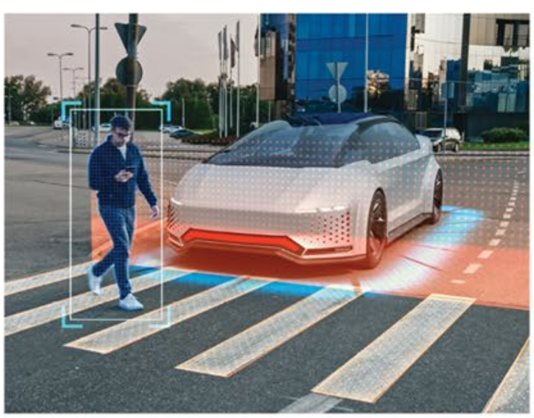
TPO

Miami-Dade Transportation Planning Organization

DOWNTOWN MIAMI TRANSPORTATION MASTER PLAN

TECHNICAL MEMORANDUM #2

EVALUATION OF EMERGING AND FUTURE TECHNOLOGY



THE CORRADINO GROUP

Table of Contents

TABLES **1**
TABLE OF FIGURES **2**
TABLE OF MAPS **4**
INTRODUCTION **5**
EXPLORING EMERGING TECHNOLOGIES **6**
MONTREAL, CANADA 6
NEW ZEALAND, AUSTRALIA, AND THE UNITED STATES 7
TEL AVIV, ISRAEL 9
SINGAPORE 10
NEW YORK CITY, NEW YORK 16
PORTLAND, OREGON 17
BEVERLY HILLS, CALIFORNIA 17
SAN FRANCISCO, CALIFORNIA 19
SANTA MONICA, CALIFORNIA 21
CHICAGO, ILLINOIS 24
SHANGHAI, CHINA 29
MIAMI, FLORIDA 31
JACKSONVILLE, FLORIDA 33
NASHVILLE, TENNESSEE 35
ATLANTA CURBSIDE MANAGEMENT ACTION PLAN 39
STRENGTHENING LINKAGES BETWEEN TRANSPORTATION DEMAND MANAGEMENT AND TRAFFIC MANAGEMENT 41
RESEARCH IN MOBILITY IMPROVEMENTS **43**
WATERBORNE TRANSPORTATION FEASIBILITY STUDY 43
DOWNTOWN MIAMI SMART CORRIDOR HUB TRANSPORTATION MOBILITY AND CONNECTIVITY STUDY 48
CONNECTED AUTONOMOUS VEHICLE STRATEGIC PLAN 58
MIAMI-DADE TPO CLIMATE RESILIENCY STUDY 61
TRAFFIC CALMING FOR PEDESTRIANS AT MIAMI DADE COLLEGE WOLFSON CAMPUS 65
BUS LANES IN DOWNTOWN MIAMI 70
NON-MOTORIZED NETWORK CONNECTIVITY PLAN 74
BICYCLE WAYFINDING SYSTEM STUDY 77
EMERGING TUNNELING TECHNOLOGIES FEASIBILITY STUDY 81
INNOVATION IN FUTURE-READY ZONES **86**

Tables

Table 1. Atlanta's curbside management strategies by curb type. 39
Table 2. MDC Wolfson Campus Tiered Recommendations 65
Table 3. Comparison of tunnel options and their characteristics 81

Table of Figures

Figure 1. A modified fire hydrant in Montreal. 6
Figure 2. A design option for New York City's pilot project. 6
Figure 3. Comparisons of transit connections made by subsidized micromobility users vs. non-subsidized users. 7
Figure 4. Bikeshare user riding within a bicycle lane. 8
Figure 5. Bikeshare docking station located on private property. 8
Figure 6. Micromobility lanes in Tel Aviv, Israel. 9
Figure 7. Current and programmed bicycle network lanes in Tel Aviv, Israel. 9
Figure 8. Singapore's MRT and LRT rail networks. 10
Figure 9. Sheltered skyway near a transit station in Singapore. 11
Figure 10. Silver Zone in a residential street. 12
Figure 12. Greenery amenities are also utilized for testing horticultural technology. 12
Figure 11. Cycling "slow down" markings near a bus stop. 12
Figure 13. Dedicated lane for buses and cyclists operates at reduced hours on Sundays. 13
Figure 14. Dedicated crosswalks for cyclists in high pedestrian zones, bicycle wheeling ramps, and bicycle parking. 13
Figure 15. A pedestrian crossing equipped with Green Man+ function. 14
Figure 16. Digital signs displaying real-time parking data, part of the PGS strategy. 15
Figure 17. Proposed air route connecting JFK Airport to downtown New York. 16
Figure 18. Prototype of eVTOL taxi in NYC. 16
Figure 19. A Portland Loo public restroom kiosk. 17
Figure 20. Diagonal pedestrian pathways are used in Beverly Hills, CA as alternative scramble designs. 18
Figure 21. Transformation of a street to San Francisco's Slow Streets. design. 19
Figure 22. Dunedin's Safer Streets design with downtown speed limits reduced to 6 mph. 20
Figure 23. E-Scooter usage rates in Santa Monica, CA. 21
Figure 24. Police officer citing e-scooter users for riding without helmets. 22
Figure 25. Designated e-scooter parking area with geofencing technology and markings. 22
Figure 26. Combined transit and micromobility stop. 23
Figure 27. Chicago Transit Alert System. 24
Figure 28. Bus stop with real-time bus route information details. 24
Figure 29. Elevator with QR code. 24
Figure 30. Fire hydrant access, secure infrastructure, and intersection daylighting tested for curb management in NYC. 25
Figure 31. Flexible strategies to prioritize curb space for community needs. 25
Figure 32. Delivery micro hubs and new loading zones tailored to neighborhood needs. 26
Figure 33. 26
Figure 34. Smart micromobility and transit strategies. 27
Figure 35. Curb management strategies for outdoor use and public realm enhancement. 27
Figure 36. Smart parking: car share, commercial, and authorized parking for government and essential services. 28
Figure 37. Non-transportation curb uses for construction logistics and media. 28
Figure 38. Layers for developing a digital twin city.. 29
Figure 39. Shanghai's digital twin city technology. 29
Figure 40. Digital twin city technology in urban planning. 30
Figure 41. Federal Bipartisan Infrastructure Bill components. 30
Figure 42. Representation of the full Urban Circulator System (U2C). 33
Figure 43. Rendering of the U2C ramp and autonomous vehicles. 34

Figure 45. Nashville's traffic signal strategies for congestion management. 35
Figure 46. Nashville's safety strategies. 35
Figure 47. Transit priority corridors strategy to enhance mobility for all users in Nashville. 36
Figure 48. Nashville's Transit Improvement Strategies 36
Figure 49. Strategies to improve active mobility and develop complete networks. 36
Figure 50. Parking permitting and enforcement for optimal curb management. 37
Figure 51. Downtown improvements: TDM, event management, and construction hubs to maintain flow during construction and events.. 37
Figure 52. Flexible curb regulation strategies in Nashville. 38
Figure 53. Reasons to Implement Atlanta's Curbside Management Plan 39
Figure 54. Photo of bike valet at Washington Stadium. 41
Figure 55. Ogden Twilight Series concert in Utah. 41
Figure 56. Transportation Network Companies prepare rideshare guides for special events like Mardi Gras. 42
Figure 57. Proposed waterborne travel route between Black Point Marina and Downtown Miami. 43
Figure 58. Recommended catamaran-style vessel for Miami water taxi. 44
Figure 59. Chopin Plaza docking station and connection to Metromover Station. 45
Figure 60. Sea Isle and potential docking sites and routes to Metromover and Metrobus. 45
Figure 61. Riverwalk Station Metromover docking location. 46
Figure 62. Rendering of a seaglider in flight. 47
Figure 63. Electric passenger ship set to launch in Sweden in 2024. 47
Figure 64. Universal charge station for e-mobility vehicles. 53
Figure 65. NYC bicycle lane equipped with rumble strips, enhanced pavement markings, and signage. 53
Figure 66. Geofencing technology used for e-scooter parking in Boulder, Colorado. 54
Figure 67. Micromobility vehicle storage pod in Jersey City. 54
Figure 68. Detroit nonprofit MoGo offers adaptive micromobility devices. 55
Figure 69. An in-ground parking sensor installed on a public parking space. 55
Figure 70. Communication networks providing free Wi-Fi, charging, and phone call capabilities. 56
Figure 71. Micromobility devices. 56
Figure 72. Electric micromobility battery exchange station in NYC. 56
Figure 73. E-bikes charging wirelessly 57
Figure 74. Micro car parked between two conventional cars in NYC. 57
Figure 75. Connected vehicle communication networks. 58
Figure 76. Autonomous high-capacity mobility vehicles. 59
Figure 77. Location of signals with ATMS technoolgy in the study area. 60
Figure 78. NYC's first solar powered bus shelter installed in 2016. 61
Figure 79. Netherlands' bee stops featuring living plants on the roof of bus shelters. 62
Figure 80. Bourke Street bioswale and cycling improvements. 62
Figure 81. Solar umbrella rendering. 62
Figure 82. Solar panel technology installed on sidewalk in Tampa, Florida. 63
Figure 83. Solar sidewalk battery pack to store energy for power outage events. 63
Figure 84. In April 2024, the White House introduced the Federal Flood Standard Support Tool. 63
Figure 85. Skate park facility redirects stormwater to collection areas 64
Figure 86. South Korea's solar-powered bike path. 64
Figure 87. Illuminated bike lanes using eco-friendly technology. 64
Figure 88. Diagram illustrating Low Emission Zones and their purpose. 66

Figure 89. Interactive pedestrian crossing in South London. 66
Figure 90. PedSafe: Pedestrian and Bicycle Collision Avoidance System by FDOT utilizing Connected Vehicle technology. 67
Figure 91. Roving eye technology sign. 68
Figure 92. Solar-powered pedestrian crossing system. 68
Figure 93. Video recording to enforce pedestrian safety. 69
Figure 94. HD lighting system technology projects street signs on road. 69
Figure 95. Example of multipurpose bus post. 72
Figure 96. Air-conditioned Bus Stop at Hialeah Metrorail Station 72
Figure 97. Automated Bus Enforcement Camera. 73
Figure 98. AI technology for bike lane enforcement. 73
Figure 99. Bicycle Detection System alert sign. 74
Figure 100. Bicycle detection system using loop vehicle detection technology. 75
Figure 101. Bicycle traffic signals can be equipped with sensors for data collection 75
Figure 102. Example of Denver Wedge installation. 76
Figure 103. Bicycle runnels on stairs. 76
Figure 104. Portable propulsion devices can convert conventional bikes to e-bikes. 76
Figure 105. Wayfinding sign in Berkely, California designed to notify users of the bike/ped routes. 77
Figure 106. A color-coded scheme is employed to facilitate navigation for both cyclists and pedestrians. 77
Figure 107. Augmented Reality wayfinding, digitalsignagepulse.com 79
Figure 108. Live Touch equipped smart furniture sign in Sydney, Australia. 80
Figure 109. Micro-delivery vehicles in NYC. 83
Figure 110. Automated Delivery Robots with multiple compartments. 84
Figure 111. Inside the LVCC loop. 84
Figure 112. Semi-automated double trolley cranes load containers onto automated guided vehicles 85

Table of Maps

Map 1. States With Active 5.9 GHz Intelligent Transportation Service licenses. 31
Map 2. Map illustrating Smart Hub Networks in the study area. 49
Map 3. The Underline Hub prioritizes active mobility services. 50
Map 4. Map of MiamiCentral Hub, which emphasizes regional mobility. 52
Map 5. Map of downtown Miami: bus transit signal prioritization locations and transit routes. 70
Map 6. East Central Miami-Dade County Corridors. 83

Tech Memo 2: Evaluation of Emerging and Future Technology

Introduction

This memo explores cutting-edge research on global trends in pedestrian and transit-oriented urban downtown areas. It delves into advancements in mobility, focusing on micro-mobility enhancements, mobility hub technologies, curb and special event management strategies, transit improvements, and safety measures. Additionally, it reviews the Miami-Dade Transportation Planning Organization's (TPO) previous work and assesses how emerging technologies can further enhance their objectives.

Based on this research, an inventory of technologies has been prepared to evaluate their potential for improving mobility in the study area. These recommendations are cataloged to identify the type of improvement, the suggested implementation location (future-ready zone), and the actions required for implementation.

Technologies are categorized into 12 improvement types, including Car Lite technology, curb management strategies, and pedestrian and cyclist safety improvements. The future-ready zones for implementing these technologies were determined through a comprehensive process involving stakeholder engagement, safety and ridership data analysis, transit access, network gap analysis, and review of programmed improvements.

The recommendations are provided with short-, mid-, and long-term timelines to facilitate the adoption of these advancements. Implementation timelines are based on the action items required for each improvement, considering factors such as policy development, enforcement, infrastructure construction, and equipment purchase.

The report begins with an overview of technology from international and national examples, explores the TPO studies and emerging technologies, and culminates with a summary table cataloging the technology recommendations.

EXPLORING EMERGING TECHNOLOGIES

The following is an overview of findings from research on emerging technologies and practices implemented worldwide in urban downtown areas to improve mobility and user experience.

MONTREAL, CANADA

In 2015, the City of Montreal launched a pilot program to introduce a water fountain design that uses its fire hydrants to improve access to drinking water. The installation works by attaching a 4.4-foot metal ring to a fire hydrant, providing water through four valves on the ring. A photograph of the system with a modified hydrant is shown in Figure 1. The design was developed in collaboration with Montreal's fire department and the city's water services to maintain the operability of the fire hydrants for emergencies and ensure the quality of the water supply. Spouts can be interchanged to serve as drinking fountains or sprays to cool down. The installation angle can be rotated, allowing flexibility for different hydrant heights and providing easy access to water for adults, children, and wheelchair users. An internal tubing system prevents water from becoming heated under the sun and ensures hygiene.

Figure 1. A modified fire hydrant in Montreal.

New York City is looking to implement a similar system to enhance access to drinking water. The city has been recognized for having some of the best tap water in the nation; however, it may not always be accessible. In February 2024, the City introduced a bill to establish a pilot program to install drinking fountains and tap them into existing fire hydrants. The pilot program will inform the city whether the program should be expanded or made permanent. Figure 2 is an example of a modified hydrant being considered for installation in NYC. The program is also contingent on the determination of the fire commissioner to investigate if the drinking fountains would interfere with the fire department's use of fire hydrants and submit a report explaining such determination.

Figure 2. A design option for New York City's pilot project.

NEW ZEALAND, AUSTRALIA, AND THE UNITED STATES

A study completed by MONASH University's Institute of Transportation Studies evaluated the impact of shared mobility programs on low-income riders. The study assessed the discount ridership program for Lime, a shared e-bike and e-scooter operator with facilities in New Zealand, Australia, and the United States. Using responses from a survey method, the study generated ridership characteristics for customers participating in the discounted ridership program (Lime Access) and non-member riders. Members of the subsidized program received discounted rides based on their income. They determined that members of the program compared to non-members are:

- ✓ 90% more likely to have a household income below the area median,
- ✓ over four times more likely to be unemployed or 2.5 times more likely to be employed part-time,
- ✓ locals who use shared micromobility for practical purposes like shopping/errands and commuting,
- ✓ three times more likely to be a student,
- ✓ more likely to report mechanical challenges and
- ✓ more likely to use bikeshare as a first/last-mile mode linked to transit.

Findings from the survey showed that micromobility had the most significant impact on sustainability. 15% of all shared-mobility users opted to use an e-bike or e-scooter instead of requesting a taxi or ride-hailing service. The survey also found that all users replaced 10% of trips that would have been taken by car with a micromobility option.

The high trip substitution with public transport (34% among riders in the discounted program) and very low substitution with taxis (4%) also indirectly suggest that these riders are less likely to have access to car-based mobility. Figure 3 highlights the difference in transit connections and use by members of the Lime Access discount program and non-members.

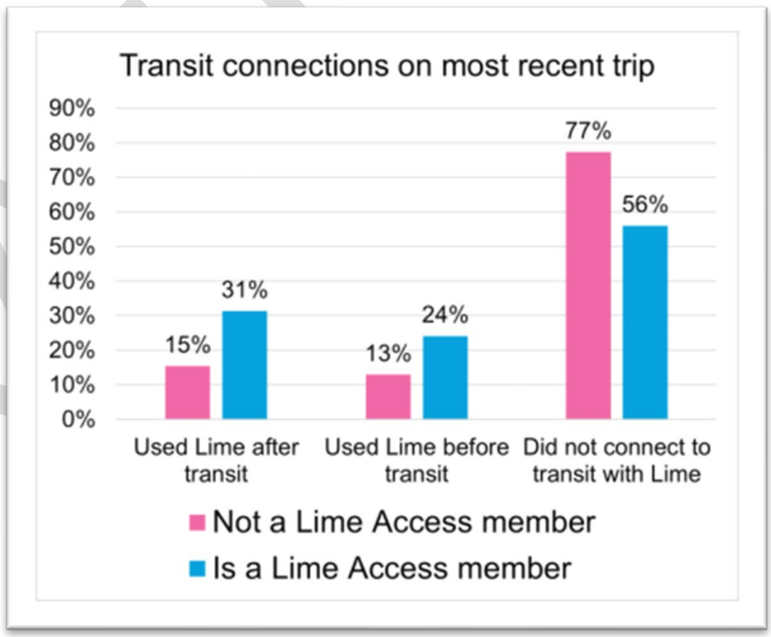


Figure 3. Comparisons of transit connections made by subsidized micromobility users vs. non-subsidized users.

The study also found that the discount program provided riders mobility despite medical conditions or physical disabilities. Many disabilities are 'invisible' and are not likely to be noticed by the casual observer. Yet, using an electric micromobility vehicle can reduce fatigue and strain experienced while walking or riding a standard bike by individuals with disabilities.

As shared scooter companies look to expand the usage of reduced-fare programs by more individuals, the most prevalent obstacle is likely to be a need for greater awareness of the program's existence. According to the survey, only a quarter of existing customers were aware of the discount ridership program before participating. Figure 4 depicts a bike-share user.

The study recommends a broader conversation about the role of governments in supplying financial support for reduced-fare programs. There are precedents from other commercial mobility providers for this approach; for example, in Australia, people with a disability eligible for subsidized taxi trips can use their discount for private-hailing operators if their wheelchair or mobility aid can fit inside the vehicle. A similar approach could be taken with the growing proliferation of e-bike rebates. While most rebate programs aim to offset the cost of purchasing a personal e-bike with more significant rebates for low-income individuals, these funds could also be directed to subsidize membership in a shared e-bike or e-scooter program. This approach addresses barriers experienced with personal ownership around the availability of safe, secure storage and maintenance costs.

Figure 4. Bikeshare user riding within a bicycle lane.

Shared scooter programs often have restricted service areas and limited fleet sizes. Companies typically are interested in expanding to serve larger areas and providing more vehicles to riders, and cities could use this interest as a carrot for achieving equity goals. Simultaneously, expanding fleets and service areas could give low-income riders better access to safe riding facilities. For example, e-scooters and e-bikes are prohibited in Chicago's Lakefront Trail or the Loop. Yet, these two facilities supply some of the best infrastructure for people riding bicycles and scooters. Low-income residents on Chicago's South Side would receive help from these facilities being opened to connect them to more destinations safely.

In New York City, Citi Bike is the official bike-sharing system. Due to complex permit processes for private companies looking to station vehicles in public spaces, other transit alternatives may be more challenging. However, shared micro-mobility is pursuing a new model: putting shareable bikes on private property instead. Bicycles can be stationed on private properties across the city, out of the public right of way, bypassing the permitting and regulations and allowing riders to reserve, pick up, and drop off at private property locations. The initiative aims to show that private and public options can work together to meet the high demand for transport options. An example of this system is proven in Figure 5, where the private rideshare operations are located within the building, and an alternative rideshare docking station on the right of way can be seen in the rear.

Figure 5. Bikeshare docking station located on private property.

TEL AVIV, ISRAEL

According to the 2021 edition of the TomTom Traffic Index report, Tel Aviv ranked 16th on the list of cities with the worst traffic congestion globally. On average, travel times in Tel Aviv were 43% longer than during the baseline non-congested conditions established by the study. Given the high reliance on automobiles, Tel Aviv has been pursuing implementing one of the world's most extensive shared mobility networks by establishing over 215 miles of dedicated bike paths by 2025. An example of the network's bike lanes is provided in Figure 6.

Figure 6. Micromobility lanes in Tel Aviv, Israel.

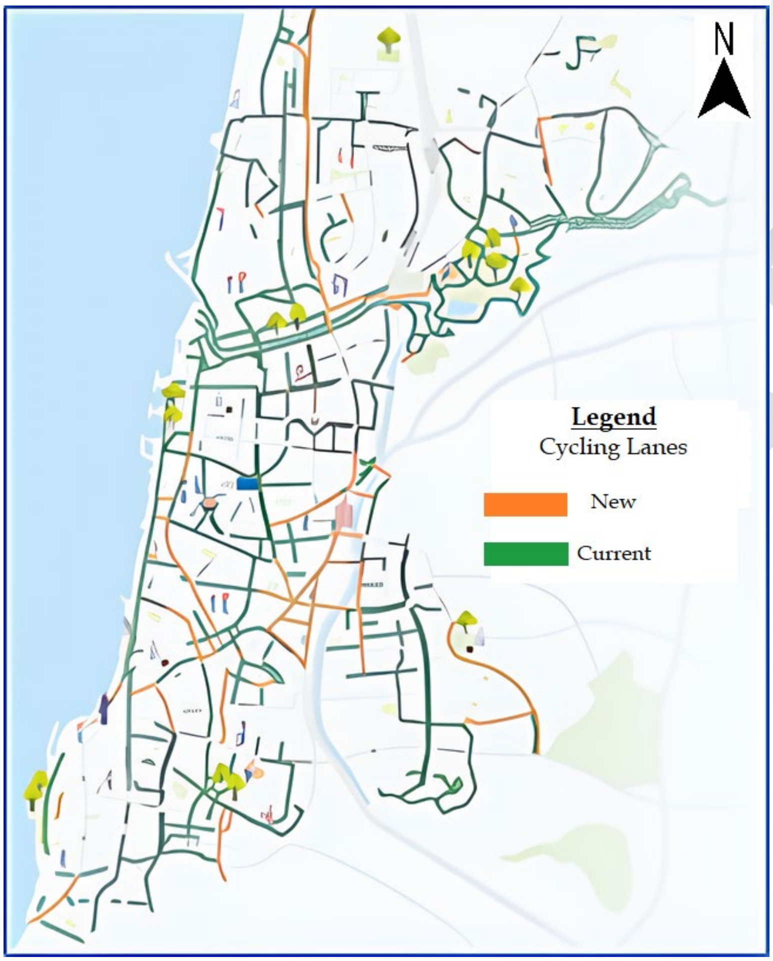


Figure 7. Current and programmed bicycle network lanes in Tel Aviv, Israel.

Tel Aviv has a population of just half a million; however, the greater Tel Aviv metro area has a population of 3.9 million, significantly impacting mobility in the 20-square-mile city. In 2020, the modal share observed was 16% walking, 12% cycling, 17% public and shared transportation, and 55% driving in single-occupancy vehicles. The target for 2030 is 20% walking, 25% cycling, and 25% public and shared transportation, reducing single-occupancy vehicle use to 30%.

Figure 7 highlights the extent to which the 215-mile cycling network is being implemented. The existing network is shown in green, and the new connections are shown in orange. Riders operating bicycles or electric scooters can both use these facilities.

The city's shared mobility network has proven successful, with daily rides totaling around 170,000. Factors like warm weather, a flat topography, and robust infrastructure have contributed to the system's success.

Regulations in Tel Aviv play a pivotal role in shaping a safe micromobility environment. Requirements include a license for electric scooter riders, mandatory helmet usage, adherence to speed limits, and designated parking areas. Local authorities also work with providers of shared e-scooters to identify restricted zones where the equipment automatically shuts down. Finally, while Israeli law allows users to operate vehicles at age 16, e-scooter users are restricted to users 18 and older.

SINGAPORE

Singapore's transportation system is highly regarded for its efficiency and effectiveness. It comprises a well-integrated network of roads, Mass Rapid Transit (MRT), Light Rail Transit (LRT), and comprehensive bus services.

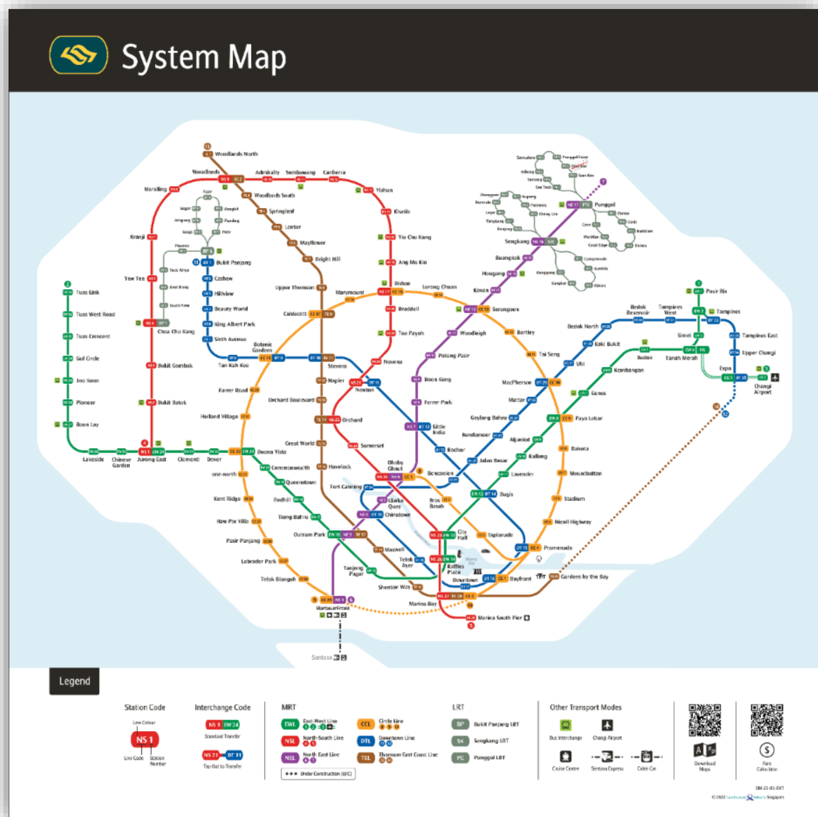


Figure 8. Singapore's MRT and LRT rail networks.

The MRT system boasts a daily ridership of over 3 million on a 200-kilometer network of over 140 stations across six lines spanning the island. Complementing the rail system are two LRT systems that function as feeder services to bring commuters closer to their homes. The LRT system comprises a 28-kilometer network with over 40 stations and a daily ridership of over 200,000 commuters. Figure 8 shows the system map prepared by the Land Transport Authority (LTA), which oversees public transport in Singapore.

Bus service in Singapore is provided in various types, including trunk, feeder, premium, city direct, and shuttle bus services. Trunk Bus Services are the backbone of the public bus network because they provide longer routes that take riders from one neighborhood to another or into the center of town. Feeder Bus Services offer transfers from MRT stations and bus interchanges to surrounding residential and industrial areas. Premium Bus Services, typically providing service between major residential areas and critical industrial/ commercial nodes during peak hours, are designed to ease the rush-hour crowd by charging a premium fare but offering a more direct connection than other public transport options. City Direct Services primarily serves commuters and operates between major residential areas and the Central Business District (CBD) during weekday peak hours. Shuttle Bus Services cater to specific transport needs, such as connecting to places of interest, tourist attractions, commercial or retail centers, and medical institutions. Shuttle service can be a fare collection or a free shuttle service.

The public transportation system is supported by privately operated taxis and ride-hailing, which provide door-to-door transportation. Taxis can be hailed along roads, at designated taxi stands and stops. They are not allowed to pick up or drop off passengers in bus lanes during operating hours, within 9 meters of a bus stop, and in areas with regulatory signs and lines that do not allow vehicles to stop. Users of private hire cars can book their rides through one of the licensed ride-hailing operators. A private hire decal identifies vehicles at the front and back of the car. Ride-hails are not allowed to pick up or drop off riders at taxi stands and are encouraged to use private driveways as pick-up points.

The LTA has looked into Mobility as a Service (MaaS) to facilitate payment and transportation mode changes. MaaS integrates various transport and transport-related services into a single, comprehensive, and on-demand mobility service and offers end-users the added value of accessing mobility through a single application and payment channel (instead of multiple ticketing and payment operations). To meet a customer's request, a MaaS operator hosts a diverse menu of transport options, like public transport, active modes such as walking and cycling, ride/ car/bike-sharing, taxi, and car rental or lease, or a combination thereof. Mobility as a Service (MaaS) is a comprehensive approach integrating various transportation and related services into a unified, on-demand mobility solution.

In Singapore, MaaS was discontinued after 2-years of launching the application. Factors like Singapore riders do not require as many modes to travel throughout the city, and its well-organized and efficient public transit network makes MaaS unappealing to general riders in Singapore. Users mainly saw it as anything other than a planning app, which Google Maps or other programs can ultimately serve. However, the system's success may have also been hampered by COVID-19.

Figure 9. Sheltered skyway near a transit station in Singapore.

Walking and cycling are additional mobility options encouraged in Singapore, even though the county’s climate makes them challenging for users. Several strategies have been implemented to improve the comfort and convenience of pedestrians, including over 200 kilometers (km) of sheltered walkways island-wide, as shown in Figure 9. The Walk2Ride program guarantees a sheltered walkway within 400 meters of all MRT stations and 200 meters of bus interchanges, LRT stations, and bus stops with high commuter volumes. The LTA is actively improving the accessibility of the pedestrian overhead bridges that are part of the sheltered walkway systems by increasing the number of elevators at overheard bridges.

Silver zones, highlighted in Figure 10, are pedestrian schemes built in selected residential areas to enhance road safety for older adults. The zones feature bright fluorescent yellow-green signs and yellow rumble strips to alert motorists that they are entering a Silver Zone. They can include "rest points” along the road median so that the roads can be crossed in two stages, include features like rumble strips, chicanes, and lanes with reduced widths to lower vehicle speeds to 30 or 40 km per hour, roundabouts, and low height median dividers to reduce lane widths and encourage motorists to drive slower. In emergencies, emergency vehicles can still drive over them safely.

Figure 10. Silver Zone in a residential street.

The LTA extensively experiments with road safety technology, especially for areas near schools and neighborhoods. LTA works with schools, representatives from the traffic police, town councils, and the Ministry of Education. Some initiatives include pedestrian crossings with raised zebra patterns painted black and yellow checkered to enhance visibility. Use of bollards to make bus stops more visible and protect riders at bus stops from traffic. Additionally, they have implemented the Green Man+ crossing system, which extends the time it stays on and gives elderly pedestrians and persons with disabilities extra time to cross the road.

Cycling is a popular transportation alternative with over 525 kilometers of cycling paths, with plans to extend the network to 1,300 kilometers by 2030. These cycling paths serve as first and last-mile connections, connecting commuters from their homes to MRT stations, bus interchanges, and nearby shopping malls and schools. Cycling infrastructure is designed to improve safety and convenience. Some unique features implemented include pedestrian priority zones where pedestrians and cyclists need to share the space, such as behind bus stops and road crossings, as demonstrated in Figure 11. Space under the MRT viaduct was converted into a sheltered cycling path with greenery. The LTA, in partnership with the country's National Parks Board, tests new horticultural technology in these spaces while increasing greenery in the area. An example is provided in Figure 12.

Figure 12. Cycling "slow down" markings near a bus stop.


Figure 11. Greenery amenities are also utilized for testing horticultural technology.

In October 2022, LTA introduced the West Camp Road Sunday Cycling Lane, as seen in Figure 13. This lane sets aside dedicated road space along West Camp Road for cyclists to ride during low vehicular traffic hours. The lane is operational every Sunday from 5 a.m. to 11 a.m. During operating hours, only buses and cyclists are allowed in the lane. Cyclists are not subject to the group size limit during operating hours.

Figure 13. Dedicated lane for buses and cyclists operates at reduced hours on Sundays.

Bicycle parking is critical for the system to work correctly. Over 267,000 public bicycle parking lots are provided at public transport nodes, public housing, void decks, and public parks, and most residential areas and transport nodes are within a 5-minute walk to a bicycle parking facility. Bicycle amenities are provided near transit facilities through dedicated bicycle crossings, bicycle wheeling ramps on stairs, and safety marks near bus stops, as highlighted in Figure 14.

