian Signal (APS) Unit

The Manual on Uniform Traffic Control Devices (MUTCD) [1] requires that APS provide both audio and vibrotactile formats of communication. A vibrotactile device has a vibrating surface that blind or visually-impaired pedestrians touch/press to know which direction is being controlled. In NYC, the vibrotactile device is a raised vibrating arrow, as seen in Figure 3.30. The arrow points in the direction to be travelled on the crosswalk. Additionally, a locator tone is emitted to guide the user to the arrow. Once the arrow is pressed, the arrow will vibrate and a distinct rapid clicking tone and/or the verbal cue "Wait" indicates that communication with the controller has been initiated, and cue(s) will be repeated until the pedestrian walk interval begins. When the walk interval begins, the APS emits a rapid percussive tone and/or the verbal cue "Walk" will be repeated until the Flashing Don't Walk Interval begins. The locator tone will then be emitted from FDW until the next time the push button "arrow" is activated.

To determine where APS Signals are placed, NYCDOT uses a ranking system to prioritize intersections for APS installation. Some of the criteria used to determine rank include off-peak traffic volume, traffic signal control, the geometric complexity of the intersection, the length of the crosswalks, proximity to facilities for the blind or visually impaired, requests for APS, and intersections with LPI phasing. Criteria are based on the National Cooperative Research Program (NCHRP) document 117B [5] and the federal version of the latest MUTCD. As of January 2016, NYCDOT is required by law to add 75 new APS signals each year.

Additionally, NYCDOT is required by the Americans with Disabilities Act to consider APS at intersections whenever a new traffic signal is being installed and where existing signals are being modified.

3.1.7 Midtown in Motion

In 2011, NYCDOT installed a real-time adaptive, active traffic management system at over 300 intersections in midtown Manhattan, which was then expanded to another 200 intersections in 2013. The system was nicknamed “Midtown in Motion (MIM).” MIM installed cutting edge technology in order to detect and respond to fluctuating traffic conditions.

At each intersection, Advanced Solid State Traffic Controllers (ASTC) were installed that can be controlled wirelessly, allowing for quickly adjusting signal timings in real-time responding to localized congestion, due to increased demand and/or isolated incidents, such as, double-parked vehicles, a temporary lane closing, or crashes.

Real-time data is collected from microwave sensors, video cameras, and E-Z Pass readers and is transmitted wirelessly through NYC’s wireless system (NYCWin) to the Traffic Management Center (TMC) in Long Island City. Figure 3.31 shows the transfer of data wirelessly to the TMC, which can remotely adjust the signal timing of the ASTC controllers.

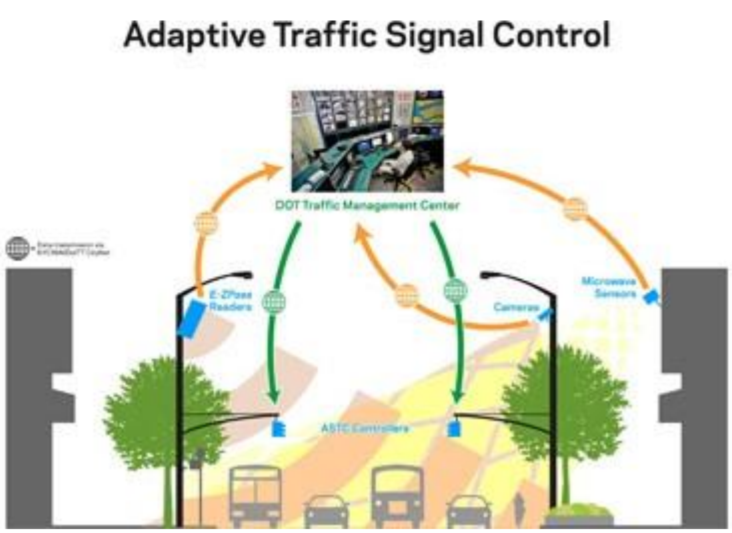


Figure 3.31 Wireless transfer of data for MIM

MIM operates at two levels of control for managing traffic:

- Level 1 Control manages traffic to the area by redistributing incoming traffic at the peripheral arterials so as to lessen the flow of vehicles into midtown. This is accomplished by a set of predetermine timing plans (offsets and splits) for intersections at the periphery. Which timing plan is used is determined from real-time travel time data as a measure of the level of prevailing congestion.

- Level 2 control takes affect inside the MIM area, using adaptive signal control. The goal of the level 2 control is active queue management to avoid spillback. Locations where congestion is identified, “hot spots,” are sent to the TMC. Adaptive control strategies, which change the split at critical intersections, can be reviewed at the TMC to accept the recommended plan or not.

The type of control implemented is dependent upon the data received:

- The E-Z Pass readers are used to determine travel time
- The microwave sensors measure traffic volume and queues at mid-block locations
- Cameras allow the engineers in the TMC to observe real-time conditions

Figure 3.32 shows sample decision support stages for one day in 2011. The Basic Plan is implemented until it is found that speed decreases and stops increase. Level 1 control (AC1) may be implemented when travel time and stops increase over a specified level (in this case 2 stops). When there is an unusually large drop in speed and increase in stops, level 2 control (AC2) may be implemented.

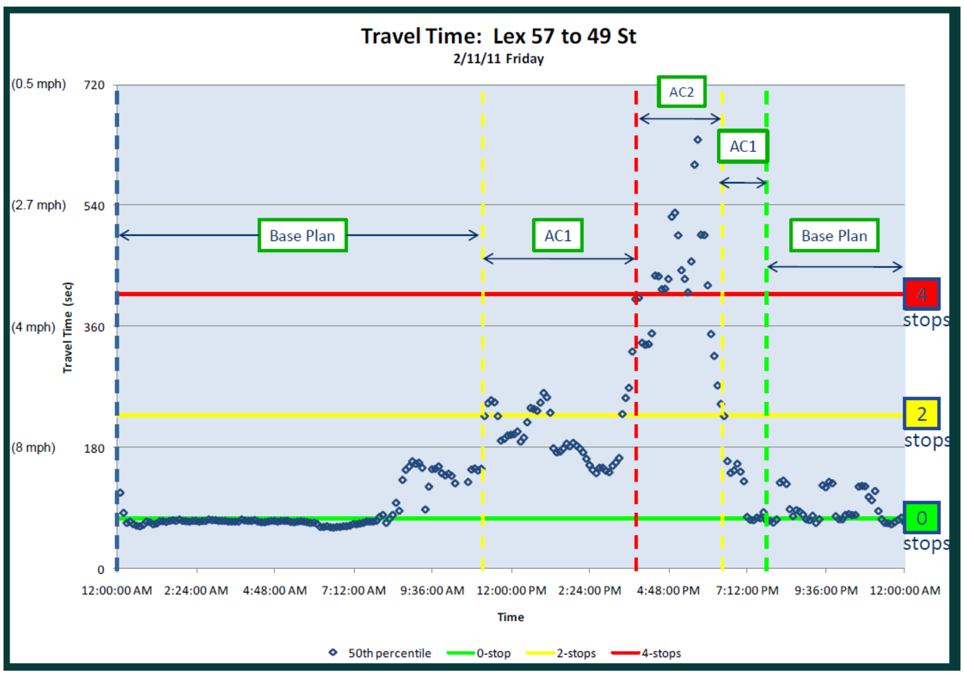


Figure 3.32. Sample Decision Support Stages

The program success is assessed by looking at: average vehicle speed, obtained from the E-Z Pass readers and Taxi GPS data; Vehicle delay and queues, obtained from the microwave sensors; and Vehicle volume entering, within, and leaving midtown, obtained from automatic traffic recorders (ATR).

APPENDIX 3A

Article on Modeling NYC's First TSP [7]

Tripping the light fantastic (literally)

Modeling New York City's first implementation of centralized wireless Transit Signal Priority (TSP) by **Ernest Athanailos, Mark Yedlin, Tra Vu**

A fast and reliable bus service is desirable anywhere but in a high-density urban environment like Manhattan it can mean the difference between traffic flow and gridlock.

Transit Signal Priority (TSP) is an important element of Bus Rapid Transit (BRT) that involves coordinated efforts between transit vehicle detection systems, traffic signal control systems, and communication technologies. In a nutshell, TSP means that buses signal their impending arrival at a signalized intersection and then receive the green light to drive straight through.

The New York City Department of Transportation (NYCDOT) and Metropolitan Transportation Authority (MTA) are embarking on an ambitious program to provide TSP to 6,000 buses in New York City. A key component of the project is New York City's dedicated broadband wireless infrastructure (NYCWiN), which was created by the city's Department of Information Technology and Telecommunications (DoITT) to support public safety and essential urban operations.

Because NYCWiN supports the implementation of TSP without any additional hardware or infrastructure changes, this approach is particularly cost-effective and attractive for widespread implementation of TSP in New York.

The City's Traffic Management Center in Queens, New York can use NYCWiN to process real-time messages from buses indicating their position and route, and then transmit wireless TSP instructions to local traffic signal controllers. These controllers can then expedite bus movements in one of three ways: by extending a current green signal; by cutting short a current red signal and returning early to green; or by queue jumping, that is, providing an advanced green signal at a specially configured near-side bus stop allowing only buses to jump the queue.

Mark Yedlin

Prioritising buses at signalized intersections is key in trying to keep traffic flowing

GOING GREEN

The first implementation of this system will serve buses on the M15 Select Bus Service (SBS) route in Lower Manhattan. SBS routes offer BRT features including low-floor three-door buses, special branding and stations, and pre-boarding fare payment. TSP is provided for the 2.2-mile section of the M15 SBS route where an exclusive bus lane is not feasible, stretching from the Staten Island Ferry Terminal up through the Wall Street Financial District. An ideal test bed, it

"The section of the route is characterized by slow-moving buses and heavy cross-street, pedestrian, truck and bicycle traffic with 34 signalized intersections"

TSP STUDY

Figure 1 – study area

Figure 2 – tracking bus with and without TSP

is characterized by slow-moving buses and heavy cross-street, pedestrian, truck and bicycle traffic with 34 signalized intersections.

NYCDOT selected Greenman-Pedersen, Inc. (GPI) to simulate all traffic operations in the corridor and to assess and recommend improvements for optimal TSP implementation, which included changes to geometry, striping and signal timing. Simulations of morning, midday, and afternoon peak traffic conditions were performed to provide answers to critical TSP implementation questions. This allowed GPI not only to assess the benefits of TSP for M15 Select Buses and the effects of TSP on other traffic along the corridor and its cross streets, but also to identify which intersections might be able to successfully support TSP operation. Simulation was also the key to understanding how the system could handle competing calls for service. At the level of individual intersections earmarked for TSP, simulation helped to establish: the maximum green signal extension time for buses; the minimum time for cross-street phases; how far upstream calls for TSP service should be acted upon in each direction and whether queue jumping should be offered or not and how it should be implemented.

TECHNICAL APPROACH

The Aimsun software developed by Transport Simulation Systems (TSS) was used for this analysis, which called for the development of several custom software features including specific NYCDOT policies to maintain signal coordination, define vehicle queues and process subsequent TSP calls after servicing the first call in a cycle. The GPI team developed logic specifications representing each of these policies and TSS then created the corresponding custom Application Programming Interface (API) software to model them.

Trafficware's Synchro software was also used to help identify existing traffic problems, evaluate low-cost geometric and striping improvements, and develop optimal signal timings and coordination for the corridor. This effort was found to be critical to maximize the benefits of TSP by alleviating existing traffic problems and providing timing adjustments that facilitate TSP. This set of improvements is referred to as "Passive TSP" since it lays the foundation for TSP success without actual implementation.

