Multimodal Network Development Methodology & Multimodal LOS Overview

DRAFT – July 8, 2019

Introduction

The development of a multimodal transportation network is dependent on a variety of factors, from street network and roadway characteristics to trip generators and destinations. As the City of Manhattan continues to incorporate bicycle and pedestrian facilities into the transportation system, an underlying framework will be necessary to guide objective decision-making for active transportation investments in a manner consistent with the vision, goals, and objectives of the Bicycle and Pedestrian Systems Plan (Systems Plan).

Bicyclist and pedestrian comfort are at the heart of this network development framework. The Systems Plan envisions a community in which people of all ages and abilities can safely and comfortably travel by foot, bike, and other forms of non-motorized transportation. To achieve this vision, the City of Manhattan’s active travel network will consist of bicycle boulevards, separated bike lanes, shared-use paths, sidewalks, and similar facilities that provide a low-stress experience for people walking and bicycling.

The City has created the following methodology and framework to analyze the transportation system’s current and future ability to integrate low-stress facilities. The framework also provides the parameters and data inputs for developing general network recommendations and more specific facility recommendations for individual corridors. Figure 1 on the following page depicts the process through which the City can integrate GIS-based data, network planning principles, and facility design guidance with plan values and public input to create an active transportation network that meets the needs and aspirations of the community.

This document provides a brief description of the five steps in the multimodal level of service and network development processes. Each step builds on the findings of the previous step(s) to arrive at a complete bicycle and pedestrian network.

