RWR 4013

Digital Twins for Smart Cities

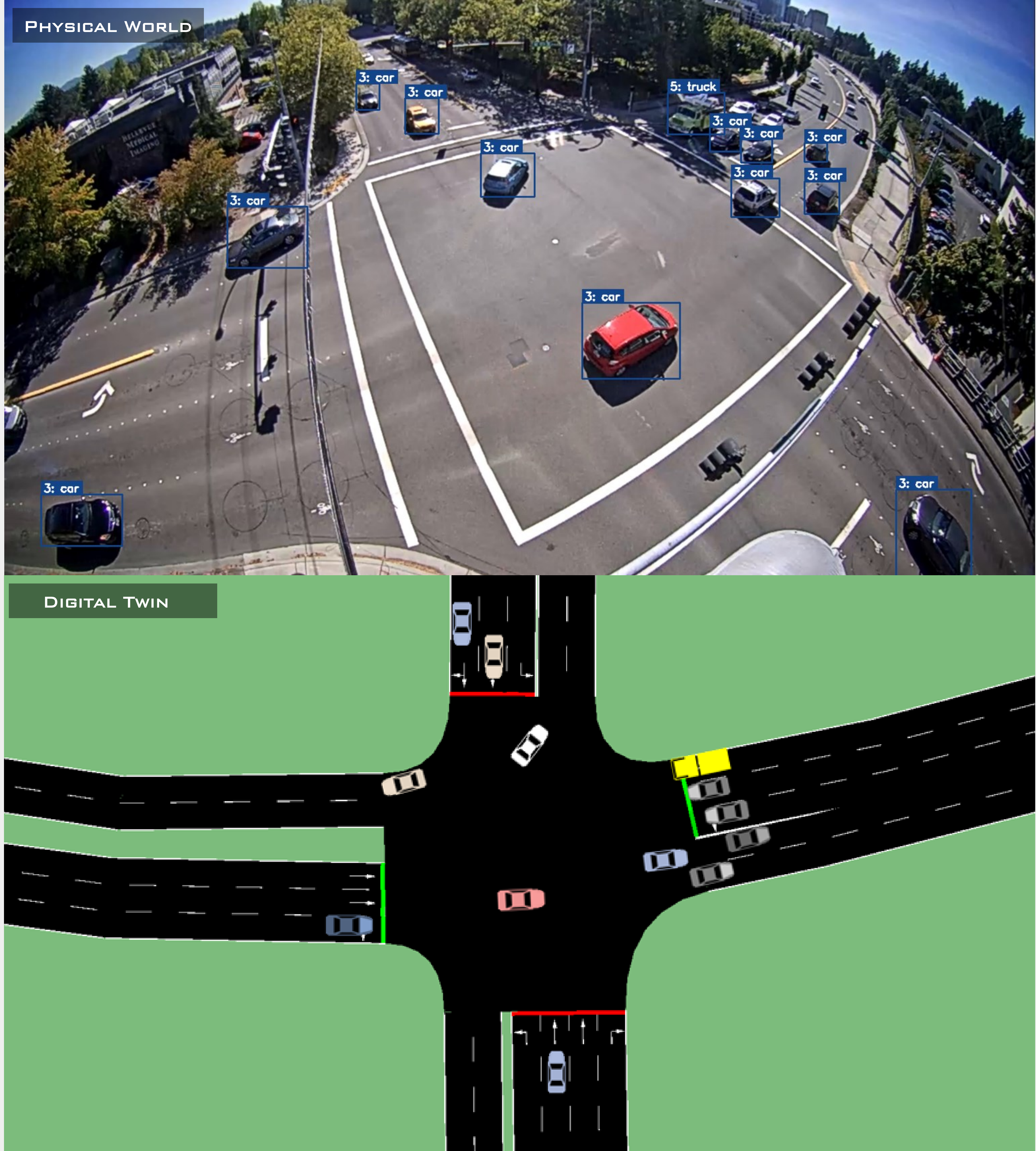
Dr. Ahmad Mohammadi

Week 5 | Session 1:
Digital Road Network
Modelling with GIS

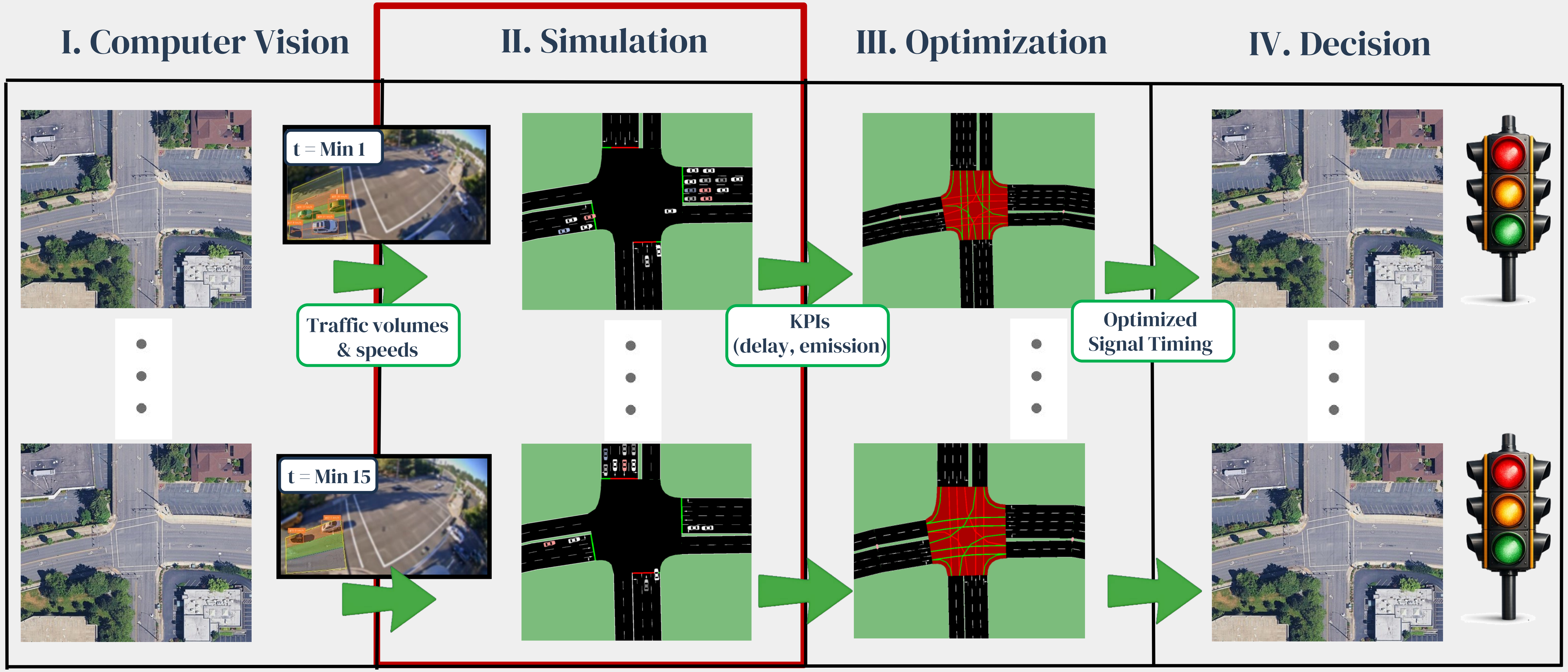
Fall 2026

RoadwayVR

roadwayvr.github.io/DigitalTwinsforSmartCities



Overview of Course Syllabus in One Shot



Agenda