The Aimsun simulation analyses were conducted in three stages: First GPI created and validated a baseline model of current conditions for each peak period (7:30am to 10:30am, 12:30pm to 3:30pm and 4:00pm to 7:00pm). Secondly the team looked at passive TSP, evaluating the benefits of recommended traffic improvements and Synchro optimal signal timings relative to existing conditions. In the third and final stage, they looked at active TSP, evaluating the effectiveness of all improvements in addition to TSP and then studying and resolving the TSP implementation issues. >>>

TRAFFIC SIGNALS

"Results suggest that TSP will bring significant benefits to riders of M15 Select Buses and other traffic in the corridor"

Simulation model of Lower Manhattan with traffic

MODELING CHALLENGES

The complexity of the traffic environment in Lower Manhattan, as well as the need to simulate the operation of a new wireless TSP system (including communication time-lags) posed several challenges. As well as the custom software needed to model NYCDOT protocols for TSP operation, challenges included high pedestrian volume, and calibrating driver behaviors for lane changing and yielding at conflict zones. Manhattan's notorious double-parking problem also necessitated repeated and extensive field observations to quantify double-parking activity and its effects on traffic delay.

For the purposes of analysis, it was more important to accurately represent the delay caused by pedestrians to vehicular traffic rather than the actual number of pedestrians observed in the field, which included numerous mid-block jaywalkers. Similarly, calibration parameters for driver behavior in the corridor were particularly difficult to quantify. Therefore, GPI employed an iterative process to carefully adjust these parameters until model predictions of travel time, throughput and queues matched field observations of these traffic measurements within their normal weekday variation.

TSP SUCCESS

An important outcome of the analysis was the identification of intersections that were suitable for TSP implementation. Factors influencing this decision included the availability of time to shorten cross-street phases and meet minimum requirements for pedestrian crossing and also the ability to provide TSP without significant adverse effects on cross-street vehicular traffic.

Since traffic volumes and signal timing plans vary during the day, these factors vary by analysis period so the set of intersections recommended for TSP has to be unique to each period. Periods when human traffic agents controlled certain intersections were not suitable for TSP.

Even intersections recommended for TSP were not necessarily recommended for both directions of travel on the M15 SBS route. None of the candidate intersections exhibited both sufficient queuing and adequate real estate to provide queue jumping so TSP was not offered to buses on any approach with a near-side bus stop. Therefore, if an intersection selected for TSP had approaches both with and without a near-side bus stop, GPI recommended TSP for the approach without the near-side stop.

After applying these factors to the 34 candidate intersections, GPI recommended TSP for 19 to 21 intersections for northbound buses and 22 to 24 intersections for southbound buses depending upon the time of day.

The simulation model provides detailed animation displays that track a bus along its route both with and without the proposed TSP system. In addition, the model identifies the travel time savings due to TSP and the TSP action occurring for each intersection. Drive-through animation is particularly useful when examining the planned TSP operations and identifying refinements such as adjustments to the signal progression, maximum phase extensions or starting points for TSP actions.

NEW YORK'S TSP FUTURE

Given the numerous issues involved in TSP implementation, and the impact of these decisions on TSP benefits, simulation modeling is essential to optimize TSP operations. In this case, a custom model was required to accurately represent all operating protocols for TSP recently established by the NYCDOT. This model is now suitable to represent any TSP implementation within New York City and could be adapted to represent TSP implementations elsewhere. GPI is currently applying this model and optimization process for the implementation of TSP along three other corridors in New York City.

Results from this model suggest that TSP will bring significant benefits to both the riders of M15 Select Buses and other traffic in the corridor: the combination of TSP and recommended geometric and signal timing improvements will reduce peak-hour average travel time for M15 Select Buses by 7.4 per cent to 14.2 per cent and up to 3.2 minutes. It will also reduce peak-hour delay for all traffic along the corridor by 11.9 per cent to 14.6 per cent and reduce peak-hour delay for all side street traffic by 3.5 per cent to 10.8 per cent. Total peak hour delay for all traffic in the study area will reduce by 8.4 per cent to 11.9 per cent.

TSP implementation with NYCWiN will happen gradually over the coming months in accordance with the recommendations of this simulation analysis, followed by a comparison of actual travel time savings with the simulation predictions.

fyi

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For previous articles on this subject visit our ARCHIVES section at thinkinghighways.com

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Chapter 4 USEFUL REFERENCE BOOKS

PART I. THE MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES (MUTCD)

The Federal Highway Administration (FHWA) of the United States Department of Transportation (USDOT) publishes the Manual on Uniform Traffic Control Devices (MUTCD). It provides national standards for all aspects of traffic control devices, including design, placement, guidance on what type of control to use and where. Traffic control devices include everything from roadway markings, size and color of highway signs, yield and stop signs, traffic signals, and S traffic controllers, to name a few.

This chapter details Chapter 4C of the MUTCD, which defines the warrants for installing a traffic signal at an intersection. Table 4.1 lists the nine warrants in the current 2009 MUTCD used for determining if installing a signal should be considered.

Table 4.1 List of Warrants

Warrant Number	Warrant Name
Warrant 1 Condition A Condition B Condition C	Eight-Hour Vehicular Volume Minimum Vehicular Volume Interruption of Continuous Traffic Combinations of A and B at 80%
Warrant 2	Four-Hour Volume
Warrant 3	Peak Hour Volume
Warrant 4	Pedestrian Volume
Warrant 5	School Crossings
Warrant 6	Coordinated Signal System
Warrant 7	Crash Experience
Warrant 8	Roadway Network
Warrant 9	Railroad Grade Crossings

The manual *does not require* that a signal be installed because one of the warrants is met. It requires that a comprehensive engineering study be conducted that includes studying the traffic conditions, pedestrian characteristics, and physical characteristics of the location, including the factors in each of the warrants. The installation of a signal is based on a complete engineering study to determine if the installation of a signal would improve the safety and/or operation of the intersection. Engineering judgment is final deciding factor, that is, when the engineer is convinced that the signal will improve safety, improve operations, or increase capacity.

The following sections describe each of the nine warrants.

WARRANT 1: Eight Hour Vehicular Volume

As the name implies, Warrant 1 considers 8 hours of vehicular volume in vehicles per hour (vph). The warrant can be met in three possible ways. If any one of the conditions is met, then Warrant 1 is met and the other conditions are not needed.

Condition A is known as the minimum vehicular volume warrant because the volume shown is the minimum volume for which a signal shall be considered. It checks for heavy volumes of intersecting traffic (heavy traffic on both cross streets).

Condition B is known as the Interruption of Continuous Traffic warrant. It covers situations where there is such heavy volume on the main street that it does not allow for sufficient gaps for the minor street movements.

Warrant 1 can be met in three ways.

- Condition A or Condition B volumes exist at the *100%* level
- Condition A or Condition B volumes exist at the *70%* volumes, when the major street speed (either posted speed, legal speed, or 85th percentile speed) is greater than 40mph *or* the intersection is located in an isolated community with population less than 10,000
- Both Condition A and Condition B volumes exist at the *80%* level. This combination is intended to cover intersections that do not meet either Condition A or B alone and "*only after adequate trial of other alternatives that could cause less delay and inconvenience to traffic has failed to solve the traffic problems*."

Tables 4.2 and 4.3 show the volumes that are needed to meet Condition A and Condition B, respectively.

Table 4.2 Warrant 1, Condition A

Condition A – Minimum Vehicular Volume									
		MAJOR STREET VOLUMES				MINOR STREET VOLUMES			
Number of Lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)				Vehicles per hour on higher volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour
1...............	1...............	500	400	350		150	120	105	
2 or more....	1...............	600	480	420		150	120	105	
2 or more....	2 or more....	600	480	420		200	160	140	
1...............	2 or more....	500	400	350		200	160	140	

Table 4.3 Warrant 1, Condition B

Condition B – Interruption of Continuous Traffic									
		MAJOR STREET VOLUMES				MINOR STREET VOLUMES			
Number of Lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)				Vehicles per hour on higher volume minor-street approach (one direction only)			
Major Street	Minor Street	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour	100%[a] Absolute Minimum Required	80%[b] of minimum Reduction for 5 Acc.	70%[c] of minimum Reduction for 40+MPH	ATR'S 8TH Highest Hour
1...............	1...............	750	600	525		75	60	53	
2 or more....	1...............	900	720	630		75	60	53	
2 or more....	2 or more....	900	720	630		100	80	70	
1...............	2 or more....	750	600	525		100	80	70	

Note that the major street volume used is the sum of both approaches, but the minor street volume used is the higher of the two opposing minor street approaches.

The warrant is satisfied if a minimum of 8 hours meet the applicable criteria. The eight hours do not need to be consecutive, but the major and minor street volumes used must be for the same eight hours. The volumes for the eight minor street hours do not need to be on the same approach, however.

WARRANT 2: Four Hour Vehicular Volume

Warrant 2 checks for volumes that need traffic control for at least four hours of the day. Figure 4.1 shows the warrant, which is in the form of a continuous graph, for normal conditions. Figure 4.2 is the graph for isolated communities with low population (<10,000) or high major street approach speed (≥40mph). Warrant 2 is met if four hours of two-way major street volume plotted against the highest one-way minor street volume lies above the appropriate curve. As in Warrant 1, the minor street volume does not have to be from the same approach for each of the four hours.

