



SANDAG

Concept of Operations for Smart Intersection Systems

Final | February 2021



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LIST OF ACRONYMS

Acronym	Definition
ADA	Americans with Disabilities Act of 1990
ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
ATMS	Advanced Traffic Management System
AVL	Automatic Vehicle Location
CAD	Computer Aided Dispatch
Caltrans	California Department of Transportation
CCTV	Closed-Circuit Television
CMCP	Comprehensive Multi-Modal Corridor Plan
CMM	Capability Maturity Model
CMS	Changeable Message Sign
ConOps	Concept of Operations
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Everything
EVP	Emergency Vehicle Pre-emption
FHWA	Federal Highway Administration
GHz	Gigahertz
HOV	High Occupancy Vehicle
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
NCRC	North County Regional Corridor
NEV	Neighborhood Electric Vehicle
OS	Operating System
RAMS	Regional Arterial Management System
RBMS	Regional Border Management System
RSE	Roadside Equipment
RTP	Regional Transportation Plan
SANDAG	San Diego Association of Governments
SE	Systems Engineering
SIS	Smart Intersection System
SRC	Short-Range Communications
TMC	Traffic Management Center

Acronym	Definition
TSMO	Transportation Systems Management and Operations
TSP	Transit Signal Priority
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything
VMT	Vehicle Miles Traveled
VRU	Vulnerable Road User

1 INTRODUCTION

The Regional Transportation Systems Management & Operations (TSMO) Plan for the San Diego Region provides a roadmap to implement integrated strategies that focus on operations and performance that use existing infrastructure and cost-effective solutions. TSMO strategies identify the institutional, organizational, and technical components that support the entire system. The Plan was developed for the San Diego region by San Diego Association of Governments (SANDAG), with critical input from California Department of Transportation (Caltrans), County of San Diego, regional transit providers, and local agencies.

Historically, transportation agencies across the United States have been organized to deliver capacity-based infrastructure improvements. Today, agencies are shifting their focus from solving congestion problems by expanding capacity to utilizing the existing transportation system more efficiently, managing the system to perform reliably, and utilizing technology to share real-time information with incident responders and the public. The Federal Highway Administration (FHWA) has developed research and guidance resources for transportation agencies, metropolitan planning organizations (MPOs), and other transportation organizations to plan for and utilize TSMO strategies within organizations.

TSMO offers integrated strategies to “improve system performance through multimodal, intermodal, and cross-jurisdictional systems, services, and projects that preserve capacity, enhance public safety and security, enhance seamless connections between modes, and improve reliability” (FHWA. 2017)¹. The strategies are designed to improve safety and reliability by managing traffic congestion and minimizing any unpredictable delays to the transportation system. TSMO strategies are characterized into three buckets – institutional, operational, and technical. Some examples of TSMO strategies may include redefining agency roles and responsibilities to break down silos between planning and operations (institutional) or sharing data between agencies to track performance measures on a corridor-wide basis (operational). To implement a successful TSMO program, agencies often need to evaluate the institutional, operational, and technical aspects of its day-to-day processes for planning, programming, designing, constructing, and maintaining projects.

1.1 Overview of the 5 Big Moves

SANDAG is developing *San Diego Forward: The Regional Plan* (Regional Plan), the Regional Transportation Plan (RTP) update for the region. This plan introduces a transformative vision for the San Diego region revolving around the 5 Big Moves, which are 5 key mobility strategies that reimagine how people and goods will move around San Diego County. The 5 Big Moves include:

- ▶ **Complete Corridors** – A variety of travel choices within a more dynamically managed road network with a shift in how space is allocated to different modes.

¹ Federal Highway Administration (FHWA) Office of Operations, “Developing and Sustaining a Transportation Systems Management & Operations Mission for Your Organization: A Primer For Program Planning,” April, 22, 2020, <https://ops.fhwa.dot.gov/publications/fhwahop17017/ch1.htm>

- ▶ **Transit Leap** – A network of high-speed and high-capacity transit services that connect major residential and employment centers and regional attractions, such that transit is convenient, fast, and an attractive alternative to driving.
- ▶ **Mobility Hubs** – Places of connectivity where different modes of travel converge near concentrations of employment, housing, shopping, and/or recreation.
- ▶ **Flexible Fleets** – Flexible options for making first- and last-mile connections to transit or to other destinations through shared vehicles, such as ride share, microtransit, ride hailing, e-bikes, drones, bots, or automated vehicles.
- ▶ **Next Operating System (OS)** – The system that will connect all devices, vehicles, and travel options through a proactively managed approach that includes integrated trip planning, payment and reservation choices.

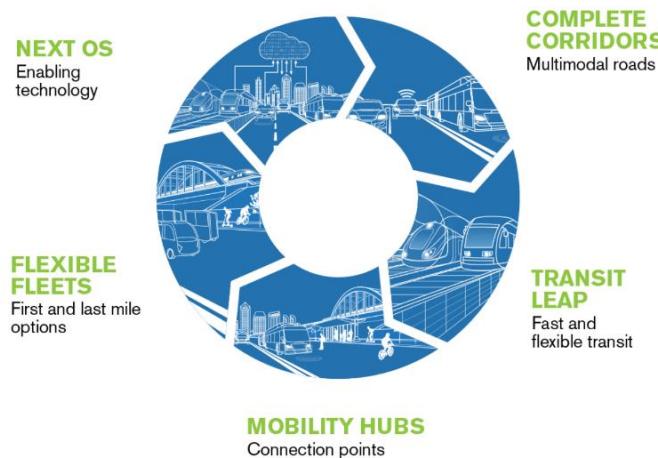


Figure 1.5 Big Moves from San Diego Forward: 2021 Regional Plan

Source: SANDAG. (2021) *A Bold New Transportation Vision in 5 Big Moves*

The 5 Big Moves vision is to leverage innovative, new technologies to improve the region's connectivity, safety, and sustainability. These strategies are envisioned to work hand in hand, with all of the strategies complementing each other to fully enhance the transportation network, as shown in **Figure 1**. This balanced approach is directly linked to the practices of TSMO, wherein institutional, operational, and technical aspects of each project must be considered. Data is a driver to project success, maintenance, and regular assessment. Projects are focused on multiple modes to ensure that the system is not designed around the personal automobile. These practices align with the 5 Big Moves and allow for a comprehensive and coordinated approach for transportation planning and innovation.

The Regional Plan is under development at the time of writing of this document. The 5 Big Moves Vision of the Regional Plan can be accessed at the public facing website here:

- ▶ <https://www.sdforward.com/mobility-planning/5-big-moves>

Smart Intersections Systems is an application of the 5 Big Moves and is most closely connected to Complete Corridors but uses principles from all five strategies.

Use Cases of Next OS

The Regional Plan effort produced the accompanying Next OS Summary Report, which provides a plan for implementing the Next OS digital platform. The report established six use cases for Next OS:

- ▶ Mobility-as-a-Service
- ▶ Curb Access Management
- ▶ Regional Border Management System (RBMS)
- ▶ Transit Optimization
- ▶ Next-Gen Integrated Corridor Management System (ICMS) and
- ▶ **Smart Intersection System (SIS)**

Each use case will interact with Next OS according to the respective needs of their stakeholders and users. This document is exploring the capabilities and concepts for SIS, which will enable a more comprehensive approach to system management through data sharing between agencies, third-party service providers, and with the public. Next OS will serve as the data hub that manages this information transfer. While SIS is one of several components of Next OS, SIS is also a key component of the Complete Corridors strategy.

Access to the full Next OS Concept White Paper is provided at this link:

- ▶ https://www.sdfoward.com/docs/default-source/2021-regional-plan/san-diego-forward_next-os-concept-white-paper.pdf?sfvrsn=9499fe65_2

1.2 Purpose of the SIS Concept of Operations Document

The purpose of this document is to provide a Concept of Operations (ConOps) for SIS implementation in the San Diego region. The ConOps provides a non-technical description of the SIS from the point of view of the stakeholders, giving each stakeholder a conceptual look at how the system will function and their roles and responsibilities in operating and maintaining the system. This ConOps provides stakeholders the opportunity to provide input on the high-level system concept and provides a description of how the system will operate, who will operate what, and a description of three operational scenarios.

Stakeholders can use this document as a framework for further development of projects, policies, and projects that reflect the goals, objectives, and needs presented here. While the ConOps provides a regional vision for deployments that are consistent with the San Diego Forward: 2021 Regional Plan, implementation will be performed by local stakeholder groups. The existing capabilities of each agency and each corridor vary significantly across the region, and the operational scenarios presented in this document have been chosen to represent a cross-section of possibilities for the diverse user groups across the region. Stakeholders should conduct a capability maturity assessment to determine strategies that will enable them to benefit from the full range of functionalities.

The ConOps is a critical step in the Systems Engineering (SE) process that assesses the planning and management throughout the major phases of the system's lifecycle. Because the document considers the positions of all the stakeholders, it fosters agreement for the approach, organizational structure, and processes for how the system will be run. **Figure 2** provides a general overview of the elements of the SE process needed for Intelligent Transportation Systems (ITS) projects, with the ConOps stage circled in red. The ConOps informs the steps that follow which eventually lead to project implementation. The ConOps helps build consensus among

stakeholders regarding project components, roles and responsibilities, and operations. This helps minimize risks of conflict or change later in the project development process.

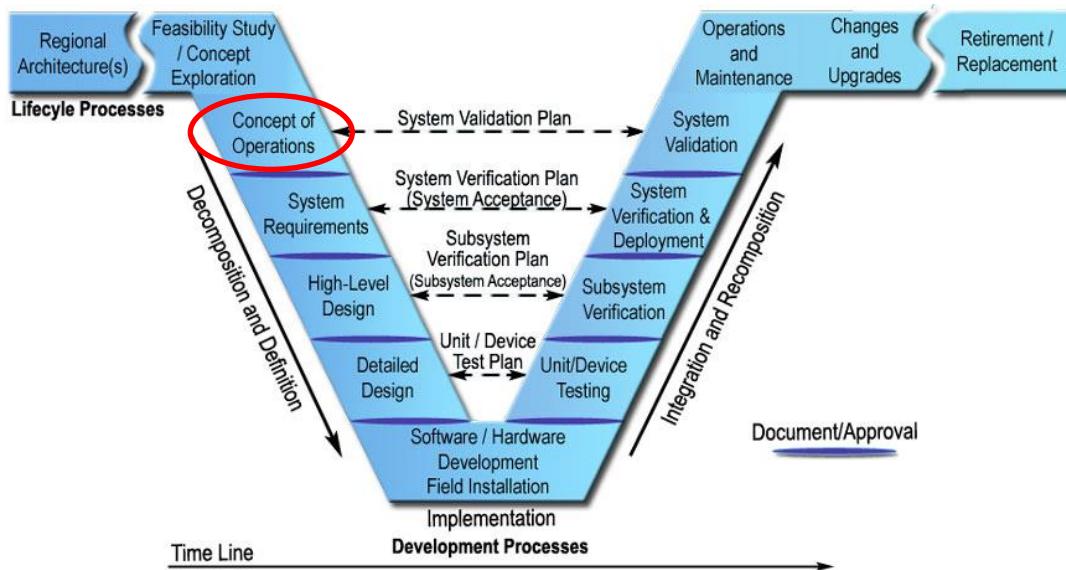


Figure 2. Systems Engineering Process

2 BACKGROUND

This section provides the existing conditions context for the future SIS implementation. Agencies have already deployed many elements of SIS within the San Diego region, but the majority of technology deployments have been ad-hoc. This section provides the baseline of existing SIS related technologies and existing regional institutional partnerships that coordinate SIS technologies.

2.1 Existing Smart Intersection Technology

Many elements of smart signals have already been deployed throughout the San Diego region. Inconsistencies in deployment strategies, interoperability, and technological readiness may exist due to access to funding and staff resources, regional traffic patterns, and local transportation options. The SIS will connect these individual deployments into a comprehensive regional approach to smart intersection technology, data collection, reporting, and operations. This consistent approach will utilize the Next OS as the framework for information exchange between the intersection and the user and the intersection with partner agencies. Infrastructure and technology today vary widely across the region.

TSMO and the regional approach to SIS work together to solve some of the pre-existing challenges. Though not an exhaustive list, here are some examples of existing equipment and strategies that local agencies have previously adopted or piloted:



Coordinated Signal System – signal system that provides smooth traffic flow along signalized corridors through synchronization



Adaptive Signal System – signal system that adapts in real time to changes and fluctuations in traffic demand



Fiber and Wireless Communications Network – communications infrastructure for real-time communications between field devices and traffic management centers



Federally Approved Short-Range Communications (SRC) – a low latency communication within the 5.8 Gigahertz (GHz) band, previously dedicated to ITS applications; the reserved bandwidth has been reallocated for Cellular Vehicle-to-Everything (C-V2X) communication as of November 2020



Bluetooth Detectors – detects Bluetooth devices to estimate travel time, vehicle presence, and other applications



Traffic Management Software – an integrated system for active traffic management to improve safety and traffic flow



Caltrans Traffic Management Center (TMC) – center for active traffic management activities to process and respond to traffic demands on the roadway network



Closed-Circuit Television (CCTV) Cameras – video surveillance used for monitoring or actively supporting various connected applications



Transit Signal Priority (TSP) – signal system that modifies phasing or timing in response to transit vehicle presence or schedule



Emergency Vehicle Preemption (EVP) – signal system that allows emergency vehicles the right of way when responding to an emergency



Smart Streetlights – connected and efficient streetlight systems that measure activity and environmental conditions

2.2 Existing Regional Arterial Management System

Coordinated, regionwide traffic signal integration and arterial management is currently conducted through SANDAG's Regional Arterial Management System (RAMS). Arterial operations are performed by individual agencies through their traffic signal control systems, most commonly QuicNet or Transparency, to manage timing plans and check system status. RAMS has been serving as the regional data exchange system for many years, but the needs for the SIS go beyond what RAMS can currently provide.

Under the existing RAMS-Transparency platform, agencies share a variety of traffic data relevant to traveler information, ramp metering rates, signal timing, long-term planning activities, and more. Ongoing coordination processes have been developed for the I-15 Integrated Corridor Management (ICM) subsystem that activates alternate timing plans for arterials adjacent to the freeway during periods of congestion. The SIS represents the next progression in ICM strategies by expanding to include all modes (rather than focusing on vehicle traffic) and by scaling up for consistent deployment on arterials across the region.

The existing system is not structured to accommodate several of the proposed elements of the RTP, like preparing the region for a connected vehicles environment. For a truly smart intersection, a system is needed that can provide real-time, high speed data exchange that can accommodate connected vehicle applications to improve safety for people with varying levels of mobility who might need more time in crossing busy intersections or smart traffic signals that can communicate with users of all modes. As such, RAMS is expected to be retired and replaced with the Next OS to meet the needs of the SIS.

3 CONCEPT OVERVIEW

3.1 *Introduction to Smart Intersection Systems*

People are choosing to travel using an ever-broadening range of modes such as walking and biking, driving and carpooling, transit, for-hire passenger ride services like Uber and Lyft, micromobility services like scooter share, and more. Each mode has unique needs and challenges within the transportation network, and these modes pose

different considerations for agencies. These needs often conflict with one another and with other critical services that intersections support, such as freight movement, emergency responders, and infrastructure maintenance.

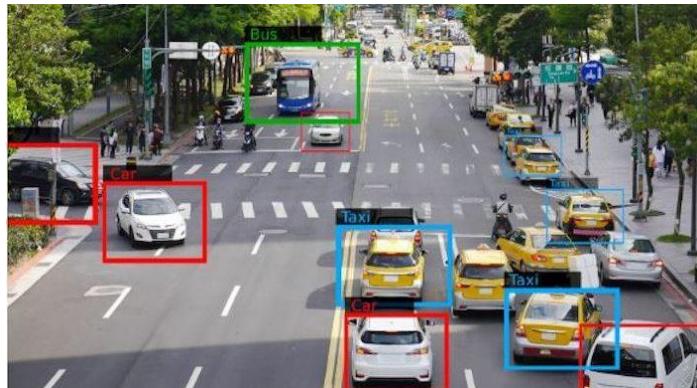


Figure 3. Video Detection

Source: *Traffic Technology Today*

Operating smart intersections as a system enables greater coordination across agencies to assess priorities, optimize network performance, and increase resilience to disruptions.