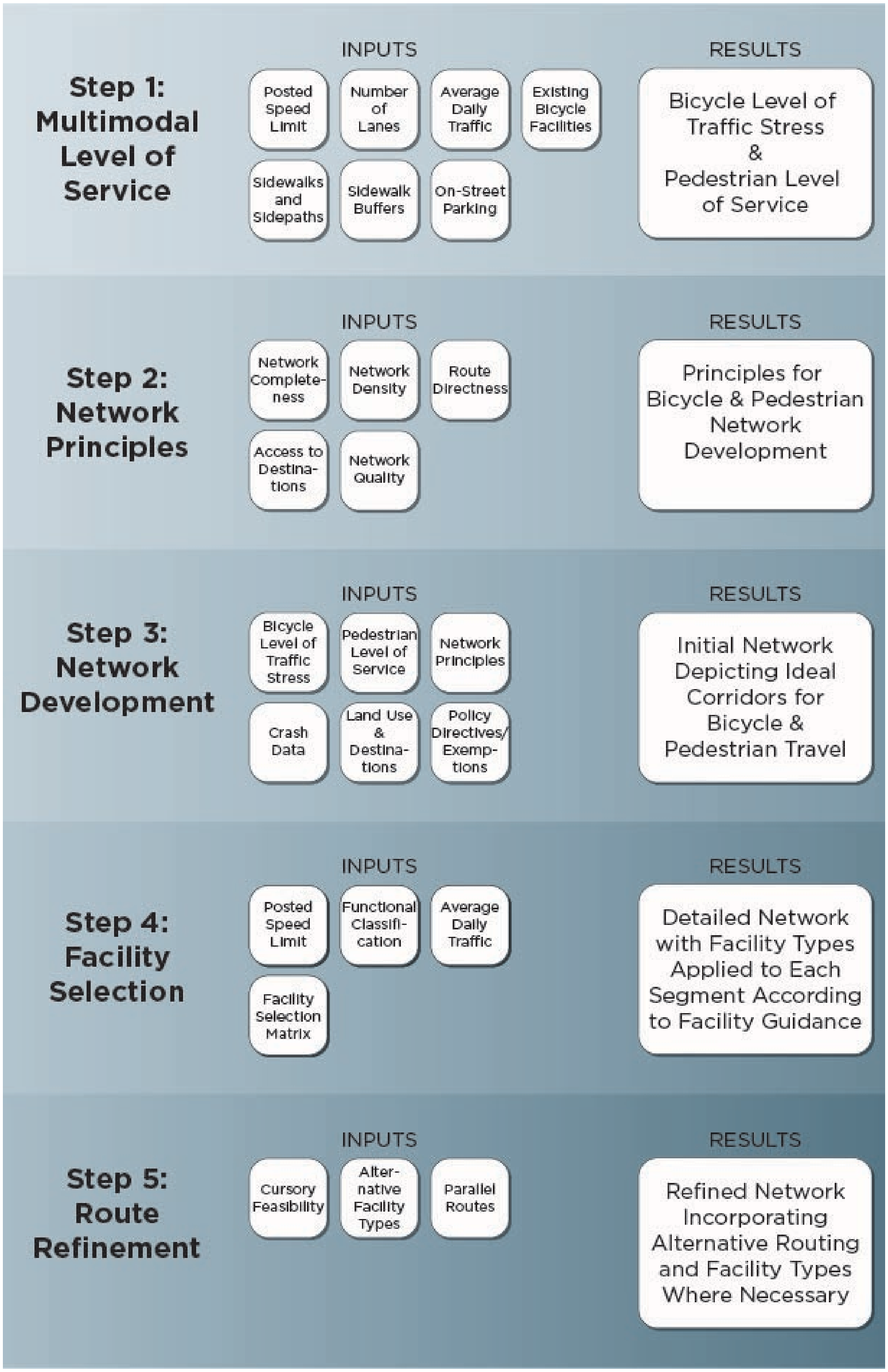

Figure 1: Multimodal Level of Service and Network Development Process Overview

Level of Service and Network Development Methodology

Step 1: Level of Service for Bicycling and Walking

Multimodal level of service analysis is a data-driven process that uses roadway characteristics, location and type of bicycle and pedestrian facilities, traffic volume and other available data to understand existing conditions for bicycling and walking, to locate system gaps, and to identify opportunities to create an interconnected system for bicycling and walking. This analysis consists of two separate components: Bicycle Level of Traffic Stress and Pedestrian Level of Service. Each of these individual analyses uses a number-based scoring system to rate travel conditions.

Bicycle Level of Traffic Stress

A majority of the public would like to walk or ride bicycles more but are discouraged from doing so by perceived safety concerns, lack of facilities, or a lack of knowledge about where the appropriate facilities are located. Surveys nationally show that 50-60 percent of people say they would ride a bicycle more (or start riding) if they had access to facilities that provided more separation from traffic, lower traffic speeds, and/or lower traffic volumes.[1] Additionally, evidence has shown that increasing the number of bicyclists on the road improves safety for all transportation modes. Cities with high bicycling rates tend to have lower crash rates.[2]

The Bicycle Level of Traffic Stress (LTS) Analysis evaluates "a combination of perceived danger and other stressors (e.g., noise, exhaust fumes) associated with riding a bike close to vehicle traffic"[3]. The analysis incorporates roadway and traffic characteristics, including posted speed limit, street width, and the presence and character of bicycle lanes, to categorize each roadway segment and intersection into one of four levels of traffic stress:

- LTS 1 - tolerated by most children
- LTS 2 - tolerated by the mainstream adult population
- LTS 3 - tolerated by "cyclists who are 'enthused and confident' but still prefer having their own dedicated space for riding
- LTS 4 - tolerated only by those characterized as "strong and fearless"

The results of the LTS analysis help identify existing areas with a high level of service as well as focus areas for improvement. LTS provides an intuitive framework to describe the benefits of bicycle infrastructure, and demonstrates that some roadways need more intervention than others to provide a truly comfortable experience.