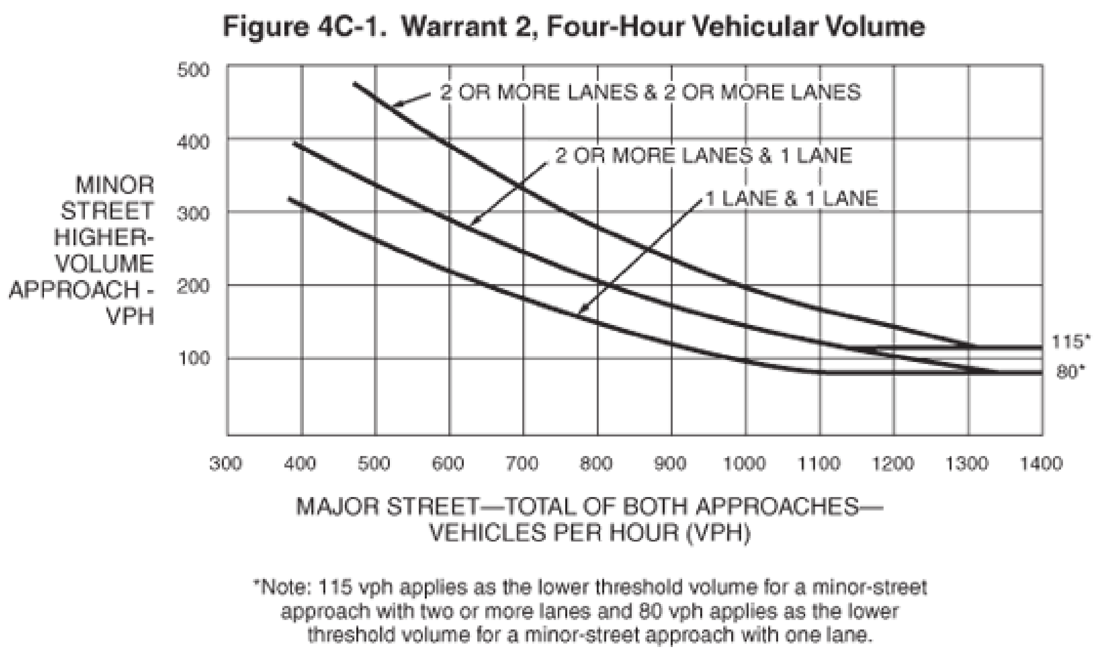


Figure 4.1 Four-Hour Volume Warrant, Normal Conditions

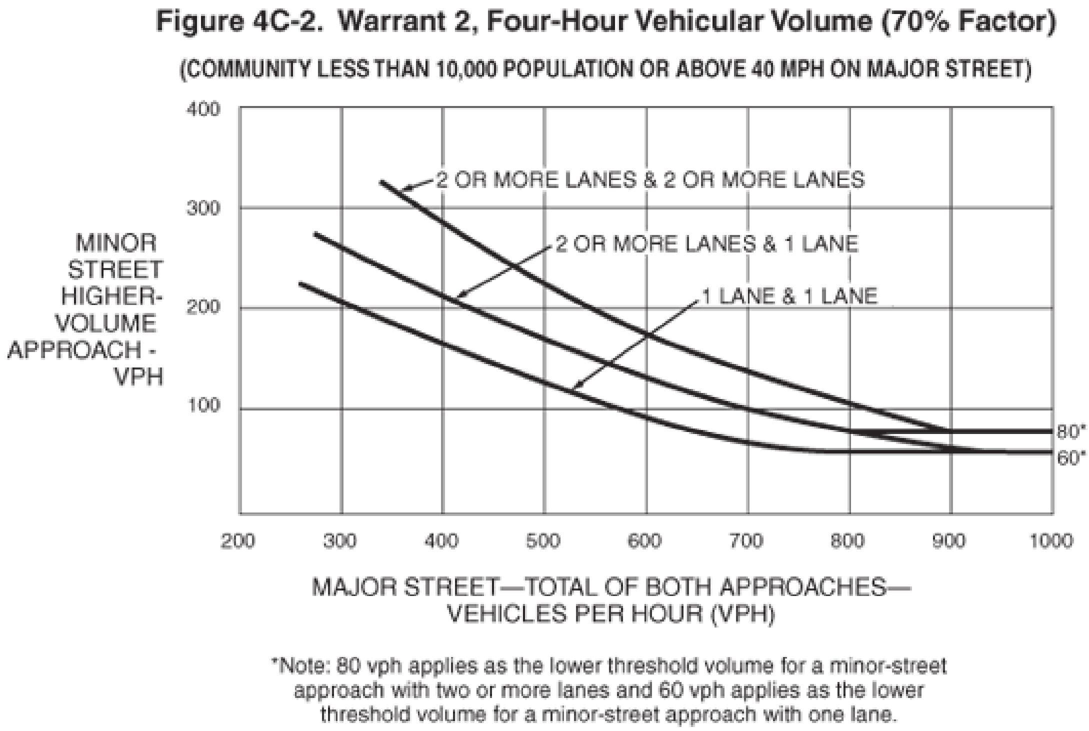


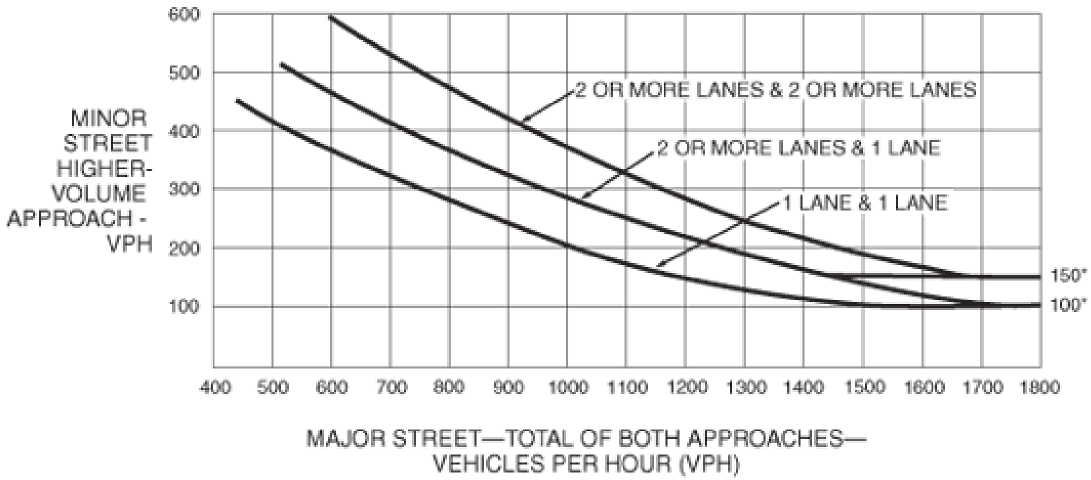
Figure 4.2 Four-Hour Volume Warrant for Small Communities (<10,000) or High Speed Major Street (≥40mph)

WARRANT 3: Peak Hour

The peak-hour warrant is intended to address two critical traffic conditions that can occur in the peak hour that could warrant a traffic signal. The first condition, Warrant 3A, considers the volume conditions in the peak hour. The second condition, Warrant 3B considers delay.

Figures 4.3 and 4.4 show the graphs for the volume portion of the warrant. They are used in the same manner as Warrant 2, except that only one hour must meet the criteria.

Figure 4C-3. Warrant 3, Peak Hour



*Note: 150 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 100 vph applies as the lower threshold volume for a minor-street approach with one lane.

Figure 4.3 Peak-Hour Warrant for Normal Conditions

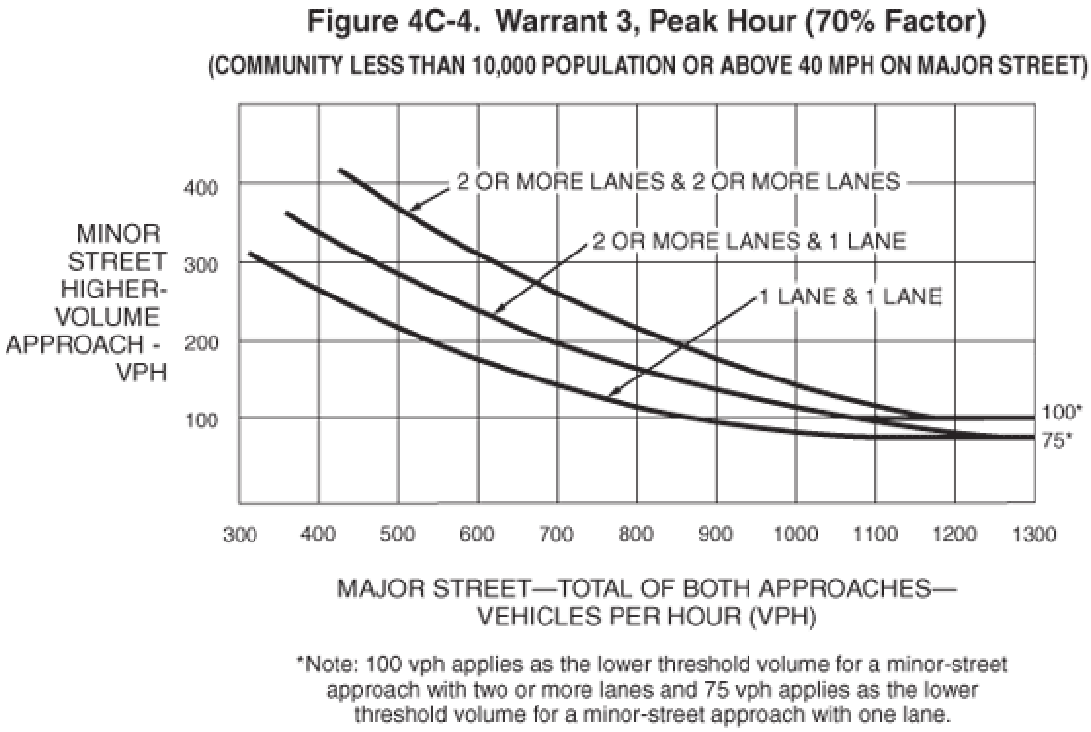


Figure 4.4 Peak-Hour Warrant for Small Communities (<10,000) or High Speed Major Street (≥40mph)

The delay portion of Warrant 3 may only be used at an intersection that is currently being controlled by STOP control on the minor street approach. Additionally, the MUTCD states that this delay warrant only be applied for unusual cases, such as office complexes, manufacturing plants, industrial complexes, or HOV facilities that attract or discharge large numbers of vehicles over a short time. The criteria for the delay portion of the warrant are met if all three of the following conditions exist for the same hour (any four consecutive 15-minute periods) of an average day:

1. The total stopped time delay experienced by the traffic on one minor-street approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach or 5 vehicle-hours for a two-lane approach; and

2. The volume on the same minor-street approach (one direction only) equals or exceeds 100 vehicles per hour for one moving lane of traffic or 150 vehicles per hour for two moving lanes; and

The total entering volume serviced during the hour equals or exceeds 650 vehicles per hour for intersections with three approaches or 800 vehicles per hour for intersections with four or more approaches.

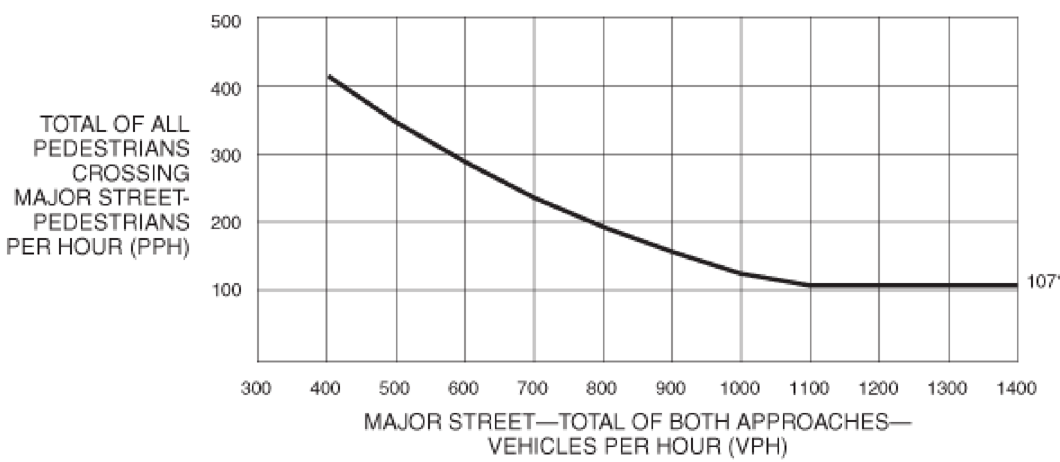
WARRANT 4: Pedestrians

The pedestrian warrant addresses situations where the major street vehicular traffic is so heavy that pedestrians experience inordinate delay when trying to cross the street. This warrant may be used to consider installing a signal either at an intersection or a midblock crossing. The pedestrian warrant can be met when volume criteria for either four-hours or the peak-hour are met. The graphs plot total major street volume (both directions, vph) versus the corresponding total pedestrians crossing the major street (PPH).

Figures 4.5 and 4.6 show the graphs for the four-hour pedestrian warrant. If any of the four hours falls above the applicable curve, the warrant is met. Figures 4.7 and 4.8 show the graphs for the peak-hour pedestrian warrant. If the peak-hour volume falls above the applicable curve, the warrant is met.

The pedestrian volume criteria may be reduced by as much as 50% if the 15th-percentile crossing speed is less than 3.5 ft/sec. This could occur, for example, at locations where there are many seniors or disabled pedestrians in the area.

Figure 4C-5. Warrant 4, Pedestrian Four-Hour Volume



*Note: 107 pph applies as the lower threshold volume.