The system-oriented approach also allows the opportunity to fill existing gaps in service and infrastructure preparedness, particularly in disadvantaged communities. With these network elements in place, SIS lays the groundwork for an

equitable future connected environment through vehicle-to-infrastructure (V2I) and connected vehicle (CV) technology.

The SIS is presented as an intersection concept but is relevant to a group of intersections along a corridor or in a subarea such as around a mobility hub. SIS deployments are more likely to occur within a corridor context within agencies that have more advanced capabilities and near destinations with regional significance (such as employment centers and concert venues) or along critical evacuation routes.

3.2 *Business Case for SIS*

Smart intersections strategies and transportation systems management strategies offer low-cost, high-benefit solutions that maximize the efficiency of the limited space within the transportation network and improve the day-to-day operational processes through the application of technology. Some examples of the anticipated outcomes of the re-imagined data hub and SIS include:

- ▶ Real-time system operational awareness of locations of transit vehicles, personal vehicles, pedestrians, and bicyclists
- ▶ Reduced delay and greenhouse gas emissions resulting from improved overall corridor signal progression
- ▶ Scalable region-wide application of the existing I-15 ICM standardized interface, command and control, data exchange formats, and proposed improvements
- ▶ Enhanced engagement of regional and local transportation partners to help advance the Next OS and to prepare for deployment of connected vehicle technologies

Following the development of the 5 Big Moves vision, SANDAG has been awarded a \$9.3M grant through FHWA's Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program to begin the deployment of the Next OS, Mobility Hub, Flexible Fleet, and Connected Corridors components of the 5 Big Moves. The ATCMTD project will include systems engineering and deploy concepts that will optimize multimodal system performance, offsetting worsening traffic congestion and travel inefficiencies that result in lost productivity and a reduction of the national gross domestic product.

Building upon the progress made by the existing RAMS platform, the project will fund the deployment of 33 smart intersection systems near the California-Mexico border to deliver adaptive and smart signal management with V2I roadside equipment (RSE) sited in key Mobility Hub locations. The ATCMTD planning documents and system deployments will help set up local stakeholder groups for additional funding opportunities.

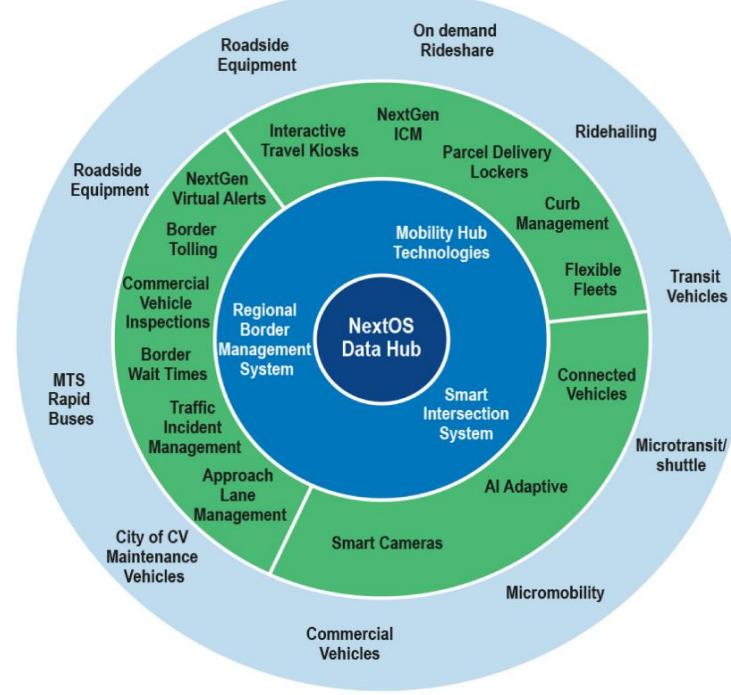


Figure 4. ATCMTD Project Technology Elements

3.3 Smart Intersection Typologies

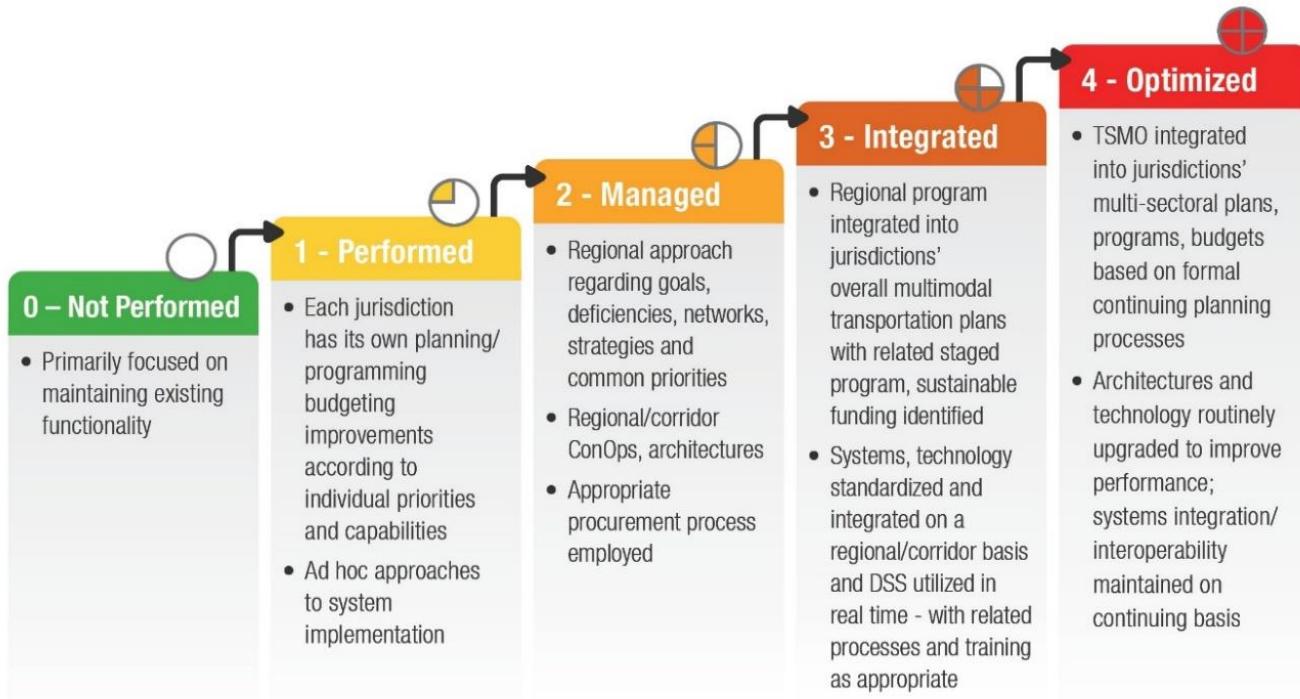
Like any traffic infrastructure deployment, smart intersections come in many shapes and sizes according to existing conditions, geography, traffic patterns, local priorities, regional plans and initiatives, and characteristics of the users of the facility. Each agency and corridor can have any combination of maturity levels within these four capability dimensions: Institutional Approach, Multi-Modal Accommodations, Technology and Innovation, and Intersection Utilization. Capabilities and needs vary across agencies, across corridors, and from one intersection to the next based on land uses, the presence of transit, and previous deployments.

Institutional Approach

An agency's institutional approach is characterized by the legislation, policies, and local mobility plans. Agencies and corridors that take a regional approach to planning, budgeting, procurement, and performance measurement represent higher levels of institutional capability. Agencies and corridors that are operating at Level 0 or 1 as described below will face significant barriers to providing the benefits of Next OS and SIS to the users of those facilities.



Institutional



Level 0 – Agencies do not share information with other agencies or within internal departments. Level 0 agencies characterized by isolated operations with little operational information or performance measurement analysis shared with planning staff or with other agencies.

Level 1 – Agencies share information internally but have an isolated approach to decision making. Level 1 agencies set goals and make decisions by sharing information between internal city departments, but do not coordinate operations or decision-making outside of city staff.

Level 2 – Agencies use regional tools and vision to make decisions, use an ad hoc approach with other agencies to coordinate operations. Level 2 agencies set goals and make decisions using regional priorities and plans. They coordinate operations with other agencies when the need arises on an ad hoc basis.

Level 3 – Agencies coordinate planning and operations with other agencies, performance measures are used to provide feedback on decisions. Level 3 agencies coordinate operations across agency boundaries using real time performance metrics. They often have dedicated funding for operational improvements.

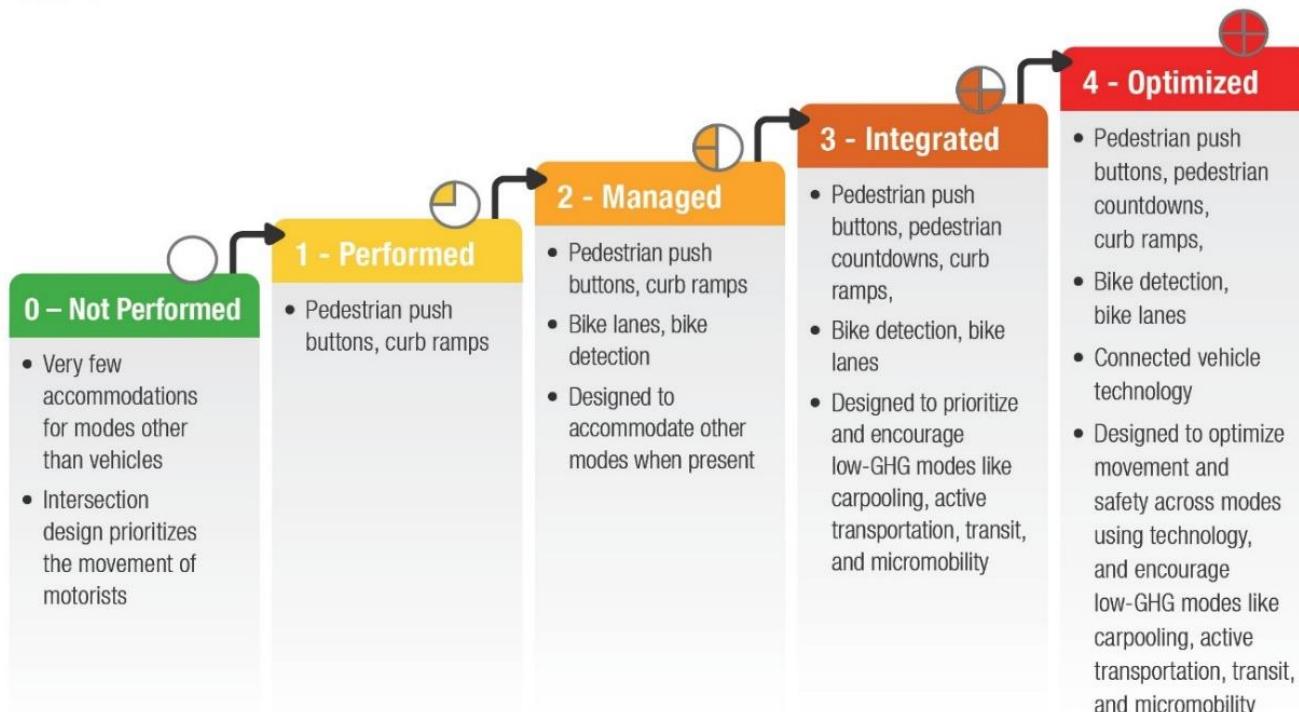
Level 4 – Agencies utilize TSMO principles for real time performance measurement across agency boundaries to develop plans, programs, and budgets. They make continuous improvements based on real time information. Level 4 agencies embrace TSMO principles to the fullest using continuous improvements based on real-time information and feedback from other agencies. Coordination is done regularly, and agencies share real time information.

Multi-Modal Accommodations

Multimodal accommodations include the technology and infrastructure related to serving pedestrians, cyclists, other micromobility options such as scooters, transit, carpools, neighborhood electric vehicles (NEVs), and future modes such as connected and autonomous vehicles. Examples include accessible pedestrian push button systems, bike lanes, bike boxes, high occupancy vehicle (HOV) lanes, transit-only lanes, and signal timing that gives priority to non-vehicle modes. Agencies and corridors that have local multi-modal plans, infrastructure, and policies that encourage low-carbon modes and optimize safety and efficiency across all modes represent higher levels of capability.



Types of Multi-Modal Accommodations



SIS technology can have the greatest impact within agencies and corridors that provide signal timing and dedicated space that serves the needs of vulnerable roadway users like active transportation, transit, and those with varying levels of personal mobility. Agencies and corridors that are operating at Level 0 or 1 will face significant barriers to providing the benefits of Next OS and SIS to the users of those facilities.

The 2021 RTP vision constitutes a shift towards a heavier focus on sustainability, equity, and efficiency of the overall system. As such, certain modes may receive higher priority than in the past. For example, within corridors that the RTP identifies as NextGen *Rapid* sites or part of the bicycle network, transit and active transportation modes will be elevated, whereas regional arterials or rural corridors may remain more focused on vehicle traffic movement.

Level 0 – Agencies do not consider other modes (active or transit) for planning or operations. Level 0 agencies characterized by planning and operating for the single occupancy vehicle.

Level 1 – Agencies may utilize strategies to integrate modes as secondary to vehicles. Level 1 agencies characterized by isolated strategies such as pedestrian push buttons at localized areas on an ad hoc basis.

Level 2 – Agencies integrate multiple modes using strategies appropriate to the specific location. Level 2 agencies may use additional features based on local priorities and transportation needs include:

- ▶ Transit queue jump lanes
- ▶ TSP
- ▶ Micromobility device detection

Level 3 – Agencies prioritize active transportation and transit in planning and operations. Level 3 agencies may use additional features that include:

- ▶ Passive pedestrian detection
- ▶ Coordinated signal offsets optimize bicycle or transit progression
- ▶ TSP
- ▶ Signal coordination with at-grade transit crossings
- ▶ Managed lanes (transit-only lanes, no street parking during peak hours, etc.)
- ▶ Transit queue jump lanes, transit signal pre-emption, curbside bus pull-outs
- ▶ Ramp meter coordination

Level 4 – Agencies prioritize active transportation by using performance metrics and real time information to improve performance. In addition to Level 3 features, Level 4 agencies may use additional features that include:

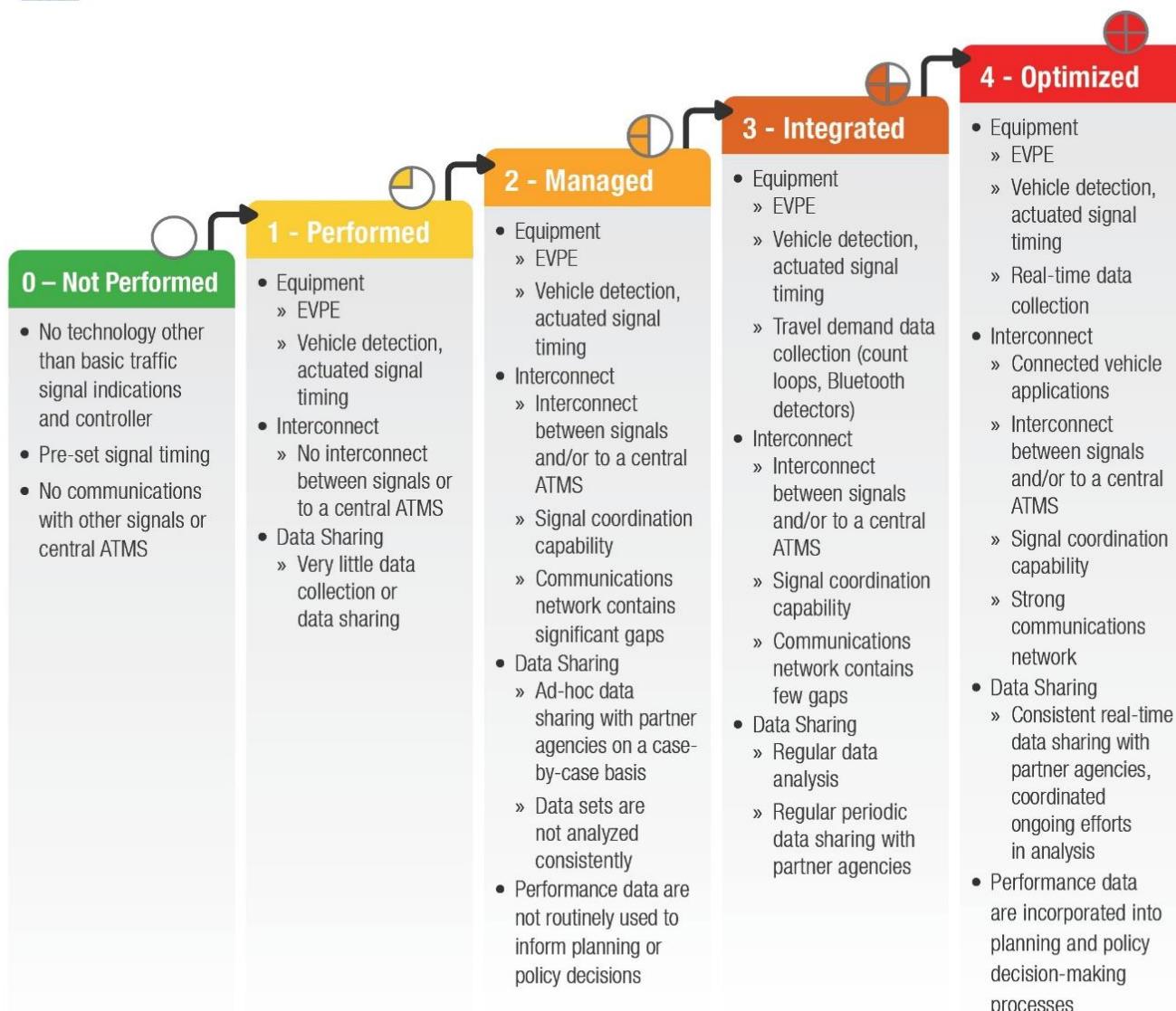
- ▶ Vehicle conflict detection
- ▶ Proactive near-miss safety analysis
- ▶ V2I communications
- ▶ Cyclist dilemma zone detection and green time extension
- ▶ Walk time extension for vulnerable pedestrians
- ▶ Coordinated signal offsets optimize bicycle or transit progression
- ▶ TSP
- ▶ Signal coordination with at-grade transit crossings
- ▶ Ramp meter coordination
- ▶ Managed lanes (transit-only lanes, no street parking during peak hours, etc.)
- ▶ Passive pedestrian detection

Technology and Innovation

Field equipment, technology solutions, data collection, and the agency's approach to data sharing and collaborative operations are critical elements of the success of SIS implementation. Agencies and corridors that transmit field data through robust communications networks to a central advanced traffic management system (ATMS) for real-time system management and incorporate performance metrics into their planning processes represent higher levels of capability. Agencies and corridors that are operating at Level 0 or 1 which lack interconnectivity will face significant barriers to providing the benefits of Next OS and SIS to the users of those facilities.



Technology and Innovation



Level 0 – Simplistic signals operate entirely offline. Level 0 intersections are characterized by a focus on the personal automobile and a lack of interconnectivity with other signals or a central ATMS. While there may be other modes on the road, the intersection is designed to primarily accommodate the automobile.

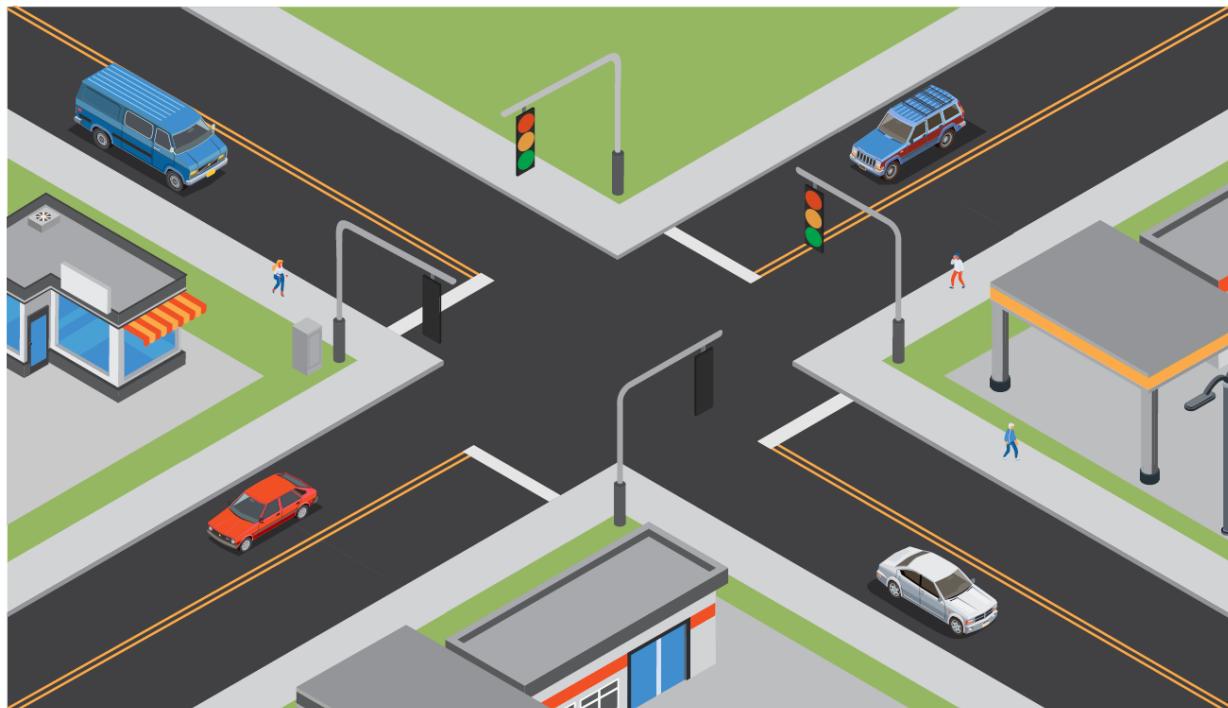
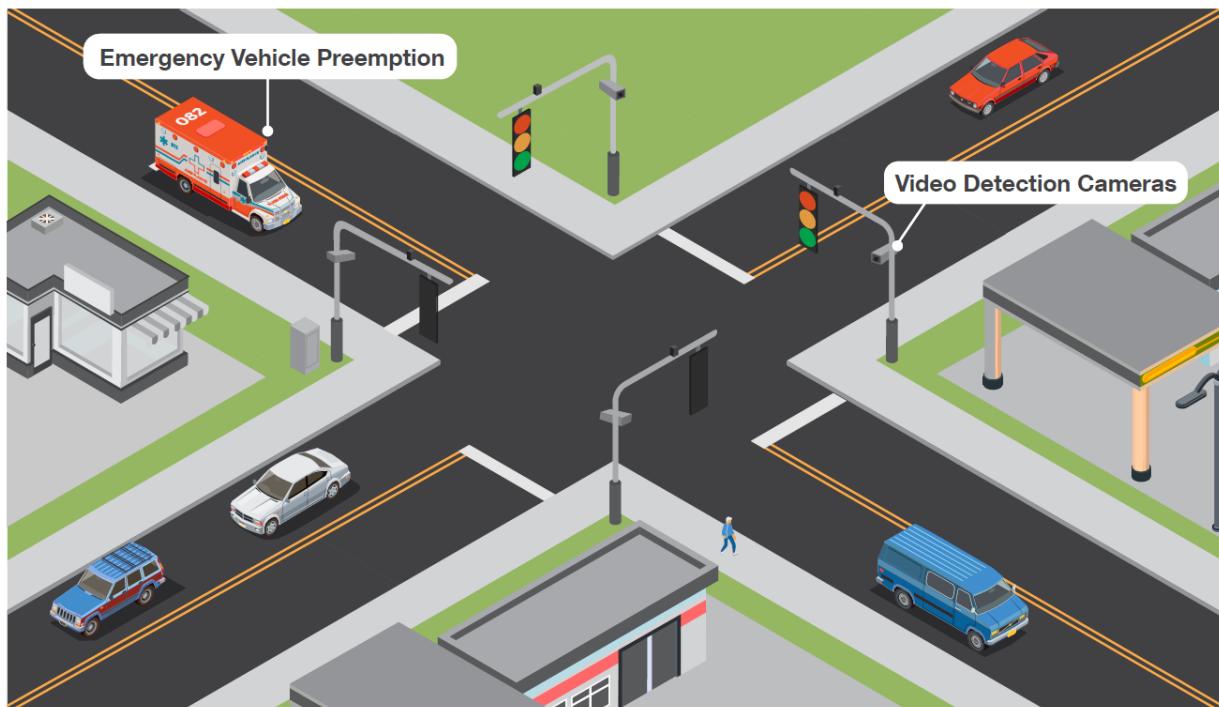


Figure 5. Level 0 Technology and Innovation

Level 1 – Signals respond to some demand variability and support multiple modes.

Like Level 0, Level 1 intersections are primarily designed for the single occupancy vehicle, but Level 1 intersections support other modes with pedestrian push buttons and signal preemption for emergency vehicles. Although they can respond to some demand variability through vehicle detection and actuated signal timing, Level 1 signals do not connect with other signals or a central ATMS.

**Figure 6. Level 1 Maturity**

Level 2 – Signals are interconnected within a multi-modal network.

Level 2 intersections are characterized by a more regional institutional approach to strategies and priority-setting. Many elements of complete streets that encourage active transportation and transit are incorporated, and signals have interconnect that enables synchronization with other signals and monitoring from a central ATMS. Basic ATMS features enable operators to check conditions and update signal timing parameters remotely.

As intersections become more advanced, there is a greater degree of functional variability depending on the location and local transportation priorities. Although Level 2 intersections are interconnected, not all corridors will benefit from signal coordination. Similarly, Level 2 corridors with multiple transit routes and high ridership will look very different from other that focus more on active transportation.

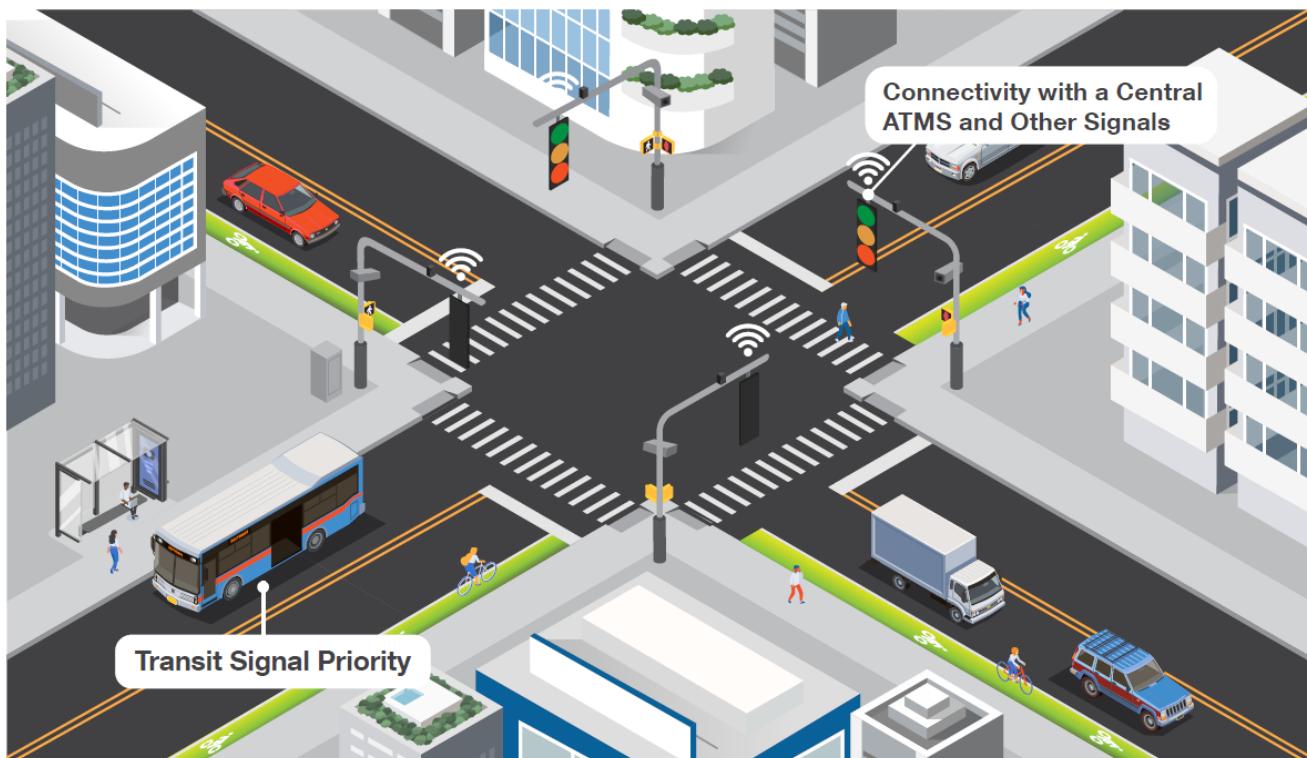


Figure 7. Level 2 Maturity

Level 3 – Connected signals enable active traffic management and encourage low-carbon modes.

Level 3 intersections are characterized by an institutional approach that integrates the regional program and multimodal transportation plans to obtain funding and standardize technology. Traffic demand management strategies are implemented to prioritize and encourage low-carbon modes to meet regional goals. System performance is measured with consistent data collection and analytics. These performance measures are routinely used to inform proactive operations, maintenance, and planning decisions within the agency and with regional partners.

Examples of additional features that can appear in Level 3 intersections based on local priorities and transportation needs include:

- ▶ Transit only lanes, queue jump lanes, signal priority
- ▶ CCTV
- ▶ Federally approved short-range communication
- ▶ Adaptive signal timing
- ▶ Alternate timing plans for incidents
- ▶ Flush plans for special events