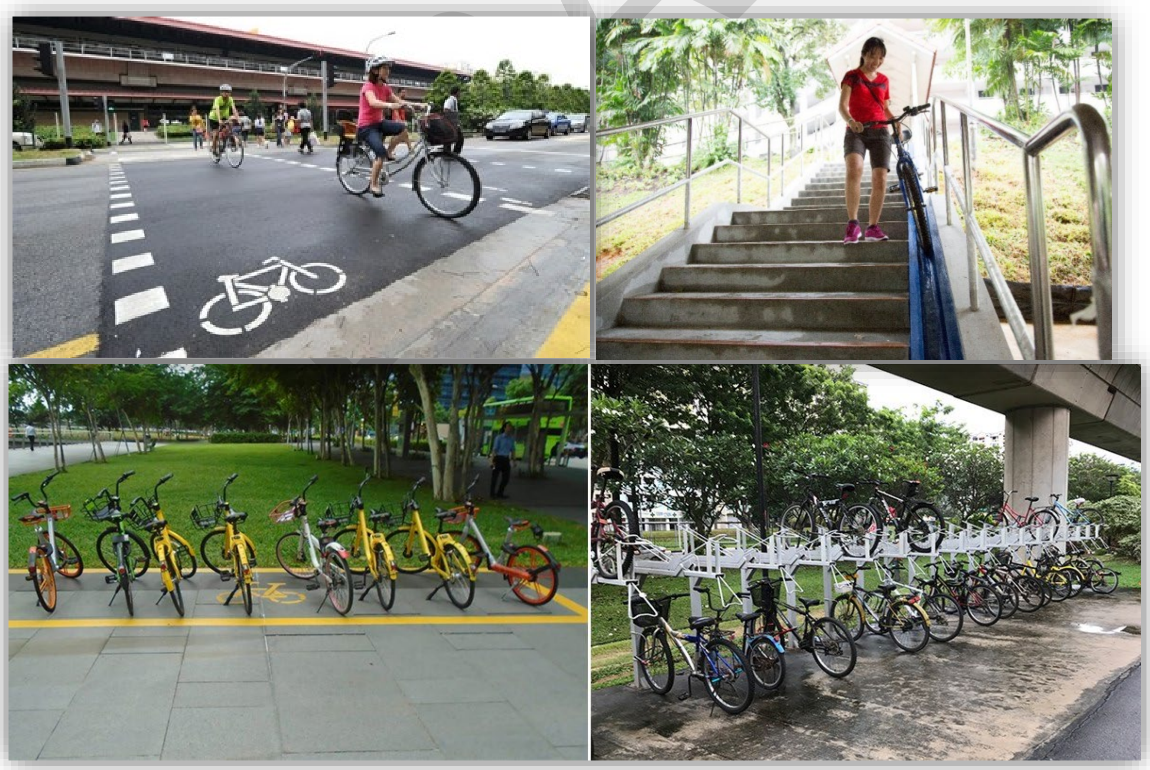


Figure 14. Dedicated crosswalks for cyclists in high pedestrian zones, bicycle wheeling ramps, and bicycle parking.

Strategies aimed to reduce congestion include electronic road pricing (ERP). Recently, the technology was updated to feature onboard units (OBU) on registered vehicles in Singapore. The units alert motorists when approaching an ERP-charging location and display real-time traffic incident alerts so that motorists can make more informed decisions on their travel routes. Through the OBU, motorists can also pay for usage licenses for off-peak cars, tolls, and roadside parking.

The LTA uses data from OBUs, gadgets, sensors, and cameras to gather data on traffic flow, traveling times, and road demand. The technology called Intelligent Transport Systems (ITS) uses the collected data to form a dynamic, real-time picture of the ebb and flow of a population. ITS uses sensors, traffic and control systems, and data analytics to maximize road network efficiency capacity, monitor and manage traffic flow, and make our roads safer. Other systems developed with ITS technology include:

- **The Expressway Monitoring Advisory System (EMAS)** is an intelligent incident management tool that manages traffic along expressways and promptly detects accidents, vehicle breakdowns, and other incidents, ensuring fast response to restore normal traffic flow. It also provides information on travel time on signboards before entering and along the expressways.
- **The Green Link Determining (GLIDE)** system controls all traffic signals in Singapore by adjusting the green time as traffic flow changes. GLIDE also links adjacent traffic signals, allowing vehicles to travel from one junction to another with minimal stops. The system also detects the presence of vehicular and pedestrian traffic at intersections to make traffic signal adjustments and allow motorists to catch the "green wave" and travel from one junction to another without stopping at the red lights as often.
- **Green Man+** allocates a longer green man time for the elderly and Persons with Disabilities (PWD). Elderly pedestrians and PWD can expect up to 13 seconds more Green Man time when they use signalized pedestrian crossings fitted with Green Man+. They need to tap their CEPAS-compliant senior citizen concession card or PWD concession card on the reader mounted above the standard push-button on the traffic light pole to extend green man time by between 3 and 13 seconds, depending on the width of the crossings. Over 1,000 pedestrian crossings have been equipped with Green Man+ function across Singapore. An example is shown in Figure 15.

Figure 15. A pedestrian crossing equipped with Green Man+ function.

- **TrafficScan** collects travel information from many taxis on Singapore's roads. It uses taxi Global Positioning System (GPS) data to calculate the average road traffic speed. The ITS Operations Control Centre then provides motorists with real-time travel information to plan their routes for a smoother journey.
- **The Parking Guidance System (PGS)** de. This real-time information reduces circulating traffic searching for available parking facilities in the central business district and major shopping areas. The data is also available via

various digital platforms, including mobile applications. This technology, highlighted in Figure 16 below, helps motorists make more informed parking decisions and optimizes the use of existing parking facilities.

Figure 16. Digital signs displaying real-time parking data, part of the PGS strategy.

NEW YORK CITY, NEW YORK

In New York City, commercial operations for urban air mobility using Electric Vertical Takeoff and Landing (eVTOL) planes are expected to begin in 2025. Electric vertical takeoff and landing (eVTOL) aircraft, a recent aerospace innovation, ascend vertically like helicopters but use electric motors instead of traditional combustion engines. These electric vehicles employ propellers or rotors for vertical takeoff, stationary hovering, and horizontal flight, featuring large omnidirectional fans for drone-like maneuverability.

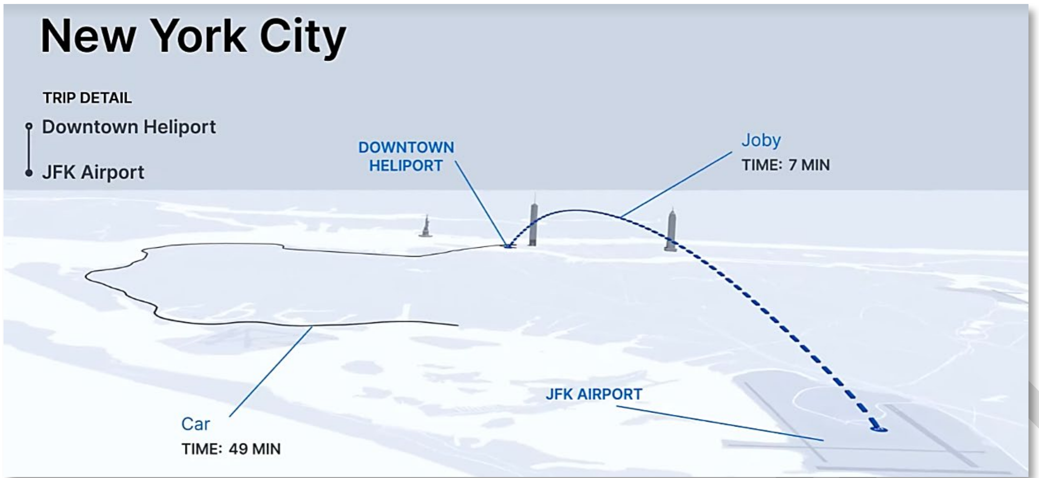


Figure 17. Proposed air route connecting JFK Airport to downtown New York.

Commercial electric air taxi operations typically follow a rideshare app business model, and the NYC operations intend to provide service from downtown Manhattan to John F. Kennedy International Airport. The technology anticipates replacing the almost-hour commute by car with a seven-minute flight. Figure 17 depicts the proposed flight path the new service will take and details the time savings compared to driving.

The eVTOL planes are piloted, accommodate up to four passengers, and have zero operating emissions. They are also designed to have a radically lower acoustic footprint than a helicopter, allowing them to operate in densely populated areas such as New York City without adding to the background noise. The aircraft is optimized for rapid, back-to-back flights and can fly up to 100 miles on a single charge. A prototype of the plane in flight over Manhattan for this new service can be seen in Figure 18. Research into Electric Vertical Takeoff and Landing technology is being expanded to develop vehicles that can transport up to 40 passengers at once and create an aircraft to carry freight with up to a 10,000-pound cargo load.

Figure 18. Prototype of eVTOL taxi in NYC.

The vehicle's mobility in urban settings facilitates the technology in the urban landscape. A notable strategy involves retrofitting parking garage rooftops into vertical lift-off ports and designated landing sites for these electric aircraft. The eVTOL vehicles show promise for passengers and cargo, reducing costs and expediting deliveries.

PORTLAND, OREGON

The Portland Loo, seen in Figure 19, was an idea that originated in response to Portland's growing homeless population. It is used in city parks and is a product that the City of Portland owns and sells to other communities. It was introduced over ten years ago and has grown to 22 installations throughout the city.

Figure 19. A Portland Loo public restroom kiosk.

Without restroom facilities, people experiencing homelessness were left to their own devices. The city realized that public restrooms, open 24 hours a day, would alleviate disturbance to local businesses, help keep sanitation under control, prevent unsightly waste throughout public areas, and hinder the spread of disease. Today, only downtown locations are open 24/7, but they are generally open during park hours, where they are predominately located.

The design of the facilities was developed to prevent potential common problems like vandalism, illegal drug use, or prostitution. The kiosk discourages crime with graffiti-proof wall panels and open grating. Maintenance is limited to cleaning and upgrading standard components when needed.

The system features solar power, no running water to deter any clothing or body washing inside, and exterior handwashing stations. The Portland Loo was designed in cooperation with the city of Portland and earned the city's first patent. The city gets a percent of the profit each time one is sold to another municipality or organization and uses a portion of the sales to support Portland's provision of public restrooms locally.

BEVERLY HILLS, CALIFORNIA

Beverly Hills, California, has a residential population of 35,000 people. Still, its daytime population swells to almost 170,000 due to visitors and employees, mainly concentrated in the city's downtown area, known as the Golden Triangle. Daytime pedestrian activity is notably heavy in this area, leading to numerous conflicts between pedestrians and vehicles at intersections, especially during holidays and tourist seasons.

Large pedestrian flows at crosswalks often obstruct turning traffic throughout the green signal phase, resulting in a backlog of vehicles needing to turn left. A review of collision history revealed several reported vehicle-pedestrian collisions, with data collectors noting numerous close calls. In 1987, the City of Beverly Hills changed traffic signals at eight intersections to include an exclusive pedestrian phase, halting all approaches to allow pedestrians to cross diagonally or conventionally.

The exclusive pedestrian signal phase was perfected based on the diagonal pedestrian path length, with a 20-22-second range for the total pedestrian signal phase. Introducing this pedestrian phase increased the operating cycle of traffic lights from 50 to 60 seconds, efficiently clearing vehicles through the intersections.

Pavement marking indicating that diagonal crossing is allowed was added at each intersection, along with "diagonal crossing OK" signs on each corner. To enhance visibility, pedestrian signal heads were installed facing the diagonals of intersections for a more precise indication of diagonal crossings. The average cost per intersection for these enhancements was under $1000 per signal. This exclusive pedestrian phase proved to be a low-cost, effective tool in improving safety and reducing potential conflicts between automobiles and pedestrians in Beverly Hills' bustling downtown. Figure 20 illustrates the installation at the intersection of N Canon Drive and Brighton Way.

Here are recommendations drawn from the implementation of the pedestrian phasing program:

- Total pedestrian crossing volume should be high, preferably exceeding one thousand pedestrians per hour for at least four hours daily. Efficiency may be compromised if pedestrian volume peaks only during a single hour of peak periods.
- Vehicular volumes should be moderate and consistent for many hours of the day, with a high percentage of left or right turns. Intersections experiencing extreme peak hour conditions may struggle to manage traffic demand and cause delays during the pedestrian phase. Vehicular peak periods must align with pedestrian peaks. The recommended total intersection approach volume should be less than two thousand vehicles per total approach per hour.
- It is advisable for selected intersections to have an existing level of serviceability at level "C" or lower.
- Smaller intersections require less time for an exclusive pedestrian phase, reducing vehicular delays. The recommended area inside crosswalks is forty feet for minor streets and 40 to 60 feet for major roads.
- Caution is advised when selecting intersections for an exclusive pedestrian phase, mainly where both streets are two-way, and left-turn or right-turn phasing is used.
- Selected intersections should be well-illuminated to ensure pedestrian diagonal crossings are visible to motorists during dark hours.

Figure 20. Diagonal pedestrian pathways are used in Beverly Hills, CA as alternative scramble designs.

SAN FRANCISCO, CALIFORNIA

Slow Streets are designed to be safe, comfortable, and low-traffic routes that prioritize active transportation and community connection. They are recommended for residential streets to offer secure alternatives to driving and accommodate all forms of transportation, emphasizing inclusive slow and safe speeds. Conceived initially as a pandemic response, Slow Streets evolved into more than just travel options; they foster community bonds and encourage residents to perceive city streets as shared spaces.

In San Francisco, the city's Municipal Transportation Agency (SFMTA) adopted the program in December 2022 as part of efforts to implement a citywide Active Transportation Network. The program aims to end deaths and severe injuries related to transportation and encourage more people to choose low-carbon ways to travel for their daily trips. Recognizable by distinctive purple signage and road markings, Slow Streets provides spaces for walking, biking, scooting, wheelchair use, and driving. Figure 21 shows a street in San Francisco with improvements in Slow Streets.

Figure 21. Transformation of a street to San Francisco's Slow Streets.

Funding for these initiatives is provided in part by Proposition K Sales Tax dollars through the San Francisco County Transportation Authority. The Proposition K Sales tax is a general sales tax that increases the effective sales tax in San Francisco by 0.75 percent to 9.25 percent to fund the city's homelessness and transportation programs.

Slow Streets are inclusive and accessible to all, whether walking, rolling, riding a bicycle, or driving. The following are recommendations for Slow Streets:

- Encourage Safe Behaviors
  - Move safely and be considerate of speeds.
- Make space for others – pedestrians must make room for vehicles to pass, and bikes and cars must give plenty of room when passing; under California law, vehicles have the right of way on streets.
- People riding bicycles or using a personal mobility device:
  - Must yield to pedestrians, children, and people with disabilities.
  - Must keep driving on Slow Streets, which are reserved for local trips.
  - Must obey all traffic laws and signs, like speed limits and STOP signs.
  - Must not be hostile toward other Slow Street users or make people feel unwelcome on the designated Street.

The SFMTA has launched the Slow Streets Mural Pilot Program to enhance placemaking along Slow Streets. This pilot program aims to engage community members living on or near Slow Streets by putting mural art on the pavement. Murals will help promote Slow Streets as community spaces and slow vehicle traffic. Implementing a mural involves several steps, including an application to the SFMTA and the San Francisco Arts Commission (SFAC) approval.

Slow Streets can be implemented as quick, low-cost improvements to enhance safety, move people through the city, and pilot new projects. They can be applied in streets with low vehicle volume and low to moderate speeds, where vehicle volumes have dropped, or serve redundant through traffic. Once a street is selected, an installation with traffic barriers and "Local Traffic Only," Slow/Shared, or branded signs (Slow Streets or Stay Healthy Street) should be placed at main vehicle entry points. New technologies and best practices for curb management can also be tested as Slow Streets are implemented to align curb uses with the community's needs.

For neighborhoods, establish a grid of entry points into the local street network where barricades should be installed.

- Identify stewards to take care of and monitor barricades
- Allow local access, deliveries, and emergency vehicles.

Internationally, Slow Streets have been implemented in places like Dunedin, New Zealand, where they are called Safer Streets. The city approved a Safer Streets plan that reduced speeds to 10 km/hr.—and allowed city center businesses to extend into the streets, creating shared spaces for multiple modes. The Safer Streets project aims to improve road safety for all users along the city's busiest streets and make getting to bus stops, local shops, and schools easier. Strategies used included more crossing points, curb cuts, bus super stops that provide better shelter and seating, and potential facilities such as toilets, bike stands, and lockers. Dunedin's Safer Streets design can be seen in Figure 22.

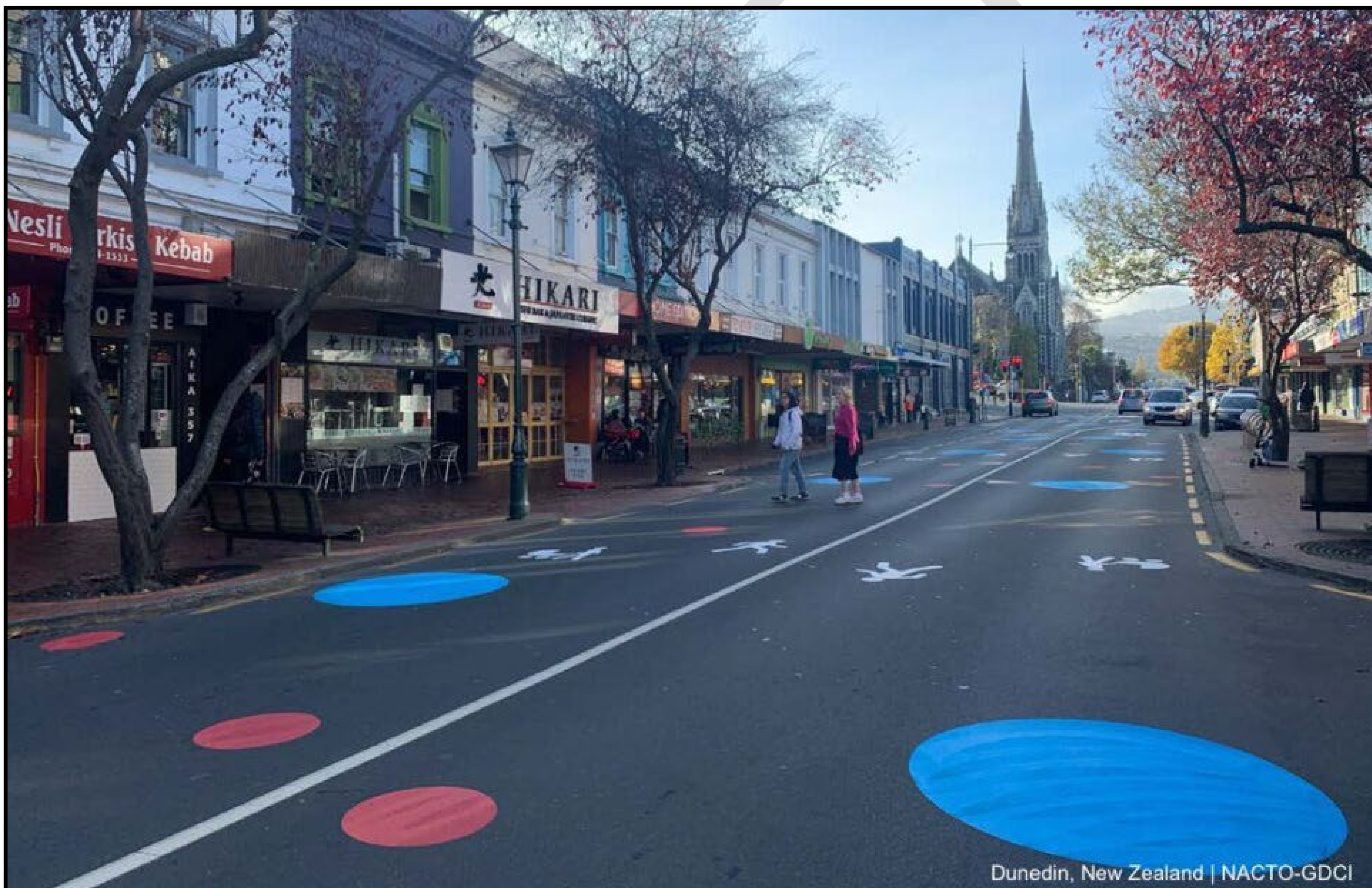


Figure 22. Dunedin's Safer Streets design with downtown speed limits reduced to 6 mph.

SANTA MONICA, CALIFORNIA

The City of Santa Monica, California, designed the Breeze Bike Share pilot program to test technology and best practices for shared electric scooters and bikes operated by private companies on the city's right-of-way. The program was implemented from January 2017 to September 2019 and began with a fleet of 2,000 e-scooters and 500 e-bikes. At peak operations, the fleet had 3,250 devices and generated 2,673,819 rides from October 2018 through September 2019, with ridership peaking during the spring and summer.

The pilot program uncovered that the typical shared mobility device user is male, under 34 years old, and typically earns above $75,000. Only 17% of riders earned less than $30,000. The study suggests that ridership imbalance may be due to the following factors:

1. Trip Cost Barrier.
2. Required access to smartphones and data packages.
3. To pay for these services, Access to banking services and credit cards is required.
4. Access to devices near low-income housing and low-income jobs.
5. Language barriers in marketing and in-app experience.

In terms of use, Santa Monica's shared mobility devices averaged 14-minute trips with a typical distance of 1.3 miles. Figure 23 highlights that most riders used the devices for short work-related trips, recreation, eating out, getting to/from home, and shopping. While people rode all over Santa Monica, the highest concentration was observed in its downtown area (28%), beach areas (13%), and Expo Line Downtown Santa Monica Station (4%).

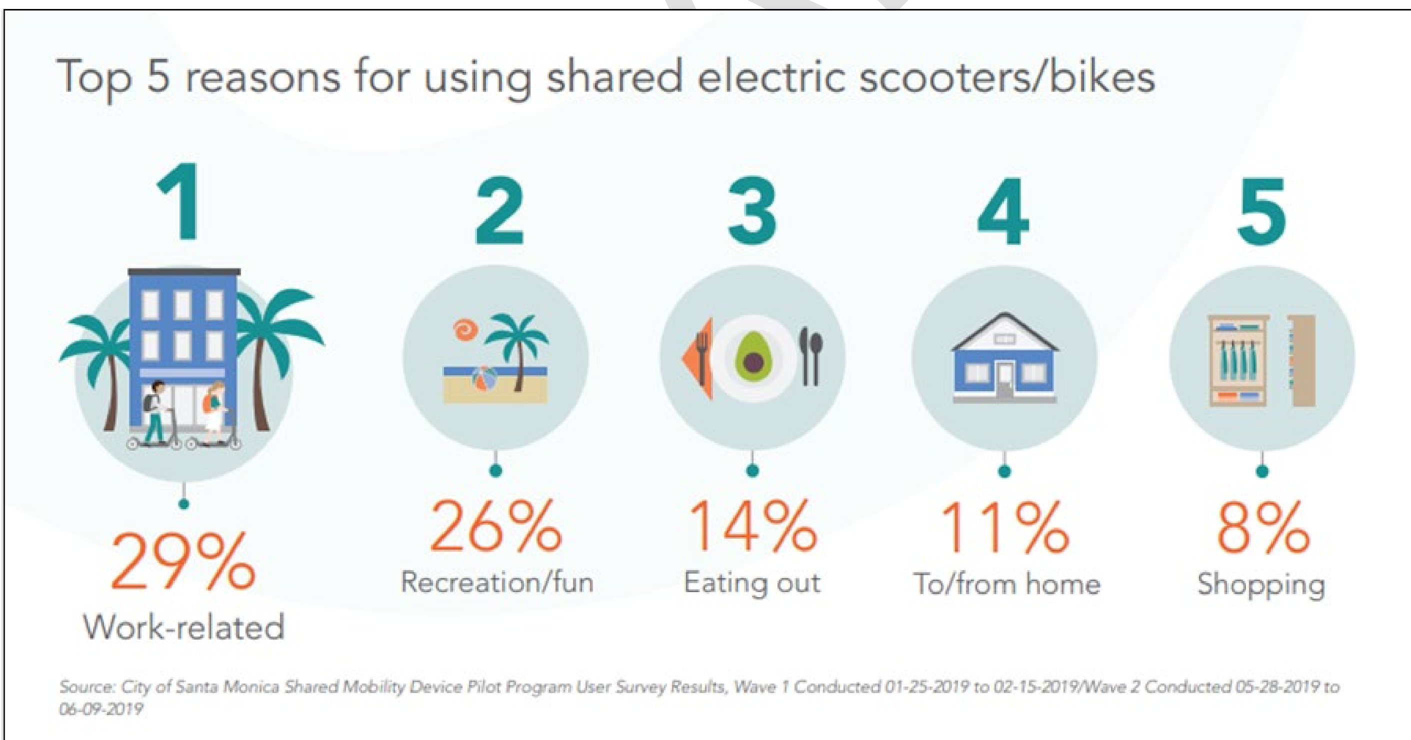


Figure 23. E-Scooter usage rates in Santa Monica, CA.

Nearly half (49%) of shared mobility trips replaced trips that would have otherwise been made by car, either driving alone or ride-hailing. Thirty-nine percent of trips replaced walking trips—in some cases serving as a walking accelerator for those commuting to work or running errands, and in other cases serving tourism or recreational purposes.

Figure 24. Police officer citing e-scooter users for riding without helmets.

The City proactively educated the public and increased public awareness about the program and its rules. City Code Enforcement officers issued 299 citations for 929 violations and impounded over 1,200 devices for blocking access for people with disabilities, parking in the street, slow operator response time, and other violations. Between June 2017 and early September 2019, the Santa Monica Police Department issued 1,006 citations to e-scooters and e-bike riders. Figure 24 depicts an officer issuing a citation to individuals violating this new program. Typically, code officers can only give citations for incidents on sidewalks or public right of way, while police cite on—road users.

In response, the city installed 107 parking and pick-up zones citywide, helping to organize rider parking and manage service provider fleet deployment using geofencing technology. Santa Monica was one of the first cities to enforce geofencing and digital policy tools to remedy parking, safety, and oversaturation problems. Figure 25 shows a geofenced e-scooter parking area with pavement markings in Santa Monica. Figure 26 shows a geofenced e-scooter parking area adjacent to a bus stop for improved access.

Using geofencing, the City and service providers implemented a deactivation zone around the beach area, which brought devices to a complete stop in these areas, ending conflicts, safety issues, and the number of devices left along the beach path. Companies also introduced e-bikes and other field staff to manage devices, complementing the City's added field oversight staff.

Recommendations from the pilot project include:

- ✓ **Public Right-of-Way Management** – improve fleet management and user parking to reduce clutter and obstructions.
- ✓ **Rider Behavior** – reduce sidewalk riding, tandem, and other unsafe behaviors.
- ✓ **Equity and Access** – increase access and engagement among diverse users, emphasizing income, ability, and disadvantaged communities.
- ✓ **Device Design and Maintenance** – accelerate device improvements to durability to withstand long-term shared use on public streets.
- ✓ **Effective Management** – refines tools to manage the dispersed devices, including data and internal systems.
- ✓ **Manage Volatility** –protect the public from industry volatility through partnerships that supply consistent, reliable, fair, and safe shared mobility options.

Figure 25. Designated e-scooter parking area with geofencing technology and markings.

- ✓ **Dedicated Staff** – the shared mobility program coordinator manages the program's implementation. The code enforcement officer documents non-compliance in the field and enforces Shared Mobility Program regulations and issues.
- ✓ **Enforcement and Public Awareness** – reduce code violations and increase public knowledge about the program and how to ride safely and legally. New rider etiquette and education campaigns.
- ✓ **Adapt** - the city rapidly adapted to device parking challenges by installing 107 drop zones citywide, helping to organize rider parking and manage service provider fleet deployment.
- ✓ **New Technology** - Santa Monica was one of the first cities in the world to enforce geofencing and other digital policy tools to help remedy parking, safety, and oversaturation problems. A geofencing toolkit can be developed for speed zones, drop zones, parking restrictions, and incentivized parking. Active experimentation with new tools like sidewalk riding detection technology is also recommended.
- ✓ **Data** - use Mobility Data Specification to ingest trip and vehicle data from permitted service providers to manage and evaluate services actively.
- ✓ **Partnerships** - The city partnered with third-party contractors for enforcement and analytics support, effectively expanding staff capacity. Joint safety and education campaigns with service providers and community organizations
- ✓ **Price Signals and Incentives** - fare capping removes price volatility and keeps fare structure cheaper than automobile options.
- ✓ **Affordable Access** - expand programs and outreach, provide rider credits and parking incentives.
- ✓ **Fines** - Refined and progressive fee structure for violations to facilitate operational improvements without service disruption.
- ✓ **Wayfinding and Signage** – expand visual tools in the right-of-way, including sidewalk decals and stencils, large education banners, signs, and more.

Figure 26. Combined transit and micromobility stop.

CHICAGO, ILLINOIS

The Chicago Transit Authority (CTA) *System Status & Alerts* program webpage, as shown in Figure 27, provides real-time details of the CTA's bus system and the 'L' Train via the Authority's website.

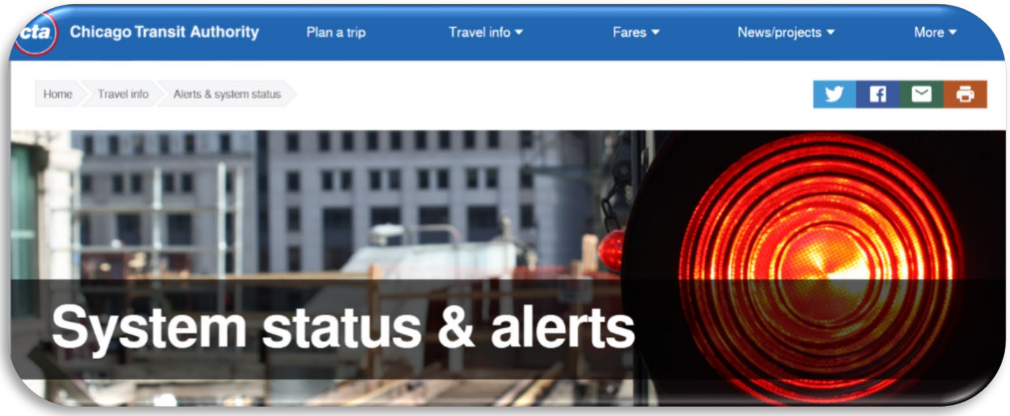


Figure 27. Chicago Transit Alert System.

It also alerts users of any elevator service outages at train stations. Users can access the city website for current elevators and upcoming servicing details. Summaries of planned service changes are supplied weekly, including those for temporary work, construction, and events. Users can opt to receive text or email updates for the accessibility status of elevators, as well as planned and unplanned service changes that affect bus or rail service on routes, via CTA Updates. Details include how the trip is affected, the directions for any route modification needed, and the reason for the service change.

Figure 28. Bus stop with real-time bus route information details.

Bus stop users, without access to the Bus Tracker system, can text the CTABUS location shown at the bus stop and the bus route in question, as seen in Figure 28, to receive details on the expected arrival time of the bus at that location and details of the next bus.

Figure 29. Elevator with QR code.

In the United Nations Headquarters building in New York City, elevators are equipped with a QR code to facilitate reporting an issue with an elevator car. Figure 29 provides an example of the QR code in the elevator. Users can scan the code with any smartphone to open an email to the facilities helpdesk. The code automatically populates the email subject line, indicating which elevator car was causing the problem. All the user needs to do is type in the email what the issue was, like "the car did not stop on my floor," "the elevator made strange noises," or "the door did not fully open," and notify technicians and investigate. If users cannot use the QR code, issues can also be reported via e-mail or by calling the number posted along with the QR code.

NEW YORK CITY, NEW YORK

Since the 1950s, overnight parking has been permitted in New York City, leading to most curb space used for parked cars. However, this benefits only a minority of New Yorkers who own cars and park on the street. New York City has the highest rate of car-free households among major U.S. cities, with only 46% of households owning a vehicle in 2021, compared to the national average of 92%. Approximately 56% of workers in the city commute to work using public transit, while only 27% use private vehicles.

To effectively manage curb space, a Curb Management Action Plan with ten action items has been created to optimize the City's curb space and meet the diverse needs of New Yorkers. These action items are discussed below and illustrated in Figures 30 through 37.

1. Pilot NYC's first "Smart Curbs" neighborhoods to test new and innovative curb uses. High demand for curb spaces requires a comprehensive approach, so working with Business Improvement Districts (BIDs) is recommended to test a blank slate approach to curb programming and activation. New policies and technologies should make curb access easier and adaptive to community needs.

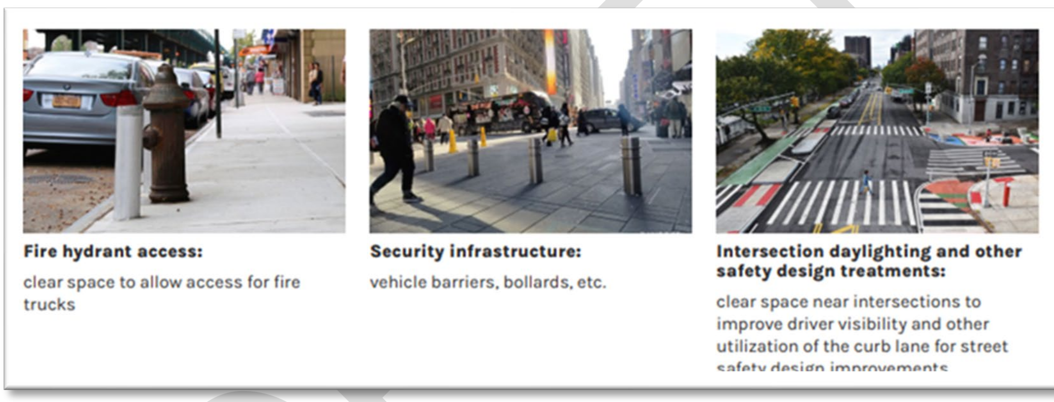


Figure 30. Fire hydrant access, secure infrastructure, and intersection daylighting tested for curb management in NYC.