Figure 4.5 Warrant 4: Pedestrian Four-Hour Warrant, Normal Conditions

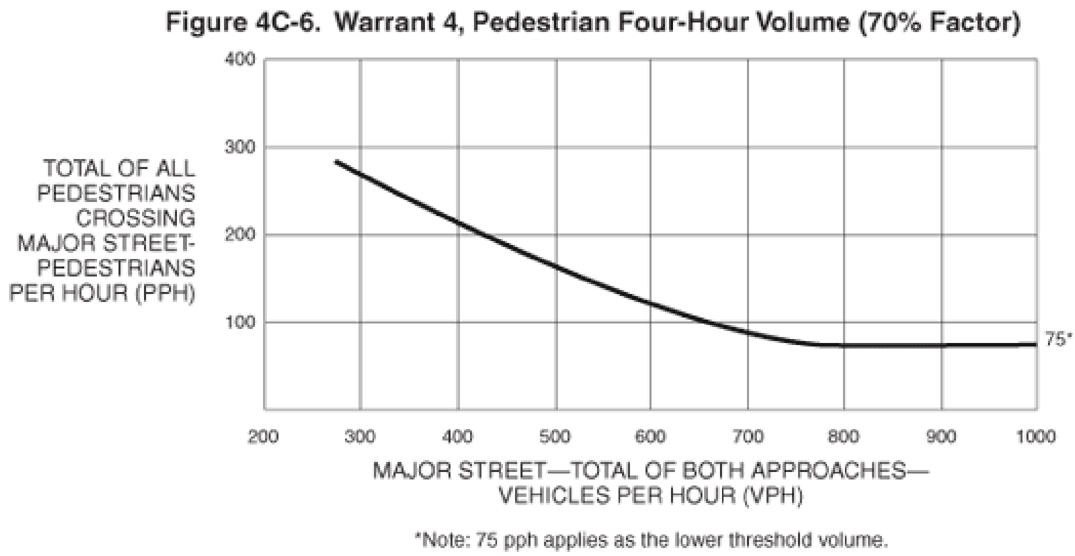


Figure 4.6 Pedestrian Four-Hour Warrant for Small Communities (<10,000) or High Speed Major Street (≥40mph)

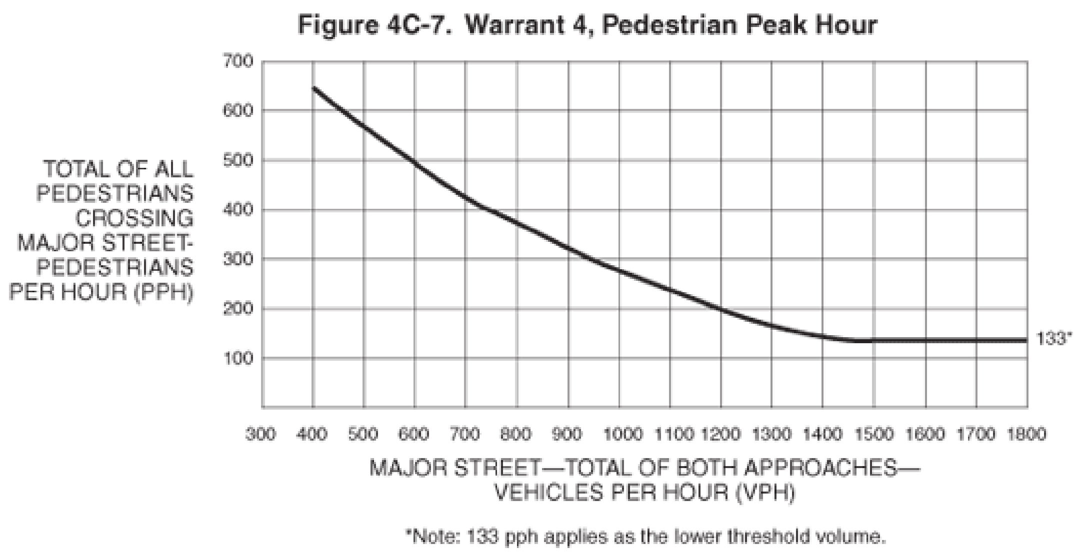


Figure 4.7 Pedestrian Peak-Hour Warrant for Normal Conditions

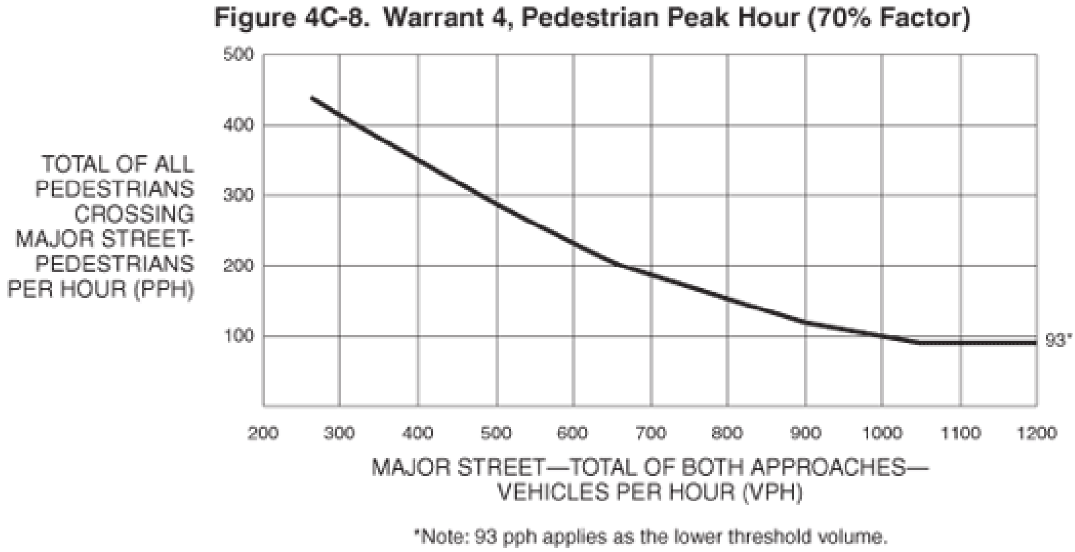


Figure 4.8 Pedestrian Peak-Hour Warrant for Small Communities (<10,000) or High Speed Major Street (≥40mph)

WARRANT 5: School Crossing

This warrant is similar to the pedestrian warrant except that it is limited to locations at school crossings. The warrant requires an examination of the gaps available to see whether they are adequate for school children to cross the street. Adequate gap time depends upon the number and size of groups of children crossing. The rate of acceptable gaps should be no less than one gap for each minute during the time that children are crossing and there should be a minimum of 20 children crossing during the highest crossing hour.

Before making a decision concerning the installation of a signal, the MUTCD recommends that other measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing should be considered.

If the warrant is met, the following guidance is given in the MUTCD.

Guidance:

If this warrant is met and a traffic control signal is justified by an engineering study, then:

A. *If it is installed at an intersection or major driveway location, the traffic control signal should also control the minor-street or driveway traffic, should be traffic-actuated, and should include pedestrian detection.*

B. *If it is installed at a non-intersection crossing, the traffic control signal should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs, and should be pedestrian-actuated. If the traffic control signal is installed at a non-intersection crossing, at least one of the signal faces should be over the traveled way for each approach, parking and other sight obstructions should be prohibited for at least 100 feet in advance of and at least 20 feet beyond the crosswalk or site accommodations should be made through curb extensions or other techniques to provide adequate sight distance, and the installation should include suitable standard signs and pavement markings.*

C. *Furthermore, if it is installed within a signal system, the traffic control signal should be coordinated.*

WARRANT 6: Coordinated Signal System

Maintaining platoons of vehicles is critical in a coordinated arterial system in order to keep the progression of vehicles moving smoothly. This warrant allows for the placement of a signal in such a system even if none of the other warrants are met. The logic behind this is that the larger the distance between signals, the more likely the platoons will disperse. This warrant allows placing a signal to maintain platoon cohesion.

Warrant 6 should not be used to place signals that would result in spacing of less than 1000 feet. The following guidance is given:

The need for a traffic control signal shall be considered if an engineering study finds that all of the following criteria are met:

A. On a one-way street or a street that has traffic predominantly in one direction, the adjacent traffic control signals are so far apart that they do not provide the necessary degree of vehicular platooning.

B. On a two-way street, adjacent traffic control signals do not provide the necessary degree of platooning and the proposed and adjacent traffic control signals will collectively provide a progressive operation.

It should be noted that it is not always possible to install a signal on a two-way street and maintain the desired progression in both directions, whereas on a one-way street it is always possible.

WARRANT 7: Crash Experience

At locations with a high incidence of crashes, a traffic signal may be installed under this warrant if it is determined that this will reduce the severity of crashes and/or the frequency of crashes.

The guidance given in the MUTCD is as follows:

A. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency; and
B. Five or more reported crashes, of types susceptible to correction by a traffic control signal, have occurred within a 12-month period, each crash involving personal injury or property damage apparently exceeding the applicable requirements for a reportable crash; and

C. For each of any 8 hours of an average day, the vehicles per hour (vph) given in both of the 80 percent columns of Condition A of Warrant 1, or the vph in both of the 80 percent columns of Condition B of Warrant 1 exists on the major-street and the higher-volume minor-street approach, respectively, to the intersection, or the volume of pedestrian traffic is not less than 80 percent of the requirements specified in the Pedestrian Volume warrant. These major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

There is a second method in the MUTCD for meeting this warrant. On major roads where the posted speed, legal speed, or 85th-percentile speed is greater than or equal to 40mph or in isolated communities with a small population (<10,000), the Warrant 1 tables at the 56 percent level may be used and both conditions A and B must be met at these 56% volumes. Tables 4.4 and 4.5 show the 56% level traffic volumes for Warrant 1, Condition A and B, respectively.

Table 4.4 Warrant 1, Condition A – Minimum Vehicular Volume

Number of lanes for moving traffic on each approach		VPH on major street (total both approaches)	VPH on higher-volume minor street approach (one direction only)
Major Street	Minor Street	56% Volumes	56% Volumes
1	1	280	84
≥ 2	1	336	84
≥ 2	≥ 2	336	112
1	≥ 2	280	112

Table 4.5 Warrant 1, Condition B – Interruption of Continuous Flow

Number of lanes for moving traffic on each approach		Vph on major street (total both approaches)	VPH on higher-volume minor street approach (one direction only)
Major Street	Minor Street	56% Volumes	56% Volumes
1	1	420	42
≥ 2	1	504	42
≥ 2	≥ 2	504	56
1	≥ 2	420	56

WARRANT 8: Roadway Network

This warrant may be used to consider installing a traffic control signal where present conditions are not sufficient to meet any of the previous warrants, however new developments are forecasted to generate considerable traffic. The MUTCD gives the following guidance for using this warrant.

To meet this warrant, the intersection of two (or more) major streets must meet at least one of the following criteria:

A. The intersection has existing, or immediately projected (the traffic expected on day 1 of project opening) volume entering the intersection of at least 1,000 vehicles per hour during the peak hour of a typical weekday; and has 5-year projected traffic volumes, based on an engineering study, that meet one or more of Warrants 1, 2, and 3 during an average weekday;

or

The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a non-normal business day (Saturday or Sunday).

B. The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a non-normal business day (Saturday or Sunday).

A major route, as defined in this signal warrant, shall have at least one of the following characteristics:

A. It is part of the street or highway system that serves as the principal roadway network for through traffic flow.

B. It includes rural or suburban highways outside, entering, or traversing a city.

C. It appears as a major route on an official transportation plan, such as a major street plan in an urban area traffic and transportation plan.

WARRANT 9: Railroad Grade Crossings

Warrant 9 considers intersections close to at-grade railroad crossings that do not meet any other warrant, but pose a safety hazard. The MUTCD cautions that other solutions should be investigated before applying this warrant.

The warrant applies when the railroad crossing is on the minor street within 140 feet of the intersection. A traffic signal installed after an engineering study and meeting this warrant, shall be a semi-actuated signal with a train preemption feature and flashing lights at the grade crossing. The grade crossing should also have automatic gates.

Figures 4.9 and 4.10 show graphs of volume criteria for a one-lane approach and multi-lane approach, respectively.