Methodology

The methods used for the LTS analysis were adapted from the 2012 Mineta Transportation Institute (MTI) Report 11-19: Low-Stress Bicycling and Network Connectivity. The approach outlined in the MTI report uses roadway network data, including posted speed limit, the number of travel lanes, and the presence and character of bicycle lanes, as a proxy for bicyclist stress/comfort level. The method used in this analysis utilizes additional data such as on-street parking, traffic signals, shared-use paths, and motor vehicle volumes

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[1] Roger Geller, City of Portland Bureau of Transportation. Four Types of Cyclists. (2009). http://www.portlandonline.com/transportation/index.cfm?&a=237507.
[2] Marshall, Wesley E., and Norman W. Garrick. "Evidence on why bike-friendly cities are safer for all road users." Environmental Practice 13, no. 1 (2011): 16-27.
[3] Mekuria, Maaza C., Peter G. Furth, and Hilary Nixon. Low-Stress Bicycling and Network Connectivity (2012), 1.

(ADT) to provide a more nuanced, context-sensitive interpretation of on-the-ground conditions. A recent study by Furth et al provided additional methodological guidance for incorporating ADT.[4]

The Level of Traffic Stress analysis is completed through an assessment of street segments, intersection approaches, and intersections using spatial data and aerial imagery. Figure 2 below depicts these three elements. Broadly, every street link (a section of roadway) receives three scores based on its characteristics: one score for its segment, the space of roadway between intersecting streets; one score for the approach to an intersection, accounting for right turn lanes; and one score for its intersection, where one segment crosses another. See Table 1 below for more information about data limitations and assumptions.

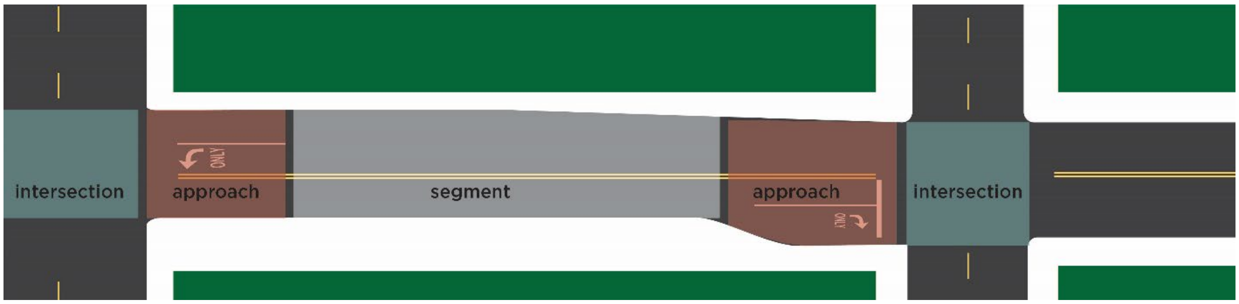

Figure 2: Street link showing the three possible scores it could receive. Because not all links have these three sections, some links may instead receive one or two scores.

The scores assigned are based on a link's characteristics that affect a bicyclist's perception of safety and comfort. The scores range from 1 to 4, where 1 represents the lowest stress, and 4 represents highest stress and discomfort. These three scores determine the overall LTS score. It is important to note that LTS scores are assigned based on a weakest link principle; this means that while a segment may provide a relatively low-stress path, a high-stress intersection will result in an overall high-stress score. Tables 2-6 below summarize the scoring methodology used in this analysis.

Table 1: LTS Data Assumptions and Limitations

Inputs	Notes	Assumptions
Bicycle Facilities	Bicycle lanes have a positive impact on bicycle level of travel stress and are a primary input for developing an LTS model. The width of facilities can have an impact on the associated comfort level. Wider facilities provide greater comfort, especially on higher-speed roadways.	For analysis purposes, a standard width of 5 feet was assumed for all bike lanes within the city. Buffered bike lanes, which provide an additional degree of separation from motor vehicles and great operating space for bicyclists, were considered to be greater than 6 feet, meeting the requirements for the LTS 1 widths outlined in Table 2-6 below.
Speed Limit	Higher speed roadways are considered to be less comfortable for bicyclists, particularly in mixed traffic or with minimal separation from motor vehicles. Low-speed roadways are considered more comfortable.	Speed limit data was available for a subset of roadways within the city limits.
Presence and Width of On-Street Parking Adjacent to Bicycle Lanes	On-street parking is particularly important for corridors on which bicycle lanes are present. Bicycle levels of travel stress are greater on bicycle lanes adjacent to parking than on bicycle lanes without parking due to the potential for 'dooring' incidences.	A standard width of 7.5 feet was assumed for all parking lanes.