2. Prioritize curb uses to meet neighborhood needs. A diverse array of curb needs necessitates policies to guide which uses get prioritized. The city published a guide detailing how NYC DOT will prioritize curb uses in a way that is consistent with the city's transportation goals and needs while allowing flexibility to tailor curb management tools to local neighborhood conditions.

Figure 31. Flexible strategies to prioritize curb space for community needs.

3. Make deliveries to businesses and homes safer, sustainable, and more efficient. The rapid growth of e-commerce makes accommodating deliveries at the curb essential. Expanding loading zones, implementing micro hubs, increasing the use of cargo bikes, incentivizing off-hour deliveries, and piloting new types of loading zones (e.g., reservation, restriction of vehicles, time of day management) are all strategies proposed.

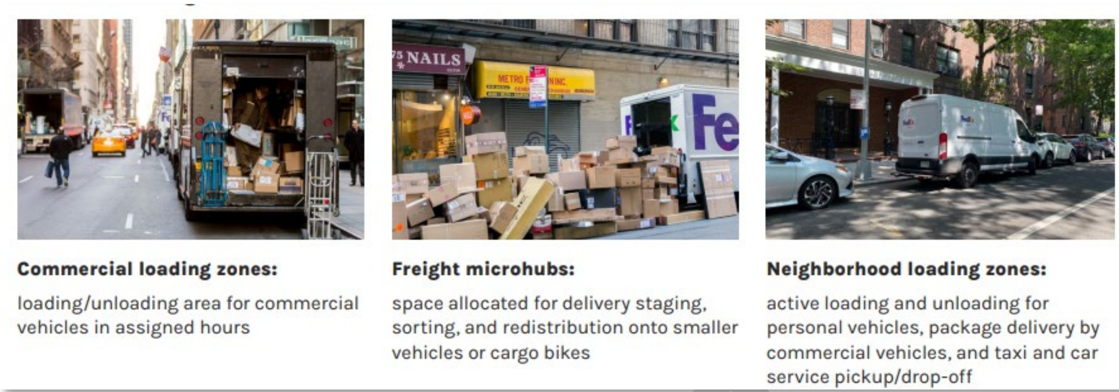


Figure 32. Delivery micro hubs and new loading zones tailored to neighborhood needs.

4. Pilot the East Coast's first low-emission zone. Curb management can play a role in incentivizing or requiring zero—or low-emission vehicles. The city studies pricing, regulatory practices, and incentive options to develop the East Coast's first EV pilot program.

5. Designate curb space to facilitate passenger pickups and drop-offs. The surge in for-hire vehicle trips must be managed with better curb access for passenger loading. Examples include more for-hire vehicle passenger pickup/drop-off zones and paratransit lading zones.

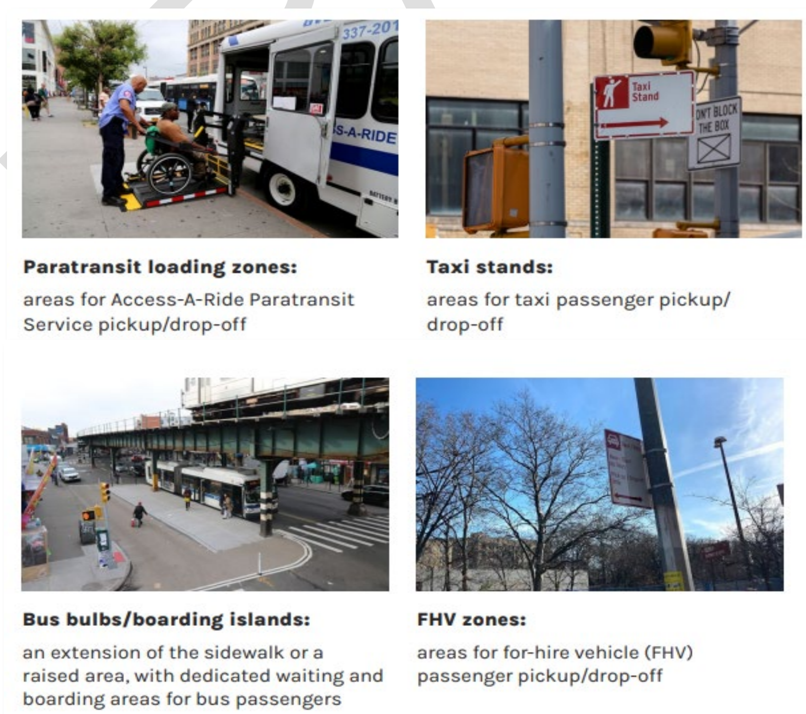


Figure 33. Curb space management to simplify passenger pickups and drop-offs.

6. Expand bike parking to make biking more convenient. NYC's bicycling boom requires additional bike parking without congested sidewalks. Expand on-street and sidewalk short-term bike and micromobility parking, continue and expand bikeshare, and create thousands of secure public bike parking spots.

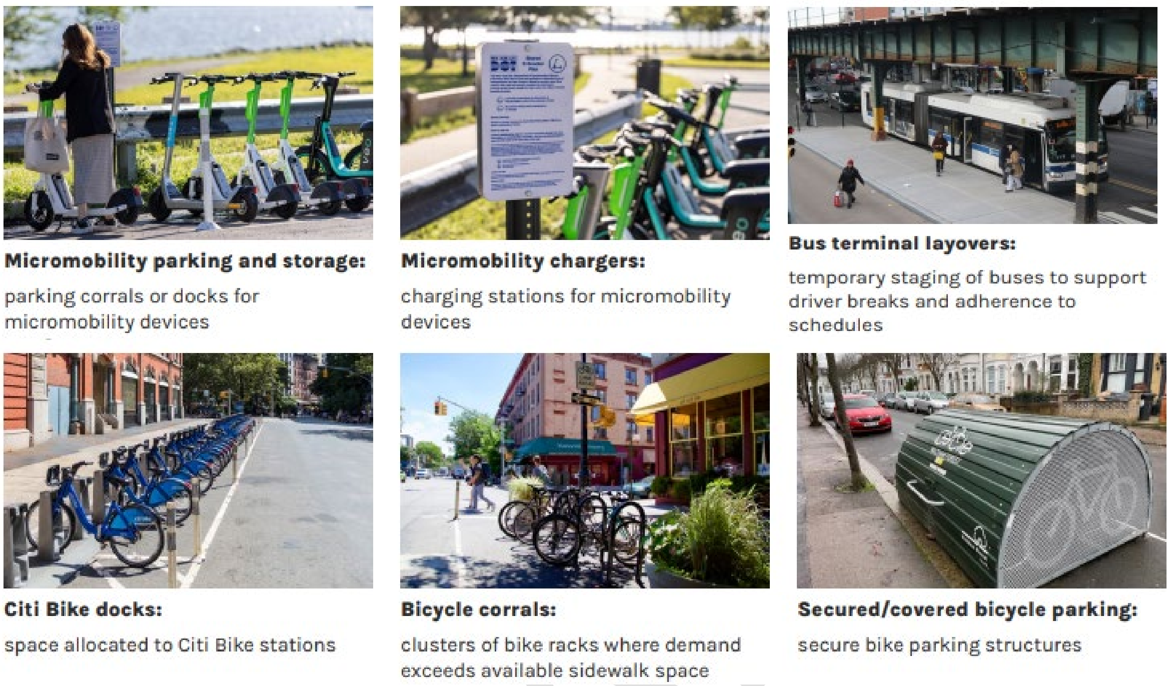


Figure 34. Smart micromobility and transit strategies.

7. Provide space for Dining Out NYC, waste containerization, street furniture, and other public realm improvements. The curb lane provides an opportunity to create a cleaner, safer, and more vibrant public realm. Strategies being pursued include implementing a permanent Dining Out NYC program, providing space for waste containerization, and activating the curb lane with public space improvements like sidewalk widening, street seats, and plantings.

Figure 35. Curb management strategies for outdoor use and public realm enhancement.

8. Test new technologies for remote and flexible curb management and enforcement. Proven and emerging technologies can enable more efficient, data-driven, and user-friendly curb management. Implementing strategies like a more flexible and convenient parking payment system; working with MTA to use new authority to camera enforce bus stops, bike lanes, and double parking; and, in conjunction with Smart Curbs pilot, test technologies to improve data collection and remote curb management to move toward automated enforcement of more violation types; and expand access to curbside charging.

9. Price on-street parking to increase commercial activity. Parking pricing should reflect demand to encourage the most efficient use of limited space. Over the next year, establish a demand-based pricing proof of concept, update meter rates and geographies to reflect the market and increased demand, expand meters (regular and commercial) to improve access in commercial, industrial, and high-demand areas, develop pricing mechanisms to support policy goals, improve fine citation structures, and adjust reserved curb space policies.

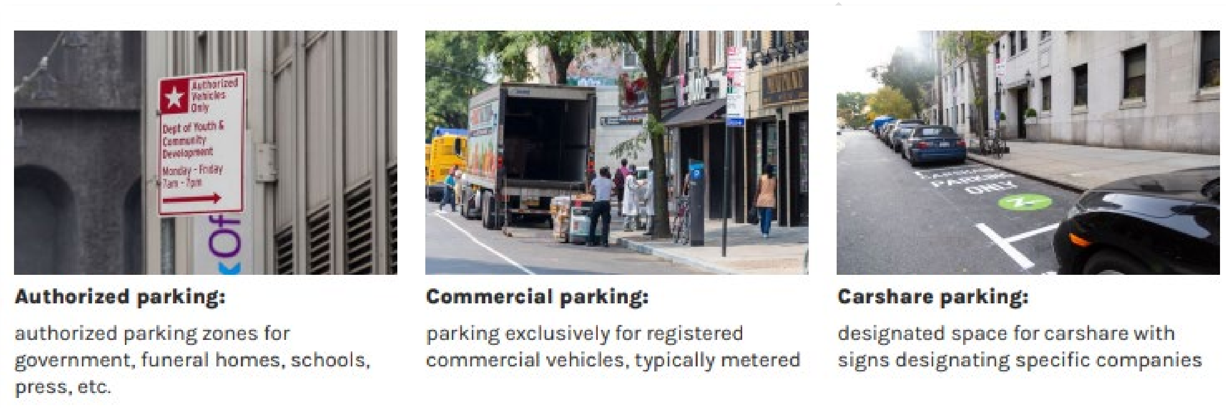


Figure 36. Smart parking: car share, commercial, and authorized parking for government and essential services.

10. Charge non-transportation users of curb space. The curb lane is a valuable resource that should be priced for businesses that benefit from it. To disincentivize excessive use of curb space and minimize community impact, NYC DOT will develop a framework to charge for street occupancy in metered spaces and seek state authorization to charge in non-metered spaces.

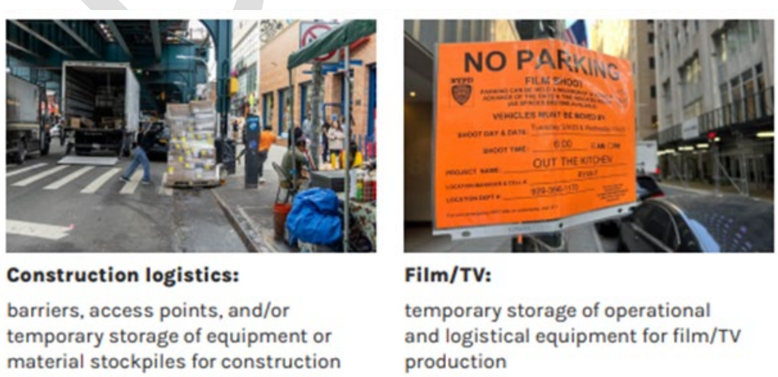


Figure 37. Non-transportation curb uses for construction logistics and media.

SHANGHAI, CHINA

With over 26 million residents, Shanghai has the highest population of any city in China and is the third most populous city in the world. Shanghai is also one of the leading adopters of digital twin technology for city operations and management.

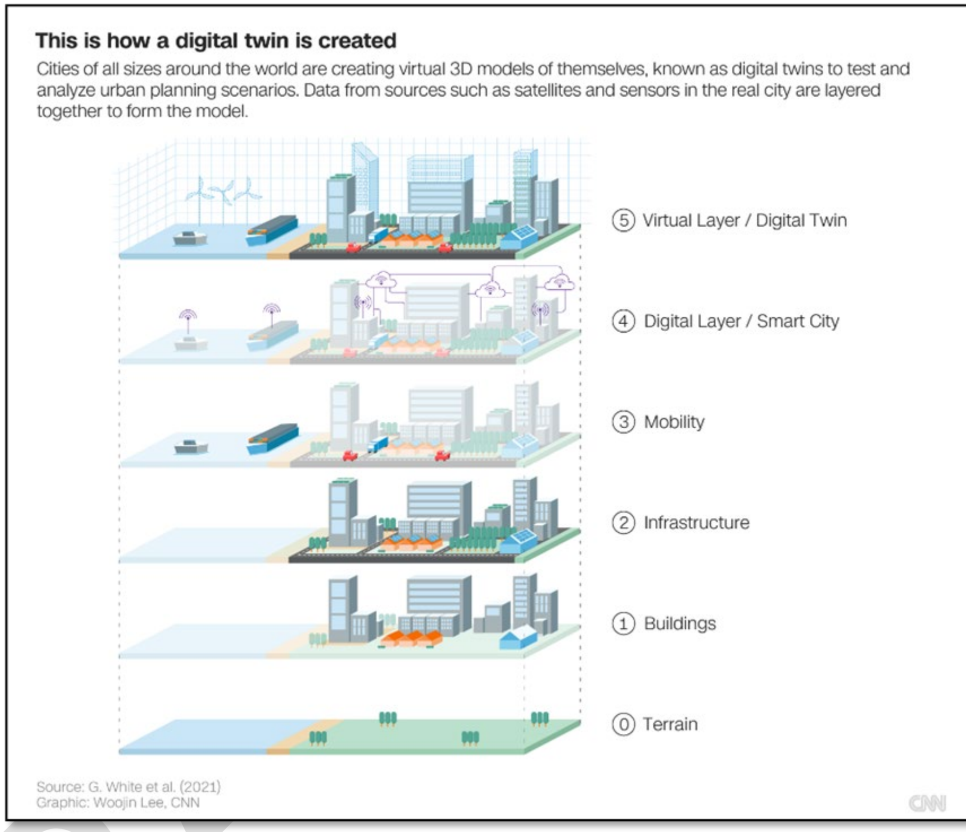


Figure 38. Layers for developing a digital twin city..

Digital twin cities are virtual representations of physical assets (like buildings, roads, waterways, and green spaces) that use connected digital information—from geographic information sensors, satellites, drones, and other sources—to mirror reality and create a digital twin of the current physical conditions. This process is highlighted in Figure 38. In the case of cities, planners and engineers can study digital twins and gain insights for improving services, planning developments, optimizing buildings' systems, and monitoring traffic flow. Designers can simulate ideas in the live city environment before they are constructed and understand in advance the impact of decisions such as where to position a bus stop or the footprint of a new housing development.

While this technology applies to urban planning efforts, during the COVID-19 outbreak, digital twin cities were employed to control and prevent the spread of the virus. The location and details of an infection incident would be recorded, and the digital twin would provide information about the neighborhood residents for epidemiological investigation. An example of the Shanghai digital twin city is shown in Figure 39, and Figure 40 explains how it is applied in urban planning.

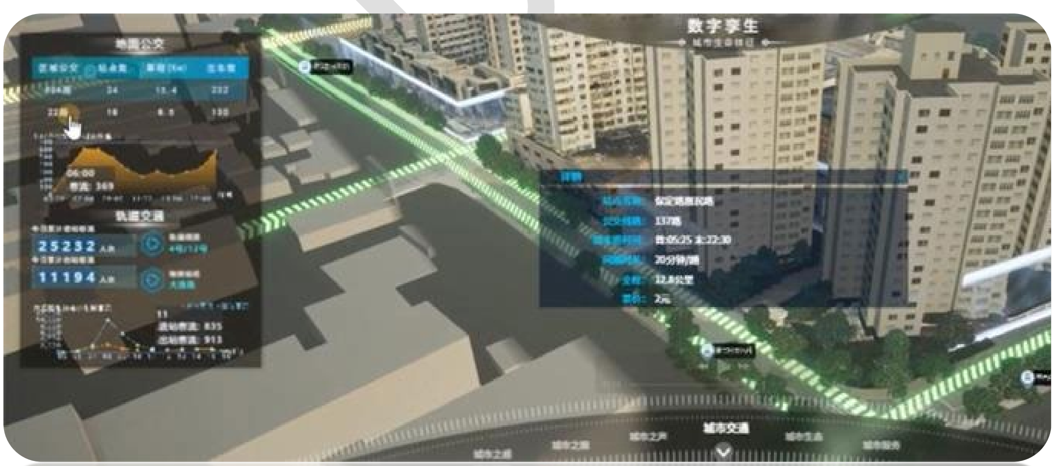


Figure 39. Shanghai's digital twin city technology.

In Shanghai, the platform has proven robust and efficient in managing local urban refuse disposal and living safety issues, such as e-bike charging stations. By 2025, the digital twin will be refined to include poles, boards, trash cans, and other elements observed in the real world and reflected virtually in the Shanghai digital landscape. Meanwhile, other pilot areas in the city will focus on information security, especially privacy protection, during the data collection and development of the digital system.

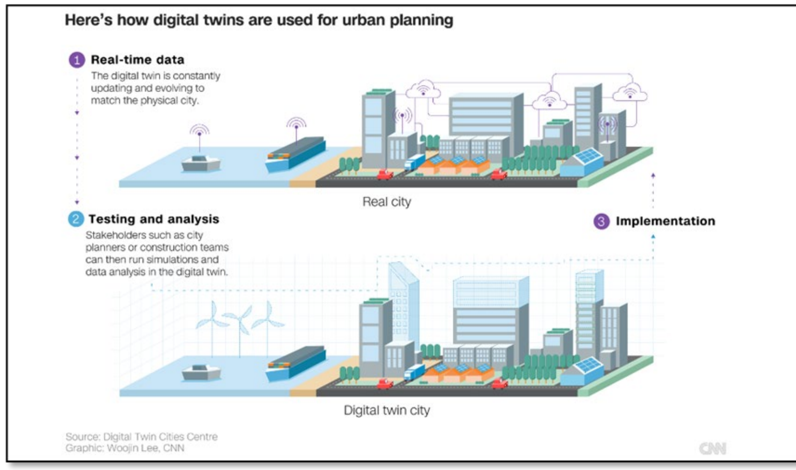


Figure 40. Digital twin city technology in urban planning.

On November 15, 2021, President Biden signed the Bipartisan Infrastructure Law (BIL), which allocates $550 billion from 2022 through 2026 for federal investment in infrastructure, including roads, bridges, mass transit, water infrastructure, resilience, and broadband. Additionally, the BIL established the Strengthening Mobility and Revolutionizing Transportation (SMART) discretionary grant program, with $100 million appropriated annually for the same timeframe.

The SMART program aims to provide grants to eligible public sector agencies for conducting demonstration projects focused on advanced intelligent community technologies and systems to enhance transportation efficiency and safety. The program prioritizes purpose-driven innovation and emphasizes the development of data and technology capacity and experience for government agencies. Eligible projects must demonstrate at least one of eight technology areas, as shown in Figure 41.

The Broward Metropolitan Planning Organization (BMPO) received the grant funding and is developing SMART METRO. This innovative transportation modeling platform will use Artificial Intelligence (AI) technology to create a regional digital twin of the County. BMPO is developing its system so city planners can improve the city's transportation logistics and test improvements before they are physically implemented.

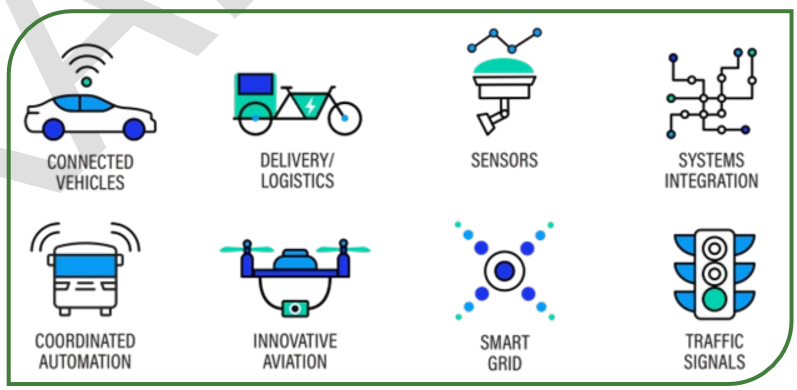


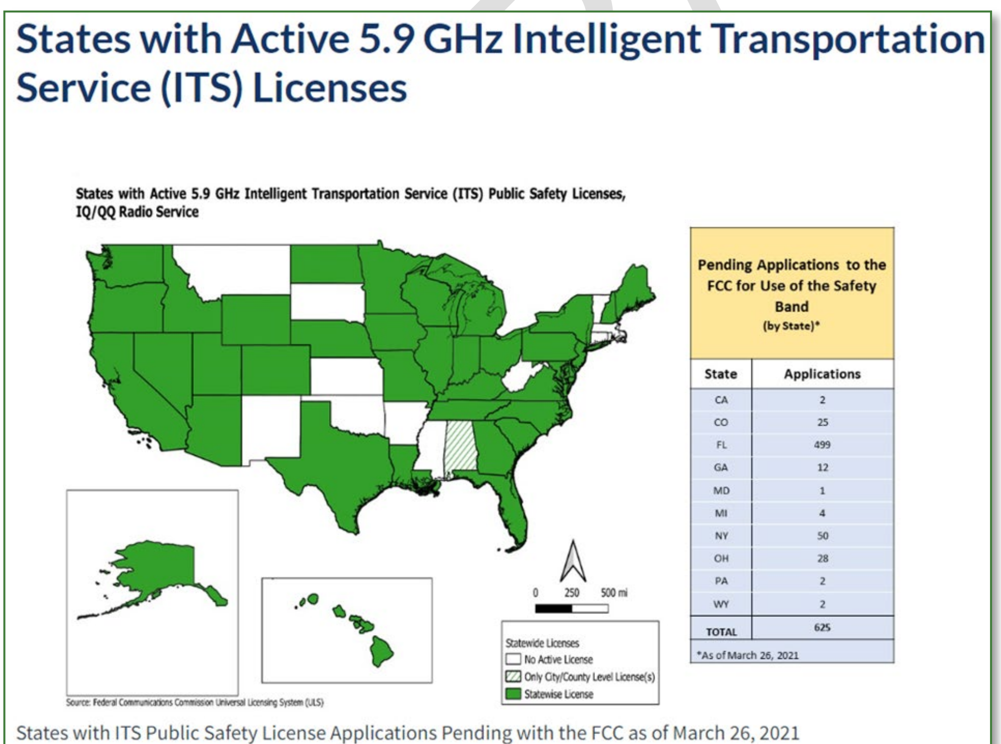
Figure 41. Federal Bipartisan Infrastructure Bill components.

MIAMI, FLORIDA

The Safety Band refers to a wireless spectrum at 5.9 GHz reserved for transportation-related communications among devices that support connected and automated vehicles. The electromagnetic spectrum includes radio waves ranging from as low and long as 30 hertz (Hz) traveling up to 10,000 kilometers to as high and short as 300 gigahertz (GHz) traveling about one millimeter (mm). This range of waves has made various inventions possible, such as long-distance communications, radio and television broadcasts, radio navigation and location, and mobile communications.

In the past, devices that use radio waves required tuning to a specific spectrum. As a result, today, frequencies within the spectrum are distributed for specific uses, such as AM/FM radio stations, defense, air traffic communications, radar, or maritime communications. The Safety Band allocation offers a dedicated set of airwaves for transportation safety. In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of radio spectrum in the 5.9 GHz Safety Band for intelligent transportation systems (ITS) services. Over the past 20 years, the U.S. Department of Transportation has collaborated with industry and the public sector to develop and deploy new technologies, such as connected vehicle technologies, to operate on the dedicated safety band. The technology has been developed in more than half of the United States. It has been designed to support safety-critical applications through continuous, fast, reliable, and secure wireless data communications among vehicles, roadway infrastructure, and mobile devices.

Connected Vehicle (CV) technologies, such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communications, now depend on the Safety Band. These technologies involve devices or connection points between people, vehicles, and transportation environments. No other radio spectrum is currently configured to provide all the critical attributes needed to support V2V and V2I safety applications. Using the interference-free Safety Band, these high-precision devices enable communications between vehicles and traffic lights, generate real-time alerts or warnings, and adjust signals to prioritize emergency vehicles in heavy traffic, significantly improving transportation safety and mobility. Map 1 depicts the U.S. states with active 5.9 GHz intelligent transportation services.



Map 1. States With Active 5.9 GHz Intelligent Transportation Service licenses.

The 5.9 GHz band is used for:

- Traffic light control
- Traffic monitoring
- Travelers' alerts
- Automatic toll collection
- Traffic congestion detection
- Emergency vehicle signal preemption of traffic lights
- Electronic inspection of moving trucks
- Red-light violation warnings
- Reduced speed zone warnings
- Spot weather-impact warnings

In Miami-Dade County, the Automated and Connected Vehicle Technologies for Miami's Perishable Freight Industry Pilot Demonstration Project uses the safety band and technology to improve the Freight Corridors surrounding Miami International Airport (MIA). The research and demonstration project will follow a three-phase approach to measuring, prioritizing, and automating portions of the floral delivery supply chain in Miami-Dade County.

The Florida Department of Transportation (FDOT) proposes improving travel time reliability within the region surrounding MIA by deploying Connected Vehicle/Automated Vehicle technologies on a limited number of operators' fleet vehicles. The three phases for implementation and anticipated findings are summarized below:

- PHASE 1 — CV technologies will allow fleet operators and FDOT to understand better vehicle progression throughout delivery corridors and where bottlenecks occur at traffic signals.
- PHASE 2 — Utilizing the installed CV, devices will connect the freight vehicles to traffic signals through the back-end systems at the Miami-Dade County Traffic Management Center.
- PHASE 3 — During non-peak congestion hours (potentially 12 -5 a.m.), traffic signal priority will be granted to study vehicles' delivery performance improvement.

JACKSONVILLE, FLORIDA

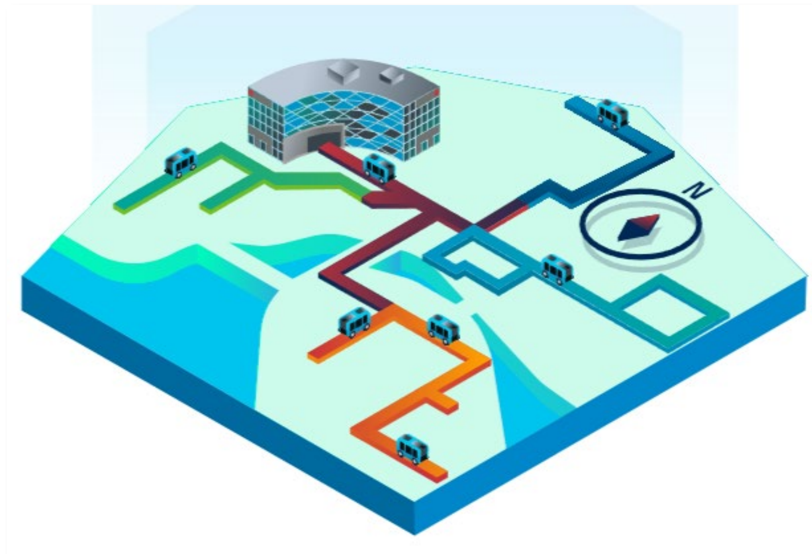


Figure 42. Representation of the full Urban Circulator System (U2C).

The BayJax Innovation Corridor is a three-mile segment of Bay Street in downtown Jacksonville, Florida, to connect people, places, and information to improve mobility in the city's urban core and surrounding neighborhoods. The project is part of the Jacksonville Transportation Authority's (JTA) plan called the Ultimate Urban Circulator (U2C), which involves replacing the elevated Skyway's monorail cars with autonomous electric vehicles that will be able to operate at street level and connect to the overhead transit system, similar to Miami-Dade's Metromover. The development of this corridor includes various projects, including integrated data exchange through the Internet of Things; autonomous shuttles; smart traffic signals that will provide surveillance and signalization priority; pedestrian sensors including enhanced mid-block pedestrian crossings; flood notification systems for streets; smart LED lighting with sensors to improve efficiency and resources; wayfinding featuring Wi-Fi, emergency services, and event information; solar sidewalks to power traffic signals; converting Bay Street into a two way from a one-way street; public broadband throughout the corridor; safety and surveillance technology that detects gunshots, gases or chemicals to be installed on lighting equipment, and; waste management by increasing trash cans to all intersection and transit stop locations in the corridor.

The U2C program aims to comprehensively modernize and expand the existing elevated people mover to fully autonomous transportation systems, as represented in Figure 42. JTA intends to complete the work in three phases to achieve this aim.

Phase I, the Bay Street Innovation Corridor, is currently underway. It extends from the Skyway's Central Station to the Sports/Entertainment District/TIAA Bank Field. The project will introduce Autonomous Vehicles (AVs), initially operating in mixed traffic in curbside lanes along Bay Street for approximately three miles, from Pearl Street (East) to EverBank Stadium, extending west to east through the Jacksonville Urban Core.

Phase II involves converting the Skyway superstructure into an elevated roadway for autonomous vehicles like the Navya model shown in Figure 43, expanding from the Downtown Northbank to the Southbank. Phase 2 is funded through the Local Option Gas Tax and represents the total conversion of the existing Skyway Superstructure and eight stations into an elevated roadway for AVs. The current bi-directional tracks run 2.5 miles in each direction. Launching from the Jacksonville Regional Transportation Center (JRTC), the U2C elevated stations will stretch to four additional stations on the Downtown Northbank and Southbank. Phase 2 also includes the street-level connection to Phase 1, the Bay Street Innovation Corridor, and an operations and maintenance facility for autonomous vehicles in the LaVilla neighborhood near downtown Jacksonville.

Phase III will include neighborhood extensions like the Southwest Corridor, Southbank Corridor, and North Corridor, expanding the system from 2.5 to 10 miles into other neighborhoods adjacent to the urban core.

- Southwest Corridor: This corridor hosts large office towers just over the edge of Downtown Jacksonville and melts into a blend of historic homes and eclectic shops and restaurants. Redevelopment in the northern portion of the corridor is bringing more places to live, work, shop, and dine. Planned autonomous vehicles will help connect future residents to areas within the corridor and nearby neighborhoods.
- Southbank Corridor: This corridor houses medical, office, and residential towers.
- North Corridor: Once served by streetcars, this historic area has undergone a renaissance with new and renovated homes and shops. The area hosts many neighborhood festivals and events.

The JTA's U2C program will serve as a testbed for mobility and transportation strategies and technologies in the North Florida region. The rendering in Figure 43 shows the planned Skyway ramp, which will connect the elevated track with the street level for continuous service.

Figure 43. Rendering of the U2C ramp and autonomous vehicles.

NASHVILLE, TENNESSEE

Downtown Nashville shares many similarities to Downtown Miami. Between 2013 and 2023, the downtown Nashville area experienced a total population growth of 365%. The growth in office space accompanies this. As of 2023, there was a total of 1.7 million square feet of office space under construction. Additionally, the area attracts many tourists, with a record of 14.4 million visitors in 2022 alone, spending over $8 billion in support of the local economy. In 2022, the Downtown Nashville area collected almost 19% of retail taxes generated in the whole of Davidson County, in an area that is less than 0.4% of the county's land area.

People experience similar mobility challenges in Downtown Nashville as well. There is a need for connections within and to Downtown Nashville. All modes of travel slow down to a crawl during peak periods, posing concerns for emergency vehicles, long-term growth, and quality of life. The city has found that while people are stuck in traffic, they may prefer it, as transit travel options do not match desired destinations, and the system is often seen as slow and unreliable.

The city developed the Metro Nashville Transportation Plan with five *Big Moves* to address mobility challenges. The projects highlighted in Figures 45 through 51 will make travel more reliable, comfortable, faster, and safer.

Big Move 1: Manage Congestion by upgrading signals, improving traffic operations, and better-managing events to keep people moving. Projects include:

Figure 44. Nashville's traffic signal strategies for congestion management.

Big Move 2: Improve Safety by advancing the implementation of Vision Zero projects. In addition, efforts include:

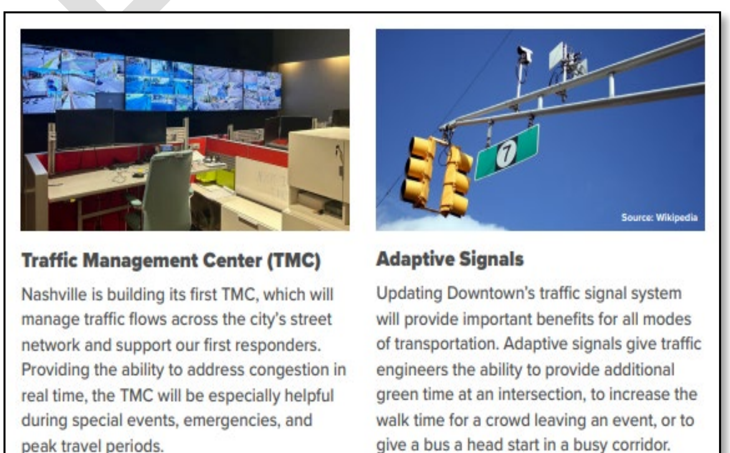


Figure 45. Nashville's safety strategies.