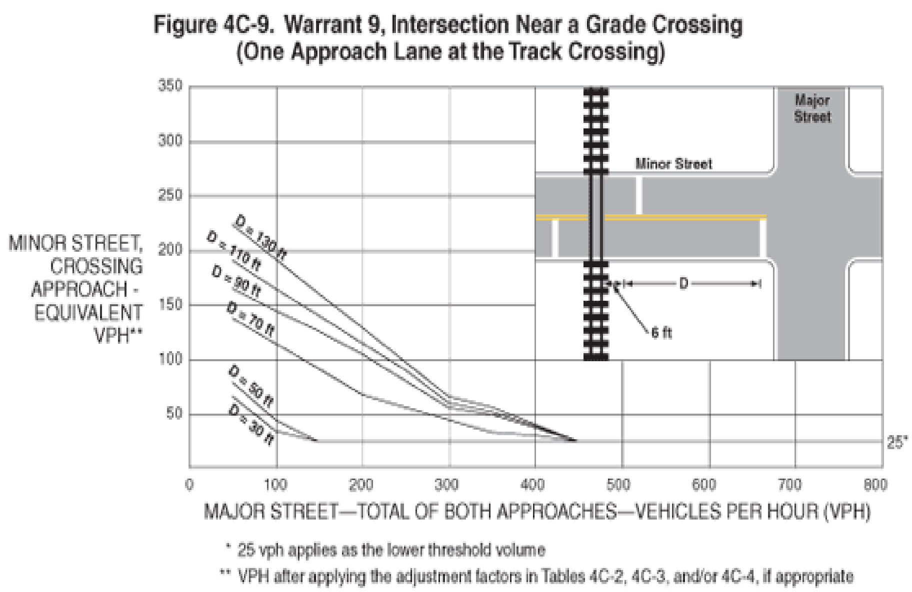


Figure 4.9 Warrant 9, One-Lane Approach

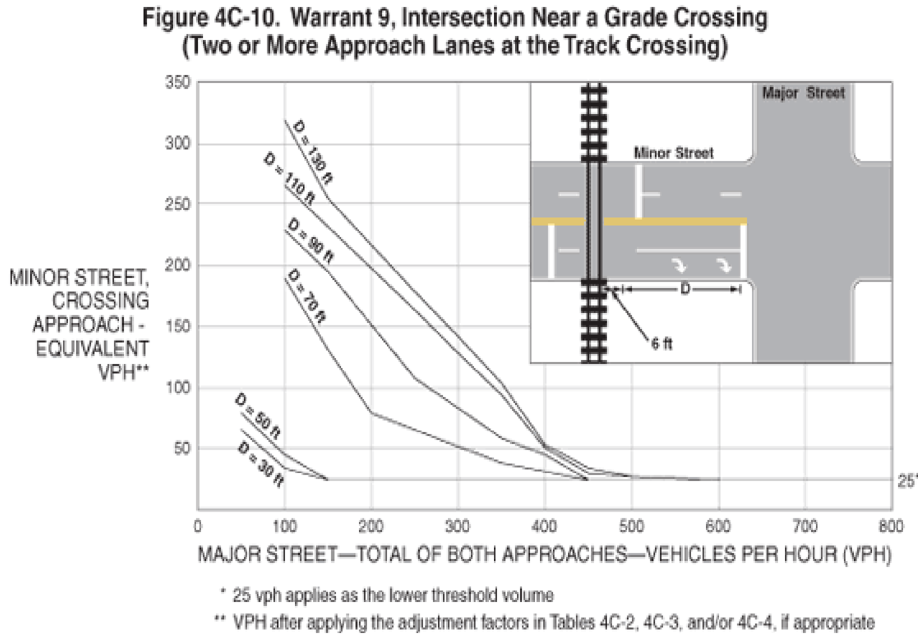


Figure 4.10 Warrant 9, Multi-Lane Approach

The volume used to enter the appropriate graph (Figure 4.9 or 4.10) may be multiplied by three adjustment factors. Table 4.6 gives the factors for the train volume passing the crossing per day. Table 4.7 gives the factors for percent high-occupancy buses on the minor street. Table 4.8 gives the factors for the percentage of tractor-trailer trucks.

Table 4.6 Warrant 9, Adjustment Factor for Daily Frequency of Rail Traffic

Rail Traffic Per Day	Adjustment Factor
1	0.67
2	0.91
3 to 5	1.00
6 to 8	1.18
9 to 11	1.25
12 or more	1.33

Table 4.7 Warrant 9, Adjustment Factor for Percentage of High-Occupancy Buses

% Of High-Occupancy Buses (≥ 20 people) On Minor-Street Approach	Adjustment Factor
0%	1.00
2%	1.09
4%	1.19
6% or more	1.32

Table 4.8 Warrant 9, Adjustment Factor for Percentage of Tractor-Trailer Trucks

% Of Tractor-Trailer Trucks on Minor-Street Approach	Adjustment Factor
1	D less than 70 feet
0% to 2.5%	0.50
2.6% to 7.5%	0.75
7.6% to 12.5%	1.00
12.6% to 17.5%	2.30
17.6% to 22.5%	2.70
22.6% to 27.5%	3.28

The MUTCD recommends that data be collected as part of an engineering study, and that the data is greater than what is needed to apply the warrants. This is because the MUTCD states that the installation of a signal *shall* be considered if a warrant is met. It does not necessitate the installation of the signal. If after the engineer considers all the data, the engineer is convinced that the signal will improve operations (reduce delay, improve safety), a traffic signal should be installed. For NYCDOT, the engineering study is accomplished by completing the ICU book, described in Chapter 2, and found in Appendix 2A.

PART II. THE HIGHWAY CAPACITY AND QUALITY OF SERVICE MANUAL

The Highway Capacity and Quality of Service Manual (HCM) is published by the Transportation Research Board. The current version of the HCM is the 2010 HCM. It contains methodologies for analyzing all types of facilities: both interrupted (such as urban streets) and uninterrupted (such as freeways and highways). NYCDOT uses the methodology from the signalized intersection chapters 19 and 31 for signal timing.

The HCM Chapters 19 and 31 detail a methodology for doing an operational analysis of a signalized intersection. The methodology calculates operational measures and defines performance measures that are used to determine the effectiveness of the intersection operations.

The methodology uses deterministic models to calculate the following variables:

Saturation Flow Rate

Saturation flow rate is the maximum number of vehicles that could enter the intersection in a lane or group of lanes under prevailing traffic and roadway conditions, if the signal was always green. The units for saturation flow rate are vehicles per hour green (vphg). Saturation flow rate is found by starting with a base saturation flow and adjusting it for prevailing factors of the traffic stream. Equation 4-1 is used to calculate saturation flow rate.

$$s = s_o\, N\, f_w\, f_{HV}\, f_g\, f_p\, f_{bb}\, f_a\, f_{LU}\, f_{RT}\, f_{LT}\, f_{Rpb}\, f_{Lpb} \qquad [4\text{-}1]$$

Where:

s = prevailing saturation flow rate, vphg
s_o = base saturation flow rate, 1900 pcphgpl
N = number of lanes
f_w = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles
f_g = adjustment factor for grade
f_p = adjustment factor for parking
f_{bb} = adjustment factor for local bus blockage
f_a = adjustment factor for area type
f_{LU} = adjustment factor for lane utilization
f_{RT} = adjustment factor for right turns
f_{LT} = adjustment factor for left turns
f_{rpb} = adjustment factor for ped/bike effect on right turns
f_{Lpb}= adjustment factor for ped/bike effect on left turns

Capacity

Capacity is the saturation flow rate adjusted for the proportion of green time in the cycle that the lane or group of lanes receives. Capacity is found using Equation 4-2.

$$c = s\frac{g}{C} \qquad [4\text{-}2]$$

Where

c = capacity, vph
g = effective green time, sec
C = Cycle Length, sec

Volume/Capacity Ratio

The volume-to-capacity ratio gives the proportion of the available capacity that is being used in the prevailing conditions. It gives the analyst an idea of how much capacity is available. A v/c ratio close to 1.0 means that there is little room for increased demand and that random variations in demand may cause excessive delay. A very low v/c ratio means that there is more capacity than needed for the current demand. In a TSP system, a low v/c ratio can mean that time may be taken from the phase to give for extending the green phase for the bus movement.

Control Delay

Control delay is the delay that is caused by the placement of the traffic signal. This includes delay from vehicles slowing in advance of the traffic signal, time stopped at the intersection, time as vehicles move up in the queue approaching the intersection, and time that vehicles spend to accelerating back to the desired speed. The calculated value is the average seconds of delay per vehicle. When optimizing traffic signal timing, one of the objective functions may be to minimize delay for certain vehicles. This could be for all vehicles, for certain approaches, or for specific vehicle types.

Back of Queue

The back of queue is the maximum end point of queued vehicles during a typical cycle. The back of queue is then used to calculate the queue storage ratio.

Queue Storage Ratio

The queue storage ratio is the ratio of the back of queue to the length of storage available (block length or turn-bay length). The queue storage ratio is important for predicting spillbacks under the prevailing conditions.

Additionally, a qualitative measure, level of service, is reported.

Level of Service

Level of service is a qualitative measure that represents the general quality of operations at the intersection. A simple scale from A to F is used that makes it easy to describe the complex movements at an intersection. Level of service (LOS) is defined based on the control delay, as shown in Table 4.9. Note that LOS F is defined as control delay being greater than 80 seconds/vehicle *or* having a volume/capacity ratio greater than 1.0. Thus there can be cases where delay is less than 80 seconds, but the demand volume is greater than the capacity and thus is defined as LOS F.

Table 4.9 Level of Service Criteria

LOS	DELAY (sec/veh)
A	<= 10
B	>10 - 20
C	> 20 - 35
D	>35 - 55
E	> 55 - 80
F	>80 or v/c > 1

Each of these measures is calculated separately for each approach. Delay and Level of service are also found for the intersection as a whole by finding a weighted average delay of all approach delays.

The signalized intersection methodology is an iterative and complex methodology that cannot be completed without the use of a computer. There are various computer programs that perform the methodology and display the results. The most commonly used computer programs are HCS and SYNCHRO. NYCDOT uses SYNCHRO, which performs the HCM methodology, but also does signal optimization and simulation. The SYNCHRO program will be described further in Chapter 5.

Chapter 5 COMPUTER SOFTWARE PROGRAMS

This chapter discusses the various computer packages that are used by NYCDOT. The software discussed in this chapter are commercially available packages, which assist traffic engineers in developing signal timing plans. Computer models can compute the signal timings, splits, and offsets for a system, but engineering judgment, based on field observations and knowledge of the system cannot be replaced by computer software packages.

The software packages described in this chapter, which are the most commonly used, are:

1. Tru-Traffic
2. SYNCHRO/SIMTraffic
3. AIMSUN

5.1 Tru-Traffic

The Tru-Traffic software package [1] creates time-space and platoon progression diagrams used for optimizing offsets and splits. The user can change the offset and/or split and instantly see the effects on the system. Tru-Traffic plots distance on the horizontal axis and time on the vertical axis, as can be seen in Figure 5.1. Breaks are shown in the platoons where stops are required. The bandwidths are shown in seconds.

As a bandwidth-based optimization, Tru-Traffic is much less data intensive than many other programs used for signal optimization. Volumes are not needed as an input for creating the time-space diagram. The program looks for the best progression based on block length.

Figures 5.1 and 5.2 are before/after optimization printouts from Tru-Traffic for St. Nicholas Avenue in the Bronx from W.111th Street to W 142nd Street. St. Nicolas Avenue is one-way from W 111th to W 117th. North of W117th street, it is a two-way arterial. The cycle length is 90 seconds.

Figure 5.1 represents the signal timing on St. Nicholas Avenue before optimization. It can be seen that there is no bandwidth progression for more than 2 intersections on the one-way portion of the avenue south of 117th Street. There are small bandwidth progressions for three or four blocks at a time going northbound, until 125th Street. There are three 12-second bandwidths: from 125th to 132nd, from 132nd to 139th, and above 139th.