[4] Furth, Peter G., Theja VVK Putta, and Paul Moser. "Measuring low-stress connectivity in terms of bike-accessible jobs and potential bike-to-work trips: A case study evaluating alternative bike route alignments in northern Delaware." Journal of Transport and Land Use 11, no. 1 (2018).

Inputs	Notes	Assumptions
Functional Classification	Functional classification refers to the character or service a street is intended to provide.	Kansas Department of Transportation's functional classification system was used to identify and remove limited access freeways from this analysis. The City of Manhattan's functional classification system was used to identify local residential roadways not likely to have a marked centerline.
Number of Travel Lanes	Roadways with multiple travel lanes in each direction are generally considered to be less comfortable for bicyclists, particularly in mixed traffic, whereas two-lane roadways are considered more comfortable.	
Shared Use Path Location	Shared use paths and sidepaths can be a vital component of a municipality's active transportation network. Increased separation from motor vehicles can improve comfort and safety; however, trails are still impacted by the quality of roadway crossings. For roadways with adjacent shared use paths (sidepaths), an LTS score was still generated for on-street bicycling.	Shared use paths are reflected on the analysis map as an LTS 1. Roadway crossings were evaluated, however most crossings occurred at a signalized intersection.

The following tables specify the scoring criteria based on roadway configuration, bike lane and parking presence, crossing condition, and presence of right turn lane. The criteria are adapted from the original 2012 Mineta Institute report. These tables are used in combination to create the segment, approach, and intersection scores described above.

Table 2: Criteria for Level of Traffic Stress in Mixed Traffic

Number of Lanes	Effective ADT*	Prevailing Speed (mph)						
		< 20	25	30	35	40	45	50+
Unlaned 2-way street (no centerline)	0 - 750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751 - 1500	LTS 1	LTS 1	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
	1501 - 3000	LTS 2	LTS 2	LTS 2	LTS 3	LTS 4	LTS 4	LTS 4
	3000+	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
1 thru lane per direction (1-way, 1-lane street or 2-lane street with centerline)	0 - 750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751 - 1500	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
	1501 - 3000	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	3000+	LTS 3	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
2 thru lanes per direction	0 - 8000	LTS 3	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	8001+	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
3+ thru lanes per direction	Any ADT	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4

**Lower value is used for streets without marked centerlines or classified as residential with fewer than 3 lanes.*

NOTE: Data was scored according to Table 2. Most local roads scored LTS 2 due to the speed limit and lack of traffic calming. The exceptions being Moro St., etc. The goal is a AAA network, and so any infrastructure (Bike Blvds, Lanes, protected lanes) will need accommodating signage, parking, & speed limit compliance to create a complete LTS 1 network.

Table 3: Criteria for Bike Lanes Not Alongside a Parking Lane

Number of Lanes	Bike Lane Width (ft)	Prevailing Speed (mph)					
		< 25	30	35	40	45	50+
1 thru lane per direction, or unlaned	6+	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	4 - 5	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4
2 thru lanes per direction	6+	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	4 - 5	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4
3+ thru lanes per direction	Any width	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4

NOTE: All lanes, with the exception of Miller Pkwy & Amherst Ave are 3-5ft in width and therefore this table was only minimally utilized.

Table 4: Criteria for Bike Lanes Alongside a Parking Lane

Number of Lanes	Bike Lane Reach (Bike Lane + Parking Lane Width) (ft)	Prevailing Speed (mph)		
		< 25	30	35
1 lane per direction	15+	LTS 1	LTS 2	LTS 2
	12-14	LTS 2	LTS 2	LTS 2
2 lanes per direction (2-way)	15+	LTS 2	LTS 2	LTS 2
2-3 lanes per direction (1-way)		LTS 2	LTS 2	LTS 2
Other multilane		LTS 3	LTS 3	LTS 3

NOTE: Table 4 was not scored in the data as all limited bike infrastructure was not alongside a parking lane.