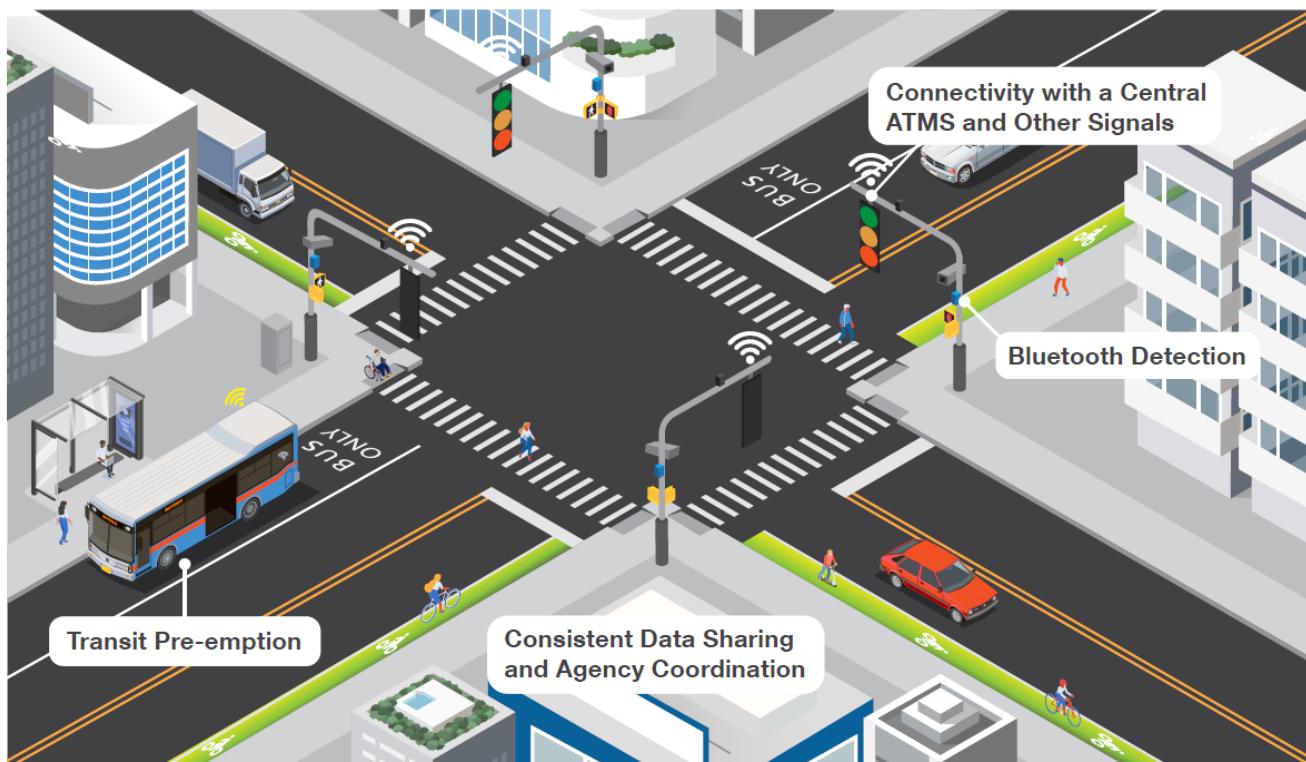


Figure 8. Urban Level 3 Maturity

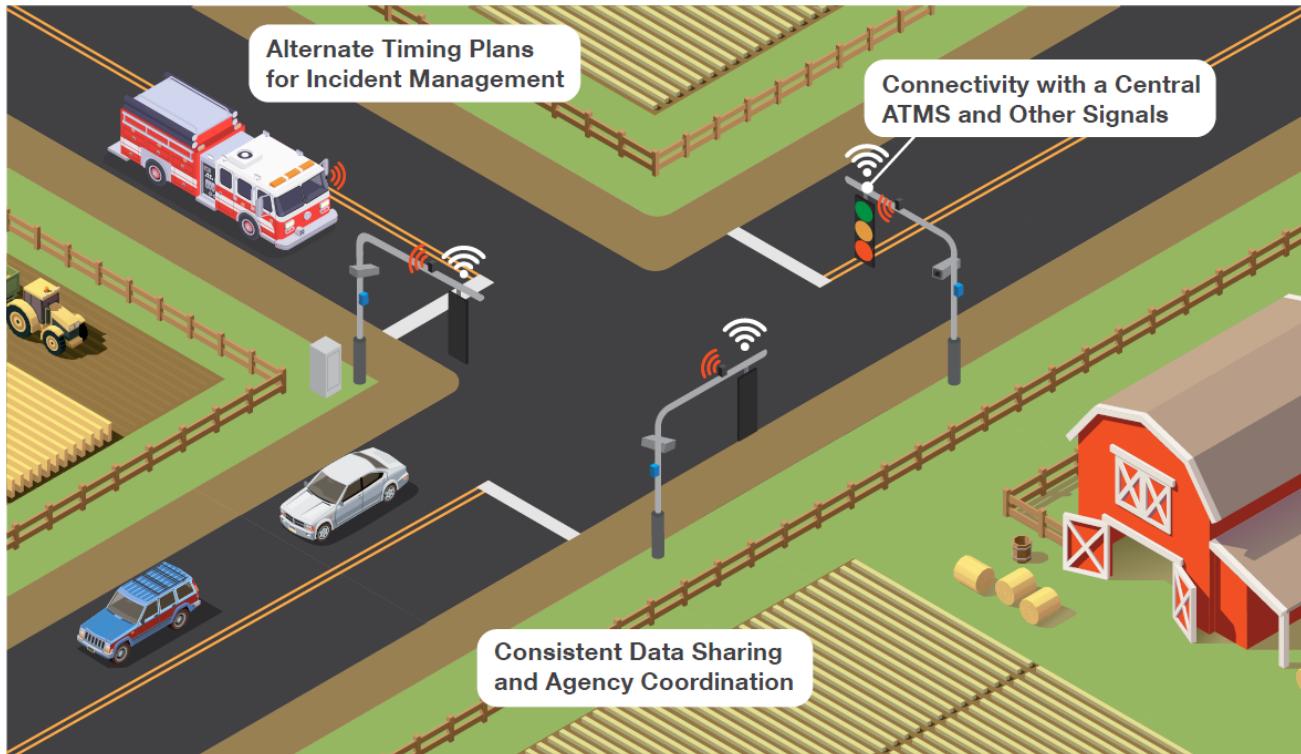


Figure 9. Rural Level 3 Maturity

Level 4 - Optimizes efficiency, monitors performance, and enhances safety for all modes in a connected vehicle environment.

Level 4 signals typically operate within a smart corridor to optimize performance and safety and promote low-carbon modes. Operations are managed in real-time with consistent performance monitoring priorities and strategies among partner agencies. Level 4 signals are characterized by their resilient and robust communications infrastructure that enables a fully connected environment for information transfer between signal infrastructure, system operators, and users.

Examples of additional features that can appear in Level 4 intersections based on local priorities and transportation needs include:

- ▶ Vehicle conflict detection
- ▶ Proactive near-miss safety analysis
- ▶ V2I communications
- ▶ Cyclist dilemma zone detection and green time extension
- ▶ Walk time extension for vulnerable pedestrians
- ▶ Coordinated signal offsets optimize bicycle or transit progression

- ▶ TSP
- ▶ Signal coordination with at-grade transit crossings
- ▶ Ramp meter coordination
- ▶ Managed lanes (transit-only lanes, no street parking during peak hours, etc.)
- ▶ Passive pedestrian detection
- ▶ Transit queue jump lanes, transit signal priority, curbside bus pull-outs

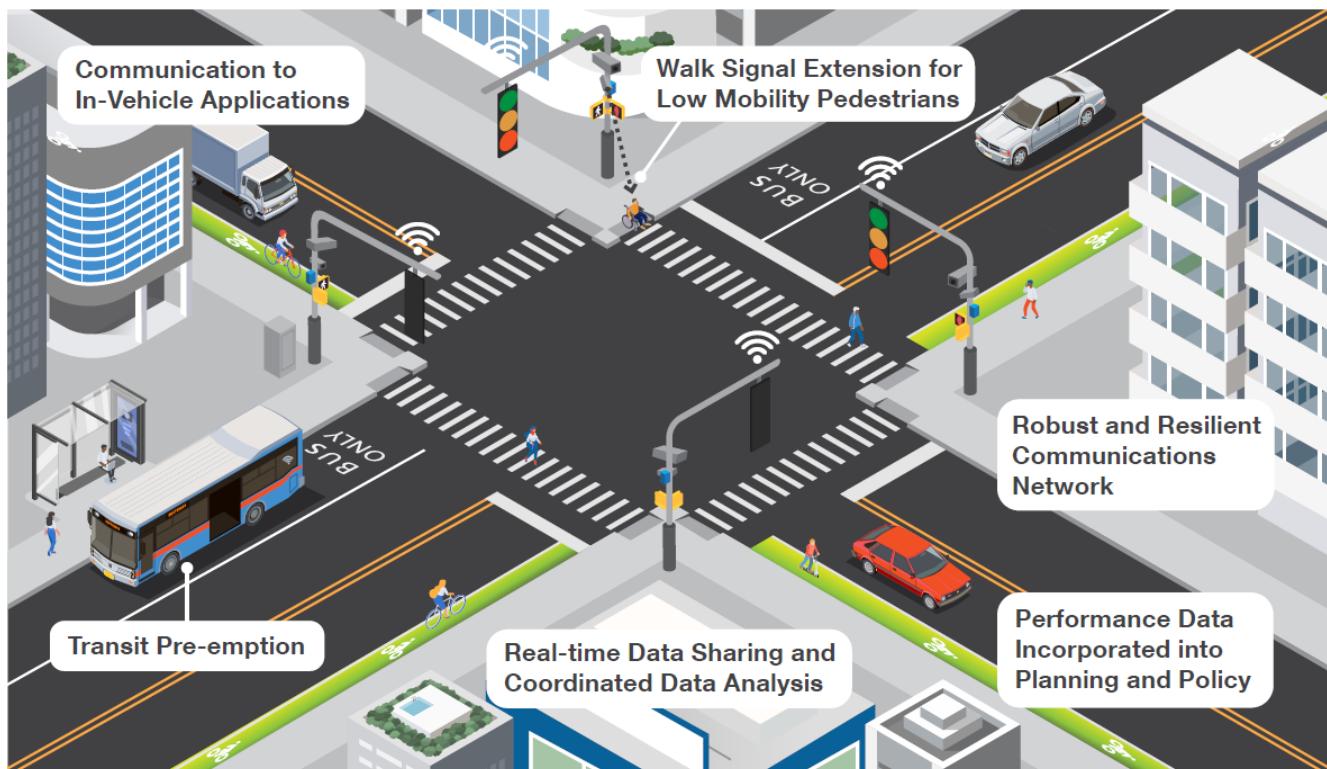


Figure 10. Urban Level 4 Maturity

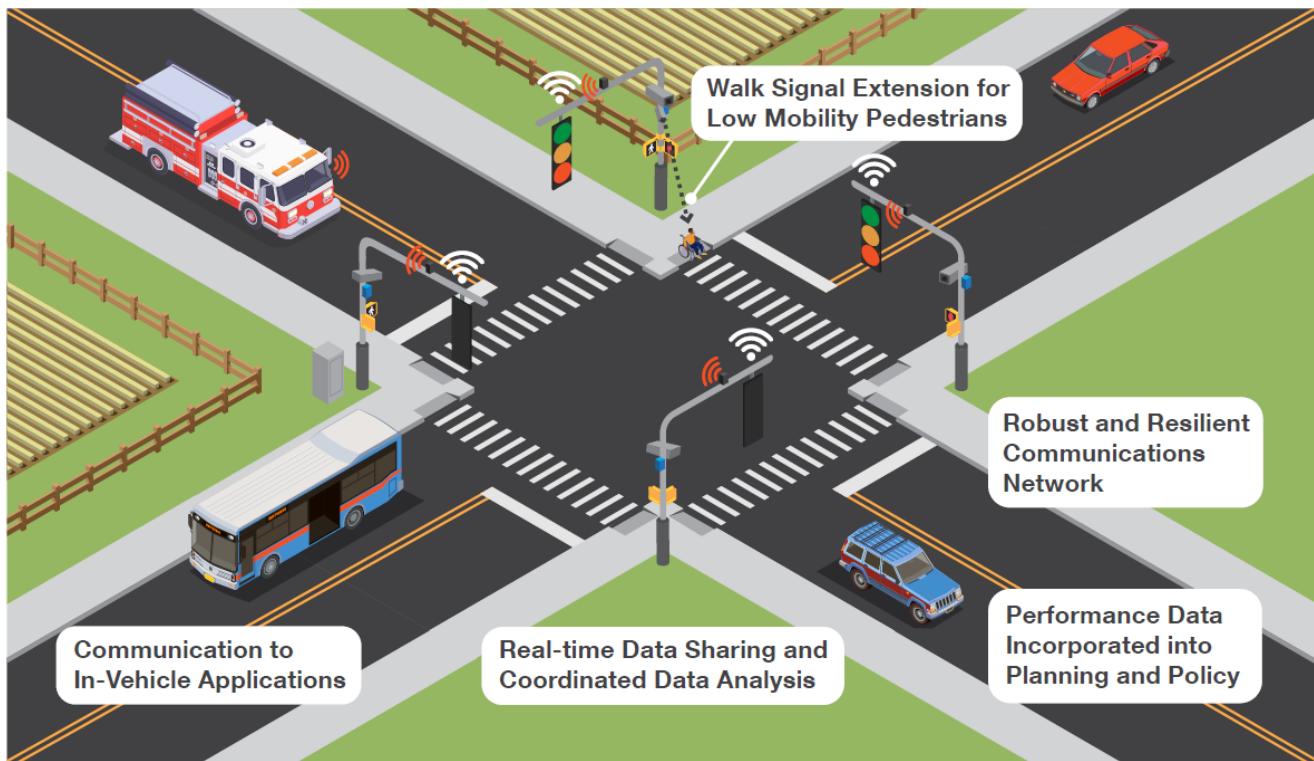
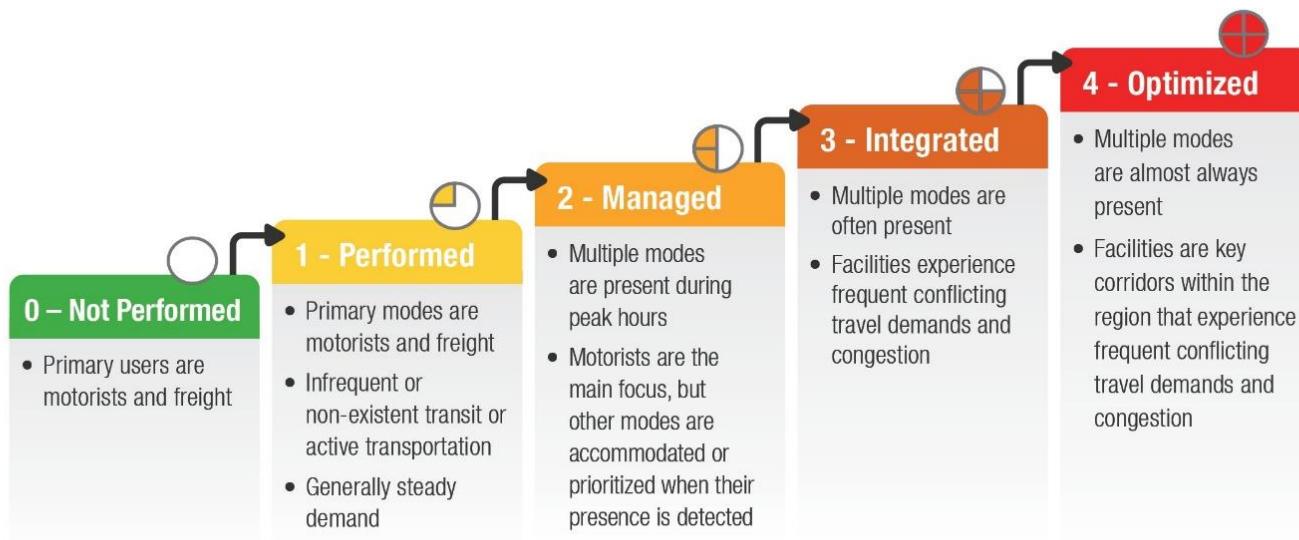


Figure 11. Rural Level 4 Maturity

Intersection Utilization

Intersection utilization describes the prevalence of certain user types, the regional significance of the facility with regard to adjacent land uses and attractions, and the criticality of the facility in the event of an emergency or major incident. These parameters affect the level to which a specific corridor will need to interact with elements of SIS and Next OS. With greater levels of diversity within user groups and greater levels of criticality to regional employment, attractions, and evacuations, the greater opportunity for the facility to benefit from SIS.

Intersection Utilization



Level 0 – Low volume, often rural intersections. Level 0 intersections are characterized by a focus on the personal automobile and a lack of interconnectivity with other signals or a central ATMS. While there may be other modes on the road, the intersection is designed to primarily accommodate the automobile. Level 0 intersections have:

- ▶ Multiple points of access to use in the event of an emergency
- ▶ Transportation network redundancy that can relieve system congestion during major incidents

Level 1 – Typically used by personal vehicles and freight with steady demand. Level 1 intersections are often found on facilities with relatively few conflicting user demands, such as:

- ▶ Rural or low-volume roadways
- ▶ Locations with demand variations resulting from seasonal or weekend tourism and recreation travel patterns
- ▶ Emergency evacuations may be a primary concern

Level 2 – Have varying demand throughout the day characterized by higher volumes peak periods. Level 2 intersections can be found on a diverse range of facilities, such as:

- ▶ Rural or urban settings
- ▶ Roads, neighborhood collectors, and arterials
- ▶ Typically travel patterns follow primary commuting hours

Level 3 – Have multiple modes with competing needs. These intersections often are constrained because of high volumes and limited right of way. Level 3 intersections can be located on a diverse range of facilities that need to balance conflicting needs of many users, such as:

- ▶ Critical emergency evacuation routes on rural highways
- ▶ Urban/suburban collectors and arterials
- ▶ University campuses
- ▶ Corridors within the urban core and local business districts
- ▶ NextGen Rapid corridors
- ▶ Roads near mobility hubs, beaches, and parks

Level 4 – Have multiple modes and are characterized by frequent congestion or specific events that trigger extreme congestion (concerts, special events, etc.). Level 4 intersections are typically found on key corridors within the region which experience frequent conflicting user demands, such as:

- ▶ Emergency evacuation routes on rural highways
- ▶ Urban/suburban collectors and arterials
- ▶ University campuses
- ▶ Corridors within the metropolitan center with regional draw
- ▶ NextGen Rapid corridors
- ▶ Near major transit stations and TOD
- ▶ Near major attractors like stadiums, parks, and employment centers

3.4 Agency Capability Maturity Focuses

To effectively manage SIS, agencies should understand their current institutional capabilities and develop a plan for reaching their desired level of capacity. Using the Capability Maturity Model (CMM) for TSMO as a foundation for self-evaluation, agencies can assess their capacity to deploy SIS across dimensions or process areas that apply to smart intersections.