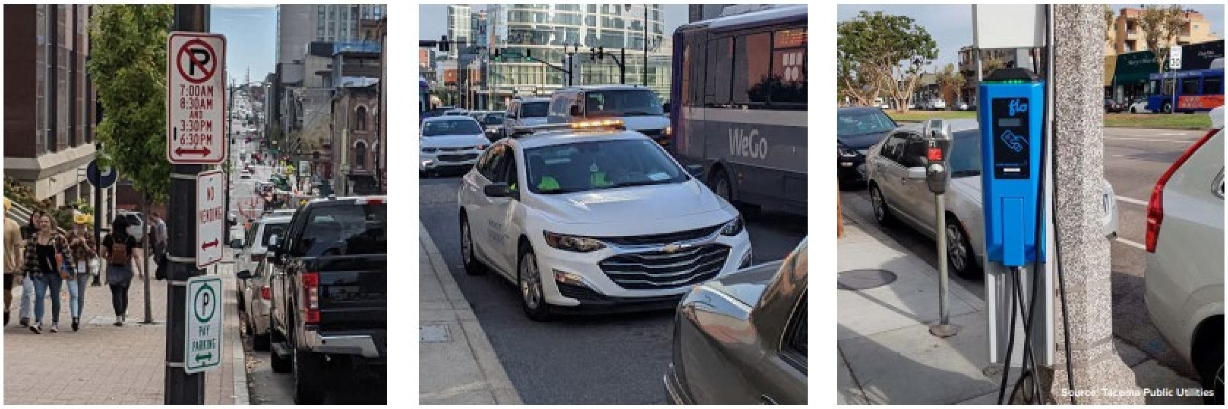
Big Move 3: Move More People by prioritizing buses on critical corridors and improving service through faster and more reliable trips. Transit Priority Corridors make moving people faster and more efficient. Figure 47 shows the strategies that can be implemented.

Figure 46. Transit priority corridors strategy to enhance mobility for all users in Nashville.

Big Move 4: Create Complete Networks to develop equitable, safe, separated, and connected facilities for walking, rolling, biking, and scooting. Examples of projects include:

Figure 48. Strategies to improve active mobility and develop complete networks.

Big Move 5: Maximize the Curb by flexing curbs throughout the day, allowing deliveries, service vehicles, and passenger pick-up and drop-off zones, including for charter buses.



Regulations and Permitting

To improve accessibility, Nashville should streamline and digitize curbside regulations; review all valet zone regulations and permits; advance the permitting system and procedural processes to support more flexible curb uses; and update the Zoning Code to better integrate curb uses.

Curb Enforcement

Nashville should add resources for enforcement, including increasing the number of staff in the parking enforcement division; procuring automated parking enforcement technology to provide real-time monitoring and enforcement; and acquiring data to improve the compliance program.

Autonomous and Electric Mobility

To support a transition toward new curb uses, Nashville should proactively evaluate its curb policies and tools to prepare for automated mobility services; deploy public charging infrastructure to promote equitable electric mobility; and create and maintain digital policy tools.

Figure 49. Parking permitting and enforcement for optimal curb management.

FOCUSED IMPROVEMENTS FOR DOWNTOWN NASHVILLE INCLUDE:

1. Develop a **Transportation Demand Management (TDM)** plan and expand the Nashville connector program to include TDM strategies for businesses, residents, and visitors. The TDM Team will guide the program at Nashville's Department of Transportation. It will encourage people to use other modes of travel, especially for short trips Downtown and trips that could be made by bus.
2. Increase **Event Management and Coordination** resources to support more comprehensive planning for multimodal needs and dual-event days. The city hosts hundreds of events a year and will add staff to help plan for and implement detours, manage traffic congestion, and promote alternative modes of travel.
3. Launch a **Construction Hubs Program** to coordinate public and private construction activities in the right-of-way. The program will help contractors coordinate efforts to reduce duplicative work and inform the public of active projects and detours. The program will also help Metro Nashville ensure that private development implements priority infrastructure.

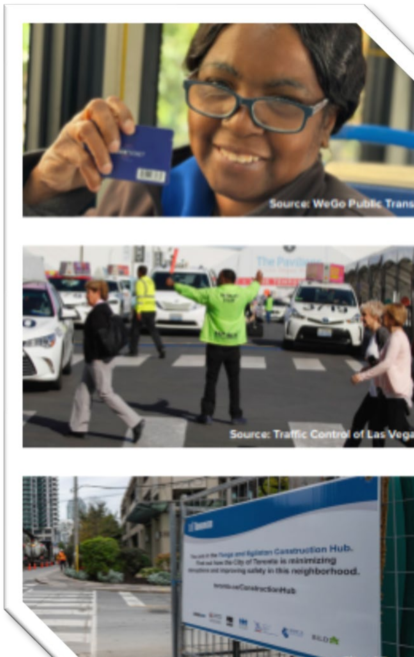


Figure 50. TDM, event management, and construction hubs to keep people moving.

Other notable efforts in the plan include curb management principles and regulations. Figure 52 shows examples of flexible curb regulations.

Curb management principles include:

- **EFFICIENT** and **EFFECTIVE** using data to optimize curb use
- **EQUITABLE ACCESS** for the diverse needs of users
- **USER-FRIENDLY** regulations
- **ADAPTIVE** and **RESILIENT** to be flexible to regulatory change
- **DECISION-MAKING CLARITY** for enforcement and users.

Figure 51. Flexible curb regulation strategies in Nashville.

ATLANTA CURBSIDE MANAGEMENT ACTION PLAN

Commercial centers in Atlanta, Georgia, feature various street and curb uses that must be balanced. Atlanta's approach was to develop action plans for curb space activation based on different types of corridors. Table 1 highlights the components of the Atlanta Curbside Management Plan and the management practices by curb type, land use, and curb use priority.

Table 1. Atlanta's curbside management strategies by curb type.

CURB TYPE	TYPICAL STREET CLASSIFICATION	ADJACENT LAND USE AND CONTEXT	CURB USE PRIORITY 1	2	3	4	5
Commercial Centers	Principal Arterials and Collectors	• High density office • High density commercial and ground floor retail • Moderate levels of high rise residential • Access to parking lots/garages and transit • On-street loading and parking is not prioritized on these streets but is provided on cross-streets	People/Green Space	Mobility	Passenger Access	Delivery Access	Storage
Entertainment Centers	Principal and Minor Arterial	• High density corridors with mixed land uses including dining, social destinations, and museums or theaters • Accessible through diverse modes of transportation • Requires on-street access as well as access on cross-streets	People/Green Space	Passenger Access	Delivery Access	Mobility	Storage
Commercial Mobility Corridors	Principal and Minor Arterials	• Sporadic businesses or entertainment options • Mostly functions as connector into the urban core • Primarily high density commercial and institutional areas • Person throughput-oriented • Storage occurs off-street or on cross-streets	Mobility	People/Green Space	Delivery Access	Storage	Passenger Access
Neighborhood Mobility Corridor	Minor Arterials and Collectors	• Predominantly low to mid rise residential • Sporadic ground floor retail • Little delivery demand • Vehicle storage space on-street	Mobility	People/Green Space	Storage	Passenger Access	Delivery Access
Neighborhood Avenues	Minor and Collector Arterial	• Moderate intensity retail and entertainment • Low intensity office • Low to mid-rise residential • Accessible through diverse modes of transportation • Limited right of way	Passenger Access	People/Green Space	Mobility	Storage	Delivery Access
People Streets	Non-arterials (Local Roads), Minor Arterials	• High intensity commercial • Moderate residential density • Ground floor retail • High walkability • Limited right of way	People/Green Space	Delivery Access	Storage	Passenger Access	Mobility

The Atlanta plan provides numerous policies and strategies. Below is a selection of methods appropriate for downtown Miami and can be implemented.

Adopt a curb-type policy to guide curb allocation and provide a framework for decision-making

1. Adopt the curb typology as part of the city street design and curb regulation process to serve as a guiding document,
2. Assign ownership of the curb typology and update it over time. The curb manager is the owner and is encouraged to update the document as conditions change.

Multimodal transportation and curb impact studies are required for significant new developments in parallel with transportation management plan requirements. Require developers to acknowledge the multimodal nature of site access and develop multimodal impact analysis and mitigation plans.

1. Developments adding at least 25,000 square feet of floor area are required to complete a transportation study evaluating impacts on bike transit loading and curb infrastructure, including ride-hailing and delivery.
2. Create templates or other assistance by which developers can estimate trip generation and modal access priorities.

Allocate targeted loading space for loading and pickup drop-off activity.

1. Identify areas where pick-up slash drop-off locations, and commercial loading zones are inadequate or underperforming by coordinating with stakeholders and integrating emerging data streams
2. Create clear protocols within Atlanta dot to install new loading zones and use geofencing to create pick-up slash drop-off locations in critical civic spaces. Enforce the existing loading zone permit program
3. Regularly assess the performance of loading zones and adjust regulations and zone dimensions accordingly.

Maintain curb inventory to facilitate changes to curbside regulations

1. Identify a curb data standard
2. Collect the initial data for the curbside inventory
3. Establish and formalize a process for real-time inventory updates

Monitor curb demand through regular curb utilization studies and use data to adjust policy

1. Formalized procedures for different utilization studies
2. Conduct utilization studies every six months
3. Require vendors to regularly share utilization data and seek partnerships with mobility service providers
4. Monitor loading activity in critical areas and assess off-street loading spaces

Adopt design standards to prevent modal conflict between modes and coordination with the curb typology.

1. Continue to refer to the national guidance, such as the NATCO urban street design guide, when designing roadway improvement to mitigate adverse impacts on non-auto modes
2. Ensure that bus bike and loading facility designs prevent modal conflicts

Allocate multimodal space for non-auto modes on streets to promote mode shift goals and create a more livable environment.

1. Develop a modal prioritization plan that builds off of the work conducted for the curb typology but incorporates specific analysis around modal network needs for buses, bikes, and other non-auto uses in coordination with other regional network plans
2. Use transportation demand management to reduce vehicular demand and free up space for multimodal improvements.
3. Use flexible roadway designs to reduce competition for the right of way and allow multiple uses to function safely in the same space

Allocate people space, providing more space for people using parklets, outdoor dining, and recreational areas through the tactical urbanism permit.

1. Determine appropriate street districts or other areas to establish as shared streets where St. Space and, in particular, curb space can or should be converted to people space about the curb typology
2. Promote the standards and processes for outdoor structures as described in Atlanta's tactical urbanism guide through continued outreach to stakeholders
3. Develop an award program for innovation and design

Curbside use and management pilot and evaluate curbside changes in management tools while gathering public feedback gather a resource pool of flexible materials that can be used to deploy right away pilots rapidly and inexpensively

1. Use outreach and surveys to determine what pilot types are in demand
2. Pilot curb management technologies to better manage the curb and understand curb behavior

STRENGTHENING LINKAGES BETWEEN TRANSPORTATION DEMAND MANAGEMENT AND TRAFFIC MANAGEMENT

Bike Parking/Bike Valet at Sports Areas

Many venues have established bike parking and bike valet services. One example is Nationals Park, seen in Figure 54, in Washington, DC, which offers free, secure bike parking for more than 250 bicycles. The lot opens two hours before game time and remains open until one hour after the game ends. Bikeshare is also available at the stadium. Bike valet parking is also accessible at AT&T Park (San Francisco, CA) and Golden 1 Center (Sacramento, CA). At Kauffman Stadium (Kansas City, MO), parking fees are waived for those who bike to the stadium. Typically, bike valets are manned by paid staff who watch the bicycles, ensuring they remain secure while owners are in the stadium.

Figure 53. Photo of bike valet at Washington Stadium.

Combining Concert and Transit Tickets

The Utah Transit Authority works with the Ogden Twilight concert series every year, as pictured in Figure 55, from June to September to provide public transit to the event. The ticket's purchase price includes a transit fare allowing ticketholders to access Ride UTA FrontRunner, TRAX, and buses with their Ogden Twilight ticket. Guests must show the concert ticket to the bus operator or UTA fare enforcement personnel when asked for proof of payment.

Figure 54. Ogden Twilight Series concert in Utah.

Establishing Ride sourcing Pickup Locations at Event Venues

During the month-long Mardi Gras celebration, many options are available to allow visitors to leave their cars at home. Since 2016, transportation network companies (TNC) have provided special promotions to encourage ride-sharing to get to the festivities. Mardi Gras presents a particular traffic challenge because many roads and entire city sections are closed to vehicle traffic for the dozens of parades over the month. TNCs developed a Mardi Gras guide to direct potential riders to permissible pickup locations, as provided in Figure 56. Similar guides prepared for the Houston Super Bowl and the Louisville Kentucky Derby. Several event venues, including Nationals Park in Washington, DC, have worked with TNCs to designate a formal pickup area and limit curbside pickup.

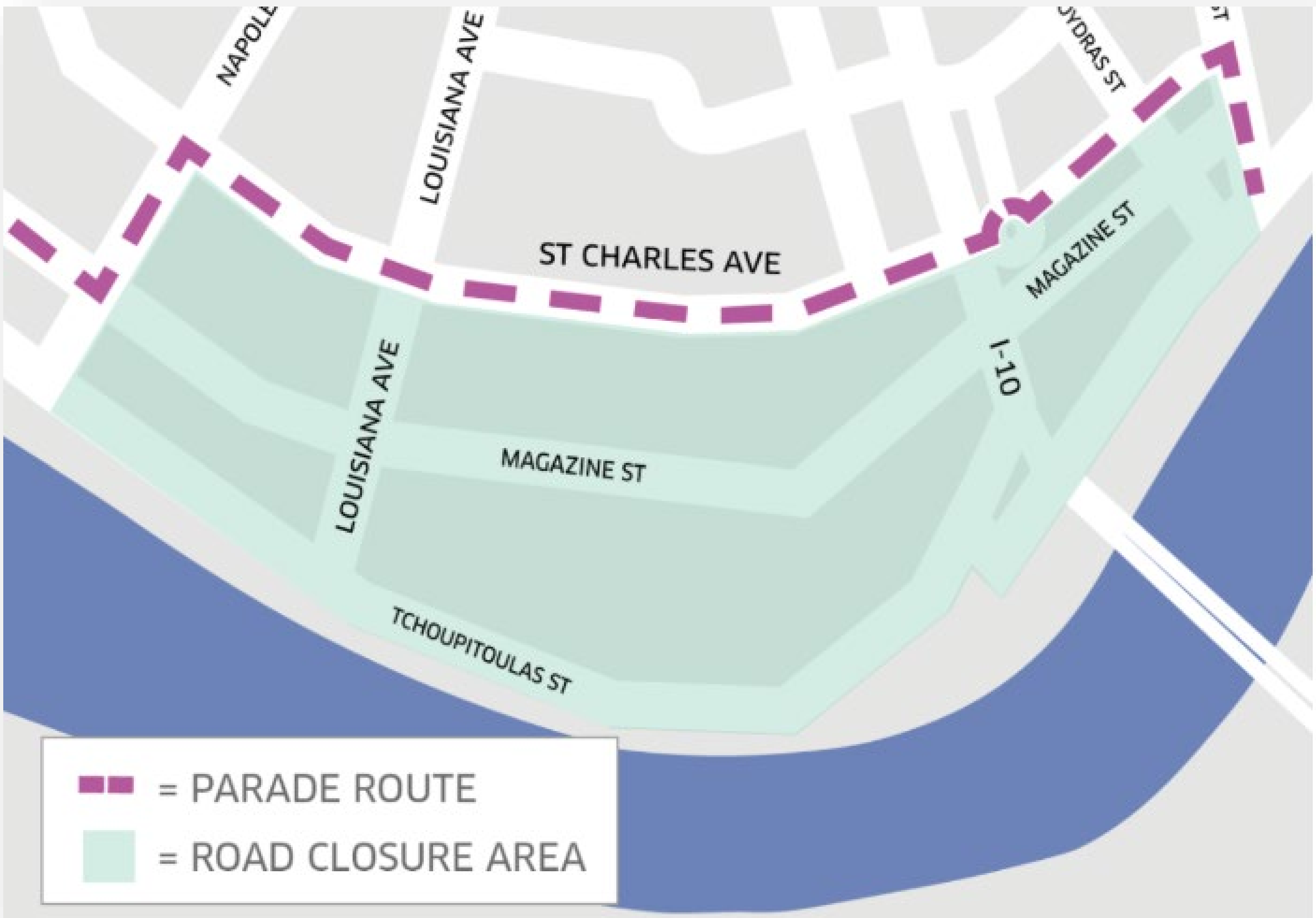


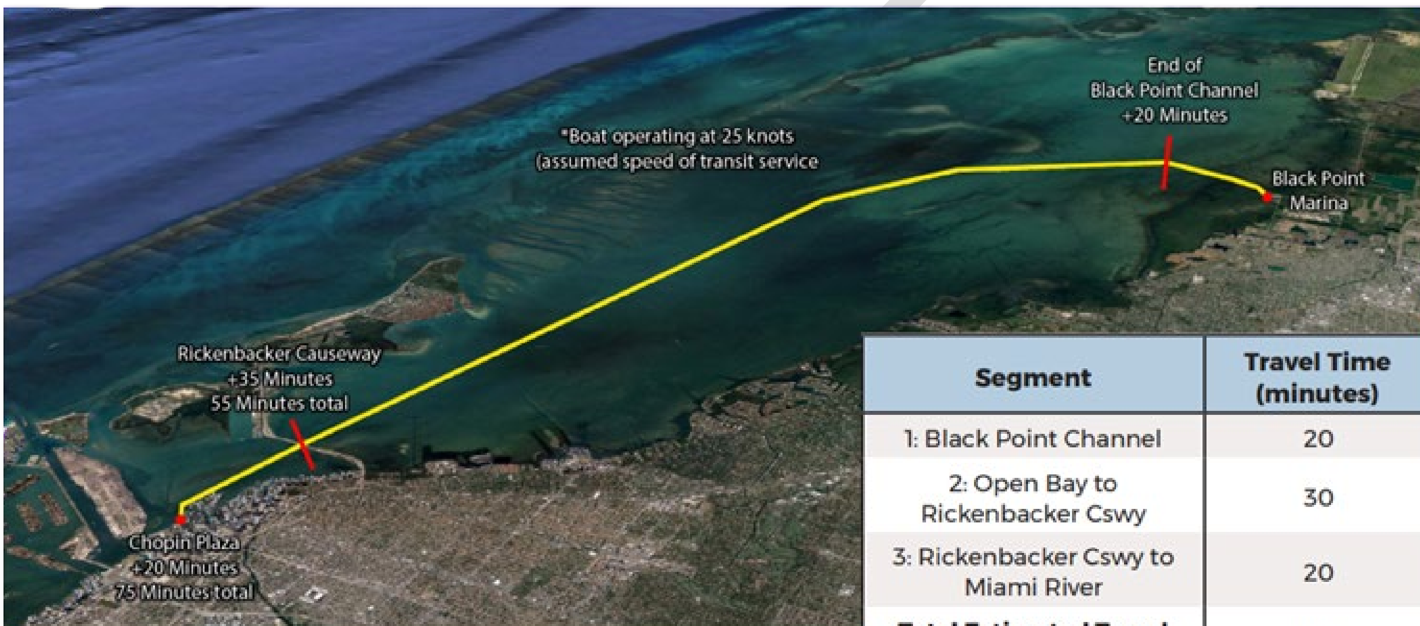
Figure 55. Transportation Network Companies prepare rideshare guides for special events like Mardi Gras.

RESEARCH IN MOBILITY IMPROVEMENTS

WATERBORNE TRANSPORTATION FEASIBILITY STUDY

In 2017, the Miami-Dade Transportation Planning Organization (TPO) conducted a Waterborne Transportation Feasibility Study for travel between Black Point Marina and Downtown Miami. The study assessed the implementation of a ferry as an alternative mode of transportation to improve travel time and accessibility into downtown Miami.

Commute times between southern Miami-Dade County and downtown Miami can take more than two (2) hours during peak travel periods to traverse the 18.5 miles. An alternative travel option is by boat, which results in a total boating trip length of 22.4 miles. Per the study, Black Point Marina would be converted into a multimodal transit location that would include a park-and-ride area, connecting feeder transit and shuttle service, and the waterside area necessary to implement a waterborne commuter service. The travel time with the proposed ferry was estimated at 70 minutes. Figure 57 provides an overview of the route.



Segment	Travel Time (minutes)
1: Black Point Channel	20
2: Open Bay to Rickenbacker Cswy	30
3: Rickenbacker Cswy to Miami River	20
Total Estimated Travel Time	70

Figure 56. Proposed waterborne travel route between Black Point Marina and Downtown Miami.

The recommended catamaran-style vessel for service, seen in Figure 58, can accommodate up to forty-nine passengers and sustain a minimum cruising speed of twenty-five knots. It is designed for improved water stability and a shallower keel depth, and it features a low profile that accounts for bridge height restrictions in Miami-Dade County.

Additional locations for waterborne service were evaluated as part of the study, including Dinner Key Marina in Coconut Grove and three Downtown Miami options connecting waterborne service with transit, including the Riverwalk Metromover station next to the Miami River, Chopin Plaza, and the Sea Isle Marina.

Figure 57. Recommended catamaran-style vessel for Miami water taxi.

Travel to and from downtown is through the Intracoastal Waterway, which allows for full-speed travel; however, the route is often slowed down to various slow-speed buffers along the route, including one near Dinner Key to protect the marina and another near the Rickenbacker Causeway. The three downtown docking stations are within 1,000 feet of a Metromover station and are described below.

Chopin Plaza: This docking location is shown in Figure 59. It was determined to be the fastest downtown stop from Black Point. It is the closest to travel to and has the least speed-restricted zones to pass through.

Sea Isle Marina: As shown in Figure 60, there are two potential docking sites for a water taxi at this location. The northern option aligns with NE 16th Street and provides a more pleasant environment as riders land. The southern option is directly adjacent to NE 15th Street and provides a shorter path to the Metromover station.

Riverwalk Station: Figure 61 shows the Riverwalk Station location, which was determined to be the most helpful for riders. It is only 200 feet from a Metromover station. However, reaching it requires passing beneath the Brickell Avenue Bridge and traveling the Miami River, which is an idle speed zone out to the northeast corner of Brickell Key.

Figure 58. Chopin Plaza docking station and connection to Metromover Station.

Figure 59. Sea Isle and potential docking sites and routes to Metromover and Metrobus.

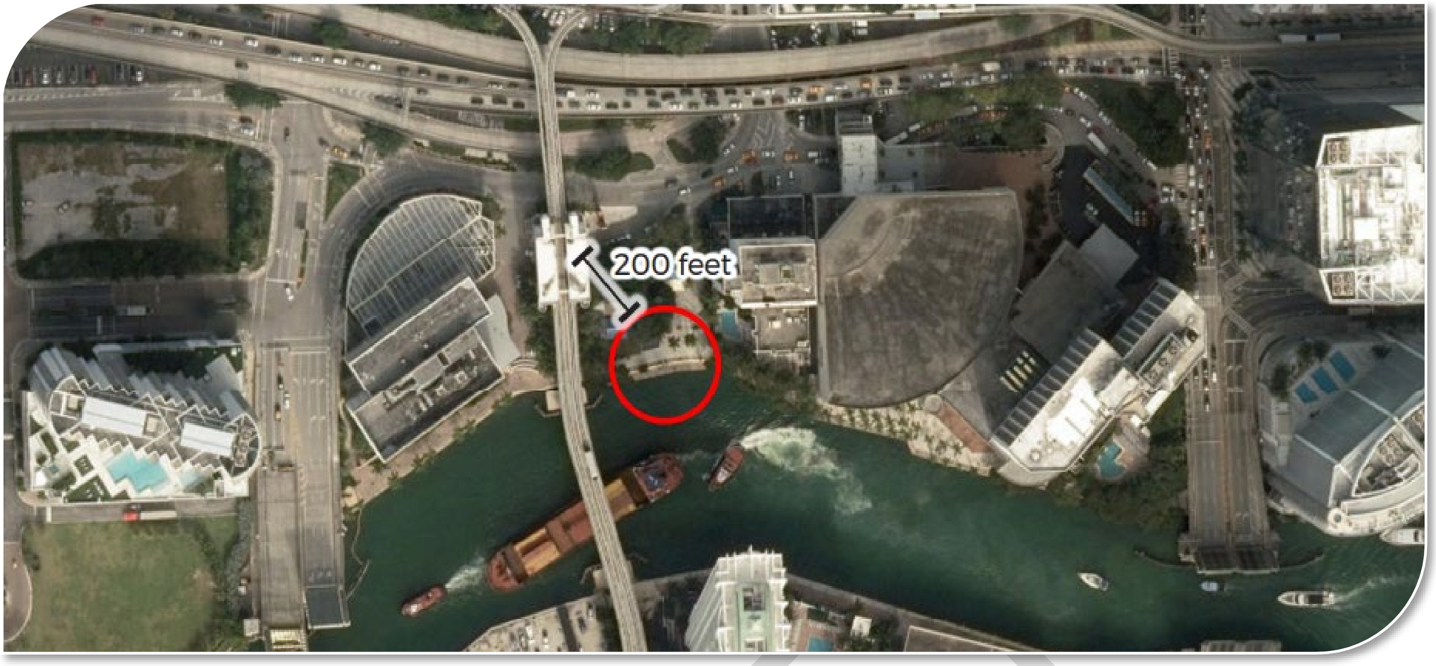


Figure 60. Riverwalk Station Metromover docking location.

Challenges to the implementation of the ferry service identified in the report include:

- **Marina Location:** Black Point Marina is situated in a relatively remote southeast corner of Miami-Dade County, outside the Urban Development Boundary (UDB), making it difficult to cultivate the desired type of development that could sustain the waterborne trail.
- **Passenger Carrying Capacity:** For waterborne service to be viable, the corridor's passenger carrying capacity may need to be increased. To accomplish this, a new water route must provide sufficient volume with frequent enough service to help alleviate traffic congestion on parallel roadways such as the Florida Turnpike, U.S. 1, and Old Cutler.
- **Regulations**: During stakeholder engagement interviews, it was also noted that Miami-Dade County's Division of Environmental Resources Management (DERM) use of the Manatee Protection Plan (MPP) to regulate water taxis may be outdated and may be restricting the full implementation of this type of travel, especially in Downtown Miami.

The study concluded that the proposed waterborne service between Black Point and Downtown Miami is not feasible at this time, given the service route length and the travel time. Both factors limit passenger carrying capacity, resulting in high operation costs with limited passenger benefits.

EMERGING TECHNOLOGY FOR WATERBORNE TRAVEL

Seagliders: Electric plane-boat hybrids, or seagliders, are being tested in Tampa, Florida, to begin commercial sales in 2025. The battery-powered craft can dock like a boat and float in no-wake zones. After leaving a busy harbor, it can take off into the air and fly above the water at speeds up to 180 mph.

Electric seagliders use hydrofoils—or underwater wings—to hover over waves with speeds between 20 and 40 mph before taking off. While seaplanes are not new in the aviation industry, they have proven impractical for commercial travel due to poor wave tolerance and the need to launch from a dock.

The first seagliders for commercial use will seat about 12 passengers, but the company developing the technology intends to create a larger version with room for about 50 to 100 passengers. Airline companies in Hawaii and Alaska plan to integrate the technology into their coastal airport networks. Figure 62 shows a rendering of the seaglider.

Figure 61. Rendering of a seaglider in flight.

Electric Flying Passenger Ship: Stockholm's public transport system is undergoing a significant transformation with the introduction of the first-ever electric flying passenger ship. This groundbreaking vessel, shown in Figure 63, is designed to revolutionize commuting by reducing a 55-minute journey between Ekerö and Stockholm to just 25 minutes.

Figure 62. Electric passenger ship set to launch in Sweden in 2024.

Measuring 39 feet in length and powered by a 252-kilowatt-hour battery, the ship can comfortably accommodate up to 30 passengers, showcasing its practicality in urban transit scenarios. Capable of gliding at speeds reaching 25 knots (29 mph) and maxing out at 30 knots (35 mph), it can travel up to 50 nautical miles (57.5 miles) on one charge. Hydrofoil technology minimizes water resistance and, consequently, power consumption.

This innovation translates into tangible benefits for commuters, particularly on the route where travel time will be halved. The ship is exempt from speed limits due to its minimized wake disturbance while navigating water. Additionally, advanced technology is harnessed to mitigate the likelihood of passengers experiencing seasickness, ensuring a comfortable journey for all aboard.

DOWNTOWN MIAMI SMART CORRIDOR HUB TRANSPORTATION MOBILITY AND CONNECTIVITY STUDY

This study guides integrated mobility hubs and expanding their use in Miami's urban core and along the SMART corridor hubs to improve mobility in the area. Integrated mobility hubs connect various transport options, allowing users to shift between modes and create new routes according to their preferences.

The following are features identified in the study to promote integrated mobility hubs in downtown Miami:

- Provide infrastructure and incentives for electric vehicles.
- Manage parking dynamically at mobility hubs and urban core areas by using parking inventory technologies to capture, display, and even pay for available parking.
- Use radiofrequency identification (RFID) based technology and biometric devices to efficiently control parking facilities' entrance and exit gates.
- Implement innovative demand-responsive valet parking services to provide low-speed, priority parking stalls for electric vehicles in micro park-and-ride facilities closer to city center entry/exit points.
- Employer-based incentives to cede parking rights, where employers allow workers to trade their parking spaces for the cash equivalent.
- Parking funds and Parking Benefits Districts for community garages (in-lieu fees) will be placed at critical locations (entry points) of city centers, paired with parking-free communities/buildings. They will reduce and ultimately eliminate parking minimum requirements.
- Design and implement a technology-driven, consistent wayfinding system around mobility hubs with supportive features throughout the city.
- Promote data-sharing between stakeholders in the public and private sectors and the general public.
- Implement a centralized, mobile, single-payment fare system platform.
- Allow for flexibility in Curbside Management to adapt to changing urban needs, including providing space for micro transit and transportation network companies, pick-up/drop-off zones, carshare parking, mobile vendors, parklets, and servicing and loading areas that do not interfere with the pedestrian network.
- Consider Congestion Pricing, which works best in areas well-served by high-quality transit services.

The following Mobility Hubs were identified in the Study Area. Map 2 depicts the location of the hubs.

The Underline (1), Brickell Point (5), and Brickell Key (4) Hubs are recommended to focus on active travel for pedestrians and cyclists and access to microtransit, such as community shuttles.

Brickell Station (2), NW 36 Street (14), and the Omni Station (9) Hubs are envisioned as Transit Access hubs with various travel options.

Brickell City Center (3) is proposed as a destination hub with access to popular destinations, including commercial areas, museums, and theatres.

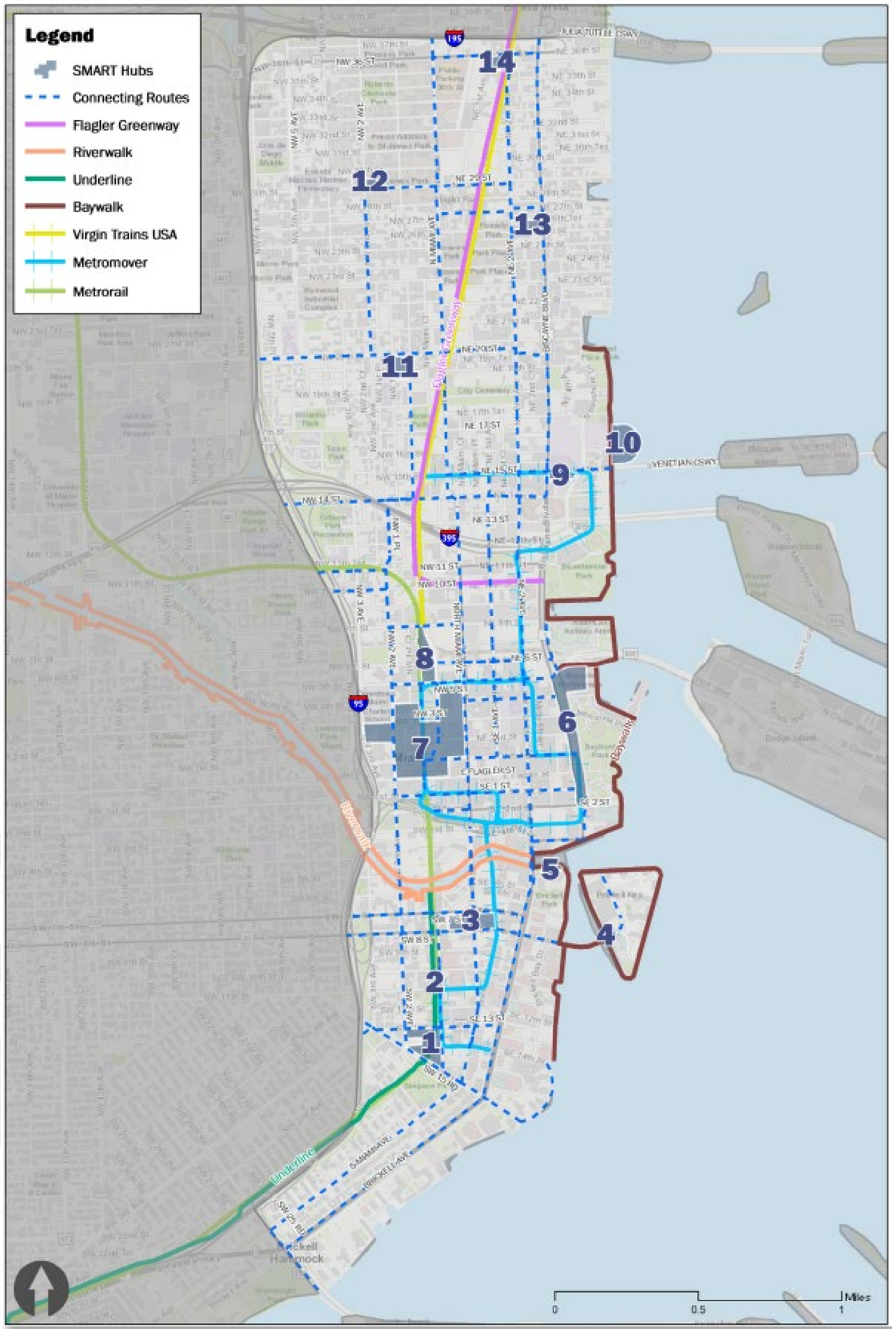
Bayfront Park Hub (6) is proposed with curb space that adapts to changing needs, including space for microtransit, TNCs, carshare parking, mobile vendors, parklets, and loading while providing clear access to pedestrians.