Table 5: Criteria for Unsignalized Crossings

Width of Street Being Crossed	Speed Limit of Street Being Crossed			
	Up to 25 mph	30 mph	35 mph	40 mph or more
Up to 3 lanes	LTS 1	LTS 1	LTS 2	LTS 3
4-5 lanes	LTS 2	LTS 2	LTS 3	LTS 4
6+ lanes	LTS 4	LTS 4	LTS 4	LTS 4

NOTE: Bike Intersection LTS was not completed. Instead the Ped LOS for intersections was used for both bikes & peds at intersections. This was due to the overall lack of bike infrastructure. The Ped LOS score reflects the highest (most dangerous) score for any segment of the intersection.

Table 6: Approach Criteria

Configuration	LTS
Single right-turn lane with length less than or equal to 75 feet	No effect on LTS
Single right-turn lane with length between 75 and 150 feet	LTS 3
Otherwise*	LTS 4

**Other conditions may include single right-turn lanes with a length greater than 150 feet and double right-turn lanes.*

NOTE: Table 6 was not used in the analysis

Pedestrian Level of Service

The Pedestrian Level of Service (PLOS) analysis examines the levels of comfort, safety, and ease of mobility that pedestrians experience traveling throughout Manhattan. PLOS analysis incorporates important roadway characteristics like posted speed limit, number of travel lanes, presence of pedestrian facilities, and presence of a buffer between pedestrian and motor vehicle traffic to identify gaps within the pedestrian network and opportunities to enhance network connectivity through targeted infrastructure improvements.

Methodology

PLOS treats segments and intersections separately. A level of service was identified for each roadway segment in the study area, apart from limited access highways, while intersections were examined that were identified as marked or unmarked crosswalks in the City of Manhattan data (includes all major crossing).

Table 7: PLOS Data Inputs

Inputs	Assumptions
Sidewalks	Data available
Crosswalk Markings	May be available, but not in dataset provided
Curb Ramps	May be available, but not in dataset provided
Traffic Signals	Data available
Stop Signs	Data available
Speed Limit	Data available for local roadways
Presence of On-Street Parking	Data available
Bicycle Lanes	Data available

Segment Analysis

The selected segment-based PLOS is rooted in the concept that a doubling of travel speed results in a four-fold increase in vehicle stopping time and resulting crash severity. According to one study, speed has the following impact on pedestrian fatalities[5]:

- At 20 mph the odds of pedestrian fatality are 5 percent
- At 30 mph the odds of pedestrian fatality are 45 percent
- At 40 mph the odds of pedestrian fatality are 85 percent

While other studies have found some variation, these approximate numbers are reported consistently across the literature.

It is imperative that dedicated travel facilities are provided to create safe travel conditions for pedestrians. This PLOS analysis is based primarily on safety and does not consider factors of the built environment known to make walking an attractive and preferred form of transportation. While built environment factors are not explicitly considered, lower posted speeds and more dedicated pedestrian space will typically correlate with places people want to walk, based on the surrounding land uses and urban form (e.g., residential neighborhoods and commercial uses in lower speed urban areas).

The segment-based PLOS measures pedestrian safety using four factors: posted speed limit, roadway width (number of travel lanes), pedestrian buffer (on-street parking or bicycle lanes), and the presence of sidewalks. Table 7 outlines the scoring methodology of the PLOS analysis. The PLOS follows a five-point scale, with 1 representing the highest comfort level. Generally, more pedestrian space on a lower speed roadway segment correlates to a higher comfort level. An incomplete sidewalk network, higher speeds, and a greater number of lanes correlate to a lower comfort level. Bicycle lanes or on-street parking act as buffers between pedestrians and motor vehicle traffic, increasing comfort.