There is no one-size-fits-all approach to developing a SIS deployment plan and actively advancing an agency's capability and maturity. Agencies should conduct a true self-evaluation to determine their specific capabilities, establish strategic goals for their respective jurisdictions, develop action items that will expand their capability and maturity as an agency, and re-evaluate their capacity as action items are completed. Using the descriptions of each dimension above, agencies should use **Table 1** as a template to evaluate their capabilities within each corridor that is under consideration for SIS deployment.

Table 1. Agency Capability Self-Assessment

Example Agency Capability Self-Assessment			
			
Institutional Approach	Multi-Modal Accommodations	Technology and Innovation	Intersection Utilization
3	4	3	2

4 USER-ORIENTED OPERATIONAL DESCRIPTION

4.1 Stakeholder Roles and Responsibilities

The purpose of this section is to identify the organizational structures and order of operations that will support Regional TSMO. This section will call out specific agencies and departments to identify their roles as they pertain to operating the proposed system. This ConOps is unique in that the approach is regional but the owners of the transportation facilities will ultimately implement it. **Table 2** identifies stakeholders and their respective roles and responsibilities in guiding Regional TSMO and Smart Intersection initiatives in the San Diego region.

Table 2. Stakeholder Roles and Responsibilities

Stakeholder	Roles and Responsibilities
SANDAG	<ul style="list-style-type: none"> ▶ Metropolitan Planning Organization for the San Diego region ▶ Leading the San Diego Forward: The 2021 Regional Plan ▶ Manages regional planning activities, including providing regional guidance and leadership on implementing transportation initiatives ▶ Provides standards and high-level guidance for how agencies can adopt and implement their own SIS practices ▶ Create regional forums for operations coordination and meetings ▶ Leads the Systems Engineering process to develop the Next OS platform ▶ Develop training programs for SANDAG and partner agencies to share knowledge and develop standard protocols
Caltrans	<ul style="list-style-type: none"> ▶ Owns, manages, and maintains their roadways, ramp meters, and right-of-way ▶ Coordinates signal timing / ramp meter timing with local agencies to reduce queuing ▶ Implements SIS strategies at their intersections ▶ Partner in Next OS Platform
Infrastructure Owner-Operators (Cities and Counties)	<ul style="list-style-type: none"> ▶ Owns, manages, and maintains local signals and public right-of-way ▶ Coordinates with partner local agencies, transit agencies, Caltrans (when applicable), and SANDAG to implement SIS strategies ▶ Partner in Next OS Platform
Transit Agencies	<ul style="list-style-type: none"> ▶ Operates public transit and paratransit services ▶ Coordinates with local agencies on signal timing ▶ Uses TSP when appropriate ▶ Implements on-board safety features such as blind spot warning whenever possible

	<ul style="list-style-type: none"> ▶ Adopts SIS strategies agency wide in coordination with local agencies / SANDAG ▶ Partner in Next OS Platform
Micromobility and Microtransit Providers	<ul style="list-style-type: none"> ▶ Distribute e-scooters / e-bikes in local agency designated areas ▶ Ensure that micromobility is distributed in public areas and does not block sidewalk, Americans with Disabilities Act of 1990 (ADA) facilities, driveway, or transit boarding access ▶ Distributes micromobility throughout communities to address the needs of residents of varying socio-economic statuses ▶ Distributes considering how micromobility can close first mile / last mile to transit services ▶ Provides microtransit services for designated areas with flexible routing options ▶ Partner in Next OS Platform
Traffic Enforcement (Local / State)	<ul style="list-style-type: none"> ▶ Enforces intersections to promote safety of all modes of transportation ▶ Watches out for any system failures ▶ Conducts traffic control if vital ▶ Incident response
Emergency Responders	<ul style="list-style-type: none"> ▶ Addresses incidents ▶ Coordinates evacuations ▶ Uses EVP on equipped intersections ▶ Partner in Next OS Platform
General Public	<ul style="list-style-type: none"> ▶ Operates private vehicles ▶ Users of transit system ▶ Utilizes all modes for movement (such as walking, biking, and micromobility options) ▶ Includes the disabled and hearing impaired who rely on modes such as wheelchairs and walkers

5 OPERATIONAL NEEDS

5.1 Vision

The vision, goals, and objectives serve as the backbone for the project. While the vision statement provides high-level guidance on the what the project strives to be long-term, the objectives provide clear benchmarks on how the project can reach its goals.

SIS is a use case of the Next OS and will therefore support the core values of the 2021 Regional Plan. The 2021 Regional Plan vision statement is *“to use the 5 Big Moves strategies to envision a balanced transportation network that gets you where you need to go quicker and easier, increases access to opportunity, and meets state greenhouse gas emissions mandates. A system that leverages technology to create a safe, adaptable, and socially equitable transportation ecosystem that responds to the unique needs of the wonderfully diverse communities throughout our region.”*

Consistent with The RTP vision statement, the vision for SIS is:

To create a safe, adaptable, and socially equitable smart intersections network that relies on technology and agency coordination to meet the needs of all user groups. At its core, smart intersections seek to balance: Safety, Efficiency, and Multi-modal Travel.

The SIS takes the smart intersection concept next level with a comprehensive regional approach by connecting signals and field devices to a central operating system for real-time management. **Operating smart intersections as a system enables greater coordination across agencies to assess priorities, optimize network performance, and increase resilience to disruptions.** The system-oriented approach also allows the opportunity to fill existing gaps in service and infrastructure preparedness, particularly in disadvantaged communities. With these network elements in place, SIS lays the groundwork for an equitable future connected environment through V2I and CV technology.

5.2 Goals, Objectives, and Needs of SIS

Before identifying individual strategies, it is important to identify the system goals and objectives, and then apply the strategies that will help achieve them. This approach helps stakeholders choose technologies, procurement methods, and operating agreements that suit their needs over time despite the ever-evolving technological landscape.

Smart intersections deployments will not all be designed with the same set of requirements, since the majority of the technology will be deployed by agencies at a local level within a corridor or community. Therefore, objectives will differ from one corridor to the next and should be sensitive to the context of the area and the regional plans for that specific location. The goals detailed below can be applied to SIS management in the SANDAG region.



Improve safety and compliance across all modes.



Support sustainability goals by elevating transit and low emission modes.



Prioritize equity and accessibility across all modes.



Actively manage operations according to transportation demand.



Provide infrastructure to promote V2I and CV technology.



Connect users with real-time information.



Promote the efficient movement of people and goods.



Promote resilience to disruptions and changing technology.

1.0 Improve safety and compliance across all modes.

The majority of fatal or injury crashes occur at or near the intersection. Improving safety at the intersection is related to improving the compliance to traffic safety laws for all modes and recognizing that modes that are capable of causing the most harm are typically vehicular modes. While there are certainly human factors and geometric design factors involved in the safety of an intersection, SIS introduces the technology factors for improving safety. These technologies include vehicle-to-everything (V2X) communications and improved data analytics.



To improve safety and compliance of all modes, the following objectives and corresponding needs are defined:

- ▶ **Identify traffic signal safety applications.**
 - Need to study equity implications and safety impacts of implementing automated traffic enforcement technology.

- Need to identify appropriate intersection hardware upgrades for each jurisdiction in support of traffic signal safety technology.
- Need to consider proactive near-miss monitoring and analysis on key corridors to help identify modifications to intersection operations and geometry and prevent injury and death.
- Need roadside devices to communicate real-time locations of vulnerable road users such as (active transportation, micromobility, active commercial loading zones) to caution nearby vehicles.
- Need to study traffic signal timing and traveler information strategies to improve safety for vulnerable road users and reduce speeding.

► **Develop strategies to improve emergency evacuation.**

- Need to allow TMC staff and emergency services staff to quickly initiate traffic signal plans to evacuate people safely and efficiently.
- Need to identify methods to control traffic signals remotely during evacuation events and identify a back-up plan to operate signals on-site during power and communications outages.
- Need to identify methods to communicate emergency evacuation related information to the public.
- Need to develop emergency evacuation plans and provide training for traffic management, emergency services, transit operators, and other staff.

► **Create innovative incident management to reduce secondary incidents.**

- Need to improve coordination between agencies during major incidents.
- Need to reduce incident clearance times.

2.0 **Prioritize equity and accessibility across all modes.**

Transportation equity is providing accessible and affordable transportation for everyone, accounting for the innate and socially imposed differences that exist among communities. The San Diego region is extremely diverse, and the smart intersection system should take into consideration the diversity of needs from minority or disadvantaged populations. Some populations do not regularly use smart phones, do not have reliable access to the internet, have low English language proficiency, or have a disability that creates a barrier to utilizing transportation services. There should not be an undue burden on these people to utilize the public travel way.



To prioritize equity and accessibility in smart intersections, the following focused objectives and needs are defined:

► **Prioritize safe access for users with disabilities within the intersection.**

- Need to identify and fill gaps in the ADA-accessible network, particularly at points of connection where users switch modes.
- Need to detect pedestrians with mobility challenges crossing the intersection and provide them with walk time extensions.

► **Deploy SIS projects across the San Diego region with a focus on the specific needs of each community.**

- Need to involve local community stakeholders in the planning and design of SIS concepts.
- Need to prioritize SIS infrastructure development in disadvantaged communities.

► **Promote equity and access for all modes and people.**

- Need to prioritize the safety of the most vulnerable road users.
- Need to prioritize access to employment opportunities, residences, and recreation for all people, including those with disabilities, those who are unbanked or underbanked, and those who speak languages other than English.

3.0 Provide infrastructure to promote V2I and CV technology.

V2I and CV technologies automate processes to reduce the risk of collision or inefficiencies. This is achieved through technology that allows connected vehicles to communicate with infrastructure such as traffic signals. The connected vehicle is notified when the signal is about to turn red and automatically knows when to stop. Information about pedestrians and cyclists can also be shared with the vehicle. These abilities limit room for human error and solve other external human-impacted factors such as lack of visibility.

Establishing standards and interoperability between connected vehicles and V2I across agency borders will be important in developing a safe and efficient smart intersection system. Another important consideration will be the role of connected vehicles at less advanced intersections. While their capabilities may not be as advanced at Level 4 intersections, there may be opportunities to use the connected vehicle technology, such as pushing out in-vehicle alerts using Next OS.



► **Implement vehicle-to-infrastructure technology.**

- Need infrastructure to support vehicle-to-infrastructure communications on transit and flexible fleets.
- Need infrastructure to communicate traffic signal data and other data collected at the intersection to all connected vehicles.
- Need to develop policies to ensure privacy of individual users.

► **Provide a communications network with suitable bandwidth for SIS.**

- Need to perform an assessment of existing communications infrastructure and develop a plan to fill existing gaps.
- Need to develop a standard approach to asset management to collect, track, and share data on existing communications infrastructure.

4.0 Promote the efficient movement of people and goods

The efficient movement of people and goods is vital to any local economy but is especially important for the San Diego Region. Its location on the border makes it a key entry point to the United States for goods movement from Mexico. It is also home to many strong industries and major employment centers making the movement of people just as important. People and goods must travel through many intersections to reach their destination, allowing for the opportunity for SIS to provide many benefits to this region.



There are many components that go into the efficient movement of people and goods, but operations and data sharing are critical parts of these components.

- ▶ **Synchronize across jurisdictional boundaries and state and local agencies to provide a seamless experience to users.**
 - Need updated processes for interchange signal coordination.
 - Need a consistent approach to adaptive signals deployments.
 - Need a consistent approach to transit priority signals operations.
 - Need enhanced coordination between transit operators and signal operators.
- ▶ **Provide system for clear and concise data sharing among partner agencies.**
 - Need data output that is simple for local decision makers, planners, and operators to interpret and act on.
 - Need to identify the origin and destination of trips to track diversion and cut-through traffic.
- ▶ **Facilitate movement of freight and commercial vehicles.**
 - Need region-wide database for local truck routes.

5.0 **Support sustainability goals by elevating transit and low emission modes.**



Traveling by single-occupant car trips is perceived as convenient for those who can afford it, but historical dedication of public right-of-way space towards efficient car travel has made sustainable travel by transit and low emission modes less desirable. In addition, systemic prioritization of single-occupant vehicles has reduced transportation options for everyone, even those in cars who may wish to utilize transit or other modes of transportation. Bus transit users typically sit in the same congestion as car modes, making it inconvenient and slow. People who bike, use micromobility, or walk are considered vulnerable road users (VRUs) when sharing lanes or crosswalks with fast moving cars, making their experience unsafe and uncomfortable. Developing smart intersections that balance the needs of all users can better enhance the experience for VRUs and transit riders. With smart intersection improvements, efficiency and overall user experience can improve, leading to mode shift away from single-occupant car trips.

- ▶ **Create policy that enables the advancement of transit and low emissions modes of transportation.**
 - Need to analyze historic travel times to help inform operations and policy decisions.
 - Need to encourage/incentivize mode shift from single occupant vehicles to HOV, active transportation, micromobility, and transit services.
- ▶ **Enhance viability of transit.**
 - Need to time signals for optimal transit progression along NextGen Rapid corridors.
- ▶ **Enhance viability of active transportation and micromobility.**

- Need to improve active transportation comfort with bulb-outs, markings, and proactive safety analysis.

► **Collect and measure environmental data, including greenhouse gas emissions.**

- Need to measure performance of intersections based on their productivity (i.e., the number of people served) and amount of greenhouse gas emissions.

6.0 Actively manage operations according to transportation demand.

Traditionally, traffic operations have been managed in a routine manner, with signal timing pre-set to accommodate the traffic during peak hours and non-peak hours. With the introduction of adaptive signal timing and different types of detection the approach to operations has become more fluid to better address the changing transportation demands. Not only does this require the adoption, implementation, training, and maintenance of the proper technologies, but it also requires agency coordination. Agencies must also adapt to the changing demands and adjust their operations accordingly.



► **Implement technology that can collect data in real time.**

- Need to share relevant corridor performance measures with adjacent or impacted agencies to improve performance.
- Need to share real-time data with Next OS platform.

► **Implement technology that can accommodate real-time demand of any mode.**

- Need to implement technology that can detect users in the dilemma zone and extend green time for any mode.
- Need to detect the presence of multiple modes at an intersection approach.

7.0 Connect users with real-time information.

Travelers in the region can make informed travel decisions before and during their trip if they have access to traveler information. Smart intersections should provide real-time data to Next OS to inform operators and the traveling public about any delays. The integration of data from multimodal sources, partner agencies, and dissemination of that data will be crucial.



Establishing standard technologies and an interoperable system among all jurisdictions are important aspects for customer experience. Customers typically do not only travel within one agency or jurisdiction. To provide a seamless traveler information experience across the region, agencies should establish a goal of interoperability, scalability, and a common customer user interface for all traveler information. This means providing quality and reliable data in real-time using a streamlined traveler information platform.

► **Provide reliable and actionable real-time information.**

- Need to provide alerts to agency representatives when conditions prompt a predetermined action.
- Need to collect real-time speed and travel time information.

- Need to share real-time video of key corridors to improve operations with adjacent or impacted agencies.
- Need to share transit information such as transit location, transit performance.
- Need to share data on accessibility, equity, equipment, and infrastructure.

► **Incorporate CV technology for real-time information.**

- Need to equip transit fleet vehicles with automatic vehicle location (AVL) system.
- Need to provide short range communication for V2X applications.