Government Center Hub (7) combines a destination hub with access to housing, employment, and cultural centers and a transit access hub to various mobility modes.

Miami Central Hub (8) is a significant regional mobility hub connecting the tri-county metropolitan area.

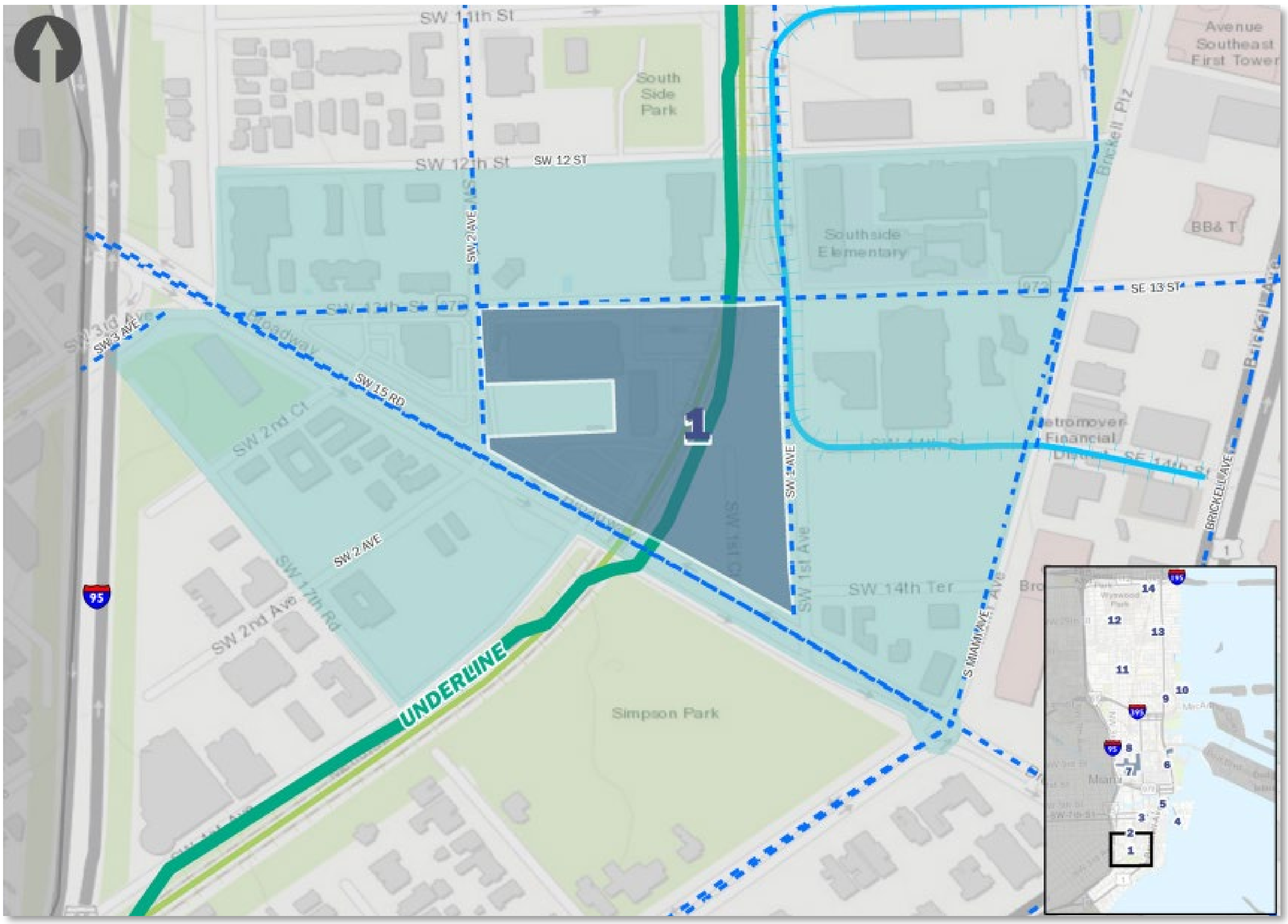
Sea Isle Marina Hub (10) is a water transit hub for a potential connection with waterborne transportation.

NW 20th Street (11), NW 29th Street (12), and Edgewater (13) are envisioned as hubs that provide access to microtransit, such as community shuttles and on-demand TNC services for ride-hailing providers.



Map 2. Map illustrating Smart Hub Networks in the study area.

THE UNDERLINE HUB: This location aims to create a mixed-use hub that functions as a focal point for the community and supports all modes of transportation, focusing on active travel. Despite being close to the urban core, surrounding areas, primarily residential single-family homes, have higher vehicle miles traveled (VMT) rates than other nearby areas. This hub, highlighted in Map 3, caters to active micromobility uses for commuting and recreational trips. This site improves first- and last-mile connections to public transit, including Metrorail.



Map 3. The Underline Hub prioritizes active mobility services.

The hub envisions a multi-story residential community featuring commercial development on the ground floor and improving connectivity with various land uses. Design flexibility along the curbside is a crucial element for this hub. Instead of restricting this space to one or no use, recommendations include using temporary materials to define uses that accommodate the different community needs throughout the day and night. For example, spaces can transform into loading areas during the day and a parklet at night or during special events. Elements of shared mobility, such as carshare parking or a TNC pick-up/drop-off zone, are also recommended for curb use considerations.

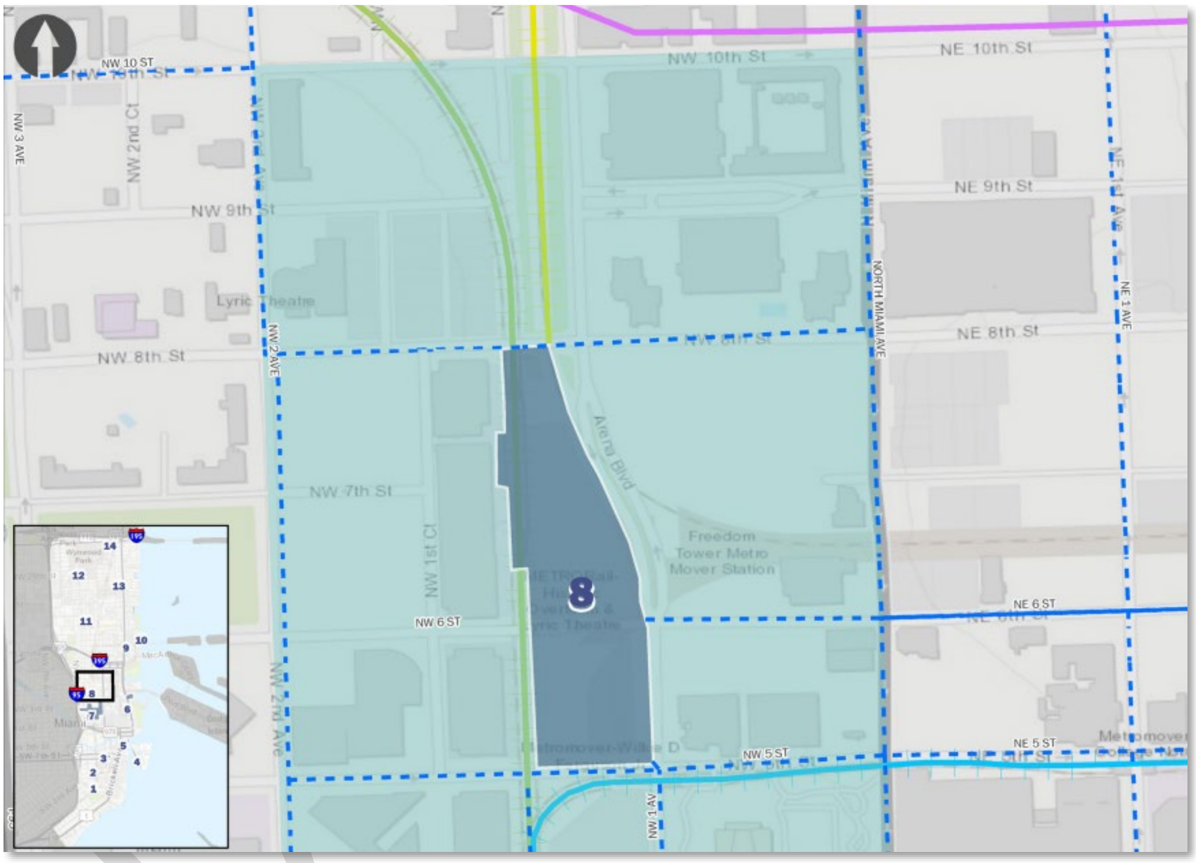
RECOMMENDATIONS

Recommended design elements for an **ACTIVE MOBILITY HUB** include:

- Wayfinding - launching a unique and comprehensive wayfinding system is recommended for the entire study area, including The Underline Hub. This location should feature signs and kiosks displaying real-time travel and destination information.
- Bicycle/Rolling Lanes - active travel will be central to this development; therefore, all supportive facilities to enable users must be provided.
- Micromobility - including micromobility options within the design of the space capitalizes on existing popular trends to further advance nonmotorized mobility in the area.
- Bicycle/E-scooter Parking - end-of-trip facilities are necessary to promote active travel and micromobility as viable mobility options. Providing safe and secure bicycle parking invites residents and visitors to choose this mode for completing nearby trips.
- Carsharing - carsharing coordinated with Curbside Management.
- Enhanced Crosswalks - should be placed at all intersections and mid-block crossings.
- Traffic Control Elements - pedestrian signalization is recommended at significant crossing points.
- Pedestrian-Friendly Designs - close the missing sidewalk gaps within the hub core area to form a continuous pedestrian path network.
- Open Plaza - adequate siting, shade trees, local art, and pedestrian-scale lighting are some of the necessary features to be incorporated.
- Mixed-Use Hub-Oriented Development (HOD) - The Underline Hub must bring together all elements of a TOD to enable urban living where people can live, work, learn, and play while having various mobility options.

MiamiCentral Hub: this hub plays a vital role in regional mobility in South Florida. The station's development aligns with Smart Growth and Transit-Oriented Development (TOD) principles. However, mobility improvements within the core area of the hub are needed to support sustainable growth, encourage active travel as a viable first—and last-mile option, and reduce the risk of injuries and fatalities. Creating a walkable built environment that attracts pedestrians and bicyclists is a priority for this hub. The boundaries of the MiamiCentral hub are shown in Map 4.

Map 4. Map of MiamiCentral Hub, which emphasizes regional mobility.



RECOMMENDATIONS

Recommended design elements for a **REGIONAL MOBILITY HUB** include:

- Wayfinding – a comprehensive wayfinding system is recommended for the entire study area. This hub must orient travelers to destinations and inform them of all the available mobility and transit options. Specific recommendations include signage in highly visible areas and wayfinding kiosks that display real-time travel information for transit services and approximate walking times to prominent destinations.
- Bicycle Lanes - bicyclists were noted as one of the most disadvantaged users at this site, with limited or no facilities providing a direct connection to the station. Designated bicycle lanes are recommended throughout the hub core area.
- Secure Bicycle Parking—Proper end-of-trip supporting facilities for bicyclists, including bike parking and repair services, are also recommended.
- Bicycle Counter—A visible bicycle counter tracking how many bicyclists travel through the designated lanes can encourage cycling, alert drivers of the presence of bicyclists, and provide data to assess needs.

- Micromobility—bike sharing and e-scooter rental are widely available and used throughout the area. Proper facilities ensure that the demand for micromobility is met proactively, reducing conflicts between modes and potential injuries.
- Enhanced Crossings—Raised and textured intersections are recommended at this hub as a traffic calming measure for improved walkability and safety. Considering the multimodal nature of the area, enhanced crossings are recommended at all intersections within the hub core area.
- Curbside Management – areas targeted along NW 6 Street and NW 1 Avenue.
- Ride and Carsharing - shared mobility should be promoted at the hub.
- Autonomous Vehicle Infrastructure - fiber optic cable coverage should be prioritized throughout the hub to enable intelligent transportation system solutions.
- Open Plaza – a plaza is recommended at the vacant governmental lots across Miami Central on NW 1 Avenue to provide a public realm feature that ties together all other pedestrian-friendly design elements.

EMERGING TECHNOLOGIES FOR MOBILITY HUBS

The following emerging technologies identified through the research can be implemented to support mobility hubs.

Figure 63. Universal charge station for e-mobility vehicles.

Battery-as-a-Service (BaaS): Battery-as-a-Service (BaaS) for micromobility electric vehicles is a subscription-based model that separates the cost of the battery from the vehicle. Subscribers can access swap stations where depleted batteries can be exchanged for fully charged ones, improving convenience and reducing downtime. This approach reduces initial costs for micromobility EVs, addresses charging accessibility challenges, promotes battery recycling, and overcomes issues related to the lack of standardization across manufacturers.

Universal Charging Station: Pictured in Figure 64, universal charging stations offer the municipality and e-mobility users a way to help organize public space, lower operation costs, and provide a simple, secure universal charge station. They are installed at locations similar to bike-share docking stations. They are adaptable solutions that can be plugged into advertising boards, bus stations, and street lighting to provide a power source.

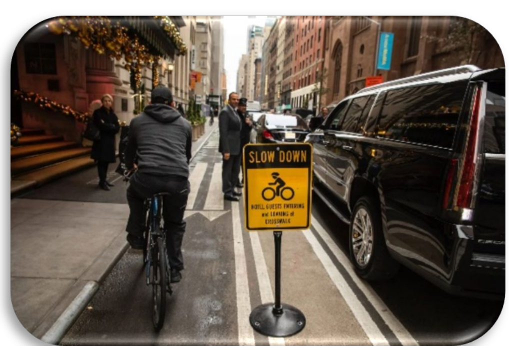


Figure 64. NYC bicycle lane equipped with rumble strips, enhanced pavement markings, and signage.

Bicycle Lane Rumble Strips: a curb management strategy to reduce conflicts between high pedestrian activity areas and bike lanes. In NYC, the DOT fitted specific bicycle lanes with rumble strips and enhanced markings to improve conflicts at residential buildings and hotel entrances, where a pedestrian would have to walk through a bike lane to access taxis or rideshare services. An example is provided in Figure 65. These areas have resulted in many issues, with damage to property and injuries to cyclists and pedestrians. In addition to these features, hotels post signs alerting guests, and the DOT provides an education campaign to cyclists on blocks with hotels to watch out for pedestrian activity.

Smart Parking Meters: Smart parking meters are designed to work with parking apps, street sensors, and mounted cameras. Cameras survey and monitor street parking availability and automate agency parking services operations, making self-parking easier for drivers. The installation cost can be reasonable when installing a single camera for a wide-area parking lot. Each smart meter installed can cost between $250 and $500, depending on the model. A provider is selected to administer innovative parking services, and they may assist in installing infrastructure to enhance their product. Businesses may also wish to contribute.

Geofencing: Geofencing is a location-based technology that creates virtual boundaries, enabling specific actions when a device, such as an e-scooter or e-bike, enters or exits designated areas. In micromobility, geofencing is commonly used to regulate and improve parking practices, restrict usage in certain zones, and contribute to overall urban mobility management. It encourages responsible behavior among riders and can be complemented by physical infrastructure, such as designated parking zones, for more effective and comprehensive micromobility solutions. Figure 66 shows how the City of Boulder, Colorado, uses geofencing to create corralling stations for e-scooters.

Figure 65. Geofencing technology used for e-scooter parking in Boulder, Colorado.

Micromobility Storage At High-Demand Stations: Improved security for bike racks is essential for commuters who park their bikes at the same station daily. As micromobility continues to evolve, storage options must also expand. Storage and parking solutions should not be limited to bike racks alone; they should accommodate all micromobility devices, including adaptive mobile devices, electric scooters, and bicycles. While bicycles remain the primary micromobility device, transportation, and mobility hubs should be equipped with storage lockers, pods, and other multi-device storage options.

In Los Angeles, California, an on-demand electronic locker rental system has been implemented, allowing users to rent lockers daily and pay only for the needed days. These lockers are fully enclosed and large enough to accommodate larger cargo bikes. In Jersey City, New Jersey, micromobility vehicle storage pods are available 24/7 and free of charge. The walk-in pods, seen in Figure 67, cost approximately $80,000, but costs are offset by revenue earned through advertising. Users must register with an online account or download the mobile app. A three-day parking limit during peak times ensures space is available for all regular users.

Figure 66. Micromobility vehicle storage pod in Jersey City.

Scooter Sidewalk Riding Detection Technology: Scooter sidewalk riding is illegal in many parts of the U.S., including Florida, as it poses significant risks to pedestrians, especially older adults and persons with disabilities. Cities can address this problem in the long term by building bike lanes or creating scooter parking bays. However, until these solutions are implemented, operators can use technology to mitigate the issue. One such solution is sidewalk riding detection technology, which uses GPS to detect when a scooter is ridden on a sidewalk in real time. Once detected, the scooter automatically slows to a safer speed. This technology is akin to advanced driver assistance systems (ADAS) found in cars, where radar sensors assist in critical situations to avoid accidents and reduce collisions.

Adaptive Micromobility: Adaptive bike share programs have emerged as a promising solution to address the mobility challenges faced by people with disabilities and older adults, enhancing their independence and participation in physical and social activities. These individuals often lack sufficient transportation options, hindering their desired level of mobility.

Adaptive cycles, including trikes, hand cycles, and recumbents, offer accessible alternatives for those who struggle with standard bicycles or require assistance.

Figure 67. Detroit nonprofit MoGo offers adaptive micromobility devices.

Two models of adaptive bike share programs include a bike/trike library and integration into existing bike share systems. In the bike/trike library model, users pick up and return cycles at specific locations, benefiting from staff assistance and storage. Examples of this model include Portland's BIKETOWN and Detroit's MoGo. Figure 68 shows a sample of vehicles provided by MoGo, including recumbents, trikes, and hand-powered cycles. The other model integrates adaptive bikes into existing docked or dockless bike share systems, providing a familiar and efficient transportation solution. Milwaukee's Bublr Bikes, which incorporated adaptive bikes in 2019, exemplifies this approach.

Challenges such as cost, resource constraints, bicycle types, program implementation, and infrastructure pose obstacles to adopting adaptive bike share programs. Despite these challenges, the potential benefits for individuals with limited mobility make adaptive bike share a valuable area of exploration for creating inclusive and accessible transportation systems.

Interactive Kiosk: Kiosks offer a range of services, including providing information about bus departures, route details, trip planning, and advertising. The software integrated into these kiosks can track individual interactions, such as users' most frequent requests and session durations while collecting data on traffic and pedestrian travel patterns.

Strategic placement of kiosks in heavily trafficked areas, public spaces, and transit stops maximizes effectiveness. Implementing these kiosks requires personalized software support and ongoing maintenance to ensure smooth operation.

In-Ground Parking Sensors: Along with hardware, parking meters, signage, and pricing algorithms, in-ground sensors have helped reduce traffic congestion and improve driver satisfaction. By integrating technology with demand-based pricing, city officials in Los Angeles sought to change driver behavior and balance demand by making 10-30% of the parking spaces on each block available throughout the day. Ensuring availability reduces congestion and pollution, shortens travel times, and encourages the use of alternative forms of transportation.

Figure 68. An in-ground parking sensor installed on a public parking space.

Results from the LA trial of the program from 2016 to 2021 indicate that the use of this technology led to faster circulation of traffic, with a 37% reduction in parking duration, up to a 10% increase in parking availability in some areas, and a 16% increase in parking revenues. However, the installation cost is a drawback, as it is relatively high compared to other Smart Parking technologies because one sensor is needed per parking space. Figure 69 shows an in-ground parking sensor for a public parking space.

Smart Communications Network: A new communications network has replaced pay phones across New York City, offering fast and free public Wi-Fi within a 750-foot radius of each kiosk. These structures also provide USB charging capabilities and feature a tablet for making phone calls and accessing city services, maps, and directions. An example is provided in Figure 70. Accessibility features such as TalkBack, HearingLoop, and Video Relay Service are available for visually and hearing-impaired individuals. Additionally, the kiosks can display public service announcements, local information, and transit schedules.

Figure 69. Communication networks providing free Wi-Fi, charging, and phone call capabilities.

The installation cost of these Smart Kiosks can exceed $30,000 per unit, but advertising opportunities are utilized to generate revenue and offset expenses. They are strategically placed in areas with high foot traffic, public spaces, and near transit stops.

Micromobility: Micromobility options are affordable, low-emission alternatives to driving and come in various forms, as seen in Figure 71. They are often intended for short trips, such as "first—and last-mile" transportation. They can be individually owned or accessed through shared fleets. According to a report by the National Association of City Transportation Officials (NACTO), users completed 136 million trips in 2019 on shared micromobility systems.

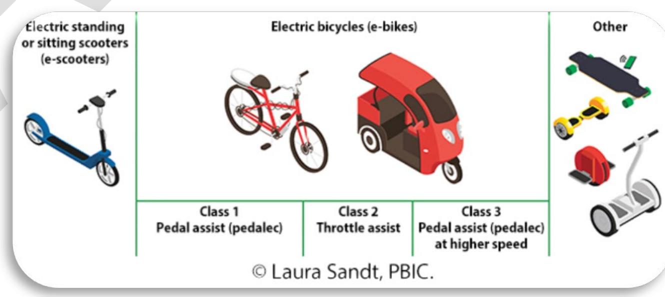


Figure 70. Micromobility devices.

Battery Exchange Stations: As part of the "Charge Safe, Ride Safe" initiative in New York, the city is introducing exchange stations for micromobility batteries to promote the safe charging of electric bicycles and prevent battery fires. This initiative aims to increase the safety of delivery drivers by improving the charging infrastructure. With the rise in e-bike usage among delivery drivers in NYC, the number of battery fires also surged from 40 in 2020 to 220 incidents in 2022. Four battery-swapping stations were installed in New York City to provide e-bike delivery workers and other users

Figure 71. Electric micromobility battery exchange station in NYC.

with safe and reliable charging options. An example of a battery exchange station in NYC is shown in Figure 72.

Wireless Charging for e-Mobility: The wireless inductive charging system for e-bikes simplifies charging by parking the bike. It comprises a weatherproof in-ground "charging tile" connected to the electrical grid and a kickstand hard-wired to the bike's battery. When the bike is parked on the tile, inductive coils transfer electrical current to the battery. The tile is installed like regular pavement tile and requires no specialized equipment. This technology is designed for e-bike rental fleets and ensures that bikes are always charged and ready. Figure 73 shows the technology in work.

Figure 72. E-bikes charging wirelessly

Street Legal Electric Micro Cars: Although resembling cars, they are legally classified as low-speed vehicles (LSVs) by the National Highway Traffic Safety Administration. LSVs have fewer regulatory requirements than traditional cars and can travel up to 25 mph (40 km/h). They are permitted on roads with posted speed limits up to 35 mph (56 km/h) as long as they meet specific safety and manufacturing regulations. These vehicles offer a cost-effective transportation solution, with prices typically around $9,000. A car-sharing scheme can be considered using these vehicles at mobility hubs. An example of a microcar in NYC is shown in Figure 74.

Figure 73. Micro car parked between two conventional cars in NYC.

CONNECTED AUTONOMOUS VEHICLE STRATEGIC PLAN

The Connected Autonomous Vehicle Strategic Plan (2023) explores the impact of Connected and Automated Vehicles (CAVs) on transportation in Miami-Dade County. It outlines the strategic planning efforts of the Miami-Dade Transportation Planning Organization (TPO) and Miami-Dade County for more multimodal transportation systems. CAV technologies are seen as transformative, with potential benefits including improved safety, increased efficiency, and reduced congestion. However, some challenges may be expected, such as data security and increased miles traveled by single-occupancy vehicles. Through the SMART Program, the Miami-Dade TPO is actively planning a multimodal transportation system, focusing on transit and transit-oriented communities (TOCs) along designated corridors. The plan considers various technologies beyond CAVs, such as electric vehicles, telework, and mobility-as-a-service (MaaS). It suggests creating a SMART CAV Concept of Integrated Operations (CIO) to coordinate the planning and operations of the multimodal network.

The study differentiates between connected vehicles (CVs) and automated vehicles (AVs) and highlights the importance of CV connectivity for realizing the full potential of AVs. AVs span a spectrum of automation levels, ranging from no automation, where the driver handles all driving tasks, to full automation, where the vehicle can autonomously perform all driving functions under any condition, with the option for manual control by the driver. In contrast, CVs utilize technology to communicate and connect with other vehicle-to-vehicle networks, eliminating the need for human presence onboard. Figure 75 presents a diagram of the vehicle communications network at work.

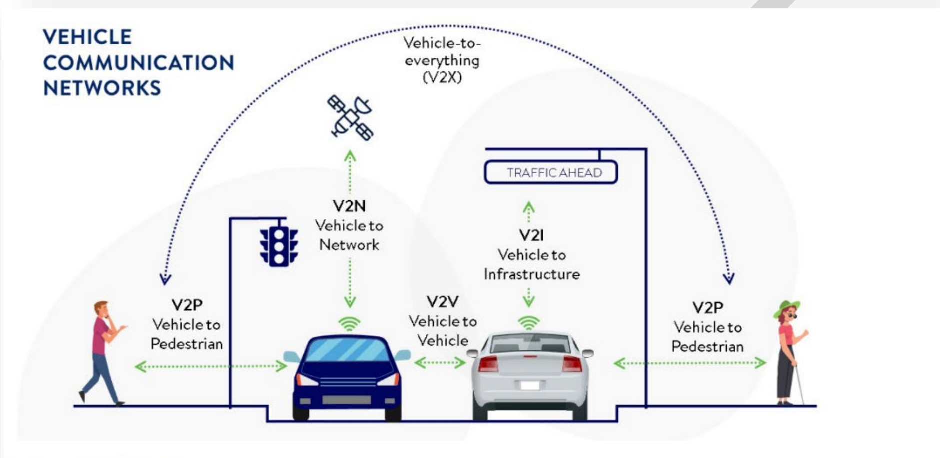


Figure 74. Connected vehicle communication networks.

Emerging technologies such as urban air mobility (UAM) and personal rapid transit (PRT) are recognized for their potential to transform transportation systems significantly. The study delves into four scenarios—Trends, Smart Cars & Roads, Smart Transit, and Smart Infrastructure Networks—with key findings advocating for using technologies to improve multimodal transportation systems. Two critical areas for future focus have been pinpointed: Multimodal Technology and Integrated Management and Operation, derived from insights gleaned from the pilot studies.

The SMART CAV Concept of Integrated Operations (CIO) framework was crafted to integrate and harness CAV technologies alongside other travel technologies, employing short--, mid-, and long-term strategies. The plan advocates for a comprehensive approach to planning for and leveraging CAV and related technologies to optimize multimodal travel and adapt to the changing transportation landscape in Miami-Dade County.

EMERGING TECHNOLOGIES FOR AUTONOMOUS VEHICLES

The following emerging technologies, identified through research, can be implemented to support connected and autonomous vehicle technology within the study area.

Autonomous Shuttle/Taxis/Ride-Hail Network Vehicles: Self-driving electric vehicles promise to address first-mile/last-mile transportation challenges. However, it's crucial to emphasize that expanding robotaxis into mixed traffic should be incremental. In California, where the technology is operational, the vast majority of collisions involving an autonomous vehicle were not the robotaxi’s fault, and no human injuries or property damage were reported in 90% of the collisions that occurred while the AV was in self-driving mode.

In Miami-Dade County, efforts to introduce the technology are being led by the Department of Transportation and Public Works (DTPW), which is testing a low-speed, automated vehicle (AV) shuttle within Zoo Miami starting in September 2022. This initiative aims to introduce the public to autonomous vehicle technology in a controlled environment.

Figure 75. Autonomous high-capacity mobility vehicles.

Technology for autonomous vehicles has advanced to provide a fully automated, on-demand ride experience similar to a personal private car at public transportation fare. High-capacity mobility systems utilizing autonomous personal cars moving in dedicated lanes, as depicted in Figure 76, can accommodate up to 10,000 passengers per hour and require significantly less capital expenditure, nearly 95% less than traditional mass transit systems. Operating costs are kept low, averaging $0.025 per passenger mile traveled, with zero greenhouse gas emissions. These systems prioritize inclusivity and are fully ADA-compliant, ensuring comfortable accommodation for passengers, including those using wheelchairs. With Continuous Flow technology, operating autonomously in dedicated lanes, they transport up to four passengers directly to their destinations without stops, resulting in travel times that are, on average, one-third shorter than alternatives.

Since 2023, autonomous taxis have been in commercial operation for driverless passenger transportation in San Francisco, enabling fare charging at any time.

Smart Street Sweepers: Smart Street Sweepers utilize sophisticated technology, including lidars, cameras, mm-wave radars to access CV technology networks, Global Navigation Satellite System, and antennas to achieve a comprehensive 360° coverage of their surrounding environment. With autonomous level 5 certification, these vehicles boast unparalleled capabilities. They operate with minimal noise pollution, enabling 24-hour use without disrupting residents. Moreover, their accurate and efficient recognition algorithms allow them to simultaneously track all objects in sight, ensuring thorough and efficient street cleaning. This advanced technology enhances the effectiveness of street sweeping operations and contributes to increased safety and cleanliness in urban environments.

Road Defect Detection System: The AI-powered road defect detection system utilized by Dubai RTA patrol cars employs laser technology capable of detecting cracks as small as 1 millimeter. This system scans motorways to identify defects and prioritize repairs, promptly alerting maintenance teams to take action. By addressing issues swiftly, the system aims to reduce accident risks and ensure the reliability of the transport network. The device, capable of identifying up to 13 types of defects, is mounted on patrol vehicles and has been used to create a highly accurate virtual map of Dubai's roads. This proactive approach seeks to extend road infrastructure lifespan and decrease maintenance costs, benefiting motorists and enhancing overall road quality.

Advanced Traffic Management (ATM) System: ATM Systems integrate technology to improve vehicle traffic flow and safety. A map of updates for this system within the study area is shown in Figure 77. In Miami-Dade County, the Department of Transportation and Public Works' Traffic Signals & Signs Division is implementing an ATMS to enhance mobility for commuters, transit users, pedestrians, and cyclists. This involves upgrading infrastructure by replacing outdated traffic signal controllers and installing new detection devices at approximately 3,000 signalized intersections. The ATMS will gather high-resolution data on vehicle location, speed, and turning movements to inform maintenance and operations decisions. It aims to optimize traffic signal performance, accommodate various transportation modes, and support innovative city initiatives by enabling two-way communication between vehicles and traffic signals. The project commenced in March 2021 and is expected to be completed within seven years, with an estimated cost of approximately $160 million.

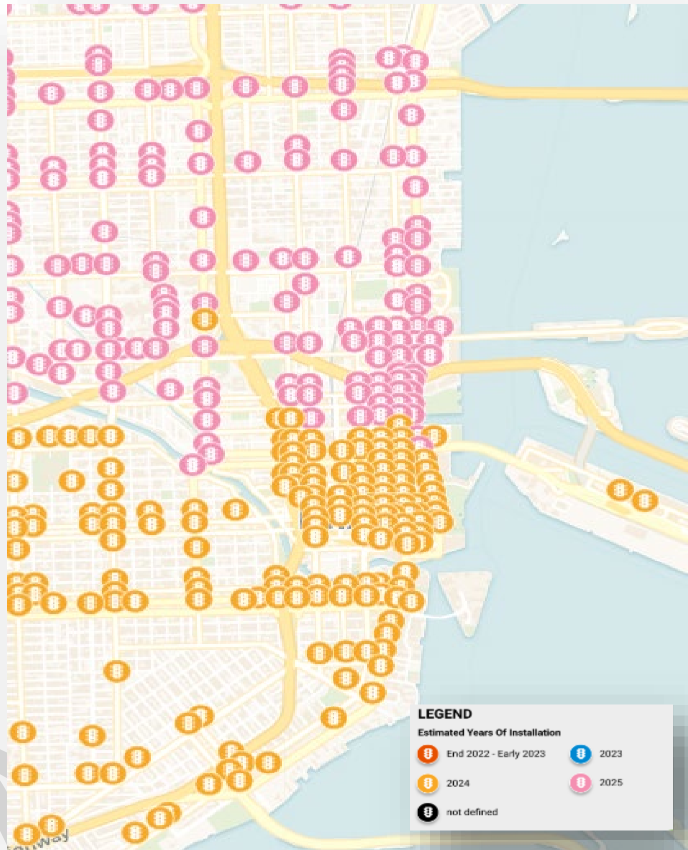


Figure 76. Location of signals with ATMS technoolgy in the study area.