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[5] Killing Speed and Saving Lives, UK Dept. of Transportation, London, England. See also Limpert, Rudolph. Motor Vehicle Accident Reconstruction and Cause Analysis. Fourth Edition. Charlottesville, VA. The Michie Company, 1994, p. 663.

Table 8: Scoring Matrix for Pedestrian Level of Service: Roadway Segments (1 = Highest Comfort Level)

Pedestrian Space along Roadway	Speed Limit (mph)					
	<= 25 mph		30 - 35 mph		>= 40 mph	
	2 lanes	> 2 lanes	2 lanes	> 2 lanes	2 lanes	> 2 lanes
Complete sidewalk on both sides next to a buffer*	LOS 1	LOS 1	LOS 1	LOS 1	LOS 2	LOS 3
Complete sidewalk on both sides	LOS 1	LOS 1	LOS 2	LOS 3	LOS 3	LOS 4
Complete sidewalk on one side next to a buffer*	LOS 2	LOS 2	LOS 2	LOS 3	LOS 3	LOS 4
Complete sidewalk on one side	LOS 2	LOS 3	LOS 3	LOS 4	LOS 4	LOS 5

**Bicycle lanes and/or on-street parking.*

Crossing Analysis

Intersections along major roadways are reviewed for the quality of pedestrian crossing infrastructure. The selected intersection-based Pedestrian Level of Service is rooted in evidence on pedestrian crash reduction factors related to design treatments or interventions[6]:

- Installation of a pedestrian crossing reduces crashes by 25 percent
- Conversion of an unsignalized intersection to a roundabout reduces crashes by 27 percent
- Installation of a raised median and crosswalk reduces crashes by 56 percent
- Speed reduction by enforcement reduces crashes by 71 percent

Signalized and unsignalized intersections are examined along roadways with a functional classification of ‘collector’ or ‘arterial’. Each intersection leg is scored based on the characteristics of the crossing. Like the segment-based scoring, a PLOS score of 1 represents the highest level of service. PLOS decreases as infrastructure gaps and speed are added using the cumulative scoring indicated in Table 9 below. Stop-sign controlled or uncontrolled crossings receive additional points since pedestrians must find gaps in traffic. For conditions that do not substantially impact PLOS, such as no marked crosswalk at crossings of streets with posted speed limits of 25 miles per hour or less, zero points are added to the cumulative score.

Table 9: Scoring Matrix for Pedestrian Level of Service: Intersections (1 = Highest Comfort Level)

Characteristics of Ped Crossing Leg	Speed Limit (mph)		
	<= 25 mph	30 - 35 mph	>= 40 mph
Baseline (Signalized intersection)	1	1	2
More than 2 lanes*	1	2	2
No marked crosswalk	0	1	1
Curb ramp missing on one or both ends	1	1	1
Crossing controlled by stop sign	0	0	1
Uncontrolled or Yield crossing	1	1	2
Total Score	Sum of applicable parameters		

**Roads with medians are treated as having the number of lanes between the curb and median.*

[6] Source: Federal Highway Administration. Desktop Reference for Crash Reduction Factors. http://safety.fhwa.dot.gov/

Step 2: Network Principles

The application of underlying principles to bicycle and pedestrian network development provides consistency and rationale to corridor selection, network coverage, and other important decisions. The following network principles correspond to measurable connectivity analysis methods described in the Federal Highway Administration's *Guidebook for Measuring Multimodal Network Connectivity*. Before beginning the network development process, the City of Manhattan should establish measures and desired outcomes for each of the principles listed below.

Network Completeness

Network Completeness describes the extensiveness or comprehensiveness of the network. This can be measured as a percentage of streets with nonmotorized facilities, percentage of streets with low-stress facilities, or percentage of planned bicycle and pedestrian facilities that have been completed.