8.0 Promote resilience to disruptions and changing technology



Technology is evolving rapidly, making it difficult for agencies to upgrade their systems with current products. A project lifespan often takes years for planning, budgeting, implementation, training, and ultimately operations. By the time a new technology is operational, it is likely that a newer version has been released. The solution to this challenge is to select modular and open-architecture systems that can be easily changed with time. This may mean regular and automatic software updates or purchasing pieces of hardware for new capabilities. The importance of this process is flexibility and compatibility with neighboring cities and communities who may use different vendors and products.

► **Implement interoperable technology to build a modular and scalable system.**

- Need to deploy devices that can exchange data with other IoT devices and Next OS, regardless of vendor or owner/operator.
- Need to be able to expand the system as local capabilities and funding become available.
- Need to procure open architecture systems for compatibility.
- Need to develop standard requirements and an approved technologies list to limit the number of unique device types to streamline maintenance.

► **Create redundancy for limited disruptions.**

- Need to build redundancies in the communications network to enable continued operations during disruptions due to construction, maintenance, and natural disasters.
- Need battery backup systems and generators capable of carrying out SIS functionalities throughout power outages.
- Need real-time alerts for system and device failures.

► **Create a proactive maintenance program.**

- Need to involve maintenance staff in technology requirements development process.
- Need maintenance agreements between agencies to streamline maintenance and staff training on highly technical systems.

Goals serve as overarching outcomes that a project strives to achieve, whereas objectives provide strategies on how to achieve the goal. The goal is the destination, whereas the objective is the steps that lead there. Sometimes one objective will lead to a goal, but generally it will take multiple objectives to reach a goal. For

example, if the goal is to reduce congestion, then there may be several objectives that lead to this including mode shift and signal timing.

Table 3 identifies the goals and corresponding objectives for the SIS.

Table 3. Summary of SIS Goals and Objectives

Goals	Objectives
Improve safety and compliance across all modes. (G1)	<ul style="list-style-type: none"> ▶ Identify traffic signal safety applications. ▶ Develop strategies to improve emergency evacuation. ▶ Create innovative incident management to reduce secondary incidents.
Prioritize equity and accessibility across all modes. (G2)	<ul style="list-style-type: none"> ▶ Prioritize safe access for users with disabilities within the intersection. ▶ Deploy SIS projects across the San Diego region with a focus on the specific needs of each community. ▶ Promote equity and access for all modes and people.
Provide infrastructure to promote V2I and CV technology. (G3)	<ul style="list-style-type: none"> ▶ Implement vehicle-to-infrastructure technology. ▶ Provide a communications network with suitable bandwidth for SIS.
Promote the efficient movement of people and goods. (G4)	<ul style="list-style-type: none"> ▶ Synchronize across jurisdictional boundaries and state and local agencies to provide a seamless experience to users. ▶ Provide system for clear and concise data sharing among partner agencies. ▶ Facilitate movement of freight and commercial vehicles.
Support sustainability goals by elevating transit and low emission modes. (G5)	<ul style="list-style-type: none"> ▶ Create policy that enables the advancement of transit and low emissions modes of transportation. ▶ Enhance viability of transit. ▶ Enhance viability of active transportation and micromobility. ▶ Collect and measure environmental data, including greenhouse gas emissions.
Actively manage operations according to transportation demand. (G6)	<ul style="list-style-type: none"> ▶ Implement technology that can collect data in real time. ▶ Implement technology that can accommodate real-time demand of any mode.
Connect users with real-time information. (G7)	<ul style="list-style-type: none"> ▶ Provide reliable and actionable real-time information. ▶ Incorporate CV technology for real-time information.
Promote resilience to disruptions and changing technology. (G8)	<ul style="list-style-type: none"> ▶ Implement interoperable technology to build a modular and scalable system. ▶ Create redundancy for limited disruptions. ▶ Create a proactive maintenance program.

5.3 **Needs Assessment**

System needs are used to communicate the expectations of the proposed system – the “what do the stakeholders want the system to do.” They are used to help define the components of the system; those that would be required to implement for enhancing safety and optimizing efficiency within the smart intersection system.

System needs were developed through a series of stakeholder workshops and surveys with staff from state, regional, and local agencies. The results of the North County Regional Corridor (NCRC) CMM were combined with surveys completed by stakeholders of other corridor Comprehensive Multi-Modal Corridor Plan (CMCP) groups and local stakeholder groups across the region to develop the needs assessment.

The needs are grouped within four categories that trace through from the needs to the concept for the SIS through the operational scenarios: Institutional, Multi-Modal/Active Transportation, Technology and Innovation, and Intersection Utilization. For traceability purposes, each need is associated with a corresponding goal.

Table 4. Smart Intersection System Needs

Smart Intersection System Needs	Goal
Institutional	
Need to study equity implications and safety impacts of implementing automated traffic enforcement technology.	G1
Need to allow TMC staff and emergency services staff to quickly initiate traffic signal plans to evacuate people safely and efficiently.	G1
Need to identify methods to control traffic signals remotely during evacuation events and identify a back-up plan to operate signals on-site during power and communications outages.	G1
Need to develop emergency evacuation plans and provide training for traffic management, emergency services, transit operators, and other staff.	G1
Need to improve coordination between agencies during major incidents.	G1
Need to involve local community stakeholders in the planning and design of SIS concepts.	G2
Need to prioritize SIS infrastructure development in disadvantaged communities.	G2
Need to prioritize access to employment opportunities, residences, and recreation for all people, including those with disabilities, those who are unbanked or underbanked, and those who speak languages other than English.	G2
Need to develop policies to ensure privacy of individual users.	G3
Need updated processes for interchange signal coordination.	G4
Need a consistent approach to adaptive signals deployments.	G4
Need to share relevant corridor performance measures with adjacent or impacted agencies to improve performance.	G6
Need to procure open architecture systems for compatibility.	G8

Smart Intersection System Needs	Goal
Need maintenance agreements between agencies to streamline maintenance and staff training on highly technical systems.	G8
Multi-Modal/Active Transportation	
Need to study traffic signal timing and traveler information strategies to improve safety for vulnerable road users and reduce speeding.	G1
Need roadside devices to communicate real-time locations of vulnerable road users such as (active transportation, micromobility, active commercial loading zones) to caution nearby vehicles.	G1
Need to identify and fill gaps in the ADA-accessible network, particularly at points of connection where users switch modes.	G2
Need to detect pedestrians with mobility challenges crossing the intersection and provide them with walk time extensions.	G2
Need to prioritize the safety of the most vulnerable road users.	G2
Need a consistent approach to transit priority signals operations.	G4
Need enhanced coordination between transit operators and signal operators.	G4
Need to time signals for optimal transit progression along NextGen Rapid corridors.	G5
Need to improve active transportation comfort with bulb-outs, markings, and proactive safety analysis.	G5
Need to implement technology that can detect users in the dilemma zone and extend green time for any mode.	G6
Need to detect the presence of multiple modes at an intersection approach.	G6
Need to share transit information such as transit location, transit performance.	G7
Need to share data on accessibility, equity, equipment, and infrastructure.	G7
Need to equip transit fleet vehicles with automatic vehicle location (AVL) system.	G7
Need to provide short range communication for V2X applications.	G7
Technology and Innovations	
Need to identify appropriate intersection hardware upgrades for each jurisdiction in support of traffic signal safety technology.	G1
Need to consider proactive near-miss monitoring and analysis on key corridors to help identify modifications to intersection operations and geometry and prevent injury and death.	G1
Need to identify methods to communicate emergency evacuation route information to the public.	G1
Need infrastructure to communicate traffic signal data and other data collected at the intersection to all connected vehicles.	G3
Need to perform an assessment of existing communications infrastructure and develop a plan to fill existing gaps.	G3

Smart Intersection System Needs	Goal
Need to develop a standard method to collect, track, and share existing communications infrastructure.	G3
Need data output that is simple for local decision makers, planners, and operators to interpret and act on.	G4
Need to share real-time data with Next OS platform.	G6
Need to provide alerts to agency representatives when conditions prompt a predetermined action.	G7
Need to share real-time video of key corridors to improve operations with adjacent or impacted agencies.	G7
Need to deploy devices that can exchange data with other IoT devices and Next OS, regardless of vendor or owner/operator.	G8
Need to be able to expand the system as local capabilities and funding become available.	G8
Need to develop standard requirements and an approved technologies list to limit the number of unique device types to streamline maintenance.	G8
Need to build redundancies in the communications network to enable continued operations during disruptions due to construction, maintenance, and natural disasters.	G8
Need battery backup systems and generators capable of carrying out SIS functionalities throughout power outages.	G8
Need real-time alerts for system and device failures.	G8
Intersection Utilization	
Need to reduce incident clearance times.	G1
Need infrastructure to support vehicle-to-infrastructure communications on transit and flexible fleets.	G3
Need to identify the origin and destination of trips to track diversion and cut-through traffic.	G4
Need region-wide database for local truck routes.	G4
Need to analyze historic travel times to help inform operations and policy decisions.	G5
Need to encourage/incentivize mode shift from single occupant vehicles to HOV, active transportation, micromobility, and transit services.	G5
Need to measure performance of intersections based on their productivity (i.e., the number of people served) and amount of greenhouse gas emissions.	G5
Need to collect real-time speed and travel time information.	G7

6 SYSTEM OVERVIEW

The system overview provides the high-level context of the potential architecture of a smart intersections system, focusing on system and subsystem connections. Each agency may have its own goals, level of capability, and priority, and may not require all of the components and data connections presented in this section. Agencies should view these system descriptions as what could be included within their own system, rather than as a guide to what needs to be included in all systems.

6.1 Collect an Inventory of Communications Network

The successful deployment of SIS depends on a network of resilient communications infrastructure and technical equipment. Collecting the initial data for the inventory will require agencies to conduct a field inventory data of the communications equipment within their jurisdiction. It is also essential that the SIS inventory is regularly updated when field devices and interconnect is constructed, modified, or maintained. Updates to the inventory should be part of the process whenever SIS assets are changed or maintained, and there should be clear guidance within the jurisdictional agency regarding who is responsible for updates, how the inventory is updated, and when it should be updated.

The SIS inventory should be map-based and include both the physical assets, and any pertinent sharing agreements. Physical assets include signal interconnect, communications equipment, signal controllers, service pedestals, cameras, detection equipment, EVP, lighting, APS, battery back-up systems, Bluetooth counters, changeable message signs (CMS), and other SIS field devices. Sharing agreements may exist in assets such as fiber in a joint trench or other equipment involving public-private partnerships.

A regional working group should be established to establish standards for the type and format of data to be collected and explore potential ways the region can work together to most cost-effectively complete the initial data collection. Some cities may also choose to expand SIS data collection to include an inventory of the street network, including sidewalks, vehicle lanes, bus lanes, designated truck routes, and micromobility lanes, allowing analysis of the street network connectivity for all modes.

6.2 Integrate Data into Next OS

Disparate data sources are envisioned to be integrated and shared through Next OS. Next OS is defined as a *digital platform* that will help transform the San Diego region's current transportation system into a world-class network. A digital platform is a set of technologies that are connected such that data can flow between separate systems, data analysis is performed, and actions can be taken based upon the data generated by each system. Businesses utilize technology in a digital platform to help create new products and services that benefit their customers.

The Next OS digital platform can assist the San Diego region's SIS operations by providing a data connectivity and integration point for various data sources to form connections. Then, the digital platform is a data warehouse that can disseminate the data to those who need it. Data that can be helpful to collect and distribute to the public primarily relates to the built environment and intersection utilization types. Other data connections can be used for planners and policymakers to examine usage trends and demand, such that they can perform regular reallocations of cycle time and modify incentives programs to encourage modes with lower greenhouse gas emissions. Some of this data may be collected through data exchange connections with Next OS. Other data may be collected manually or sampled periodically. These data connections may include:

Intersection Utilization	Institutional
<ul style="list-style-type: none"> ▶ Inventory of the street network, including sidewalks, vehicle lanes, bus lanes, designated truck routes and micromobility lanes ▶ Real-time usage data and vehicle miles traveled (VMT) ▶ Real-time delay and travel times ▶ Real-time dynamic lane assignment status ▶ Real-time evacuation areas and routes ▶ Planned lane closures ▶ Air Quality Indicators ▶ Vehicle counts ▶ Origin-destination data and travel trends 	<ul style="list-style-type: none"> ▶ Existing MOUs ▶ Data sharing agreements ▶ Contact information for coordination with other agencies' transportation system operators ▶ Data on equitable deployment of SIS functionalities ▶ Crash data and hot spots ▶ Near-miss analysis data and hot spots
Tech/Innovation	Multimodal
<ul style="list-style-type: none"> ▶ Field devices and signals equipment ▶ Real-time equipment malfunction status ▶ Signal timing and coordination plans ▶ Citizen reports of signal delay, equipment malfunctions, safety concerns, and requests for modified intersection control ▶ Performance information during special events and evacuations 	<ul style="list-style-type: none"> ▶ Usership of low-carbon modes (active transportation, transit, micromobility, carpool, vanpool, etc) ▶ EVP and TSP call log ▶ Person-throughput ▶ Accessibility data

The data connections listed are not a comprehensive list of performance measures to be collected but is a sampling of potential methods to determine the existing usage, the enhancement of safety for vulnerable road users, and performance trends under specific conditions and over time. Planners and policymakers should be looking to their desired maturity level in each of the SIS dimensions when determining the data to be measured and analyzed such that the SIS strategies are consistent with the agency's goals for the intersection or corridor under consideration.

6.3 Monitor the System

The SIS helps operators, planners, and policymakers monitor system performance. Data connections described in **Section 6.2** provide regional and local staff with an understanding of the performance of the SIS against the agencies' goals. Data collection and monitoring provides information on current intersection usage, safety, and efficiency. Performance on these elements helps planners and policymakers develop projects along corridors, update signal timing, and implement new coordination strategies.

In addition, the SIS should monitor for failures such as power and communications outages, equipment failures, and citizen complaints that may help maintenance staff identify intermittent recurring issues and strategies to address them. There should be a communications protocol, whether it be within the SIS or some other aspect of

Next OS, such that automatically detected failures and failures reported by the public or operations staff are addressed efficiently by maintenance, public works, first responders, and enforcement personnel.

6.4 Share Data with Users, Partners, and Third-Party Service Providers

A hallmark of SIS and Next OS is strategic collaboration with partner agencies across the region to actively manage the transportation system. Agencies will be able to share real-time information with other system operators, planners, and policymakers through Next OS. Benefits of real-time data sharing can improve coordination within corridors that cross jurisdictional boundaries and where multiple modes meet, including the following examples:

- ▶ Less disruption to street signals affected by at-grade rail crossings or ramp meters
- ▶ Easy access to travel demand data from regional planning studies
- ▶ Strategic collaboration on seeking opportunities to fund projects that address gaps in infrastructure, safety, accessibility, and equity.

Residents and businesses who are planning their trip can receive information gathered from SIS through SANDAG's traveler information platform or from third-party service providers. Many of these providers collect their own data and may enter into sharing agreements with agencies, such as for traffic conditions and travel times, origin-destination data, and shared mobility data. Additionally, third-party providers will be able to access public data sets gathered by SIS in an open data portal application programming interface (API), which they can then incorporate into their applications and disseminate to their respective user bases.

6.5 Report and Analyze

Finally, reporting and analysis of the SIS should be regularly performed at both the regional and local levels to measure performance against goals. Reporting of the following data sample can assist agencies with measuring the effectiveness of SIS strategies in enhancing safety, efficiency, equity, and the viability of low-carbon modes:

- ▶ Progress on filling gaps in communications infrastructure
- ▶ Origin-destination data and travel trends over time
- ▶ Efficacy of signal timing and coordination plans
- ▶ Reduction in VMT
- ▶ Delay and travel times
- ▶ Trends in equipment reliability, especially during critical events like major incidents, events, and emergency operations
- ▶ User compliance with dynamic lane assignment
- ▶ Post-incident analysis of evacuation procedures
- ▶ Trends in mode shift
- ▶ Trends in air quality and other public health indicators near SIS deployments
- ▶ Trends in crashes and near-misses
- ▶ Transit schedule reliability

- ▶ Accessibility data
- ▶ Data on equitable deployment of SIS functionalities
- ▶ Efficiency metrics for corridors that cross agency boundaries, at-grade rail crossings, and interchanges
- ▶ Consistency of data sets
- ▶ Regular and transparent reporting of these measures within both regional and local agencies will assist in continuous improvement in refining SIS strategies, and long-term responsiveness to new mobility patterns, incident and emergency management, maintenance, and daily operations.