MIAMI-DADE TPO CLIMATE RESILIENCY STUDY

In the summer of 2023, the Miami-Dade Transportation Planning Organization conducted a comprehensive Climate Resiliency Study to address the past, current, and future initiatives in South Florida that plan to combat the shocks and stressors associated with climate change. This study compiled existing resiliency efforts, local, state, and federal government strategies, and best practices from national and international efforts to help aid the resiliency and reliability of the transportation network by evaluating vulnerabilities and critical infrastructure for climate change-induced effects.

Improvements to pedestrian and bicyclist facilities and connectivity are highlighted throughout the study, emphasizing the current lack of safe pedestrian and bicycle systems. The existing conditions report concluded that “the TPO should encourage the alteration of existing roadway infrastructure and future construction projects to provide accommodations for micromobility options such as bicycles and scooters, and pedestrian travel” (Climate Resiliency Study, 2023).

The study included the following recommendations for micromobility and pedestrian improvements:

- Funding should be allocated toward acquiring additional right-of-way (ROW) for future sidewalks, bike lanes, and other mobility infrastructure.
- Initiate projects that improve neighborhood walkability, including changes through land use. Walkable neighborhoods may include quality footpaths, safety barriers, and complete streets that provide pedestrians with safe transportation options.
- Improve multimodal safety through additional bike lanes and other safety buffers to encourage increased usage of alternative forms of transportation.
- Continue to support alternative fuels micromobility services such as electric scooters, electric bikes, and Freebee.

EMERGING TECHNOLOGIES FOR RESILIENCY AND REDUCED CARBON EMISSIONS

The following emerging technologies have been identified as enhancing resiliency and reducing carbon emissions in the study area.

Sustainable Bus Shelters: Today, bus shelter facilities incorporate eco-friendly elements such as recycled plastics, sustainable wood, and energy-efficient lighting systems. Integrating solar panels to power lighting and digital displays reduces the shelters' carbon footprint and energy usage. In NYC, the Mass Transit Authority introduced the city’s first Solar-Powered Bus Stop during a pilot program in 2016. The stop, seen in Figure 78, was chosen due to a pedestrian fatality and complaints stemming back to 2009 of poor lighting conditions. Shelters can be designed to include USB charging outlets, motion sensors to conserve battery power, and high-intensity LED lighting.

Figure 77. NYC's first solar powered bus shelter installed in 2016.

Another emerging trend in bus shelter designs is the integration of green spaces and urban vegetation. Living green walls, vertical gardens, and rooftop planters are incorporated into shelter designs to enhance aesthetics, improve air quality, and provide natural shade. These green elements contribute to a healthier and more sustainable urban environment while creating inviting spaces for commuters to rest and relax. Notably, a green roof on a bus shelter in Utrecht, Netherlands, is shown in Figure 79. Over 316 bus stops have been converted to "bee stops" with the adoption of green roofs. This strategy is part of the Dutch nation's economy to be completely circular by 2050. A circular economy practices sustainable, renewable raw materials used repeatedly wherever possible. Products and materials are designed for circularity, reused, repaired, and refurbished, resulting in minimal waste production.

Figure 78. Netherlands' bee stops featuring living plants on the roof of bus shelters.

Figure 79. Bourke Street bioswale and cycling improvements.

Dedicated and Protected Bike Lanes: Creating dedicated bike lanes, separated from vehicular traffic by physical barriers, painted lines, or flexible posts, provides cyclists with safe and marked paths. One notable example of this approach is found in the city of Sydney, Australia. Sydney implemented a comprehensive program of cycling improvements as part of its 2030 master plan. Bourke Street, one of Sydney's pioneering cycleway projects, features a raised curb with a wide bioswale, serving as a protective barrier that separates two-way bike lanes from vehicular traffic. A picture is provided in Figure 80. Despite reducing travel lanes, the city experienced decreased congestion on roads and public transportation systems. This transformation also reduced emissions from fewer vehicles and enhanced particulate matter filtration, alongside carbon dioxide sequestration, facilitated by introducing new greenways.

Solar Umbrella Canopies: Many cities worldwide, such as Coral Gables, Florida, and Lisbon, Portugal, have embraced "umbrella skies" as an artificial shading technique to combat excessive urban heat while enhancing placemaking through art. However, the threat of hurricanes renders traditional umbrella canopies unsuitable for year-round installation.

As an alternative, innovative designs for solar-powered umbrellas are emerging to meet the demand for sustainable power, enhanced pedestrian comfort, and urban beautification. These solar umbrellas, exemplified in Figure 81, offer pedestrians shaded areas to seek relief from the heat while harnessing energy to power nearby streetlights or traffic signals.

Figure 80. Solar umbrella rendering.

Solar Sidewalks: Solar panels can be integrated into existing walkway surfaces, with advancements extending this technology to parking surfaces and roadways. However, the cost is substantial, averaging around $450 per square meter.

In Tampa, Florida, solar sidewalks represent a significant innovation. They can power major traffic signals at intersections, preventing outages during storms. Notably, one such sidewalk is installed at the East Cass Street and North Jefferson Street intersection, shown in Figure 82. Here, the traffic lights are powered by solar energy from the sidewalk. Comprising 84 solar panels, this sidewalk produces about 75% of the power needed to keep the lights on at this intersection. Additionally, with a battery bank, demonstrated in Figure 83, the lights can remain operational for several days during a power outage.

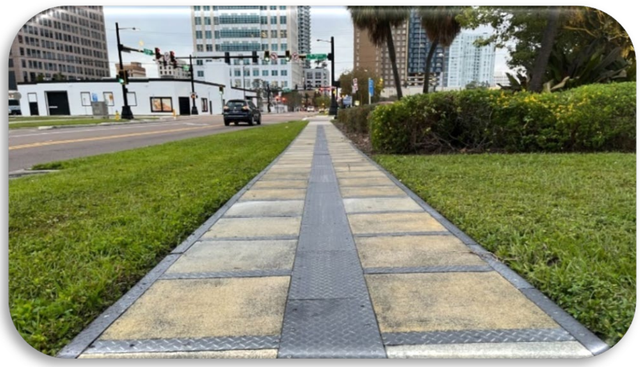


Figure 81. Solar panel technology installed on sidewalk in Tampa, Florida.

Figure 82. Solar sidewalk battery pack to store energy for power outage events.

Digital Technologies for Flood Prediction: Digital technologies play a vital role in flood prediction, prevention, and risk management. Real-time data, advanced predictive models, and early warning systems are essential for authorities and managing entities to anticipate flood events and implement effective solutions. To further protect communities from floods and enhance resiliency, the White House launched a new website and mapping tool in April 2024, shown in Figure 84. This tool allows users to search for an address to determine if it is in a high flood-risk area. The Federal Flood Standard Support Website and Tool assist users in implementing the Federal Flood Risk Management Standard (FFRMS), which applies to projects involving federal funds for new construction, substantial improvements, or repairs to address significant damage. These projects may include critical infrastructure, affordable housing developments, renewable energy initiatives, or broadband internet projects. The tool aids users in determining if their projects will be located within areas at increased risk of flooding, thereby supporting informed decision-making when seeking federal funding.

Figure 83. In April 2024, the White House introduced the Federal Flood Standard Support Tool.

Flood Infrastructure: Flood control infrastructure can take many forms, such as the example depicted in Figure 85, where a skate park facility in a park redirects stormwater to collection areas. Other methods for managing stormwater runoff include bioswales, landscaped extended swales, and utilizing permeable materials for surfaces.

Figure 84. Skate park facility redirects stormwater to collection areas

Solar Infrastructure: In Sejong, South Korea, mobility infrastructure integrates a five-and-a-half-mile bike path within the median of an eight-lane highway. An image is provided in Figure 86. This path is distinct for its integration of solar panels, illuminating the streets below. Designed initially to harness clean energy and offer recreational space, the eco-friendly cycle lane connects Daejeon to Sejong. Featuring 7,502 solar panels installed at intervals, covering three miles of the path, they annually produce 2,200 MWh of eco-friendly electricity. This power source is utilized for streetlights and electronic displays in Sejong, which are equivalent to powering 600 households, according to South Korea's Ministry of Land, Infrastructure, and Transport.

Figure 85. South Korea's solar-powered bike path.

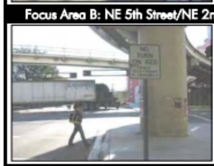
Illuminated Bike Lanes: This technology eliminates the need for traditional lights by using tiny, eco-friendly glow-in-the-dark stones that absorb sunlight during the day and emit a gentle glow at night. Figure 87 shows the technology in effect. A special coating secures the glow stones and ensures durability, creating a sturdy, smooth surface for cyclists. This coating protects the rocks from wear and tear caused by traffic and weather, providing the bike lane's longevity. This approach promotes sustainability by conserving electricity and contributing to a greener environment.

Figure 86. Illuminated bike lanes using eco-friendly technology.

TRAFFIC CALMING FOR PEDESTRIANS AT MIAMI DADE COLLEGE WOLFSON CAMPUS

The Wolfson Campus of Miami Dade College (MDC) is situated in the northern segment of Downtown Miami's Central Business District (CBD) and boasts an enrollment of over 20,000 students. Given its downtown location and sprawling layout across multiple city blocks within the grid street network, many students, faculty, and staff regularly traverse streets to access educational buildings, parking facilities, and transit stations on campus. This study endeavors to formulate recommendations for implementing traffic calming measures to mitigate the negative impacts of motor vehicle usage on pedestrians in and around the Wolfson campus. These recommendations, detailed in Table 2, encompass proposed enhancements to pedestrian connections and safety at critical locations throughout the campus.

Table 2. MDC Wolfson Campus Tiered Recommendations

Issues		Tier 1 Recommendations	Tier 2 Recommendations	Tier 3 Recommendations	Tier 4 Recommendations
Focus Area A: NE 5th Street at Wolfson Garage					
	• Heavy ped volume midblock (500-600 crossing per hour during peak hours) • Significant truck traffic • 5th St is a primary route into the Port • Potential for multiple threat ped crashes with 3-lane section	Advance Yield Line "Yield Here to Pedestrians" Signs Pedestrian Crossing Warning Sign ***($900 - $1,400)***	Tier 1 Improvements, plus the following: Overhead Sign w/ Flashing Beacons Bollards w/ Automatic Detection "Walk Between Posts to Activate Flashing Crosswalk" Signs for Peds ***($17,100 - $51,700)***	Exclusive Pedestrian Signal ***($50,000 - $75,000)***	Pedestrian Bridge ***($500,000 - $3,000,000)***
Focus Area B: NE 5th Street/NE 2nd Avenue					
	• Significant pedestrian activity (450 per hour in west crosswalk during peak hours) • Vehicle view of pedestrians can be obstructed by Metromover column • 3 ped crashes (1996-2003), 1 fatality • Lighting is very poor	"Watch Turning Vehicles" Pavement Legend for Peds "Turning Traffic Must Yield to Peds" Sign Ped-Oriented Street Lighting ***($16,500 - $25,000)***	Tier 1 Improvements, plus the following: Countdown Ped Signal Indicators Curb Extension (SE corner) "Pedestrian in Crosswalk" Internally Illuminated "Smart Sign" ***($31,500 - $71,400)***		
Focus Area C: NE 2nd Avenue/NE 4th Street					
	• Very heavy ped traffic (650-1,000 crossing per hour during peak hours) • Conflicts between WB left turning vehicles & pedestrians crossing in south crosswalk • Low volume of vehicles using 4th St	Curb Extensions (NE/SE corner; W side) Zebra Crosswalk Striping ***($16,500 - $63,000)***	Tier 1 Improvements, plus the following: Countdown Ped Signal Indicators Leading Pedestrian Signal Interval ***($20,500 - $70,300)***	Pedestrian Promenade Extension Textured Pavement (2nd Ave/4th St) Countdown Ped Signal Indicators Wolfson Campus Gateway Feature ***($1,467,000 - $1,669,000)***	
Focus Area D: NE 3rd Street					
	• Heavy pedestrian activity crossing 3rd St midblock (300 per hour during peak hour) • Bldg 1 steps are angled - peds tend to cross 3rd St at this same angle	Advance Yield Line "Yield Here to Pedestrians" Signs Landscaping Planter at Bldg 1 Steps Pedestrian Railing on Bldg 1 Steps "Use Crosswalk" Signs for Peds ***($4,600 - $13,100)***	Tier 1 Improvements, plus the following: Shift MDC Parking Lot driveway west Shift Crosswalk (Curb Ramp, Zebra Crosswalk Striping) Ped-Oriented Lighting on Walkway E. of MDC Parking Lot ***($19,900 - $36,600)***	Tier 2 Improvements, plus: Raised Crosswalk ***($29,900 - $56,600)***	
Focus Area E: NE 1st Avenue					
	• Heavy pedestrian activity crossing 3rd St midblock (400 per hour during peak hour) • Midblock pedestrian crossings occur over the entire block, not at one location • Many pedestrians cut through the MDC parking lot	Pedestrian Railing on E. sidewalk along 1st Ave ***($6,250 - $8,750)***	Tier 1 Improvements, plus the following: Fencing & Landscaping along Borders of MDC Parking Lot Countdown Ped Signal Indicators (2nd & 3rd St intersections on 1st Ave) Zebra Crosswalk Striping (1st Ave/3rd St) ***($35,690 - $83,250)***		

Alternative traffic calming measures include the potential conversion of one-way streets to two-way streets. The Miami Downtown Transportation Master Plan (MDTMP) recommends converting streets in the Downtown area, including NE 1 and 2 Avenues and NE 2 and 3 Streets near the campus, from one-way to two-way. While two-way traffic requires pedestrians to be more vigilant, as they must be aware of vehicles moving in opposite directions, it raises safety concerns. Additionally, two-way traffic travels at slower speeds, enhancing pedestrian safety.

EMERGING TECHNOLOGIES FOR IMPROVED WALKABILITY

The following emerging technologies have been identified to enhance walkability in the study area.

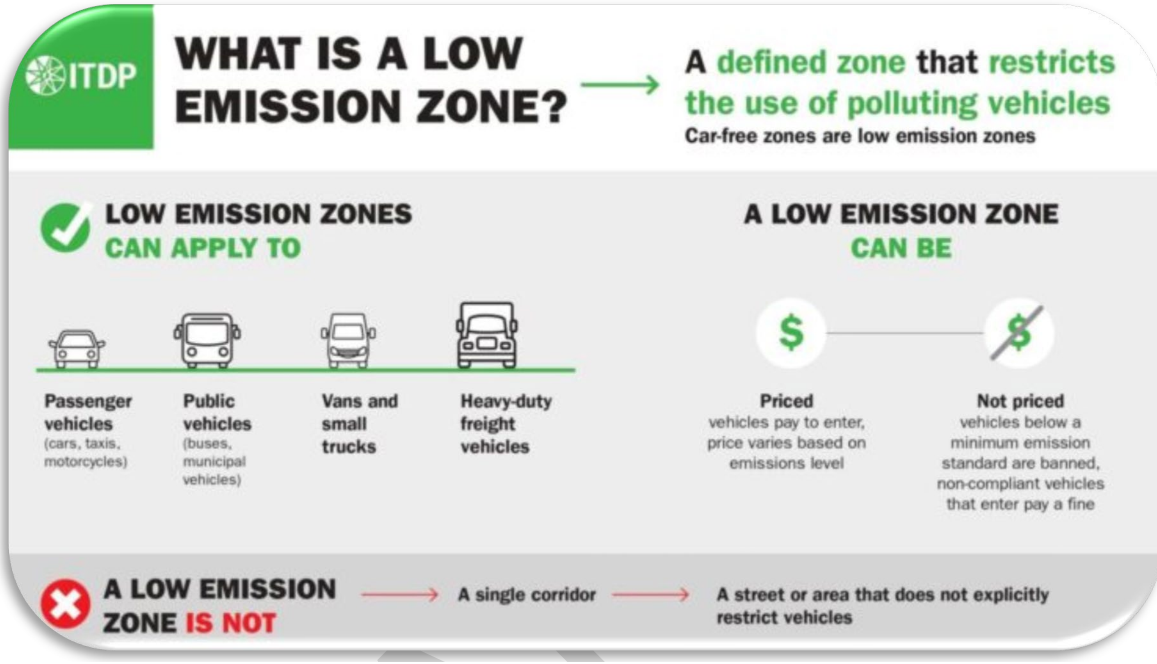


Figure 87. Diagram illustrating Low Emission Zones and their purpose.

Low-emission zones: Low-emission zones are an option for introducing traffic calming. A low-emission or car-free zone is a contiguous zone that restricts the use of polluting vehicles through priced and non-priced strategies, as shown in Figure 88. Priced LEZs restrict vehicles by charging drivers a fee to enter. Typically, higher-polluting cars pay a higher fee, while hybrid or electric vehicles pay a lower cost or enter free of charge. Non-priced LEZs restrict vehicles by banning the highest-polluting cars from entering the zone. Violators are usually charged a significant fine. Individual corridors are not considered low-emission zones because they are easy for drivers to avoid and will not spur a shift to cleaner vehicles. LEZs can generally have different sizes, pricing structures, operating models, terminology, and restrictions.

Interactive Pedestrian Crossing: This dynamic crossing caters to all users and is tailored for the smartphone era. By utilizing cameras to track objects, the crossing adjusts its orientation, markings, and colors based on the number of people needing to cross. In high-traffic areas, especially where smartphones are prevalent, additional prompts are provided for pedestrians, drivers, and cyclists to enhance road safety.

Figure 88. Interactive pedestrian crossing in South London.

The crossing, shown in Figure 89, employs dynamic road and pavement patterns designed to catch the attention of pedestrians immersed in their phones and encourage them to focus on crossing safely. It features a non-slip, waterproof surface that ensures safety in all weather conditions. An illuminated warning pattern also activates in hazardous situations, such as when a child unexpectedly enters traffic.

Powered by cameras capable of analyzing frames 25 times per second, the system tracks the trajectory of objects or individuals, anticipating their movements. During peak hours, the crossing expands to accommodate increased foot traffic, while during quieter times, such as early hours, it seamlessly blends into the surroundings. This innovative system was trialed in South London in October 2017.

Automated Pedestrian Detection: Automated pedestrian detection devices can sense when a pedestrian is waiting at a crosswalk, triggering an automatic signal switch to initiate the pedestrian WALK phase without requiring pedestrians to press a button. Moreover, advanced devices can assess whether a pedestrian requires additional time to cross the roadway, extending the crossing interval to accommodate slower pedestrians.

Various technologies can be employed for pedestrian detection, including infrared, microwave, thermal sensors, pressure mats, and computer-assisted video. Research conducted in Florida found that the thermal machine vision system performed best, exhibiting the highest detection accuracy and the lowest false detection rate when not required.

The installation of a pedestrian hybrid signal system typically incurs costs ranging from approximately $50,000 to $120,000, depending on site conditions and equipment availability. Operational expenses are estimated to be around $4,000 per year. Integrating automated detectors into an existing pedestrian signal may range from $10,000 to $70,000 per crosswalk.

PedSafe represents an innovative pedestrian and bicycle collision avoidance system currently under development by FDOT. This system, highlighted in Figure 90, aims to enhance road safety by alerting drivers when pedestrians or cyclists are nearby. Additionally, traffic signals will be equipped to detect pedestrians crossing the road.

PedSafe will leverage advanced signal controller technology, Connect Vehicle technologies, and existing communication capabilities to reduce the occurrence of pedestrian and bicycle crashes effectively.

Figure 89. PedSafe: Pedestrian and Bicycle Collision Avoidance System by FDOT utilizing Connected Vehicle technology.

Animated Eye Displays: Animated or "roving" eye displays on pedestrian signals are undergoing evaluation in Las Vegas and San Francisco to assess their effectiveness in prompting pedestrians to watch for vehicles turning into the crosswalk from adjacent streets. An example is provided in Figure 91. These displays feature animated eyes that scan from side to side during the walk indication, reminding pedestrians to check for oncoming traffic. Incorporating animated eye displays into the Manual on Uniform Traffic Control Devices (MUTCD) standards signifies their potential as a standardized safety feature.

Figure 90. Roving eye technology sign.

Moreover, LED animated eyes are considered to warn motorists about crossing pedestrians. Positioned overhead before marked but unsignalized crosswalks, these displays alert drivers to pedestrian presence. Activation of the sign can occur via a pushbutton by pedestrians or automated pedestrian detection. The direction of the animated eye display—left, right, or both—is determined by the pedestrian's crossing direction. Research teams in Las Vegas and Miami are currently evaluating the efficacy of these displays in enhancing motorists' awareness of pedestrians in crosswalks.

Accessible Pedestrian Signals (APS): APS utilizes auditory tones, speech messages, and tactile feedback to assist pedestrians, particularly those with visual impairments, in safely crossing streets.

Introduced in the 1920s and becoming more prevalent by the 1970s, APS initially emitted sounds like "cuckoo/cheep" and was integrated into pedestrian crosswalks. However, their implementation sparked debate within blind communities, with the American Council of the Blind (ACS) advocating for APS installation. At the same time, the National Federation of the Blind (NFB) expressed concerns about independence.

Despite the controversy, cities like San Francisco have mandated APS installation at all new traffic signals and significant signalized intersections undergoing upgrades. Recent legal actions in Chicago and New York, including an important ruling in 2023, have compelled the installation of APS at all light-controlled traffic intersections.

APS devices range from $500 to $10,000 per unit.

Safety Reflectors: Smart reflectors can be wirelessly controlled via a mobile phone application. When a pedestrian approaches a crossing, the reflector at the location can be made to blink and alert drivers. In the future, the reflector can communicate directly with smart traffic lights or cars.

Solar-Powered In-Road Light System: These systems have been demonstrated to have an accident rate of 80 percent less than predicted for uncontrolled, unlit crosswalks. Solar-powered in-road light systems alert motorists to the presence of a pedestrian crossing or preparing to cross the street. Lights are embedded in the pavement on both sides of the crosswalk and oriented to face oncoming traffic. In-road warning lights produce a daytime-visible light focused directly in the driver's line of sight. When the pedestrian activates the system by using a push-button or through detection from an automated device, the lights begin to flash in unison, warning the motorist that a pedestrian is in the vicinity of the crosswalk ahead. The flashing

Figure 91. Solar-powered pedestrian crossing system.

LEDs shut off after a set period, or the time required for pedestrians to cross the street safely. An example is seen in Figure 92.

Video Recording: Security cameras launched in China assist law enforcement agencies in analyzing vehicle and pedestrian traffic with real-time results. Figure 93 provides a sample of the technology in action. Background footage is automatically removed while pedestrians, cars, and bicyclists are extracted and categorized in real time.

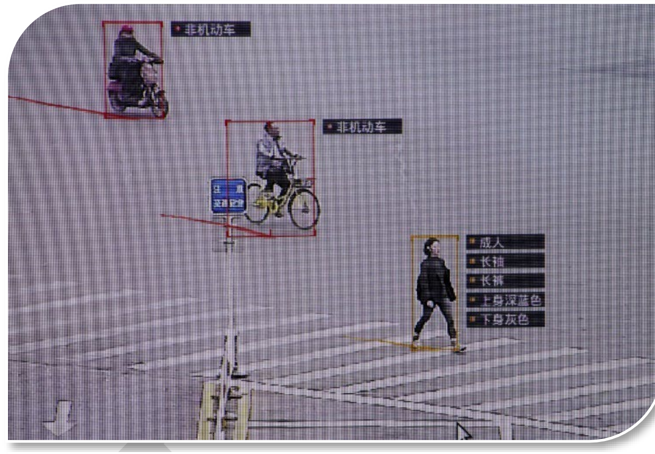


Figure 92. Video recording to enforce pedestrian safety.

RFID technology: Utilized in initiatives like Green Man+, it addresses the needs of elderly pedestrians and persons with disabilities who require more time to cross streets. Through RFID-enabled cards, users tap the card on a reader mounted above the standard push button on traffic light poles. Once verified, the system extends the green time for crossing, varying from 3 to 12 seconds based on the crossing's size.

RFID technology relies on readers detecting designated RFID cards issued to elderly and disabled pedestrians, prompting the crossing light to extend. These sensors are cost-effective to purchase and install, with associated cards incurring minimal costs. Targeted implementation areas prioritize locations with larger aging populations, identified through public input to pinpoint crosswalks most in need of extended crossing times.

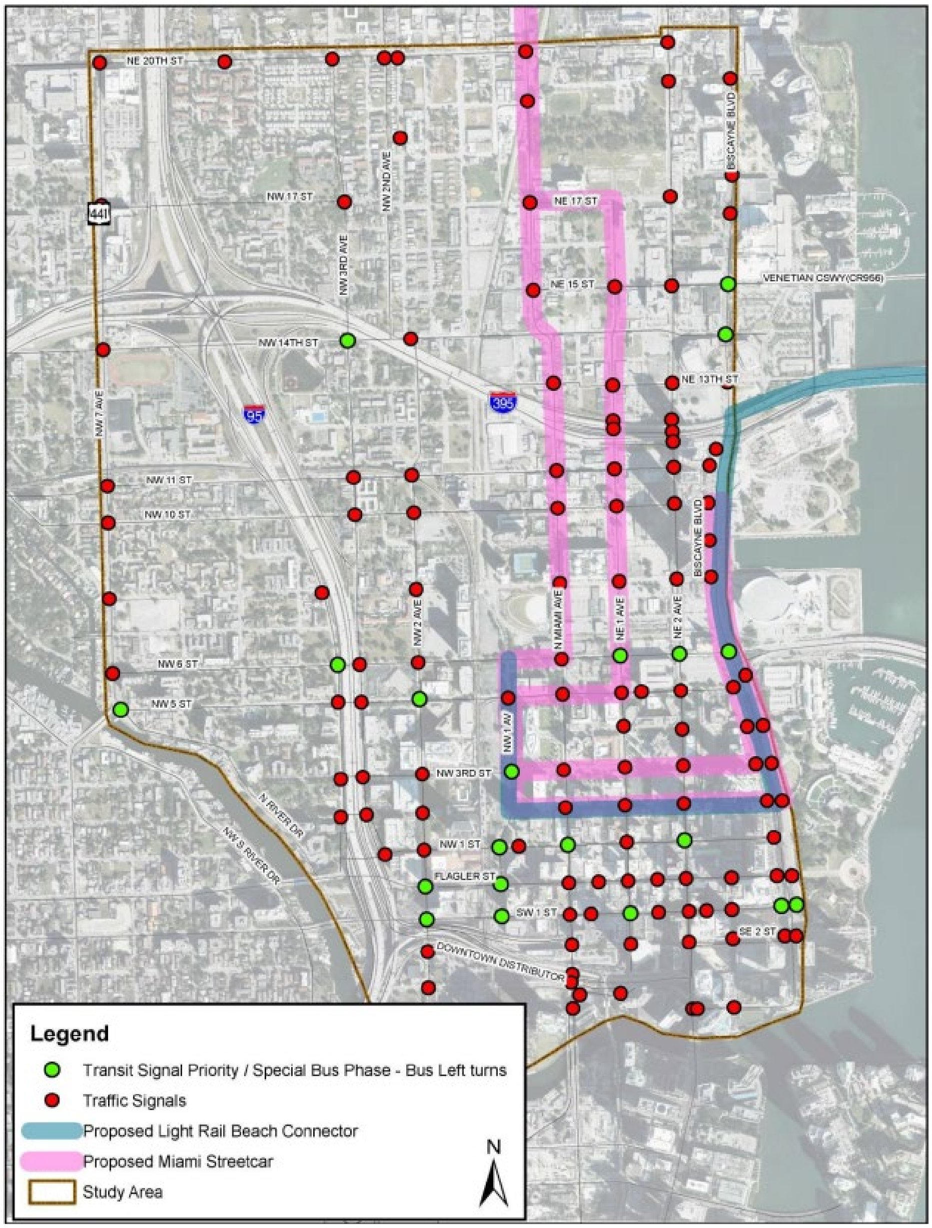
Audible Information Devices (AID): AIDs offers custom messaging with a built-in speaker and microphone, assisting visually impaired pedestrians with up to 60 seconds of pre-recorded instructions when roads and sidewalks are closed. Motion-activated recording and customizable detection range ensure efficiency, while the built-in microphone adjusts decibel levels based on surrounding noise. Compliant with MUTCD Section 6C.03 for providing audible information devices to pedestrians with visual disabilities.

HD Lighting Systems: Integrate projection technology from digital micromirror devices (DMDs) into the vehicle's headlight. A camera system captures street signs and other relevant information, then displays it on the road ahead through the car's headlights. GPS data provides additional details such as speed limits and hazards. The system can project a virtual crosswalk in stopped vehicles for pedestrian safety. Hyundai Mobis developed HD lighting technology for their cars. The technology is highlighted in Figure 94. Further research is recommended for using the technology in public transit vehicles.

Figure 93. HD lighting system technology projects street signs on road.

BUS LANES IN DOWNTOWN MIAMI

The Downtown Miami Bus Lanes Study assesses existing transportation conditions. It provides a framework for identifying and evaluating potential transit priority treatments in downtown Miami and locations where technology or infrastructure should be implemented. This includes roadway segment treatments, exclusive or semi-exclusive bus lanes and stop consolidation, and intersection treatments, such as transit signal priority (TSP), queue jumps/bus bypass lanes, and curb extension. The map below identifies traffic signals in the study area designated for transit signal priority and special phasing for bus left turn lanes. Transit Signal Priority (TSP) technology uses vehicle location and wireless communication technologies to advance or extend the green light of a traffic signal, allowing a bus to continue through an intersection. This helps to reduce travel times and ensure on-time arrivals.



Map 5. Map of downtown Miami: bus transit signal prioritization locations and transit routes.

Routes in the study area were identified based on their ability to facilitate conversion and integrate the necessary infrastructure and equipment to implement the transit signal priority technology.

- **Recommended East-West Bus Lanes -** The most significant congestion experienced by buses in the east-west direction was identified to be along NE/NW SW/SE 1 Street. A lane on SW/SE 1st Street from SW 2 Avenue to SE 1 Avenue is recommended to be designated a business access and transit lane (BAT) or bus rapid transit lane and right-turn vehicle lane during at least weekday peak periods, if not all day. On NE/NW 1st Street, providing a westbound bus rapid transit lane from NE 1st Avenue to I-95 that would mirror an eastbound BAT lane on SW/SE 1st Street is desirable; however, it will require the removal of existing parking lanes. Having BAT lanes on SW/SE and NE/NW 1 Street would facilitate BRT operations in the Flagler Street corridor west of downtown. A BAT lane was also recommended for westbound NE/NW 6 Street, from Biscayne Boulevard to west of I-95. With the construction of the PortMiami Tunnel and the diversion of some truck traffic off this street, NE/NW 6 Street was identified as having excess capacity to convert the right curb lane to a BAT lane and provide two travel lanes. This route also offers direct access to MiamiCentral and Government Center stations. Ideally, an eastbound BAT lane on NW/NE 5 Street is desirable to mirror the westbound lane on NE/NW 6 Street. However, since the study's completion in 2015, these streets are no longer viable routes since they are fitted with protected bike lanes.

- **Recommended North-South Bus Lanes -** Developing bus lanes on the north-south street system is more challenging. A potential reduction of Biscayne Boulevard to four lanes with the Biscayne Green project and the magnitude of traffic on that street suggest the corridor would be adversely impacted if a lane in one or both directions were converted to a BAT lane. This leaves the through north-south streets west of Biscayne Boulevard as potential BAT lane candidates. These include NE/SE 2 Avenue (southbound), SE/NE 1 Avenue (northbound), and Miami Avenue (southbound).

EMERGING TECHNOLOGIES FOR TRANSIT

In addition to the Transit Signal Prioritization technology identified in the study, the following emerging technologies are recommended to enhance bus and public transit use.

Transportation as a Service (TaaS): Leverages on-demand services like ride-sharing and public transit to offer flexible and cost-effective alternatives to traditional car ownership. The core idea is to optimize services using cloud-based technologies, data analytics, and machine learning. TaaS challenges the conventional notion of car ownership, advocating for a model prioritizing renting over owning. This reduces congestion and emissions in urban areas and redefines the need for extensive parking infrastructure. The emergence of self-driving cars adds a layer to TaaS, potentially reshaping the automotive industry. As the shift towards TaaS gains momentum, it's anticipated to impact traditional car sales, significantly changing consumer behavior.