Network Density

Network density describes the number of facilities within a given area. In Manhattan, it is likely that nonmotorized facility development can occur at a denser scale in Downtown Manhattan and surrounding neighborhoods than in neighborhoods and areas further from Downtown. As such, more routing opportunities will likely be available within and closer to Downtown. Network density measurements can include lane miles of nonmotorized facilities per square mile, intersection density, or intersection density of nonmotorized facilities.

Route Directness

Route directness relates to the network's ability to support nonmotorized travel via shortest, straightest paths. This can be measured in terms of out-of-direction travel as a percentage of shortest path route, or network permeability.

Access to Destinations

This principle relates to how well bicycle and pedestrian facilities connect to important destinations in the community. There are a variety of performance measures for this network principle, including number of homes and/or jobs accessible by nonmotorized travel, percentage of parks and schools accessible by nonmotorized travel, or nonmotorized travel shed size.

Network Quality

Network quality relates to the character of the nonmotorized travel environment and can be measured through the bicycle level of traffic stress and pedestrian level of service indicators described in the previous section. Manhattan may consider aiming for a certain percent of the network to have low ratings for bicycle level of traffic stress and a certain percent with high ratings for pedestrian level of service.

To assist with the network development process, this memorandum includes sample measures and desired outcomes for each of the five network principles. These measures can be changed and desired outcomes adjusted to better reflect the community's values and aspirations.

Table 10: Network Principles and Performance Measures

Network Principle	Performance Measure	Desired Outcome
Network Completeness	Existing bicycle facilities as a percentage of the sum of all existing and planned bicycle facilities	100 percent of all bicycle facilities are complete
	Existing pedestrian facilities as a percentage of the sum of all existing and planned pedestrian facilities	100 percent of all bicycle facilities are complete

Network Principle	Performance Measure	Desired Outcome
Network Density	Lane miles of bicycle facilities per square mile	To be determined based on existing and desired outcomes
	Intersection density	To be determined based on existing and desired outcomes
Route Directness	Signalized crossings of multi-lane roadways	80 percent of multi-lane roadway intersections on the bicycle network offer a signalized crossing
Access to Destinations	Percentage of parks and schools served by the bicycle network	100 percent of all parks and schools are within 1/4-mile of a bicycle facility
	Percentage of parks and schools served by the pedestrian network	100 percent of all parks and schools are directly served by the pedestrian network
Network Quality	Percentage of streets that offer low-stress environments for bicycling (LTS 1-2)	85 percent of all streets
	Percentage of streets that offer high pedestrian level of service (PLOS 1-2)	75 percent of all streets

The desired outcomes should be calibrated during the network development process to account for baseline measurements and availability of resources to achieve the desired outcomes.

Step 3: Network Development

Applying the network principles described above, the City of Manhattan can piece together an initial nonmotorized network connecting key destinations throughout the community. The complete network should reflect the ideal corridors and routes for bicycle and pedestrian travel. Other important inputs may include bicycle and pedestrian crash data, bicycle LTS and pedestrian LOS, existing nonmotorized facilities, land uses and destinations, and policy directives or exemptions that may dictate facility development on specific corridors or roadway types.

Step 4: Facility Selection

With an initial conceptual network in place, the City of Manhattan must determine the appropriate facility type for each segment/corridor of the network. The selection process is based on the facility selection matrix, which provides contextual guidance to identify appropriate nonmotorized facility or facilities based on two key roadway attributes: posted travel speed and average annual daily traffic. Like the previous network development step, the facility selection step will determine ideal conditions for the proposed network.

Step 5: Route Refinement

The final step of the network development process is the verification of route recommendations and refinement of proposed facilities to address existing or future roadway geometry or other characteristics that may limit or prohibit ideal facility installation. If through a cursory evaluation of feasibility it is determined that an ideal facility cannot be implemented, alternatives should be explored, including downgraded facility types or parallel routes. By refining route recommendations, the City will arrive at a proposed nonmotorized network that best meets the desired network principles targets and incorporates practical considerations to support future implementation.