6.6 High-Level Context Diagram

The diagram in **Figure 12** provides a graphical view of the context for the proposed SIS. This diagram presents Next OS as a possible central clearinghouse for data collection and data exchange related to transportation systems management and operations. Next OS also powers the processes that agency administrators, planners, and policymakers perform to manage the network.

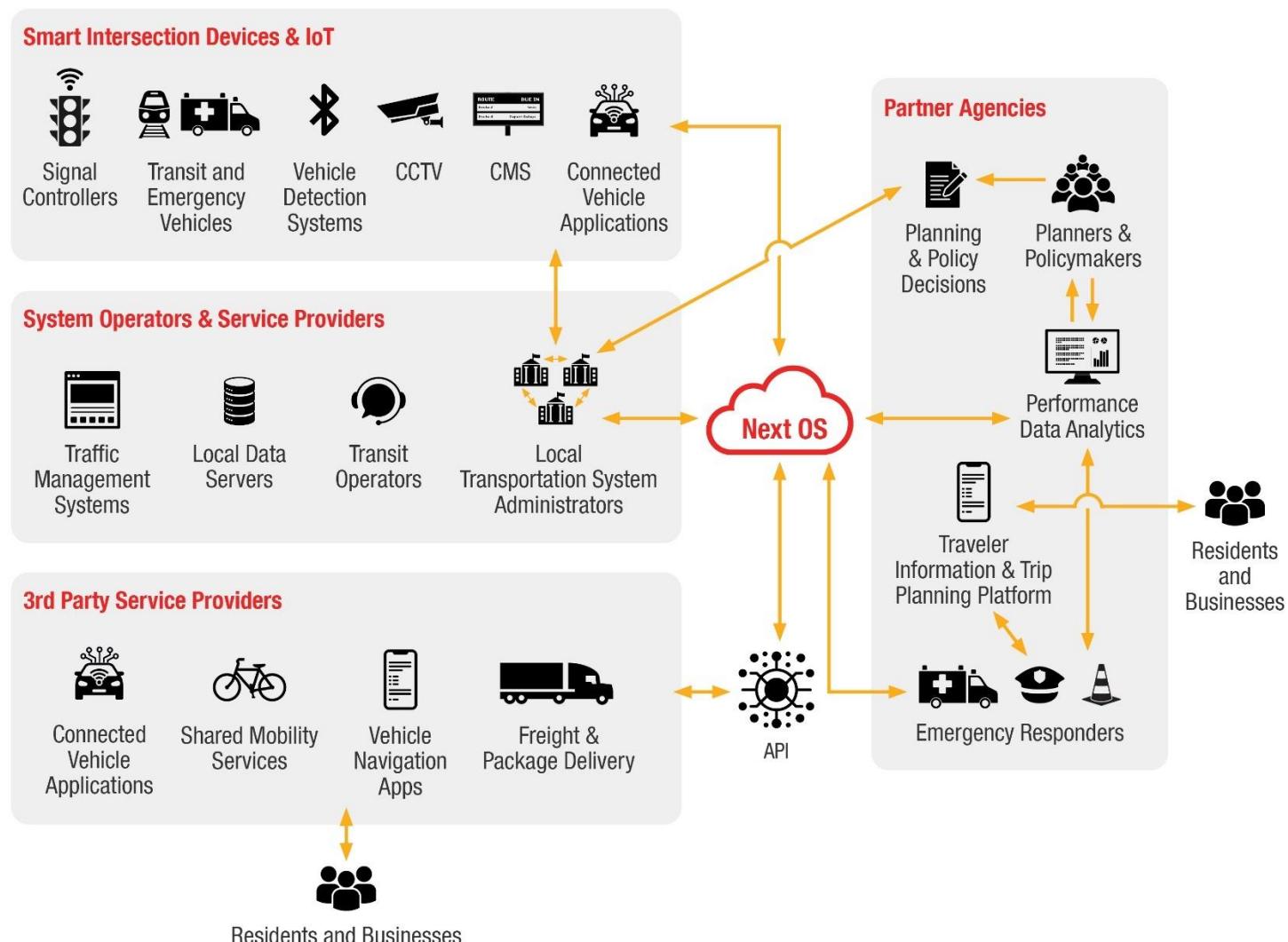


Figure 12. SIS System Diagram

7 OPERATIONAL SCENARIOS

Operational scenarios provide an opportunity for understanding how the proposed system can behave during different circumstances. It also provides an opportunity to discuss how roles and responsibilities may change during each scenario. The goal of an operational scenario is to put the system into action and identify how dynamic shifts occur depending on external factors.

Cast of Characters

- ▶ Peter the Pedestrian
- ▶ Maggie the Motorist
- ▶ Tommy the Transit Rider
- ▶ Olive the Operator
- ▶ Clyde the Cyclist
- ▶ Michael the Micromobility Rider
- ▶ Agency Adam
- ▶ Eloise the Emergency Responder

Operational Scenarios – all typologies will feature these operational scenarios but will have different sub-strategies within them.

Regular Operations

During regular operations, Pedestrian Peter requests to cross the intersection. The actuated signal timing adjusts to demand variabilities and extends the green for the major road. Maggie the Motorist and Cyclist Clyde also benefit, cruising through the intersection, enjoying the extended green. Speaking of Clyde, he is safely riding in a dedicated lane equipped with either loop or video detection. Even if Peter had not requested to cross, Clyde's bike would have been detected and could also extend the green. Micromobility Michael experiences the same benefits of Clyde, as he uses a dedicated bike lane to travel and can activate detection with his e-scooter.

Tommy the Transit Rider is waiting at a bus bay that allows for easy loading and unloading, with minimal disruption of the adjacent vehicle flow. The bus bay is equipped with real-time arrival displays which notify him of the buses estimated time of arrival. He has chosen to take transit more often now that transit signal priority gives his bus route signal pre-emption and queue jump lanes. Even though transit signal priority typically only activates when the bus is five minutes behind schedule, he has noticed a difference in his on-time arrival to work.

All of this is monitored by Olive the Operator who is observing on the CCTV cameras from the TMC. These functions can also be supported by ATMS software that monitors real-time conditions. ATMS connects to field devices such as traffic signals and CMS and allows for operators to make changes remotely. Olive and other operators in the area are well trained with these systems and easily share data across agencies using the Next OS. Next OS disseminates information to the public via 511 and other traveler information platforms, which allow people to plan their trips.

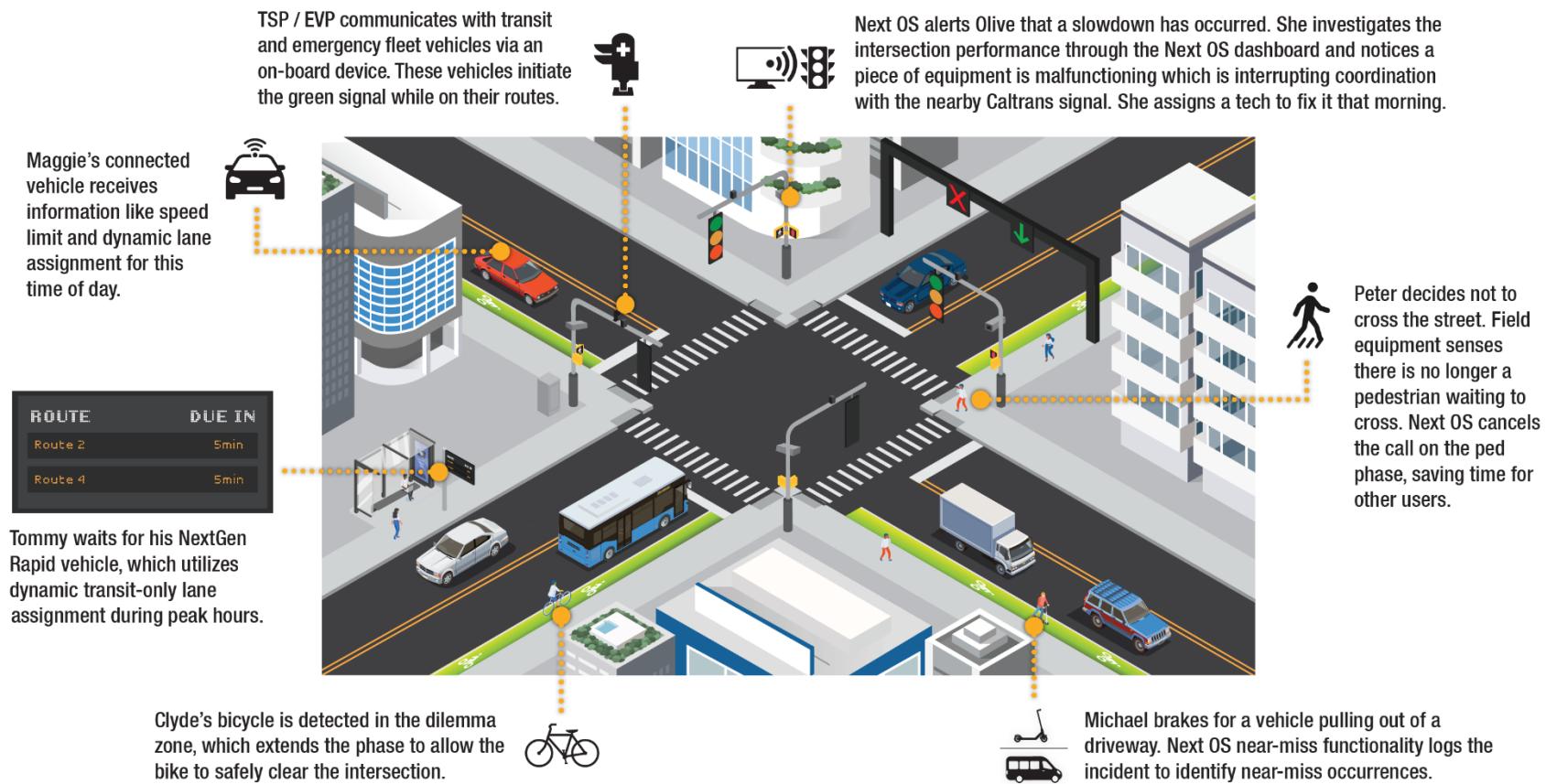


Figure 13. Regular Operations

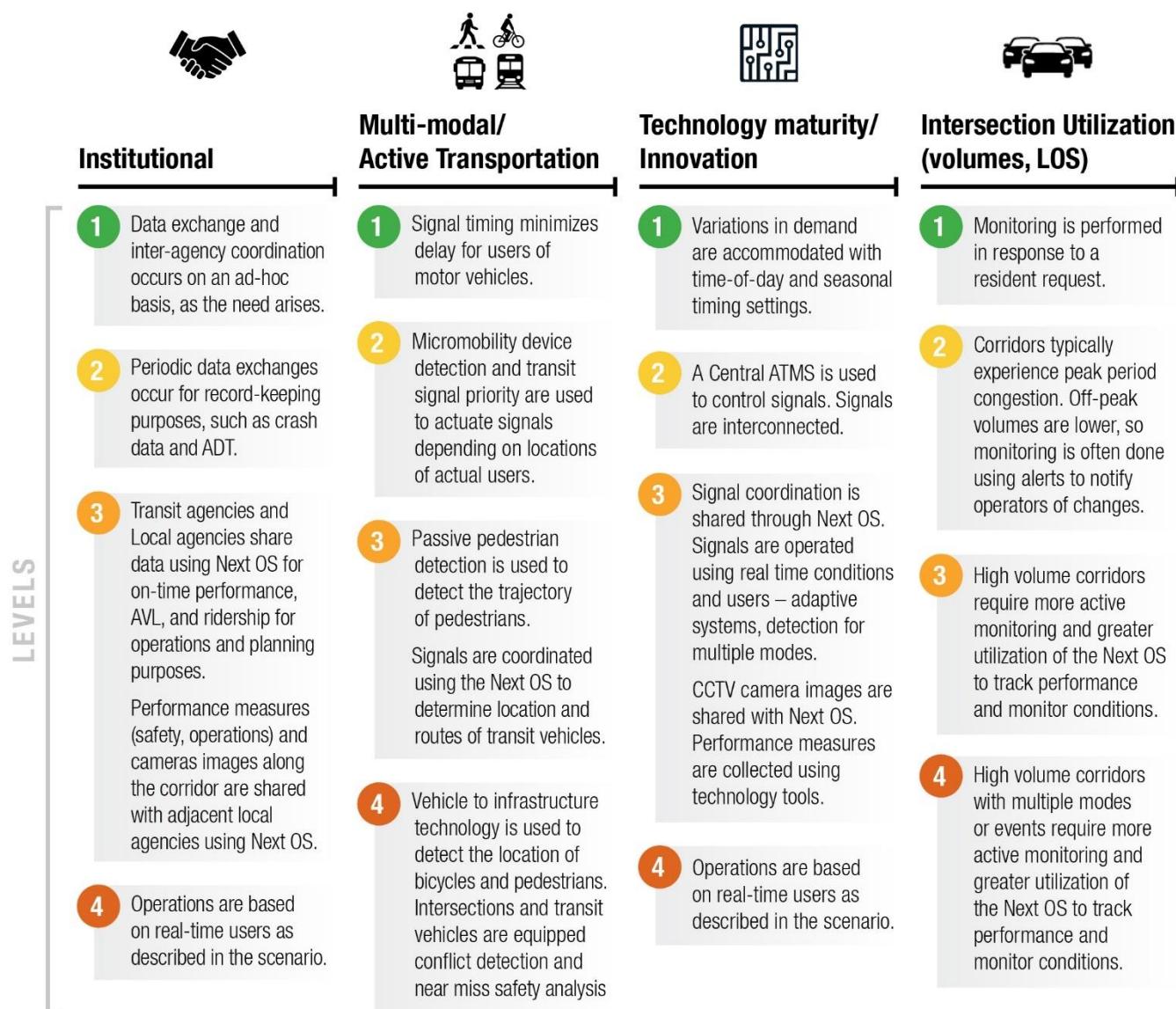


Figure 14. Normal Operations at Varying Capability Levels

Incident Management Scenario

An incident occurs at an intersection, where Motorist Maggie is waiting. The travel lanes are blocked, so the ATMS sends out an alert to the police department's Computer Aided Dispatch (CAD) using the Next OS portal about the delay and possible incident. Olive the Operator's CCTV cameras are accessed at the dispatch center through Next OS and the appropriate personnel are dispatched. Olive also receives an alert from the ATMS regarding the slow down. She logs into the ATMS and views the intersection on CCTV and visually confirms that there is an incident in the intersection blocking traffic.

Next, the ATMS sends performance information to Next OS, which disseminates it to operators in neighboring areas who are likely to experience network impacts from the incident. Based on a set of pre-determined performance parameters, affected signals transition to a pre-approved alternate timing plan to accommodate increased network demands.

Transit agencies receive alerts of the slowdown through Next OS and update expected arrival times through their traveler information platforms and real-time arrival displays at bus bays and stations.

Then, real-time information is released to the public through SANDAG's central traveler information platform (511 SD) and 3rd party traveler information providers via an open data portal in Next OS. This information includes the impacts to vehicles, transit, and active transportation users such as blockages of bike lanes, sidewalks, or travel lanes. Traveler information platforms update estimated travel times through the area and suggest alternate routes.

Freida the First Responder's dispatch team also views the CCTV feed using Next OS. They use this information to determine necessary equipment and personnel for the incident. Then, Frieda the First Responder and her team can travel to the scene using pre-designated routes, activating EVP through their on-board device on the way which reduces their need to stop while traveling to the scene. When major incidents occur, dynamic lane assignment may be initiated for emergency vehicles.

When Freida arrives on scene, she treats and transports the injured individuals to the hospital, if needed. Then, the tow company clears the scene and traffic enforcement can re-open the lanes.