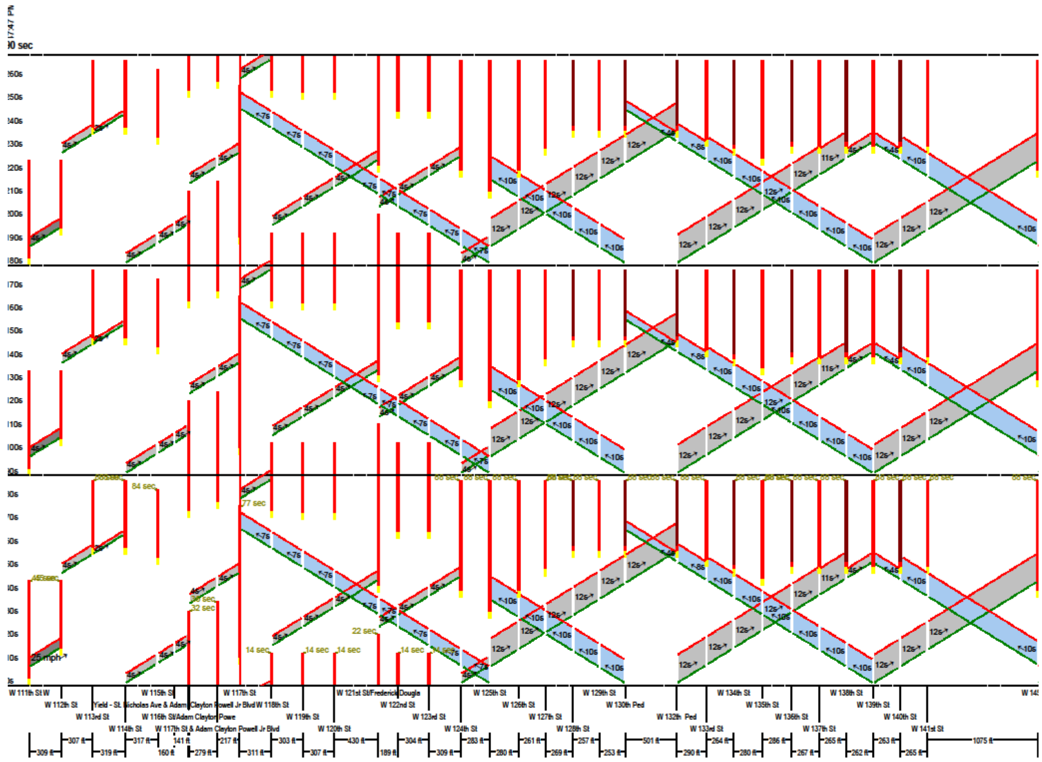


Figure 5.1. Tru-Traffic Diagram for Before Optimization Progression on St. Nicholas Avenue

Figure 5.2 represents the signal plan after optimization. Tru-Traffic allows the traffic engineer to design the timing for different goals, for example, favoring one direction or creating equal bandwidths in both directions. In the after plan of Figure 5.2, it can be seen that the northbound direction is favored. There is some bandwidth almost throughout the entire length of the avenue northbound. There is a continuous bandwidth from 125th street through 145th street. The northbound improvement was accomplished without negatively affecting the southbound bandwidths in any substantial way.

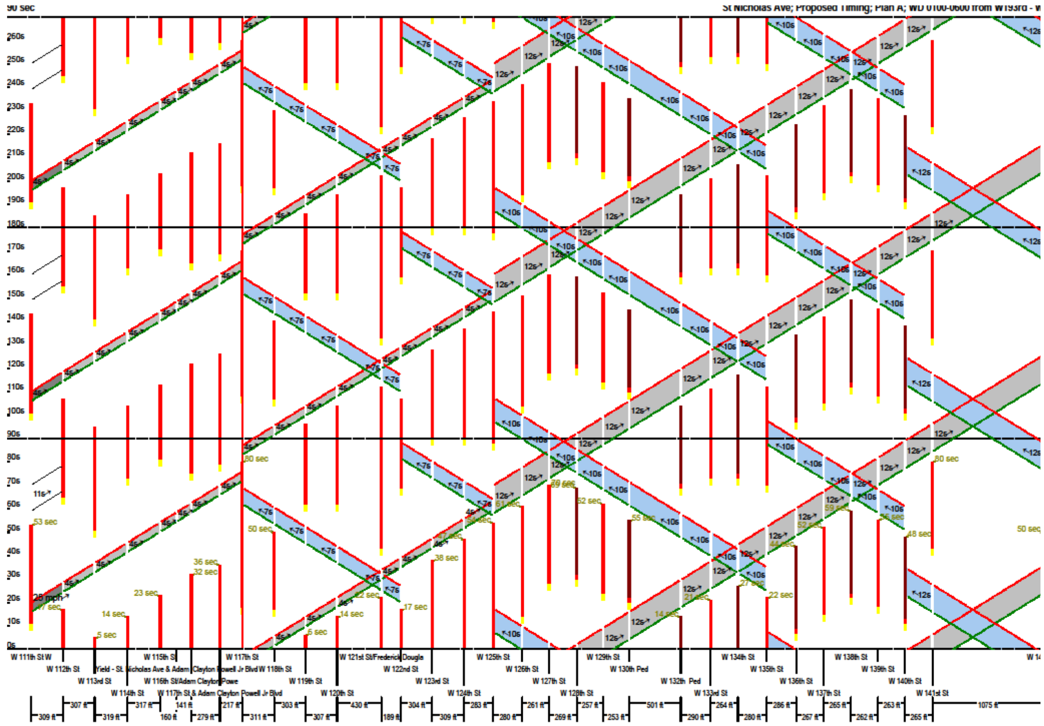


Figure 5.2. Tru-Traffic Diagram for After Optimization Progression on St. Nicholas Avenue

5.2 Synchro/SimTraffic Computer Package

The Synchro/SimTraffic computer package [2] models individual intersections (signalized, unsignalized, and roundabouts), arterials, and/or entire networks. It is developed and supported by Trafficware, Inc. and has the following functions:

- Optimizes signal timings
- Optimizes offsets/coordination
- Capacity analysis
- Creates Time-Space Diagrams
- With SimTraffic, does microscopic simulation

Synchro is a macroscopic model that optimizes signal timing plans: phase times, cycle length, and coordination. Macroscopic models do not simulate individual vehicle movements, but instead represent groups of platoons. Users of Synchro can set priorities by giving more weight to specific phases that will be used in the optimization

Synchro replicates the HCM 2010 methodology for signalized intersections to estimate such measures as capacity, delay, and back of queue, as described in Chapter 4.

Synchro also implements the Intersection Capacity Utilization (ICU) methodology. ICU calculates the amount of time needed to accommodate each of the critical movements. The sum of these numbers is then divided by the reference cycle length, which is set to 120 seconds. If the value is over 100%, the intersection is over capacity.

SimTraffic is a microscopic simulation model. Microscopic models represent the detailed movements of each individual vehicle in the traffic stream. This means that the model defines the characteristics of each individual vehicle, including its speed, location, acceleration, driver characteristics, such as aggressiveness of the driver, to name a few. These characteristics are assigned stochastically.

Because Synchro replicates the HCM deterministic equations, the results may be very different from those of the microscopic model of SimTraffic. For example, the HCM models do not consider the effects of bottlenecks on downstream intersections, nor is the impact of queues or blocking considered. In such cases, the predicted delays of Synchro versus SimTraffic would be very different.

Synchro also includes another method for calculating delay in addition to the HCM and SimTraffic. Synchro's Percentile Method tries to account for variations in traffic arrival patterns by using a Poisson distribution. Five scenarios are modeled: the 90th, 70th, 50th, 30th, and 10th percentile scenarios. Vehicle delay is reported using a weighted average.

Figures 5.3 and 5.4 show a summary of the HCM level of service (LOS) results for the existing and proposed timing of Meeker Avenue in Brooklyn using Synchro. The results show that at the intersection of Meeker Avenue WB and Union Avenue, levels of service in all directions improved, and most importantly the LOS E in the existing condition is LOS D in the proposed condition. However, at the intersection of Meeker Avenue EB and Union Avenue, the level of service on Union Avenue deteriorates from LOS C to LOS D. This is considered an acceptable result since it is more important to improve a LOS E at the Meeker Avenue WB intersection.

In addition, the detailed Synchro report in Figure 5.5 shows that the actual delay at Meeker Avenue EB and Union Avenue in the proposed plan is 36.7 sec/veh. Level of service D ranges from 35 to 55 sec/veh. Thus it is at the very low range of the D values.