Mobility as a Service (MaaS): MaaS is a comprehensive approach integrating various transportation and related services into a unified, on-demand mobility solution. MaaS simplifies the user experience by providing a single application and payment channel, eliminating the need for multiple ticketing and payment processes. MaaS operators curate a diverse menu of transportation options, including public transit, active modes such as walking and cycling, ride-sharing, car-sharing, bike-sharing, taxis, car rentals, and even combinations of these modes. This means users no longer have to locate, book, and pay for each mode of transportation separately. Instead, MaaS platforms enable individuals to plan and book door-to-door trips through a single app. These platforms consider real-time conditions across the entire transportation network, considering all available options and the user's preferences, such as time, convenience, and cost. Additionally, MaaS streamlines the payment process, moving us toward a more user-centered and convenient approach to mobility.

Multi-Purpose Bus Posts: The AI-driven multi-purpose bus stop post, powered by solar energy, offers a versatile platform capable of displaying a wide array of information, ranging from transit schedules to advertisements and local crime or advisory alerts. Complemented by IoT sensors and onboard computers for edge computing, this infrastructure extends across the entire transport network. Transport operators and partners can access and archive real-time data collected via the bus post's open data architecture.

Similar posts, like the one in Figure 95, have been deployed in Montreal, Canada, with remarkable results. These installations have increased transit ridership and enhanced customer satisfaction and efficiency in transit operations. Through innovation and technology, these bus stop posts contribute to advancing sustainable and efficient public transportation systems.

Figure 94. Example of multipurpose bus post.

Real-time Public Transit Vehicle Arrival Information System: GPS technology can provide passengers real-time bus arrival information, including waiting times and essential service messages. This can help increase ridership and hold the service accountable. The capital costs for implementing real-time bus arrival information can vary, ranging from $60,000 for a small deployment to $69.75 million for a more extensive deployment (as seen in London buses). Real-time information can be installed at bus stops and made available on the web and mobile applications, enabling users to plan their trips more effectively.

Air-conditioned bus shelters: These enhance the comfort and appeal of public transportation, particularly in areas with warm climates. For instance, the bus shelter in Hialeah, Florida, was constructed for $65,000. These shelters are typically prioritized for installation at bus stops with the most significant sun exposure and highest passenger usage, making them a valuable investment in improving the overall transit experience.

Figure 95. Air-conditioned Bus Stop at Hialeah Metrorail Station

Figure 96. Automated Bus Enforcement Camera.

Cameras & Artificial Intelligence (AI) Enforcement: Automated camera enforcement laws are becoming more prevalent nationwide following recent enforcement bills in Illinois, California, and New York. In 2019, the New York State Legislature extended authorization to allow camera-based enforcement on all bus lanes within New York City. The initiative combined camera-enforced bus lanes with other bus improvement strategies tailored to specific corridors and yielded significant bus speed improvements, ranging from 15% to 31%, depending on the corridor. Before, the NY DOT only relied on a fixed-location camera system. In the fixed system, two cameras are mounted above the bus lane to capture potential actions in the bus lane and show other activity on the street that might have forced a vehicle to use it. If a vehicle other than a registered bus continues through either of the cameras without turning right, these cameras identify a potential violation. An automated bus enforcement camera can be seen in Figure 97.

The NYC MTA has partnered with HaydenAI to enhance camera enforcement using advanced Artificial Intelligence technology. Since July 2022, the MTA has deployed 300 mobile lane enforcement systems as part of the Automated Bus Lane Enforcement (ABLE) program. An example of the camera system is provided in Figure 65. The goal is to equip 500 buses with this technology by June 2023. ABLE has proven successful in changing driver behavior and keeping bus lanes clear for buses. As of October 2022, 80% of drivers who committed a parking violation in a bus lane did not commit a second violation.

In 2021, California passed Legislation AB 361, allowing towns and cities to install cameras on parking enforcement vehicles to enforce bike lane violations. This new technology, highlighted in Figure 98, uses AI enforcement to keep bike lanes safe and accessible for riders by reducing illegal parking that endangers cyclists' safety. It operates similarly to the technology developed for bus lanes.

Figure 97. AI technology for bike lane enforcement.

NON-MOTORIZED NETWORK CONNECTIVITY PLAN

The Miami-Dade Non-Motorized Network Connectivity Plan aims to identify and fill critical gaps in the County's non-motorized transportation network. These networks primarily focus on walking, wheelchair travel, and bicycling and supply numerous benefits, including environmental sustainability, healthier communities, and increased mobility for young, old, and low-income residents.

The study determined that Miami-Dade County currently provides over 250 miles of bicycle facilities, including on-road bicycle lanes, shared-use paths, paved shoulders, and wide curb lanes. These facilities were often implemented as projects of opportunity in conjunction with other road work like resurfacing streets. As a result, the existing non-motorized network is often fragmented and needs to allow seamless trip-making to common destinations.

Non-motorized transportation improvements should be implemented as a coordinated set of inter-disciplinary methods, including implementing sidewalks, crosswalks, bicycle lanes, shared-use paths, non-motorized shortcut paths, traffic calming, street furniture, safety education programs, law enforcement programs, encouragement activities, end-of-trip facilities (such as bicycle parking and showers/changing rooms at employment centers), automated bicycle rental systems (to improve access to bicycles for trip-making) and developing pedestrian-oriented land use and building design.

The M-path route, highlighted in the Non-Motorized Network Connectivity Plan as a significant route, faces a hurdle with the M-Path Bridge over the Miami River. A pedestrian and bicycle facility would demand substantial capital investment, necessitating either a fixed bridge meeting minimum height clearance for boats to pass under or a movable bridge structure, suboptimal for bicycle-pedestrian use. Instead, enhancing connectivity to the Miami Avenue Bridge via the Miami River Greenway is the preferred solution.

The Commodore Trail Connection to the Rickenbacker Causeway project identifies routes for linking the non-motorized network, extending the Commodore Trail connection to Brickell Avenue and onto the Rickenbacker Causeway. A connection from the Vizcaya Metrorail overpass along SE 32nd Road provides connectivity between the Commodore Trail and the M-Path. Given the high usage of the Commodore Trail and the M-Path, a connection between them would yield significant benefits. Furthermore, these non-motorized transportation network projects emphasize the link to transit in the study area, especially the Vizcaya Metrorail and Brickell Station.

EMERGING TECHNOLOGIES FOR NONMOTORIZED NETWORK IMPROVEMENT

Emerging technologies for nonmotorized network improvements identified from the research include:

Bicycle Detection Systems are essential components of actuated signals, alerting the signal controller to the demand for bicycle crossings on specific approaches. Detection methods include push buttons or automated systems such as in-pavement loops, video cameras, or microwave sensors. In Figure 99, a sign notifying users of a bicycle detection system is installed on a traffic post.

Figure 98. Bicycle Detection System alert sign.

Traditionally, inductive loop vehicle detection is calibrated to detect vehicle size or metallic mass. An example is provided in Figure 100. However, adjustments must account for bicycles' smaller metallic mass to detect them. Otherwise, bicyclists may have to wait for a vehicle to trigger the signal, dismount and use the pedestrian button (if available), or cross unlawfully. In addition to inductive loops, video detection, and miniature microwave radar can also be calibrated to detect bicycles.

Figure 99. Bicycle detection system using loop vehicle detection technology.

Implementing this technology enhances cycling efficiency, improves the convenience and safety of bicycling, and legitimizes bicycling as a mode of transportation. Maintenance involves monitoring and adjusting the sensitivity settings of inductive loop detectors over time. Several cities, including Austin, TX, San Luis Obispo, CA, and Madison, WI, are incorporating these technologies into their transportation systems.

Bicycle Traffic Signals: Implement bicycle-specific traffic signals with dedicated green lights for safer and more efficient intersection crossings. Equipped with bicycle signal heads with sensors, these signals enhance safety and collect valuable rider data, aiding project prioritization and grant applications. An example is shown in Figure 101. Bicycle signals are electrically powered devices used alongside existing traffic signals or hybrid beacons to address safety and operational issues related to cycling. Installed at signalized intersections, these signals indicate bicycle-specific phases and timing strategies, typically using standard three-lens configurations in green, yellow, and red. By incorporating these signals, cities can improve cyclist safety and promote active transportation.

Figure 100. Bicycle traffic signals can be equipped with sensors for data collection .

Automated Bicycle Counters: Utilize sensors embedded in the pavement to gather data on bike traffic, providing valuable insights into ridership patterns. This data aids in prioritizing projects and assessing their impact. By promoting transparency and normalizing biking, these counters encourage increased bicycle usage. However, each counter typically has a price tag of around $60,000. Counters should be installed in areas with high bicycle traffic for optimal effectiveness.

Radio Beams: Utilizing ultra-low power, high-frequency pulses transmitted and reflected off target objects like bicyclists, radar sensors installed in the pavement analyze return pulses to determine object type, distance, and motion. This detection technology enables traffic signals to adjust timing and phasing, significantly enhancing cyclist safety by increasing visibility and ensuring fair passage. While sensor costs can reach upwards of $3,000, economies of scale may reduce per-site expenses with bulk purchases. Identifying streets with high bicycle usage and analyzing crash data guides the deployment of these sensors to problematic areas.

Thermal Imaging Technology: Thermal imaging cameras differentiate between vehicles, pedestrians, and bicyclists, aiding in identifying problematic areas. Pedestrian sensors control traffic signals or warning lights by detecting pedestrians at intersections and transmitting data to the controller for dynamic traffic signal adjustments. The technology also activates warning lights for better visibility. Installation costs for thermal sensors at intersections can amount to up to $16,000 each. Examining streets with high bicycle usage and crash data identifies intersections with high pedestrian and bicycle crash rates, making them prime candidates for thermal sensor installations.

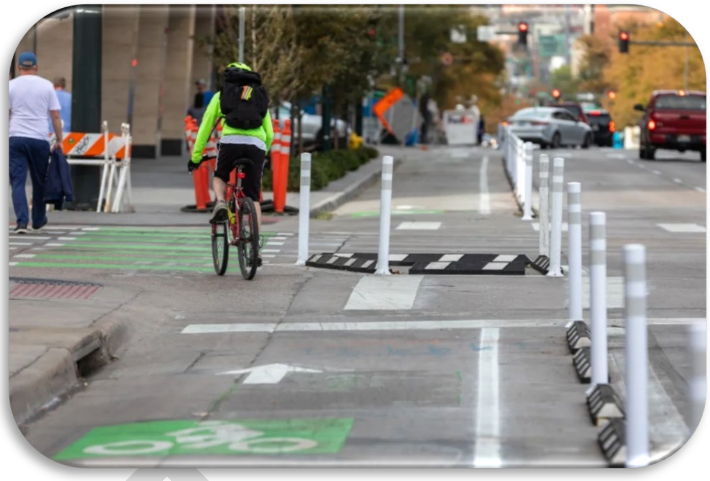


Figure 101. Example of Denver Wedge installation.

The Denver Wedge: The City and County of Denver's Department of Public Works recently implemented a pilot project in downtown intersections, installing rubber curbs and plastic posts to create "corner wedges," an example shown in Figure 102. These wedges slow down left-turn drivers, promoting safer interactions with cyclists and pedestrians. Additionally, cyclists can safely advance at red lights without obstructing pedestrians, addressing concerns about drivers rushing to turn left at green lights. The project encourages cyclists to navigate these intersections cautiously, enhancing the overall interaction between cyclists and pedestrians, particularly during peak periods of pedestrian activity.

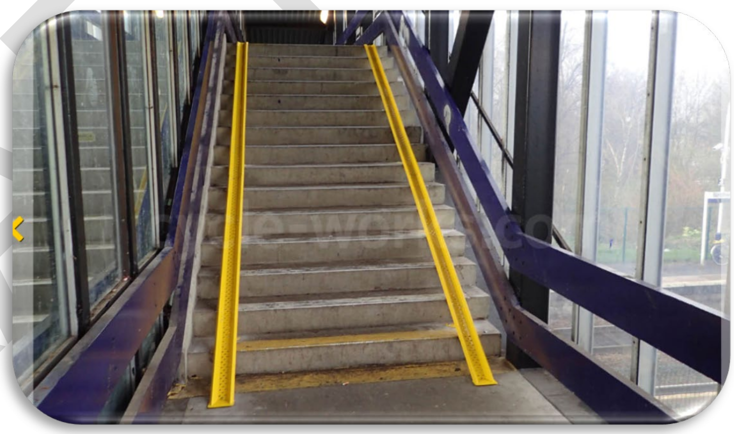


Figure 102. Bicycle runnels on stairs.

Bicycle Runnels: Runnels, or bicycle stair channels, run alongside pedestrian stairways, facilitating the movement of bicycles up or down stairs. Although accessible stations may have elevators for bikes, runnels are often faster and can accommodate more bicycles. Additionally, runnels help maintain forward movement and passenger safety by guiding bicycles along designated paths. Ideally, runnels should be incorporated into new stair designs rather than retrofitted later. This approach ensures easier accessibility and smoother integration into station infrastructure. An example is provided in Figure 103.

Portable Propulsion Device: The portable propulsion device in Figure 104 is designed to instantly upgrade any bike, including shared bikes, to an e-bike without needing tools. The unit features optical sensors that detect when the pedals are being pushed and use a lithium-ion battery pack designed for minimal environmental impact. Additionally, it can recapture energy during downhill riding and braking, enhancing efficiency and sustainability.

Figure 103. Portable propulsion devices can convert conventional bikes to e-bikes.

BICYCLE WAYFINDING SYSTEM STUDY

Miami-Dade County's bicycle route numbering and wayfinding system has existed since the early 1980s. Since then, the bicycle network has significantly expanded. While the existing route numbering system has continued to provide route designation to several facilities, a more dynamic and expansive numbering system was recognized as needed.

In 2016, the TPO commandeered a study to develop guidelines for implementing an update to the extensive bicycle wayfinding system in Miami-Dade County. Ideas were gleaned from wayfinding systems used in other cities and practices developed by the National Association of City Transportation Officials (NACTO) and the requirements outlined in the Manual on Uniform Traffic Control Devices (MUTCD). For example, in Berkeley, California, in addition to traditional bicycle wayfinding signs, streets that are part of the bicycle route network have a similar purpose coloring and logo as the bicycle boulevard signs. Figures 105 and 106 highlight these wayfinding signs.

Figure 104. Wayfinding sign in Berkeley, California designed to notify users of the bike/ped routes.

Figure 105. A color-coded scheme is employed to facilitate navigation for both cyclists and pedestrians.

The current bicycle wayfinding system provides even numbers for east-west routes and odd numbers for north-south routes. It also includes some lettered bicycle routes, including the M-Path (Route M) and the Venetian Causeway (Route V).

The study included county-wide recommendations and route-specific recommendations. For county-wide implementation, the study recommended:

- Signage at transit stations to inform potential users of available nearby facilities and improve first/last-mile connections.
- Placing wayfinding signage at major destinations and attractions
- Implementation of three types of signs for bicycle wayfinding:
  - Confirmation Signs, which verify users are on a specific route.

  - Turn Signs lets users know when they need to change directions.

  - Decision Signs provide information when two or more potential trips diverge.

In downtown Miami, the Baywalk shared-use path along Biscayne Bay was identified as a pilot project to implement route-specific wayfinding signage. Being in the urban core, this project provides wayfinding to serve cyclists and pedestrians, which differs from the wayfinding recommended for other county areas. The wayfinding in the Downtown project aims to offer bicyclists and pedestrians directions to nearby attractions, transit stations, parks, routes, and the several disconnected sections of the Baywalk.

Wayfinding in an urban core, particularly for pedestrian use, is best provided through the combined use of maps, information kiosks, and decision signage. It should inform users of their immediate surroundings within a ¼ mile or 5-minute walking distance. Locations for kiosks are recommended in areas with high pedestrian traffic and at crossroads of various strips. Within Downtown Miami, it is recommended that they be on the main path into Bayfront Park, between the arena and Museum Park, and at Brickell Point. Signs for key attractions should be placed where the Baywalk runs near Biscayne Boulevard. This would provide wayfinding to pedestrians on both Baywalk and along Biscayne Boulevard.

Three distance ranges were developed to guide wayfinding sign installations:

1. Less than 2 miles or a less than 15-minute bicycle ride
2. Up to 5 miles, or about a 15 to 30-minute bicycle ride
3. More than 5 miles or a bicycle ride over 30 minutes.

Based on the installation guideline, the study recommended:

- Wayfinding to downtowns may vary depending on the size of the municipality but should typically be signed further out as far as 5 miles or more than 30 minutes.
- Wayfinding to transit stations should be primarily located along bicycle routes. It should be geared towards major transit: Tri-Rail, Metrorail, and Metromover stations and placed as far as 15-30 minutes from the facility.
- Wayfinding to regional and local parks may be placed on- and off-route depending on proximity to the park and placed as far as less than 15 minutes from local parks or 15-30 minutes from regional parks.
- Entertainment venues include sporting arenas, zoos, museums, and other amusement or themed parks. Signage shall be placed at least 15 to 30 minutes from the site.
- Wayfinding to key neighborhoods such as Wynwood, Midtown, and South Beach should be provided both on- and off-route and placed at locations within 15 of the neighborhood.
- End-of-line destinations should be signed along respective routes as needed.

Finally, wayfinding signs should not be limited to bicycle routes only. Bicycle wayfinding should also be placed at major destinations, transit stations, bicycle parking, and bikeshare stations, and pedestrians and bicyclists should be directed to nearby bicycle routes and attractions.

EMERGING TECHNOLOGIES FOR WAYFINDING

Since the study's completion in 2016, wayfinding has emerged with new technology and includes:

Augmented Reality (AR): Wayfinding technology has advanced since the study's completion. Today, Augmented Reality (AR) can enhance wayfinding, allowing users to interact with and navigate spaces using their phones or tablets. An example of this technology is the navigation application commonly included in smartphones. Users can use their phone camera to navigate their surroundings, mimicking the real-world surroundings with visual and auditory cues. The use of the technology is showcased in Figure 107.

Using Internet of Things technology, wayfinding can be enhanced to provide real-time information related to traffic, transit, route obstructions, weather, or emergency events.

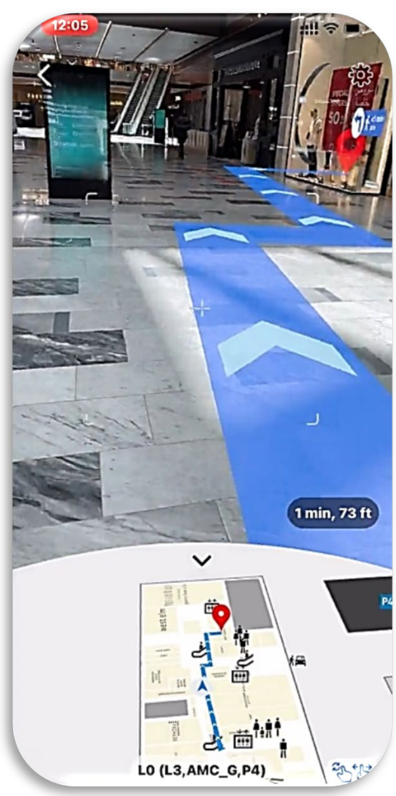


Figure 106. Augmented Reality wayfinding, digitalsignagepulse.com

Automated Pedestrian and Bicycle Counters: Counters can identify where walkers and cyclists are going, and these routes can be prioritized for wayfinding. Counters use sensors embedded in the pavement to collect data that uncovers ridership information and the route frequency of use by a pedestrian, helping prioritize projects and evaluate their effectiveness. This data and transparency normalizes active mobility and encourages more use. Each counter costs around $60,000. Counters are most effective when installed in areas with heavy bicycle and pedestrian use. The Washington DC district Department of Transportation maintains a system of automated counters to measure the number of people walking and biking. DDOT began installing these counters in 2014 and now has 18 in operation. Counters have been installed in both bicycle lanes and trails. DDOT monitors the continuous data stream to analyze trends in walking and biking, assess the value of its facility investments, and apply this data to plan new bike lanes and trails.

Smart Furniture: Smart street furniture includes signs, bus shelters, garbage cans, seats, and kiosks. This furniture serves as an inviting places to relax while offering free Wi-Fi, USB charging, integrated city maps, and real-time city information and alerts. These smart installations can also collect user data and metrics such as temperature and foot traffic counts. A data plan can cost $600 to $2,000 per year for a bench, and the purchase price for each bench unit is $3,800.

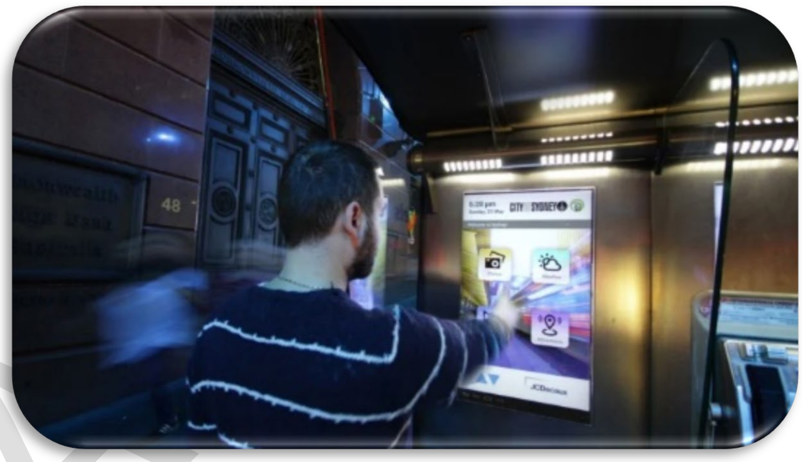


Figure 107. Live Touch equipped smart furniture sign in Sydney, Australia.

Smart furniture is best placed at bus stops, commercial areas with high foot traffic, and parks. Maintenance costs can be funded via advertising revenue. For example, New York City is funding its smart kiosks entirely through advertising proceeds, generating $500 million in revenue for the city. In Sydney, Australia, smart street furniture includes "Live Touch," an information resource that provides four apps: photos and information for main Sydney attractions, weather and forecasts, and maps with points of interest, retail directions, and transport links. Figure 67 highlights the technology in Sydney.

EMERGING TUNNELING TECHNOLOGIES FEASIBILITY STUDY

The TPO study evaluated emerging tunnel technologies to assess the implementation of transit tunnel corridors in Miami-Dade County, which would accommodate public transportation via electric vehicles. The type of vehicle, passenger or bus, depends on the tunnel's diameter. A smaller tunnel (12 feet in diameter) can accommodate vehicles with a 6-7 passenger capacity. A large tunnel (24 to 27 feet in diameter) can accommodate a larger electric bus with a carrying capacity of 60 passengers. The overall tunnel characteristics are provided in Table 3.

Table 3. Comparison of tunnel options and their characteristics

Small Diameter Tunnel (Las Vegas Convention Center)	Large Diameter Tunnel
Tunnel size 12-foot inside diameter	Tunnel size 24 to 27-foot inside diameter
Two side-by-side tunnels for two-way operation	Two side-by-side tunnels for two-way operation
Tunnel bottom approximately 40 feet below grade	Tunnel bottom approximately 52-55 feet below grade
Vehicles 6 to 7-passenger capacity	Vehicles 60-passengercapacity
At-grade stations with electric charging stations	Electric charging station at bus maintenance facility
Fire and safety, emergency egress, emergency vehicle access	Ventilation, fire and safety, emergency egress, emergency vehicle access

The preferred excavation method identified is the Tunnel Boring Machine (TBM) for its ability to cause the least amount (if any) of surface disruption. The tunnel system would be accessible via stations at street level approximately one mile apart, with an open underground platform for vehicle distribution and transfer between transit routes. The underground platforms would also be used for fire and life safety emergency vehicles to access the tunnel and for evacuation purposes. Out of the twenty-five evaluated corridors based on cost, land use, mobility, and technology, the identified corridors described below are located within our study area, with a corresponding map in Map 6.

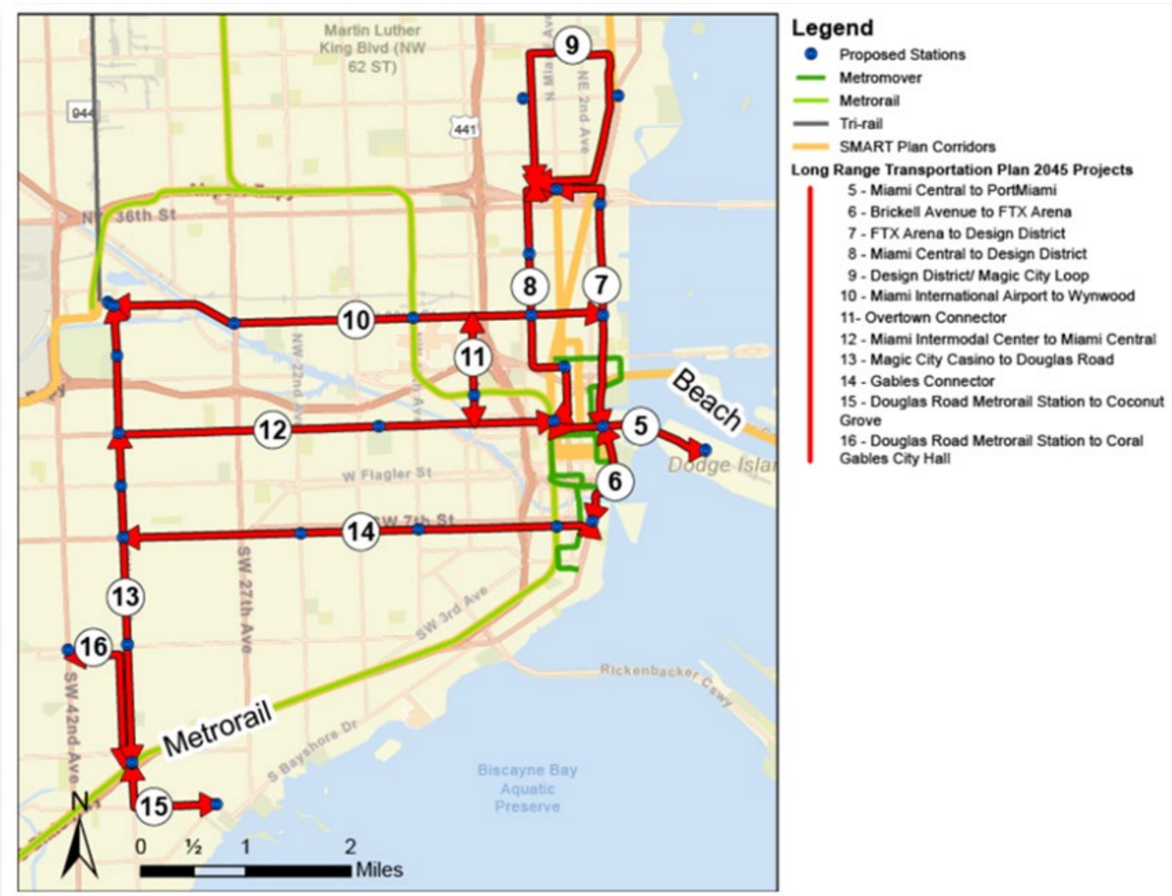
- **Corridor 5:** The Overtown Transit Village/Miami Central to PortMiami route spans 1.4 miles. It includes tunnel stations at Overtown Transit Village, Freedom Tower, and PortMiami Cruise Terminal. The corridor connects to the Overtown Transit Village, Brightline, the SMART Plan NE Corridor, and the Downtown Miami Link at Miami Central. Recognized as a premium transit and bus route terminus, it ranks highest due to its short length, supportive land use, proximity to a community redevelopment area, connection to Miami Central, and minimal utility interference.

- **Corridor 6:** The Brickell Avenue to FTX Arena route spans 1 mile and includes tunnel stations at SW 7th Street and Brickell Avenue, Biscayne Boulevard and Flagler Street, and FTX Arena. Transit connections are available via Metromover at Knight Center, Bayfront Park, Wolfson Campus of MDCC, and Freedom Tower. This corridor will also serve as a premium transit and bus route terminus. Major utilities along Biscayne Boulevard are a concern, and analysis is recommended for future studies.

- **Corridor 8:** Stretching from Miami Central to the Design District, this 2.7-mile route features tunnel stations at Overtown Transit Village/Miami Central, Miami Avenue and 14th Street, NW 2nd Avenue and NW 20th Street, NW 2nd Avenue and NW 29th Street, and NW 39th Street and NE 1st Avenue. Transit connections are available at Overtown Transit Village/Miami Central Station, with future connections planned for the NE Corridor at N. Miami Avenue and the 14th Street Station. This corridor ranks high due to supportive land uses for transit, proximity to a community redevelopment area, high traffic volume, connections to existing and proposed transit stations, minimal utility interfaces, few water crossings, and limited turns.

- **Corridor 7:** Spanning 2.6 miles from FTX Arena to the Design District, this route features tunnel stations at FTX Arena, Biscayne Boulevard at 20th Street and 36th Street, and NW 39th Street and NE 1st Avenue. Transit connections are available at the SMART Plan NE Corridor Design District Station. This corridor is highly ranked due to its concise length; supportive land uses for transit, proximity to a community redevelopment area, minimal interface with utilities, few water crossings, and limited turns. Special considerations include obtaining information between FTX Arena and Arsht Center to determine if the tunnel can be installed up to 39th Street, coordinating with Water & Sewer (W&S) for utility information, and possibly consulting the Signature Bridge foundation plans.
- **Corridor 9:** the Design District/Magic City Loop spans 4.2 miles from NE 39th Street and NE 1st Avenue to Biscayne Boulevard and NE 39th Street. Tunnel stations are located at NE 39th Street and NE 1st Avenue, 54th Street and NW 2nd Avenue, 62nd Street and NE 2nd Avenue, and Biscayne Boulevard and 54th Street. Transit connections are expected at the future NE Corridor Design District Station. Major attractions include the Design District, Magic City, and the Biscayne Station entertainment complex at 54th Street.
- **Corridor 10:** Running from Miami International Airport to Wynwood, this tunnel corridor extends from 20th Street and NE 2nd Avenue east to the east side of the South Florida Rail Corridor (SFRC), potentially via the rail spur in Allapattah, then south adjacent to the SFRC to the Miami Intermodal Center. Covering 4.2 miles, it features tunnel stations at MIC, 27th Avenue and 20th Street, 12th Avenue and 20th Street, NW 2nd Avenue and NW 20th Street, and Biscayne Boulevard and NE 20th Street. Transit connections are accessible at MIC and Allapattah Metrorail Station, with major attractions along the route, including MIA, the Miami Intermodal Center, Wynwood, and the Biscayne Corridor.
- **Corridor 12:** Connecting MIA to Miami Central, this 4.9-mile route features tunnel stations at MIC, NW 37th Avenue and Melreese/Soccer Stadium, NW 37th Avenue and NW 7th Street, and approximately 15th Street and NW 7th Street. This corridor option provides access to major attractions like Marlins Park, Melreese Golf Course, and Magic City Casino.

Map 6. East Central Miami-Dade County Corridors



EMERGING TECHNOLOGIES FOR TUNNELS & FREIGHT

As part of exploring emerging tunnel technologies, we also investigated freight technology to enhance freight connections, delivery systems, and truck operations. This strategic approach seeks to alleviate freight traffic congestion on surface roads. The following strategies were identified:

Micro-Delivery-Vehicle: Micro-delivery vehicles, as shown in Figure 109, are reshaping micro-mobility, providing tangible solutions for last-mile delivery needs. These compact vehicles operate in urban environments, swiftly and sustainably transporting goods and services. By seamlessly navigating city streets, they're not just a future vision but a present-day reality, effectively enhancing convenience and mitigating congestion in urban areas.

Figure 108. Micro-delivery vehicles in NYC.

Intelligent Freight Management: The Freight Signal Priority (FSP) service package prioritizes traffic signals for commercial and freight vehicles within a signalized network. This technology can also be utilized by emergency and personal vehicles. Freight Signal Priority aims to minimize stops and delays, enhance travel time reliability for freight traffic, and bolster safety.

Unmanned Aerial Vehicles: Drones or unmanned aerial vehicles (UAVs) can deliver lightweight packages to homes and businesses, potentially reducing the need for some delivery vehicles on the road and decreasing traffic volume and Vehicle Miles Traveled (VMT). However, implementing this technology would necessitate buildings and streets equipped with sensors, visual cues, and parameters for drones to identify feasible routes, which raises legal, zoning, and land use policy considerations.

Automated Delivery Robots: can carry up to 250 pounds and are connected via a mobile data network. The future of this technology involves establishing a network of autonomous delivery robots to collect data, which can enhance the robots themselves and contribute to the development of other technologies. As seen in other robots, advanced models can transport multiple products in separate compartments, enabling several stops on a delivery route rather than just one-to-one transactions. One potential future application is peer-to-peer deliveries, where individuals can utilize the robot delivery network to send items to friends or colleagues without making a personal trip. An example of this technology is provided in Figure 110.

Figure 109. Automated Delivery Robots with multiple compartments.

Underground Transportation Systems: The Las Vegas Convention Center (LVCC) Loop, highlighted in Figure 111, is an underground transportation system designed for efficient travel, emphasizing direct routes and minimal stops. Its electric vehicles can reach up to 150 mph. The system's passenger capacity varies depending on tunnel and station availability. Its adaptable design allows Loop to integrate stations into various urban settings, reducing congestion. In July 2021, the peak passenger flow was recorded at 1,355 passengers per hour. The LVCC Loop has been commended for its robust security measures, receiving the Gold Standard Award from the U.S. Department of Homeland Security Transportation Security Administration. Additionally, the system has demonstrated resilience to seismic activity, with past events showing no damage to its tunnels, ensuring continued safety for commuters.