Maggie is happy because those involved in the crash are getting the medical care they need, and the signal timing has adjusted to allow her through the intersection. Now, the signals are operating normally, but there is still some congestion. Traveler information systems continue to update recommended routes based on Next OS data until the incident has no further congestion effects.

The ATMS has captured key data such as response times, clearance times, delay, secondary incidents. Agency Adam and the other planners can use this data through Next OS to plan and implement future response strategies.

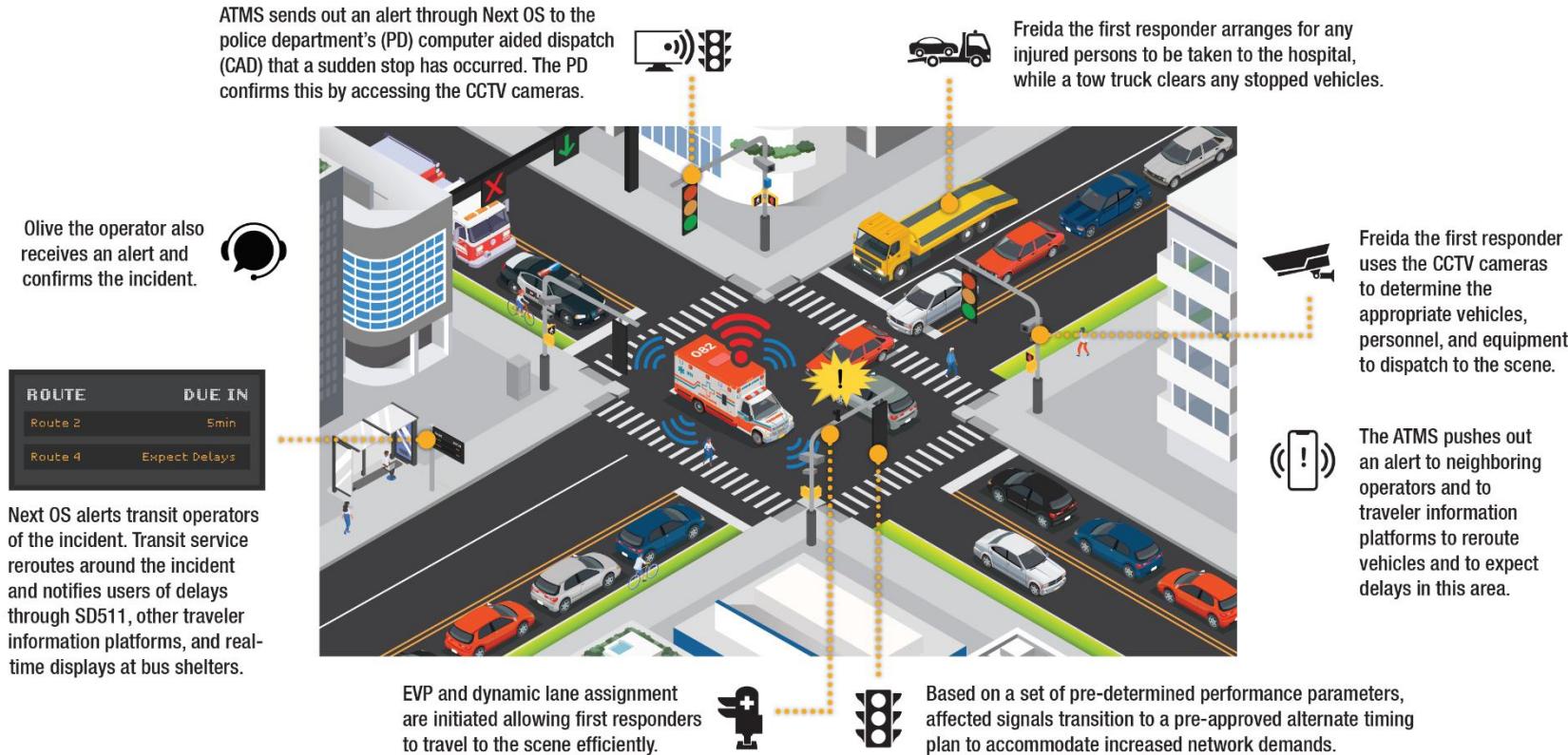


Figure 15. Incident Management Scenario

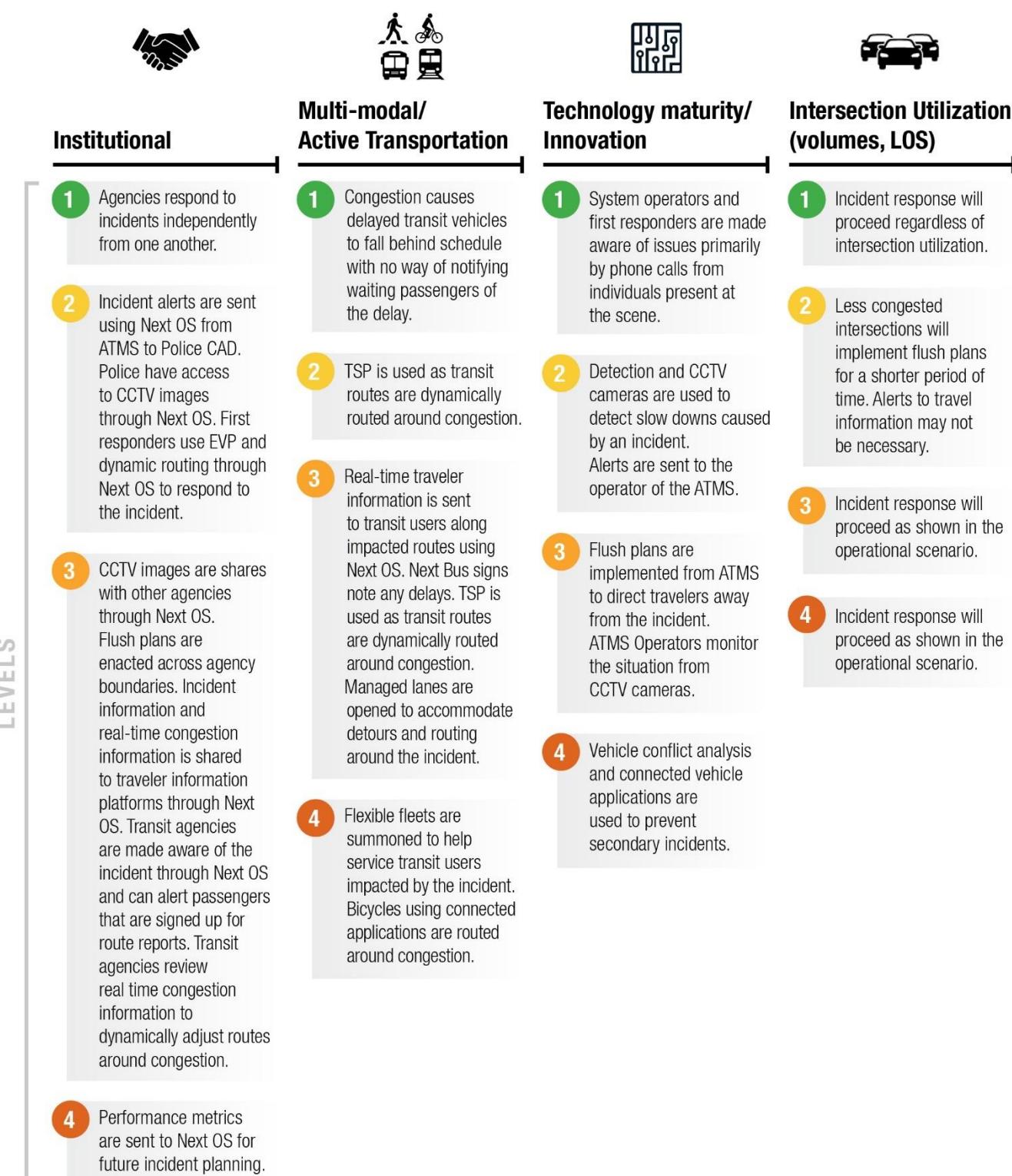


Figure 16. Incident Management Scenario at Varying Capability Levels

Evacuation Scenario

There is a wildfire that has broken out in eastern San Diego county, causing Emergency Responders to call for an evacuation. Eloise the Emergency Responder sends evacuation information to Next OS, which alerts agency operators and third-party traveler information providers of the evacuation. Olive the Operator implements pre-approved alternate signal timing plans and transit routes to efficiently evacuate and allow emergency access.

Motorist Maggie receives a notification on her smartphone that her area is evacuating. Maggie travels in her connected vehicle to a friend's house away from the evacuation zone. Along the way, her connected vehicle provides alerts from Next OS about the status of the wildfire, the location of the evacuation zone, and any potential hazards or slowdowns on her route. Transit drivers will also now be taking a new route. The transit driver can use their blind spot detection alert system to detect pedestrians or bicycles when making turns and adjusting their routes. Real-time arrival displays are bus bays can update their digital signage to indicate there is a wildfire and that there were route changes and delays due to the event.

Peter the Pedestrian receives an alert on his smartphone to stay away from the evacuation area. Instead of running errands, he decides to return home, which is far from the wildfire. He continues to receive notifications on the status of the wildfire and the evacuation zone throughout the duration of the event.

Micromobility Michael receives an alert on his e-scooter mobile application about the wildfire and that e-scooters will be prohibited within a certain radius of the evacuation zone. The e-scooter company controls this through geofencing, which turns off any electric scooter functionality once a rider approaches the prohibited area. Microtransit services, such as microshuttles, will alter their routes and coordinate with their riders to stay away from the evacuation area.

Meanwhile, Caltrans and Emergency Responders are closing roads and on-ramps that lead to the evacuation zone. They will follow their normal protocol. Ramp meters and roadside traffic count technologies provide real-time data to Olive and other operators about traffic conditions. The fire department travels to the wildfire by way of dynamic lane assignment. The fire department and supporting emergency responders are given a contraflow lane alongside the evacuating traffic. They use EVP to initiate green time at each of the intersections to avoid any sudden stops or having to cross during a red light.

In the event of a system failure or equipment failure, the ATMS will get a notification to inform maintenance and operations decisions during or after the event.

When the wildfire is controlled, Eloise the emergency responder determines that it is safe to re-enter the area, so Next OS sends a notification to agency operators and the public. Signal timing and transit routes transition back to normal operations.

All of the collected data is stored and analyzed as performance metrics. Interested agencies will review this data to determine the impacts and lessons from the evacuation. If there were any inefficiencies, Agency Adam and his team can improve operations in the future. Real-time performance data is also stored to determine if any equipment needs to be maintained or replaced.



An alert is sent by the fire department through Next OS warning of the wildfire / evacuation zone. Road closures are shared with operators through the Next OS. Olive adjusts signal timing to flush travelers away from the area. Next OS shares real-time data with traveler information platforms, connected vehicles, and field devices such as CMS.



When system / equipment failures occur, the ATMS receives a notification to alert the operators. This allows the operators to put in service requests immediately and proactively manage equipment.



Dynamic lane assignment opens shoulders/bike lanes to general traffic for increased capacity on evacuation routes.



Maggie receives a smartphone notification that her area is evacuating due to a wildfire. She plans her trip in her connected vehicle to a friend's house that is west of the fire.



Emergency Vehicles use EVP and dynamic lane assignment at the intersection to travel to the wildfire.



First responders push out emergency status updates to Next OS, which alerts partner agencies and traveler information platforms.



Peter receives an alert on his smartphone to stay away from the evacuation area. Instead of running errands, he decides to leave the area.



E-scooters are prohibited from traveling to the evacuation zone using geofencing. Users receive an update via the e-scooter's mobile application. Microtransit changes routes to get riders away from the wildfire area.

Figure 17. Evacuation Scenario

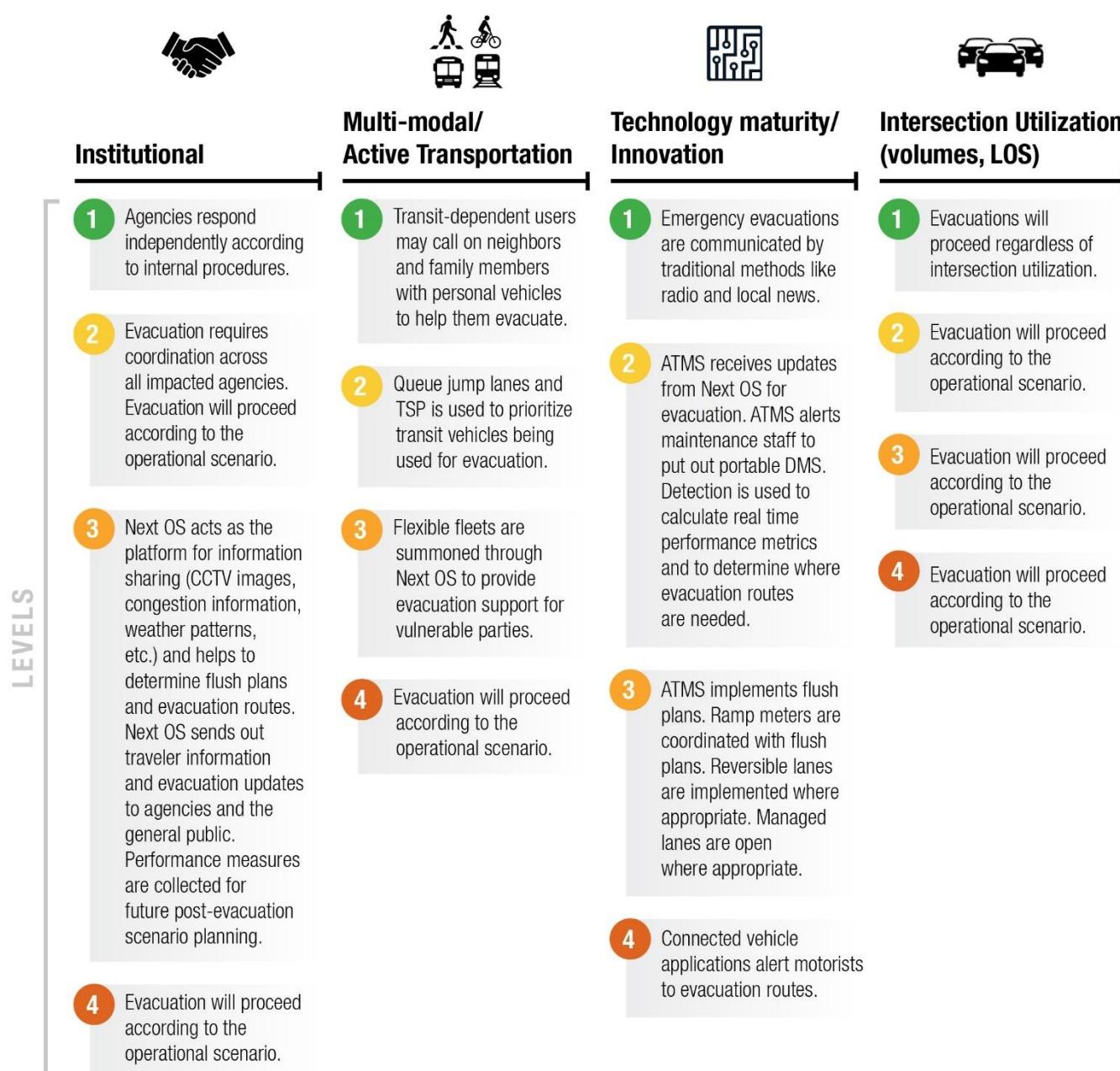


Figure 18. Evacuation Scenario at Varying Capability Levels

8 NEXT STEPS

The SIS ConOps provides a regional perspective on a locally implemented concept. The next steps for implementation of the concept of operations includes activities at both the regional and the local level. One of SANDAG's working groups can be used to coordinate amongst jurisdictions to identify needs, establish priorities, provide a data collection framework, and establish requirements for technology. Local agencies will utilize the working group and the data collection to establish their own SIS improvements with input from local stakeholders using this ConOps as a guide for identification for additional needs and to define requirements. Additionally, there will need to be a data collection effort to understand the baseline of data available to the Next OS and how it can be integrated into the regional data landscape. Agencies may want to perform a CMM assessment to determine which level they fit into as part of the SIS ConOps implementation.