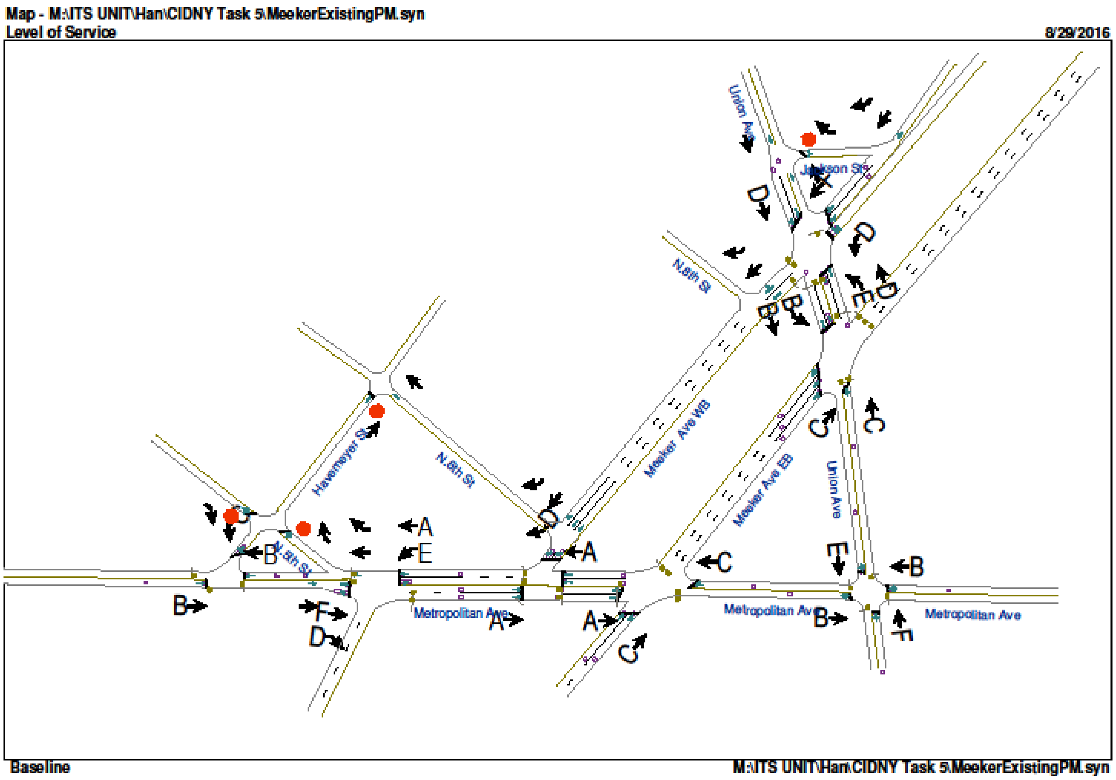


Figure 5.3 Existing Level of Service Results For Meeker Avenue

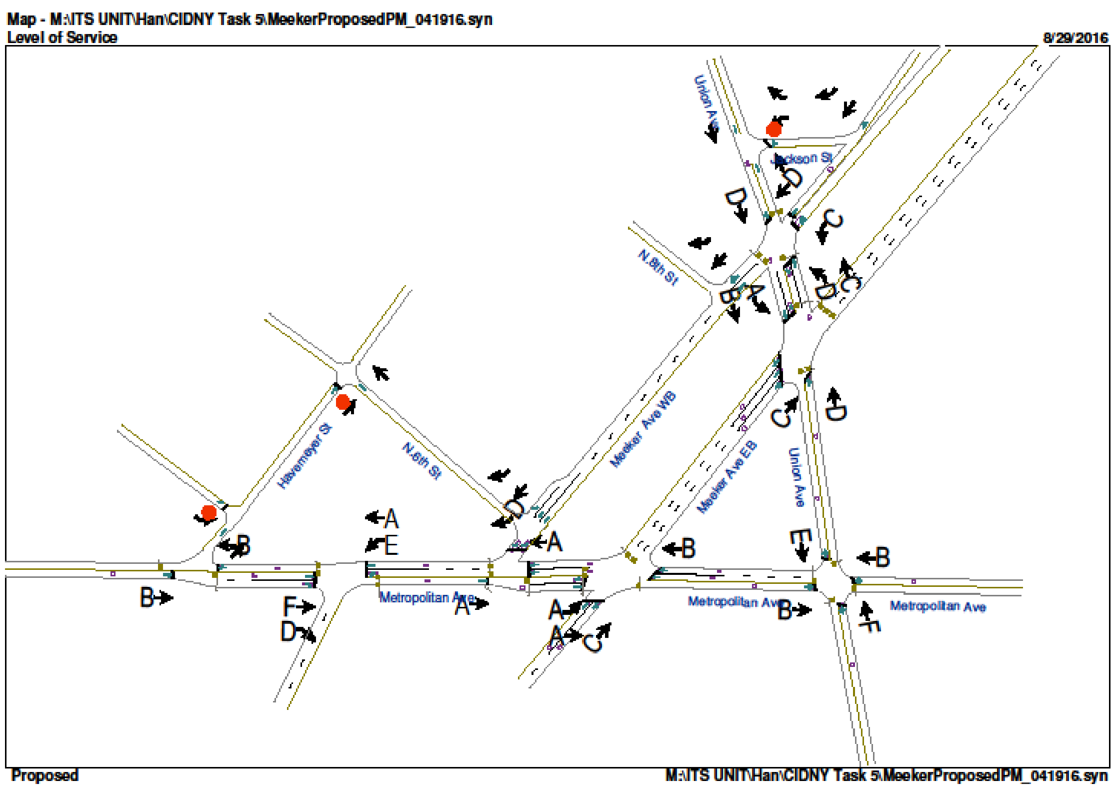


Figure 5.4 Proposed Level of Service Results For Meeker Avenue

Lanes, Volumes, Timings
6: Meeker Ave EB & Union Ave

8/29/2016

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Lane Configurations												
Traffic Volume (vph)	0	115	115	150	245	0	105	630	10	0	0	0
Future Volume (vph)	0	115	115	150	245	0	105	630	10	0	0	0
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.91	0.91	1.00	1.00	1.00
Frt		0.932						0.998				
Flt Protected				0.950				0.993				
Satd. Flow (prot)	0	1423	0	1533	1613	0	0	4196	0	0	0	0
Flt Permitted				0.561				0.993				
Satd. Flow (perm)	0	1423	0	905	1613	0	0	4196	0	0	0	0
Right Turn on Red			No			No			No			No
Satd. Flow (RTOR)												
Link Speed (mph)		30			30			30			30	
Link Distance (ft)		404			147			499			598	
Travel Time (s)		9.2			3.3			11.3			13.6	
Peak Hour Factor	0.92	0.92	0.91	0.88	0.93	0.92	0.88	0.90	0.75	0.92	0.92	0.92
Heavy Vehicles (%)	2%	13%	11%	6%	6%	2%	7%	11%	0%	2%	2%	2%
Parking (#/hr)			5						5			
Adj. Flow (vph)	0	125	126	170	263	0	119	700	13	0	0	0
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	251	0	170	263	0	0	832	0	0	0	0
Enter Blocked Intersection	No	No	No	No	No	No	Yes	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(ft)		0			12			0			0	
Link Offset(ft)		0			0			0			0	
Crosswalk Width(ft)		16			16			16			16	
Two way Left Turn Lane												
Headway Factor	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Turning Speed (mph)	15		9	15		9	15		9	15		9
Turn Type		NA		pm+pt	NA		Perm	NA				
Protected Phases		3		2	2 3			1				
Permitted Phases				2 3			1					
Minimum Split (s)		21.5		21.5			21.5	21.5				
Total Split (s)		67.0		10.0			43.0	43.0				
Total Split (%)		55.8%		8.3%			35.8%	35.8%				
Maximum Green (s)		62.0		5.0			38.0	38.0				
Yellow Time (s)		3.0		3.0			3.0	3.0				
All-Red Time (s)		2.0		2.0			2.0	2.0				
Lost Time Adjust (s)		0.0		0.0				0.0				
Total Lost Time (s)		5.0		5.0				5.0				
Lead/Lag				Lag			Lead	Lead				
Lead-Lag Optimize?				Yes			Yes	Yes				
Walk Time (s)		5.0		5.0			5.0	5.0				
Flash Dont Walk (s)		11.0		11.0			11.0	11.0				
Pedestrian Calls (#/hr)		0		0			0	0				
Act Effct Green (s)		62.0		67.0	72.0			38.0				
Actuated g/C Ratio		0.52		0.56	0.60			0.32				
v/c Ratio		0.34		0.32	0.27			0.63				
Control Delay		34.7		8.3	7.7			23.7				

Lanes, Volumes, Timings
6: Meeker Ave EB & Union Ave 8/29/2016

Lane Group	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NET	NER	SWL	SWT	SWR
Queue Delay		2.0		1.5	3.2			0.7				
Total Delay		36.7		9.7	10.9			24.4				
LOS		D		A	B			C				
Approach Delay		36.7			10.5			24.4				
Approach LOS		D			B			C				

Intersection Summary
Area Type: CBD
Cycle Length: 120
Actuated Cycle Length: 120
Offset: 8 (7%), Referenced to phase 1:NETL, Start of Green
Natural Cycle: 65
Control Type: Pretimed
Maximum v/c Ratio: 0.63
Intersection Signal Delay: 22.5 Intersection LOS: C
Intersection Capacity Utilization 52.4% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 6: Meeker Ave EB & Union Ave

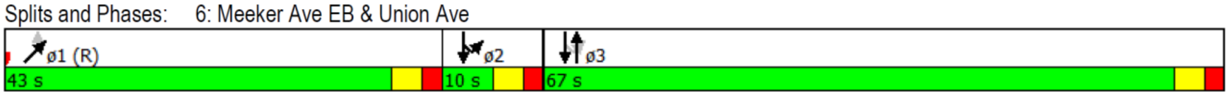


Figure 5.5 SYNCHRO results for Proposed Plan at Meeker Avenue EB and Union Avenue

Figure 5.5 is a snapshot of the SYNCHRO report for one intersection: the intersection of Meeker Avenue EB and Union Street. The complete SYNCHRO report has the same information for each intersection in the network. It includes all the input data for the intersection needed for the analysis and all the results. The lane group results are all calculated using the HCM method.

The intersection LOS is based on the percentile control delay. This is somewhat different than the HCM LOS, but uses the same LOS definitions. Percentile delay is the sum of the HCM uniform delay, the HCM initial queue delay, and a queue delay that results from demand starvation.

The ICU LOS is found from Table 5.1

LOS	Maximum ICU
A	55%
B	64%
C	73%
D	82%
E	91%
F	100%
G	109%

5.3 SIDRA INTERSECTION

The SIDRA INTERSECTION software package [3] is an intersection and network analysis tool. It can be used for design, signal optimization of timings, phasings, and coordination, as well as evaluation of an individual intersection and networks of intersections that are pretimed and/or actuated. Measures of effectiveness include delay, number of stops, and back of queue. SIDRA does its analysis on a lane-by-lane basis (unlike the HCM model which groups lanes into lane groups).

SIDRA does not only analyze signalized intersections, but analyzes all types of intersections, either individually or as part of a network. The types of intersections that can be analyzed using SIDRA are:

- Unsignalized intersections (with or without pedestrian crossings)
- Roundabouts (unsignalized, signalized fully or metering signals)
- Interchanges (single-point, diamond interchanges with signal, stop sign, or roundabout control)
- Two-way and All-way stop control
- Yield signs
- Channelized merge lanes
- Up to 8-leg intersections

SIDRA can model separate vehicle types including light and heavy vehicles, buses, bicycles, which can be allocated to different lanes and signal phases, such as for bus priority.

5.4 SIMULATION PROGRAMS

Simulation can be accomplished at three different levels of detail: Microscopic, Mesoscopic, and Macroscopic. Microscopic simulation is extremely detailed and needs a lot of data. Macroscopic simulation requires limited detail. Mesoscopic combines both simulation types for different regions of the area being simulated. Table 5.2 [4] gives the advantages and disadvantages of each.

Table 5.2 Advantages and Disadvantages of Levels of Simulation

Model	Merits	Demerits
Macroscopic	• Good planning tool to capture regional level impacts / benefits of traffic demand • Can complete 4-step modeling process • Generates demand data for meso and micro models, and sketch planning ITS tools • Extensive roadway and intersection detail not required	• Majority are static assignment • Cannot capture operational constraints
Mesoscopic	• Computation efficiency for large networks • Operationally constrained results • Multiple vehicle types	• Vehicle interactions not considered • Lane by lane analysis not available
Microscopic	•Operationally constrained results •Incorporates driver behavior •Multiple vehicle types, intersection controls •Excellent visual outputs for outreach • Interoperability with programs such as SSAM • Applicability to advanced traffic management system strategy •Efficient for moderate to heavy congested areas	• Detailed roadway and intersection characteristics • Complex network development

5.4.1 Aimsun

Aimsun [5] is a transportation simulation model developed and supported by the Spanish company TSS (Transport Simulation Systems). It is capable of simulating advanced control systems, including “Intelligent Transportation” functions, such as real-time use of data. The Aimsun simulation model allows the analyst to view a detailed animation of the system, which helps to identify where refinements are needed.

Aimsun can do macroscopic, microscopic, and mesoscopic simulation. Mesoscopic simulation combines features of both macroscopic and microscopic simulation.

Aimsun measures of effectiveness are collected on better than second-by-second time scale, including average speed, density, total vehicle miles travelled (vmt), average travel time, delay, stops, queue length (both average and maximum), fuel consumption and pollution numbers. One advantage of Aimsun is the gap-acceptance behavior of drivers, which is modified based on their delay time.

NYCDOT uses Aimsun to model the Transit Signal Priority (TSP) bus corridors and the “Midtown in Motion” network. The version of Aimsun used by NYCDOT has several custom features programmed into the software, specifically to include NYCDOT policies.

Using Aimsun for TSP design is important for many reasons. For example, Aimsun has the ability to allow signal controls to be assigned to a specific vehicle type. This is imperative in order to simulate queue jumping, by assigning specific vehicle types to different signal groups. Then a specific signal group (such as, vehicle type = bus) can be added to a signal phase while other vehicle types do not get added to that phase. The use of Aimsun for TSP design in NYC is discussed in an article in Chapter 3, Appendix A. The article discusses how Aimsun was used and the challenges involved in modeling the complex environment found in NYC.

5.4.2 Vissim

Vissim is a transportation simulation model which is developed and supported by PTV Group [6]. Vissim can be used for microscopic and mesoscopic simulation (also hybrid) by itself, or it can be connected to Visum software [8] for macroscopic modeling as well.

The flexibility of the network structure in Vissim and realistic traffic control objects such as conflict area and signal controllers available in Vissim allows for modelling many complex junctures, as they behave in the real world. One advantage of Vissim is its ability to represent on-street parking behavior and double parking. Vissim is widely used for a number of different applications, such as a signalized corridor, roundabout (and other unconventional intersections), freeways, public transit, pedestrian modeling, Intelligent Transportation Systems (ITS) strategy evaluations, and connected and autonomous vehicle (CAV) analysis.

Vissim has been used for many public transit studies by using built-in features such as Transit Signal Priority (TSP), Signal Preemption and transit station (transit mall) analysis. Vissim has a built-in signal controller (Ring Barrier Controller) which can model not only typical signal operations but also both TSP and preemption without any external component. In addition, when passengers’ behavior need to be modeled as a part of multimodal study, it is possible to take advantage of Viswalk (built-in pedestrian modeling module based on social forces theory) and have multiple modes in the same network simultaneously.

Vissim can generate many different performance measures which can be reported per vehicle, per each data collection object, and for the overall network. As shown in the figure below, one the most popular outputs that can be presented is a “Bus bunching plot,” as shown in Figure 5.6, which can be generated by collecting *distance traveled* and *simulation time* data.