Figure 110. Inside the LVCC loop.

Greening Freight Transport: Freight transport accounts for 8% of global emissions, and projections from the Intergovernmental Panel on Climate Change (IPCC) suggest it could become the leading emitting sector by 2030. However, digitalization and big data are crucial in decarbonization efforts. Freight forwarders leverage these technologies to regulate and monitor emissions while implementing environmentally friendly practices such as using modern engines and low-carbon fuels, participating in green supply-chain demand coalitions, and adopting standardized book-and-claim frameworks. These initiatives are vital steps toward reducing the environmental impact of freight transportation.

Autonomous Rail Infrastructure: Self-propelled, electric vehicle platforms, as shown in Figure 112, are being developed on top of existing rail equipment and infrastructure to introduce a new range of AI-powered tools and equipment for railroad users and operators. These innovations aim to enhance competitiveness for modal share with the trucking industry. While rail remains highly effective for transporting large volumes of goods at low costs, customers increasingly value the speed, visibility, precision, and flexibility trucking offers. It's worth noting that every ton-mile moved by rail is 9.5 times more energy-efficient than an equivalent ton-mile moved by truck.

Figure 111. Semi-automated double trolley cranes load containers onto automated guided vehicles

INNOVATION IN FUTURE-READY ZONES

This memo has provided a comprehensive overview of research on emerging technologies, infrastructure, and best practices implemented worldwide in pedestrian and transit-oriented urban downtown areas. The research covered a range of mobility improvements, including micro-mobility enhancements, mobility hub technologies, emerging curb and special event management strategies, transit improvements, and safety measures. Additionally, it examined the previous work by the Miami-Dade Transportation Planning Organization (TPO) and evaluated technological updates to enhance the goals within those TPO studies.

An inventory of technologies assembled from this research has been prepared to provide targeted recommendations for mobility improvements in the study area. These recommendations have been cataloged to identify the type of improvement, the suggested implementation location (future-ready zone), and the actions required for implementation.

The technologies are categorized into the following improvement types:

- Car Lite: Technology that reduces dependency on private transport and increases the use of high-capacity public transportation.
- Curb Management: Technologies to improve the use of public rights of way and curbs.
- Active Mobility Network: Enhancements to infrastructure and systems designed to support and encourage active modes of transportation, such as walking and cycling.
- Integrated Mobility Hub: Transportation hubs that serve as central points for connecting various modes of transportation and facilitating seamless and convenient travel for commuters.
- Event Management for Entertainment Centers: Strategies to facilitate safe travel for pedestrians and vehicles during events.
- Water Taxi: Improvements to waterborne travel.
- Micromobility: Enhanced shared micro-mobility facilities and devices for bicycles, electric bicycles (e-bicycles), and e-scooters.
- Resilience and Adaptability: Strategies to improve infrastructure resilience, adaptability, and reduce carbon emissions.
- Walkability: Improvements to pedestrian mobility.
- Pedestrian and Bicycle Safety: Enhancements for pedestrian and bicycle safety.
- Bicycle Network: Improvements to the bicycle network and facilities.
- Freight Management: Technology that improves delivery services and movements of goods.

The future-ready zones for implementing these technologies were determined through a comprehensive process involving stakeholder engagement, analysis of bicycle ridership and pedestrian activity data, assessment of proximity to transit, coordination with efforts programmed in the Transportation Improvement Program and the 2045 Long Range Transportation Plan, and a bicycle and pedestrian network gap analysis. By pinpointing these locations, the downtown Miami area can prepare for integrating emerging technologies effectively.

Detailed strategies with short-, mid-, and long-term timelines have been provided to facilitate the adoption of these advancements. The implementation timing is identified as either short-term (0 to 3 years), mid-term (3 to 5 years), or long-term (greater than five years), based on the actions required for implementation. These factors include policy development, enforcement, infrastructure construction, and equipment purchase.

Infrastructure encompasses the physical components that support the technology, such as bike-share stations, and includes digital components like mobile apps. Equipment refers to items like the bike unit, e-scooter, or microcar, and any accessories or components that enhance their functionality or safety, such as GPS trackers. Policy encompasses the rules, regulations, and guidelines that govern the use of technology or products. Enforcement refers to the mechanisms in place to ensure compliance with technology-related policies.

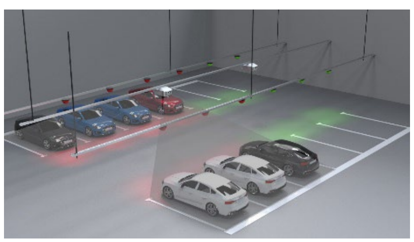
The following table summarizes these findings, including a summary of the recommendation type, the document page where the reader can learn more about the improvement and its application, the future-ready zone or location for the recommendations implemented, and the anticipated time to implement the improvement based on the action items noted.

CAR LITE IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**Low-Emission Zones (pg. 66)** Low emission zones (LEZs) are designated areas where access to vehicles with higher emissions is restricted or prohibited to reduce air pollution and improve urban air quality.	**Action:** Policy, infrastructure, enforcement **Time:** Short-Term **Location:** Downtown core, Brickell urban core, Mary Brickell Village
	**Micro-Delivery-Vehicle (pg. 83)** A micromobility vehicle is a compact, lightweight mode of transportation, typically electric, designed for short-distance travel, such as e-scooters, e-bikes, and electric skateboards.	**Action:** Policy, equipment, enforcement **Time:** Short-Term **Location:** Area-wide
	**Electric Vertical Takeoff and Landing Planes (pg. 16)** These aircraft ascend vertically, like helicopters, using electric motors instead of traditional combustion engines. These electric vehicles employ propellers or rotors for vertical takeoff, stationary hovering, and horizontal flight, featuring large omnidirectional fans for drone-like maneuverability.	**Action:** Policy, equipment, infrastructure, enforcement **Time:** Mid-term **Location:** Brickell, Downtown

	**Automated Delivery Robots (pg. 83)** Advanced models can transport multiple products in separate compartments, enabling several stops on a delivery route.	**Action:** Policy, equipment, infrastructure, enforcement **Time:** Short- to Mid-Term **Location:** Area-wide

CURB MANAGEMENT

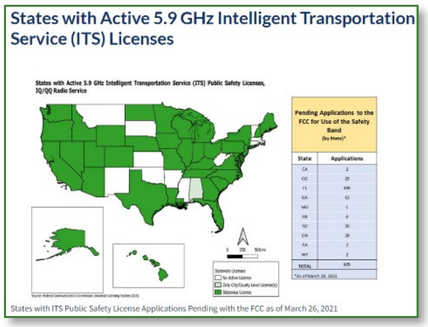
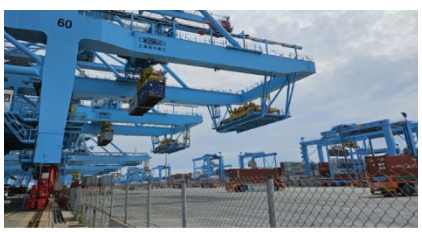
PHOTO	STRATEGY	IMPLEMENTATION
	**Smart Parking (pg. 54)** It utilizes sensors and cameras to monitor and manage street parking availability in real-time, optimize space usage, and enhance urban parking solutions.	**Action:** Policy, infrastructure, enforcement **Time:** Short-Term **Location:** Downtown and Brickell and Wynwood Surface and Parking Garages

	**Curb Management (pgs. 25-28 and 35-38)** Strategic regulation of curb space to optimize parking, loading zones, and pedestrian access, enhancing urban mobility and public spaces.	**Action:** Policy, infrastructure, enforcement **Time:** Short- to Mid-Term **Location:** Downtown CBD, Brickell, project pilots in other areas.
	**In-ground Parking Sensors (pg. 55)** Real-time parking space availability monitoring enables demand-based pricing and optimizing city parking management.	**Action:** Policy, infrastructure, enforcement **Time:** Short-Term **Location:** Downtown and Brickell and Wynwood Surface and Parking Garages
	**Smart Street Sweeper (pg. 59)** Software-equipped street-sweeping vehicles enhance operational efficiency, route management, and transparency in urban maintenance.	**Action:** Equipment **Time:** Short-Term **Location:** Area-wide

	**Road Defect Detection System (pg. 59)** AI-powered road defect detection system scans motorways to identify defects and prioritize repairs, promptly alerting maintenance teams to take action.	**Action:** Equipment **Time:** Short-Term **Location:** Area-wide
	**Underground Transportation Systems (pg. 84)** **The Transit system allows s**peeds of up to 150 mph. It has demonstrated resilience to seismic activity, with past events showing no tunnel damage.	**Action:** Policy, infrastructure, equipment **Time:** Mid- to Long-Term **Location:** Brickell Avenue to FTX Arena

FREIGHT MANAGEMENT

PHOTO	STRATEGY	IMPLEMENTATION
	**Freight Signal Priority (pg. 83)** Freight Signal Priority (FSP) is a traffic management technology that prioritizes traffic signals for freight, commercial, and emergency vehicles traveling within a signalized network.	**Action:** Policy, infrastructure, enforcement **Time:** Short-Term **Location:** Freight routes to Port and Airport.

	**Drones or Uncrewed Aerial Vehicles (pg. 84)** Drones or uncrewed aerial vehicles (UAVs) can deliver lightweight packages to homes and businesses, reducing traffic volume and Vehicle Miles Traveled (VMT) by lessening the need for traditional delivery vehicles.	**Action:** Policy, infrastructure, enforcement, equipment **Time:** Short- to Mid-Term **Location:** Downtown and Brickell pilot project in residential areas in the study area.
	**Intelligent Transportation Services (pg. 30)** The technology uses high-precision devices to enable communications between vehicles and traffic lights, generating real-time alerts or warnings and adjusting signals to prioritize emergency vehicles in heavy traffic, significantly improving transportation safety and mobility.	**Action:** Infrastructure **Time:** Short- to Mid-Term **Location:** Area-wide
 Source: GAO File Photo. | GAO-24-106498	**Autonomous Rail Infrastructure (pg. 85)** Self-propelled electric vehicle platforms are being developed on top of existing rail equipment and infrastructure to introduce a new range of AI-powered tools.	**Action:** Infrastructure **Time:** Short- to Mid-Term **Location:** PortMiami

ACTIVE MOBILITY NETWORK IMPROVEMENTS

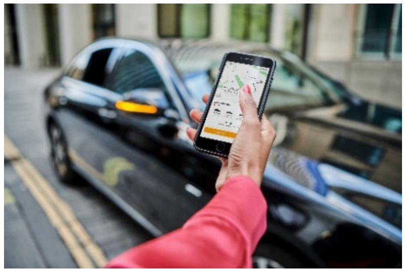
PHOTO	STRATEGY	IMPLEMENTATION
	**Automated Bicycle and Pedestrian Counters (pg. 80)** Pavement-embedded sensors collect data on bicycle ridership and pedestrian use to inform infrastructure projects and promote active mobility.	**Action:** Infrastructure **Time:** Short-Term **Location:** At intersections with major trails.
	**Scooter Sidewalk Riding Detection (pg. 54)** Scooter Sidewalk Riding Detection employs sensor, GPS, and computer vision technologies to discern instances of electric scooter operation on pedestrian sidewalks. Its function involves alerting riders or autonomously modifying scooter behavior to ensure adherence to local regulations.	**Action:** Policy, Enforcement **Time:** Short-Term **Location:** Area-wide
	**Modified Water Hydrants (pg. 6)** Water fountain design that uses fire hydrants to improve access to drinking water.	**Action:** Policy, Infrastructure **Time:** Short-Term **Location:** Near bicycle and pedestrian trails

	**Portland Loo (pg. 17)** Restroom units are patented and sold by the City of Portland for bathrooms that deter illegal activities and provide access to needed resources like restrooms and water.	**Action:** Infrastructure **Time:** Short-Term **Location:** Near bicycle and pedestrian trails

INTEGRATED MOBILITY HUB IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**Sustainable Design Bus Shelters (pg. 61)** Integral urban infrastructure provides shelter and amenities for bus commuters, evolving with innovative designs and sustainable technologies to provide a more comfortable and environmentally friendly commuting experience.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide, prioritize transit stations, major employment centers, and tourist attractions
	**Multi-Purpose Bus Posts (pg. 72)** Systems utilizing GPS to offer commuters up-to-date bus arrival information, enhancing service accountability and trip planning efficiency through various accessible platforms.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide, prioritize transit stations and stops near major employment centers, civic facilities, and tourist attractions

	**Real-time Public Transit Vehicle Arrival Information System (pg. 72)** Systems utilizing GPS to offer commuters up-to-date bus arrival information, enhancing service accountability and trip planning efficiency through various accessible platforms.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide, prioritize transit stations and stops near major employment centers, civic facilities, and tourist attractions
	**Air-Conditioned Bus Shelters (pg. 72)** Comfortable waiting environments at bus stops are strategically placed to offer relief from heat in warm climates, aiming to enhance public transportation experience and ridership.	**Action:** Infrastructure **Time:** Short-Term **Location:** Transit stations at stops near major employment centers and tourist attractions
	**Autonomous Shuttle/Taxis/Ride-Hail Network (pg. 59)** Self-driving electric vehicle networks addressing first mile/last mile challenges, leveraging technology to optimize services and reshape urban transportation.	**Action:** Infrastructure, equipment, policy **Time:** Short-Term **Location:** Area-wide, focusing on first/last mile connections near transit stations, access to major attractions, and residential areas to connect with the urban core.

	**Mobility as a Service- MaaS (pg. 71)** Integrated on-demand mobility solution simplifying transportation access and payment across multiple modes, promoting user-centered trip planning and booking.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide digital access
	**Transportation as a Service-TaaS (pg. 71)** Shift from traditional car ownership to on-demand services, leveraging technology to offer flexible and cost-effective transportation options, aiming to reshape consumer behavior and reduce emissions.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide digital access
	**Street Legal Electric Micro Cars (pg. 57)** These vehicles offer a cost-effective transportation solution, with prices typically around $9,000. A car-sharing scheme using these vehicles at mobility hubs can be considered.	**Action:** Equipment, policy, enforcement **Time:** Short-Term **Location:** MiamiCentral Station, on-street parking near residential developments and major employment centers.

EVENT MANAGEMENT FOR ENTERTAINMENT CENTER IMPROVEMENTS		
PHOTO	**STRATEGY**	**IMPLEMENTATION**
	**Interactive Kiosks (pg. 55)** Information hubs at transit stops provide bus-related information and data collection services for transit agencies, enhancing user experience and infrastructure planning.	**Action:** Equipment **Time:** Short-Term **Location:** Civic centers, transit stations, major attractions
	**SMART Communications Network (pg. 56)** Modern kiosks offer connectivity, device charging, and city services, enhancing accessibility and revenue opportunities while requiring strategic placement and maintenance.	**Action:** Equipment **Time:** Short-Term **Location:** Mobility hubs like MiamiCentral, the Underline, and major attractions
	**Parking Guidance System (pg. 15)** It delivers real-time information through roadside electronic information panels and mobile devices so drivers can view parking availability even while driving.	**Action:** Infrastructure, equipment, policy **Time:** Short-Term **Location:** Near public parking garages and surface lots located in Downtown, Brickell and Wynwood

	**Combining Event and Transit Tickets (pg. 41)** The ticket's purchase price includes a transit fare allowing ticketholders to access public transit.	**Action:** Policy **Time:** Short-Term **Location:** Area-wide to access special events within the study area
 	**Ride Sourcing Pickup Locations at Event Venues (pg. 42)** transportation network companies (TNC) develop guides to direct potential riders to permissible pickup locations.	**Action:** Policy **Time:** Short-Term **Location:** Area-wide to access special events within the study area

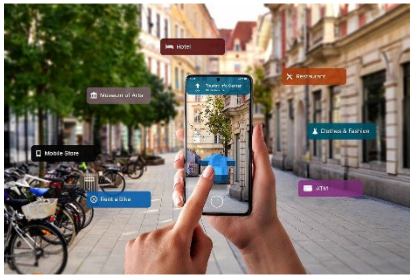
WATER TAXI IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**Seagliders (pg. 47)** Seagliders Electric-powered vessels revolutionizing water travel with zero emissions, advanced technology, and impressive range are scheduled to transform transportation options by 2025.	**Action:** Equipment, Policy **Time:** Short- to Mid-Term **Location:** Biscayne Bay, Watson Island

	**Electric Flying Passenger Ship (pg. 47)** First-ever electric flying passenger ship. Capable of gliding at speeds reaching 25 knots (29 mph) and maxing out at 30 knots (35 mph), it can travel up to 50 nautical miles (57.5 miles) on one charge. In Sweden, the ship is exempt from speed limits due to its minimized wake disturbance while navigating the water.	**Action:** Equipment, Policy, Infrastructure **Time:** Short- to Mid-Term **Location:** Biscayne Bay, Intracoastal Waterway, Miami River

MICROMOBILITY IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**Adaptive Micromobility (pg. 54)** Inclusive micro-mobility share programs offer accessible alternatives for older individuals or those with disabilities, promoting mobility and participation in urban activities.	**Action:** Equipment, Policy **Time:** Short-Term **Location:** Area-wide, prioritize mobility hubs, residential zones
	**Electric Scooter Enforcement (pg. 22)** Measures to address scooter misuse through citations and education, aiming to improve safety and compliance among users of shared mobility services.	**Action:** Enforcement, Policy **Time:** Short-Term **Location:** Area-wide, prioritize mobility hubs, Downtown and Brickell cores

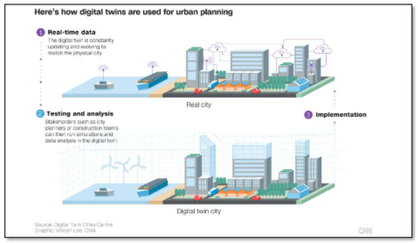
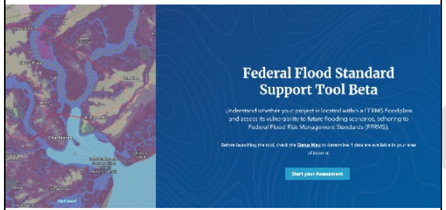
	**Wayfinding/Augmented Reality (pg. 79)** Technologies providing visual navigation aids through mobile applications enhance urban navigation efficiency by superimposing digital information onto the physical environment. This helps users locate points of interest and navigate unfamiliar areas more efficiently.	**Action:** Equipment, Infrastructure **Time:** Short-Term **Location:** Mobility hubs, non-motorized mobility networks, transit stations, major attractions
	**Bicycle Runnels (pg. 76)** Bicycle runnels are ramps alongside pedestrian stairways at transit stations. They facilitate the movement of bicycles up or down stairs, improving accessibility and safety for cyclists, reducing congestion, and ensuring a smoother flow of pedestrian traffic.	**Action:** Infrastructure **Time:** Short-Term **Location:** All transit stations.
	**Micromobility Storage At High-Demand Stations (pg. 54)** Secure parking solutions for micromobility devices at transit hubs, enhancing accessibility and encouraging sustainable transportation use. These solutions, including lockers, pods, and multi-device storage options, aim to improve accessibility and convenience for commuters and support first-mile/last-mile connectivity.	**Action:** Infrastructure **Time:** Short-Term **Location:** Government Center, Vizcaya, Brickell, near major employment centers, MDC Wolfson Campus

	**Bike Share on Private Property (pg.8)** This micromobility approach places shareable bikes on private properties to bypass regulatory hurdles and provide convenient transportation options for riders.	**Action:** Policy, equipment **Time:** Short-Term **Location:** Area-wide
	**Geofencing (pg. 21, pg. 54)** A location-based technology that sets virtual boundaries is typically used for micromobility to regulate parking, restrict certain zones, enhance urban mobility management, and encourage responsible rider behavior.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide. Geofenced e-mobility parking areas near transit stations and along areas with high pedestrian activity, such as in the core of Brickell and Downtown.
	**Wireless Charging (pg. 57)** A wireless inductive charging system for e-bikes simplifies charging and allows you to park the bike. It comprises a weatherproof in-ground "charging tile" connected to the electrical grid and a kickstand hard-wired to the bike's battery.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide. Geofenced e-mobility parking areas near transit stations and along areas with high pedestrian activity, such as in the core of Brickell and Downtown.

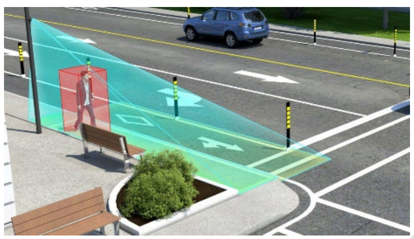
STRATEGIES TO IMPROVE RESILIENCE, ADAPTABLE INFRASTRUCTURE, AND REDUCE CARBON EMISSIONS

PHOTO	STRATEGY	IMPLEMENTATION
	**Universal Charging Station (pg. 53)** A solution facilitating the organization of public space and providing a universal charge station for e-mobility, adaptable to various urban structures like advertising boards, bus stations, and street lighting, reducing operational costs.	**Action:** Infrastructure **Time:** Short-Term **Location:** Near transit stations (Metrorail and Metromover) and active mobility hubs like the Underline.
	**Battery-as-a-Service (pg. 53)** BaaS for micromobility electric vehicles is a subscription-based model separating battery costs from micromobility electric vehicles, offering access to swap stations for depleted batteries, minimizing upfront costs, enhancing charging accessibility, promoting battery recycling, and addressing standardization challenges across manufacturers.	**Action:** Infrastructure, Policy, Equipment **Time:** Short-Term **Location:** Near transit stations (Metrorail and Metromover) and at mobility hubs
	**Solar Roads and Sidewalks (pg. 63)** Solar panels can be integrated into walkways, parking surfaces, and roadways to generate solar energy. However, they can be costly and potentially less efficient than other solar panel installations like roof panels or solar farms.	**Action:** Equipment, Infrastructure **Time:** Short-Term **Location:** Major intersections with Biscayne Boulevard or Miami Avenue.

	**Solar Umbrella Canopies (pg. 62)** Innovative solar-powered umbrellas provide shading in urban areas while capturing energy to power nearby infrastructure, such as street lights or traffic signals, addressing sustainability and pedestrian comfort needs.	**Action:** Equipment, Infrastructure **Time:** Short- to Mid-Term **Location:** Along corridors where right-of-way availability limits the growth of large canopy trees.
	**Smart Furniture (pg. 80)** Solar-powered benches with free Wi-Fi and USB charging capabilities can collect user data and metrics while furnishing streets. They are best suited for high-traffic areas like bus stops and parks.	**Action:** Equipment, Infrastructure **Time:** Short-Term **Location:** Area-wide

	**Digital Twin Cities (pg. 29)** Virtual representations of physical assets (like buildings, roads, waterways, and green spaces) that use connected digital information to mirror reality and create a digital twin of the current physical conditions, allowing the testing of new technology without physical construction.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide digital access.
	**Bioswale and Cycling Improvements (pg. 62)** Implementation reduced emissions from fewer vehicles and enhanced particulate matter filtration, alongside carbon dioxide sequestration, facilitated by the introduction of the infrastructure.	**Action:** Enforcement **Time:** Short-Term **Location:** Area-wide
	**Digital Technologies for Flood Prediction (pg. 63)** Real-time data, advanced predictive models, and early warning systems are essential tools for authorities and managing entities to anticipate flood events and implement effective solutions	**Action:** Equipment **Time:** Short-Term **Location:** Digitally accessible area-wide

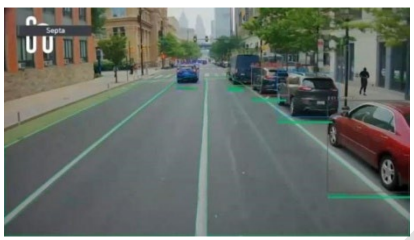
WALKABILITY IMPROVEMENTS

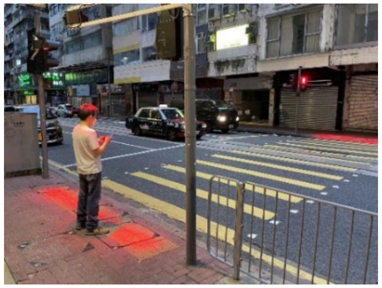
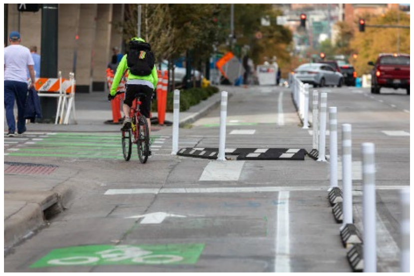
PHOTO	STRATEGY	IMPLEMENTATION
	**Interactive Pedestrian Crossing (pg. 66)** A dynamic crossing system utilizing cameras to adjust markings and colors enhances safety by prompting pedestrians, drivers, and cyclists to cross roads more attentively, with adaptable configurations based on traffic flow.	**Action:** Infrastructure **Time:** Short- to Mid-Term **Location:** Area-wide
	**Automated Pedestrian Detection (pg. 67)** Devices sensing pedestrians at crosswalks automatically adjust signals to accommodate crossing times, with installation costs varying depending on site conditions and operational costs.	**Action:** Infrastructure **Time:** Short- to Mid-Term **Location:** Area-wide
	**Extended Time (Tap Cards) for Crosswalk (pgs. 14, 69)** RFID-enabled cards trigger extended crossing times for elderly and disabled pedestrians at designated crosswalks, aiming to improve accessibility in areas with larger aging populations.	**Action:** Infrastructure **Time:** Short-Term **Location:** At intersections of Major corridors like Biscayne Boulevard and South Miami Ave, near civic institutions.

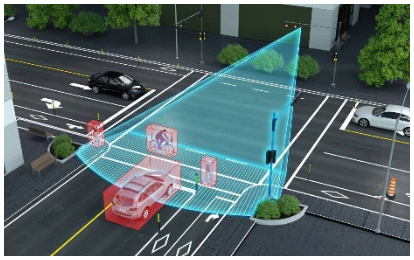
	**Accessible Pedestrian Signals (pg. 68)** Signals are designed to aid visually and mobility-impaired pedestrians with audible tones, speech messages, and vibrating surfaces, enhancing safety at crosswalks at varying costs.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide
	**Sheltered Skyways (pg. 11)** In Singapore, the Walk2Ride program guarantees a sheltered walkway within 400 meters of all MRT stations and 200 meters of bus interchanges, LRT stations, and bus stops with high commuter volumes.	**Action:** Infrastructure, Policy **Time:** Mid-Term **Location:** Area-wide with a focus near transit, employment centers, major attractions, and areas with high pedestrian activity like Brickell and Downtown Core.
	**Pedestrian Scrambles (pg. 18)** Crosswalks allow pedestrians to travel in all directions, reducing traffic-related injuries.	**Action:** Infrastructure **Time:** Short-Term **Location:** High volume intersections on Biscayne Blvd near Arena or Bayfront Park.

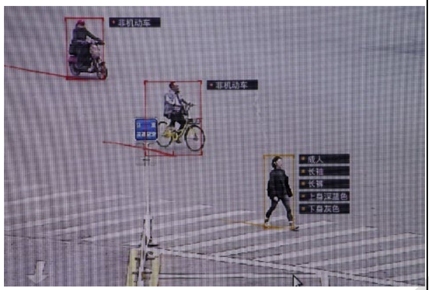
	**SLOW STREETS (pg. 19)** They are designed to be safe, comfortable, low-traffic routes prioritizing active transportation and community connection.	**Action:** Infrastructure, Policy **Time:** Short-Term **Location:** Areas with high pedestrian volume, low-speed corridors, or streets within Downtown, Brickell Core, or Wynwood.

PEDESTRIAN AND BICYCLE SAFETY IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**AI Enforcement (pg. 73)** Utilization of artificial intelligence to enforce and cite the illegal encroachment of bicycle and bus lanes by vehicles.	**Action:** Policy, Equipment, Enforcement **Time:** Short-Term **Location:** Area-wide
	**Rumble Strips on Bicycle Lanes (pg. 53)** Install rumble strips in bicycle lanes to alert cyclists to slow down, improving safety in crowded urban areas.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide at high pedestrian and cyclist zones to deter conflicts. At access drive connections with public roadways, particularly for residential and office buildings in the study area.

	**Safety Reflector (pg. 68)** Reflectors can be wirelessly controlled via a mobile phone application. When a pedestrian approaches a crossing, the reflector at the location can blink to alert drivers.	**Action:** Infrastructure **Time:** Short-Term **Location:** At intersections near educational facilities located in the study area.
	**The Denver Wedge (pg. 76)** Wedges are designed to slow down left-turn drivers, promoting safer interactions with cyclists and pedestrians.	**Action:** Infrastructure **Time:** Short-Term **Location:** Area-wide, prioritizing conflict areas in Downtown and Brickell core.
	**Thermal Technology (pg. 76)** Thermal sensors enhance traffic signal control to prioritize pedestrian and cyclist safety at intersections, particularly in high-crash areas.	**Action:** Infrastructure, equipment **Time:** Short to Mid-term **Location:** Intersections with major bicycle and pedestrian trails.

	**Radio Beams (pg. 74)** Radar sensors are installed in the pavement to detect cyclists, adjusting traffic signals for safer passage, particularly in problematic areas.	**Action:** Infrastructure, equipment **Time:** Short to Mid-term **Location:** Intersections with major bicycle and pedestrian trails.
	**HD Lighting Systems (pg. 75)** Integrate projection technology from digital micromirror devices (DMDs) into the vehicle's headlight. It captures street signs and other relevant information using a camera system, then displays it on the road ahead through the car's headlights.	**Action:** Equipment **Time:** Short to Mid-term **Location:** Area-wide to be installed on public transit vehicles.

	**QR Codes (pg. 24)** QR codes enable easy reporting of the elevator, escalator, or other maintenance issues, streamlining maintenance requests for efficient resolution.	**Action:** Equipment **Time:** Short-Term **Location:** Metrorail and Metromover service elevators
	**Video Recording (pg. 69)** Security cameras can assist law enforcement agencies in analyzing vehicle and pedestrian traffic with real-time results.	**Action:** Policy, Enforcement, Infrastructure, Equipment **Time:** Short to Mid-term **Location:** SR 5
	**Silver Zones (pg. 12)** From Singapore, these are pedestrian schemes built in selected residential areas to enhance road safety for older adults.	**Action:** Infrastructure **Time:** Short to Mid-Term **Location:** Residential zones

BICYCLE NETWORK IMPROVEMENTS

PHOTO	STRATEGY	IMPLEMENTATION
	**Dedicated and Protected Bike Lanes (pg. 62)** Separated lanes for cyclists, safeguarded from vehicular traffic, fostering safe and efficient cycling infrastructure.	**Action:** Infrastructure, Policy, Enforcement **Time:** Short to Mid-Term **Location:** ➲ Along S. Miami Avenue from the intersection of SW 32nd Road to SE 15th Road. ➲ Along SW 15th Road from the intersection of SW 11th Street to the road end at Brickell Bay Drive. ➲ Along NW 1st Street from the intersection at NW 3rd Avenue to the street's end at Biscayne Blvd. ➲ Along the southbound direction on Biscayne Blvd from the intersection at NE 11th Terrace to the intersection at SE 1st Street.
	**Solar Infrastructure (pg. 64)** Bike path within the median of an eight-lane highway that integrates solar panels, illuminating the streets below.	**Action:** Infrastructure, Equipment, Policy **Time:** Mid-term **Location:** Bicycle and Pedestrian trails with limited shade or canopy coverage.

	**Bicycle Traffic Signals (pg. 75)** Traffic signals are dedicated to cyclists, ensuring safer intersection crossings and smoother traffic flow. Sensors can be installed to capture ridership data at intersections.	**Action:** Infrastructure **Time:** Mid-term **Location:** At intersections with bicycle routes and facilities along major roadways.
	**Bicycle Detection Systems (pg. 74)** Enhancements at intersections to prioritize cyclist safety, including dedicated signals and lanes.	**Action:** Infrastructure **Time:** Short-term **Location:** At intersections with bicycle routes and facilities along major roadways.
	**Illuminated Bike Lanes (pg. 64)** Tiny, eco-friendly glow-in-the-dark stones that absorb sunlight during the day and emit a gentle glow at night, this technology eliminates the need for traditional lights.	**Action:** Infrastructure **Time:** Short-Term **Location:** Non-motorized mobility networks, parks, the Underline.

	**Smart Bicycle Parking (pg. 53)** Affordable, secure parking solutions for bicycles, strategically placed to facilitate commuter needs and promote cycling accessibility.	**Action:** Equipment, Policy **Time:** Short-Term **Location:** MiamiCentral, major transit stations, and adjacent mobility hubs. At major employment centers, attractions, and Wolfson Campus.
	**Green Infrastructure Technology (pg. 12)** In Singapore, Green amenities along the path below the rail are also used to test horticultural technology.	**Action:** Infrastructure **Time:** Short-Term **Location:** Beneath Metrorail and Metromover line, Underline, Underdeck
	**Portable Propulsion Device (pg. 76)** It is designed to instantly upgrade any bike, including shared bikes, to an e-bike without needing tools. Strategies like employee discounts for this type of equipment can encourage users to ride low-cost conventional bikes that can be adapted to electric technology.	**Action:** Equipment **Time:** Short-Term **Location:** Can be provided as a shared service at active mobility hubs, major employment centers, or transit stations