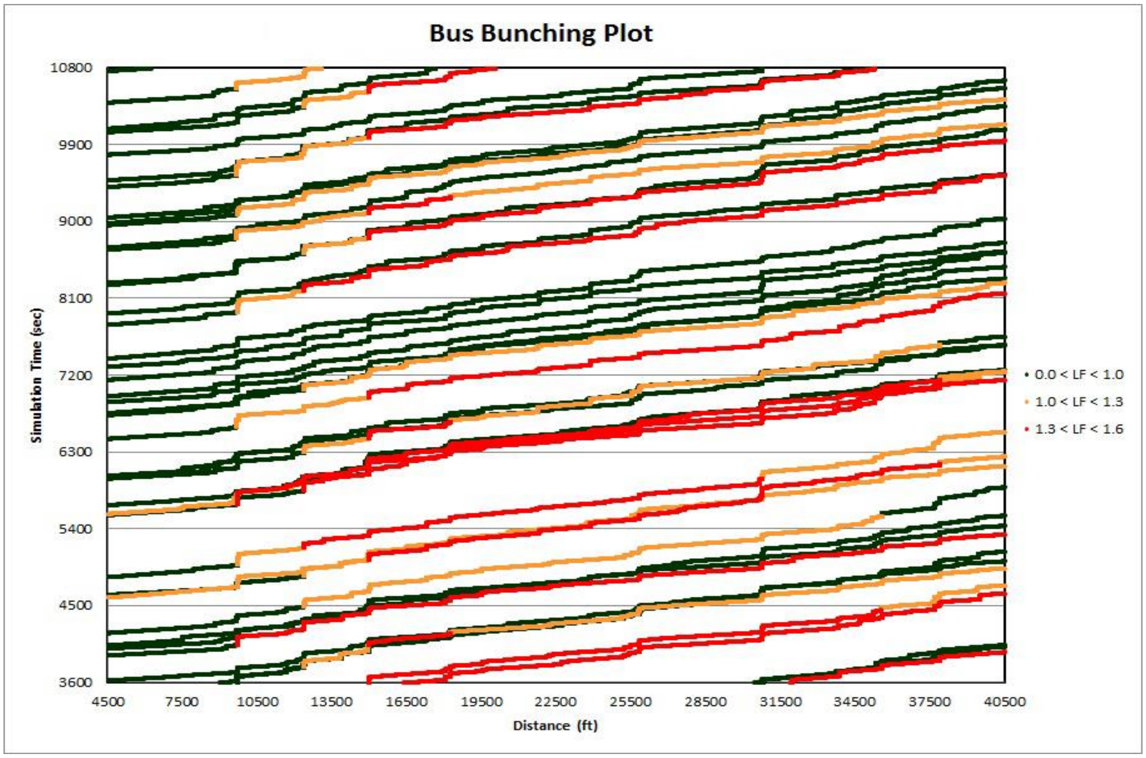


Figure 5.6 Bus bunching plot output from Vissim

In addition, Vissim generates other performance measures such as speed, density, stops, queue length, travel time (statistics including average, percentile, minimum, maximum, etc.) and more.

5.5 Conclusion

The five software packages described in this chapter, Tru-traffic, Synchro, SIDRA, Aimsun and Vissim, are the packages used in the NYCDOT signal timing division. There are other packages that perform the same or similar functions, but they are not currently being used in the signal timing unit of NYCDOT. Some examples of other software packages are listed below. More information on each of these can be found on their websites, listed in the references.

- For HCM analysis:
    - Highway Capacity Software (HCS) [7]
    - TEAPAC [8]
- For Signal Optimization:
    - HCS
    - TEAPAC
    - TRANSYT-7F^{TM} [9]
- For simulation:
    - SimTraffic
    - Paramics [10]

References

[1] Tru-Traffic Version 10, http://tru-traffic.com/

[2] SYNCHRO STUDIO, Trafficware Inc, http://www.trafficware.com/ synchro-studio.html

[3] SIDRA INTERSECTION Version 7, http://www.sidrasolutions.com/

[4] Arunachalam, K. and Peace, J., *Simulation Tool Selection Methodology*, www.atlantaregional.com/.../tp_mug_simtoolselmethod_061110.pdf

[5] AIMSUN, TSS-Transportation Simulation Systems, https://www.aimsun.com/

[6] PTV VISSIM, http://vision-traffic.ptvgroup.com/index.php?id=8970&L=9

[7] HCS 2010TM, https://mctrans.ce.ufl.edu/mct/index.php/hcs2010/

[8] TEAPAC, Strong Concepts, http://www.strongconcepts.com/

[9] TRANSYT-7FTM, https://mctrans.ce.ufl.edu/mct/index.php/hcs2010/transyt-7f/

[10] PARAMICS Microsimulation, http://www.sias.com/2013/sp/sparamicshome.htm

Chapter 6 GLOSSARY OF TERMS

Accessible Pedestrian Signal (APS): A device used at signalized intersections to help blind and visually-impaired pedestrians to cross the intersection.

Actuated Control: A type of control that uses information about the current demand for an intersection approach to determine the phase shown and timing of the phase.

Advanced Solid State Traffic Controllers (ASTC): Wirelessly controlled traffic controls that can be used to integrate ITS technologies, such as adaptive control using real-time data.

Aimsun©: A transportation simulation modeling software package.

All-red Clearance Interval: The all-red clearance interval is a period of time when all movements at the intersection have a red indication.

Automatic Traffic Recorder (ATR): A traffic volume counting device that can be temporarily installed or permanent installed at stations throughout the City.

Back of Queue: The maximum end point of queued vehicles during a typical cycle.

Bandwidth: The time between the first vehicle that can pass through a corridor and the last vehicle that can pass through that corridor without stopping, at an assumed constant speed.

Barnes Dance: A phase that is exclusive for pedestrians.

Battery Backup: A battery placed in controllers at the intersection to take over powering of the signal during an electricity blackout.

Capacity: The maximum number of vehicles that can enter the intersection under prevailing conditions, vph.

Clearance Time: The time between signal phases to transition between conflicting movements.

Clearance Lost Time: The amount of time at the end of a movement's phase that is not used by vehicles. It is the average time after the last vehicle enters the intersection on a given phase and before the first vehicle enters the intersection on the following phase.

Control delay: the delay that is caused by the placement of the traffic signal; the deceleration delay, moving up in queue delay, stopped delay, and acceleration delay.

Cycle: A complete sequence of phases

Cycle Length: The total time it takes to complete one cycle

Demand: The flow rate of vehicles desiring to enter the intersection during a certain period of time, expressed in vehicles per hour (vph)

Extended Call Feature of APS: Special features can be programmed into the APS controller when the user presses and holds the APS button

Federal Highway Administration (FHWA): An agency within the USDOT that specializes in highway transportation, as well as supporting State and Local Governments in the safety and mobility of their communities.

Flashing Arrow: A right- or left-turn arrow that flashes continuously and means that the driver may proceed with caution

Flashing Don't Walk (FDW) Interval: The portion of the pedestrian clearance time when the pedestrian interval flashes "Don't Walk"

Highway Capacity Manual (HCM): Published by the Transportation Research Board, it contains concepts and methodologies on capacity and quality of service for various types of facilities, including intersections, arterials, and highways.

Highway Capacity Software (HCS): Software package that replicates the entire Highway Capacity Manual methodologies.

Isolated Intersections: An intersection that has no offset relationship to neighboring intersections, that is, the traffic approaching the intersection does not arrive in platoons.

Interval: The time when a traffic signal indication does not change.

Lead Pedestrian Interval (LPI): An LPI phase gives a "head start" to the pedestrians before the vehicles are released. This partially separates the pedestrians and vehicles in time, reducing conflicts.

Lag Phase: A protected left-turn phase that occurs after the opposing through vehicle phase.

Lead Phase: A protected left-turn phase that occurs before the opposing through vehicle phase.

Level of Service (LOS): A scale used to represent the quality of service provided to users of a facility. A letter-grade scale from 'A' to 'F' is used to describe performance. LOS A is the best LOS and LOS F is the worst.

Manual on Uniform Transportation Control Devices (MUTCD): A reference book published by the Federal Highway Administration (FHWA). The MUTCD provides national standards for all aspects of traffic control devices, including design, placement, and guidance on the type of control used.

Measure of Effectiveness (MOE): a traffic operation measure used to assess and evaluate the transportation system. MOE's include speed, delay, and travel time.

Network: A set of signals that are coordinated as a group.

NYC Wireless Network (NYCWin): the dedicated broadband wireless network that was created by NYC's Department of Information Technology and Telecommunications (DoITT).

Offset: The time difference between a point in the cycle (often the start of green on the main street) and a system reference point. Offset is the means by which signals are coordinated.

Paramics: A microscopic traffic simulation program.

Pedestrian Clearance Time: The time it takes a pedestrian to cross curb-to-curb (including parking lanes), at an average pedestrian speed.

Pedestrian Countdown Signal: A pedestrian signal that shows the countdown of time remaining before the pedestrian signal changes to solid 'Don't Walk.' It replaces the flashing don't pedestrian signal.

Pedestrian Walk Time: A signal interval that allows pedestrians to begin crossing an intersection.

Permissive Left Turn: Permissive mode for left-turning vehicles requires the vehicle to yield to opposing through traffic as well as to pedestrians and bicycles in the crosswalk adjacent to opposing through traffic

Permissive Right Turn: Permissive right-turn phases allow concurrent moving of right-turning vehicles and conflicting pedestrians (pedestrians in the crosswalk adjacent to the right-turning vehicles)

Phase: A set of traffic signal displays that gives the right of way to a movement or group of movements.

Pretimed Control: With pretimed control, the amount of time given to each phase is fixed, regardless of changes in the traffic demand. The number and order of the phases does not change.

Progression: The result of coordinating traffic signals to move platoons of vehicles down the corridor. Good progression results in a high percentage of vehicles arriving during the green time. Bad progression results in a high percentage of vehicles arriving during the red time.

Protected Left Turn: The left-turn movement is separated in time from opposing vehicles and crossing pedestrians. Thus the left turns are protected from conflicting movements.

Protected Right Turn: Protected right-turn phase separates the right-turn vehicle movements from the conflicting pedestrians in the crosswalk.

Protected/Permissive Phase: A phase sequence that allows a turning movement to have time when the movement occurs at the same time as the conflicting movement and also time when the conflicting movement is not allowed.

Queue Storage Ratio: The ratio of the back of queue to the length of storage available (block length or turn-bay length).

Saturation flow rate: The maximum number of vehicles that could enter the intersection in a lane or group of lanes, if the signal phase was always green. The units for saturation flow rate are vehicles per hour green (vphg).

Sidra: An intersection and network analysis tool. It can be used for design, signal optimization of timings, phasings, and coordination, as well as evaluation of an individual intersection and networks of intersections that are pretimed and/or actuated.

SimTraffic: A companion program to Synchro that does microscopic simulation using the Synchro inputs.

Sneakers: Left-turning vehicles that move up into the intersection and make the turn after the opposing through-vehicle phase ends.

Spillback: A condition when the queue at a downstream intersection backs up to into the upstream intersection, not allowing the upstream vehicles to enter the link.

Split: The time assigned to the phases as a percentage of the cycle length.

Split Phase: The term split phase refers to completely separating the pedestrian signal time from the conflicting turning-vehicle time.

Start-up Lost Time: The time after the signal turns green that is not used by vehicles entering the intersection.

Synchro©: A macroscopic software package that optimizes the phase times and coordination, replicates the HCM methodology, and calculates additional measures of effectiveness as well.

Teapac: A network and signalized intersection analysis software that replicates both the signalized intersection and the urban streets chapters of the Highway Capacity Manual.

Traffic Adaptive Control: Signal timing plans changed based on real-time data.

Traffic Information Management System (TIMS): An application for managing and maintaining all the traffic-related count data collected by NYCDOT in one secure location.

Traffic Management Center (TMC): The central control facility where traffic signals are managed.

Transyt 7F: A macroscopic traffic simulation program used for optimizing signal timing, offsets, and splits.

Tru-Traffic: A software package that creates time-space and platoon progression diagrams used for optimizing offsets and splits.

VISSIM: A transportation simulation model that does microscopic and mesoscopic simulation.

Volume-to-capacity ratio The ratio of the demand volume to the available capacity under the prevailing conditions.

Walk Interval: The portion of the pedestrian phase when the pedestrian signal displays 'Walk.'

Yellow Change Interval: The yellow change interval serves the purpose of warning users that their phase is ending and allow vehicles to decide to either safely stop before the crosswalk or to safely proceed to enter the intersection on yellow.

Yellow Trap: The yellow trap occurs when there is a lag phase for one direction after a permissive left-turn phase in the opposing direction. During the initial phase, both opposing left-turning vehicles operate in permissive mode. At the end of this phase, one left-turn movement see a yellow signal for themselves and also for the through and right-turning vehicles travelling with them. These left-turn vehicles may incorrectly assume that the opposing vehicles are also receiving a yellow signal and are about to stop. Therefore the subject left-turning vehicles waiting for a gap to make the turn will either be trapped in the intersection with no way to turn, or complete the left turn assuming the opposing through vehicles are stopping, producing a serious safety concern.