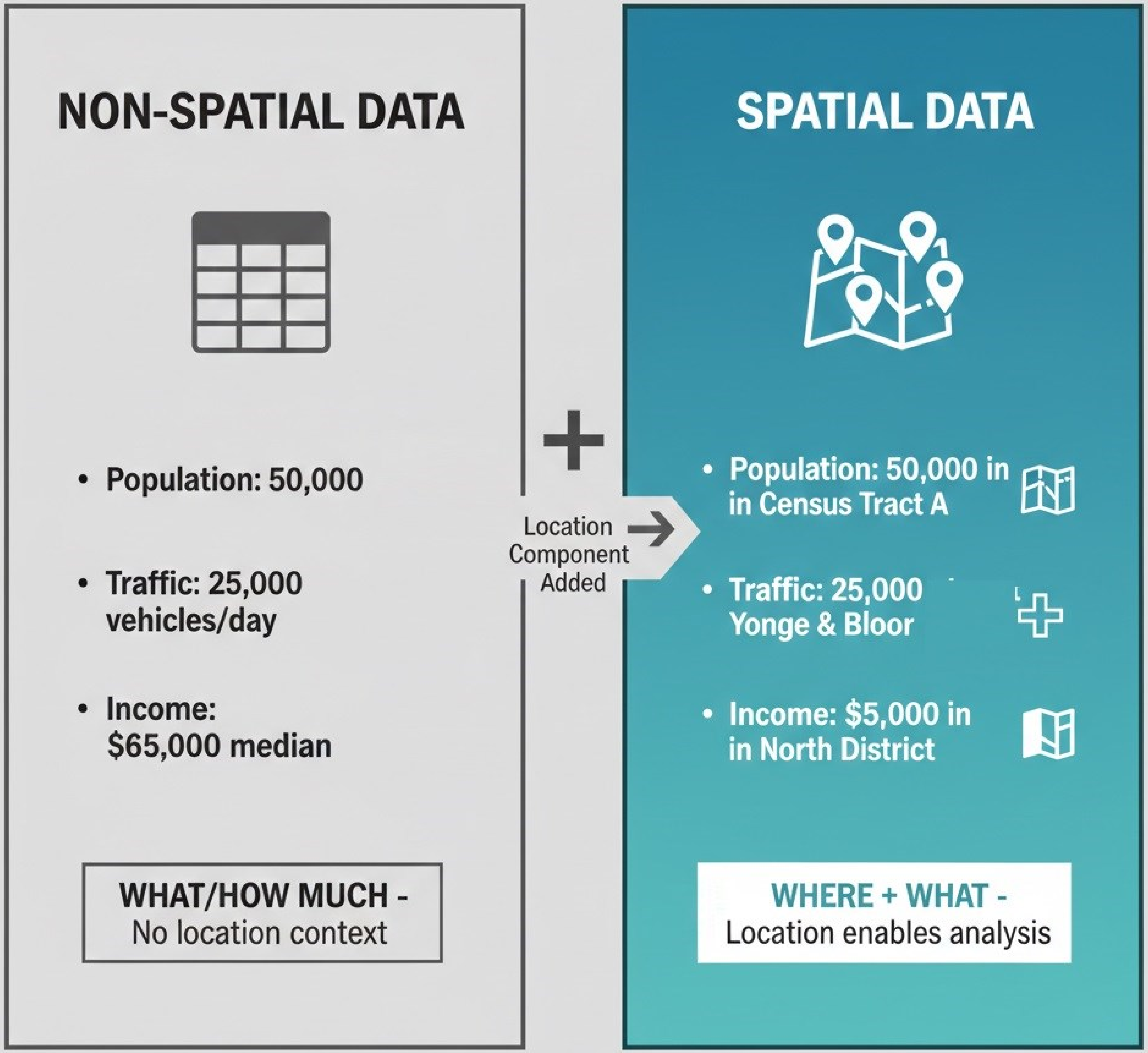
- ❑ What is Spatial Data?
- ❑ What is GIS and Seven Steps of GIS?
- ❑ GIS as a Foundation for Traffic Simulation
- ❑ GIS Software Types
- ❑ Desktop GIS Comparison
- ❑ GIS Data Layers to Simulation
- ❑ Network Elements Required for Simulation

What is Spatial Data?

Definition:
Data that has a geographic or location component - information linked to specific places on Earth's surface.

Non-Spatial Data:
Traffic count = 25,000 vehicles/day
Spatial Data:
Traffic count = 25,000 vehicles/day at Yonge & Bloor (43.67°N, 79.39°W)

Key Difference:
Non-spatial = Attributes only (what, how much, when)
Spatial = Attributes + Location (where)

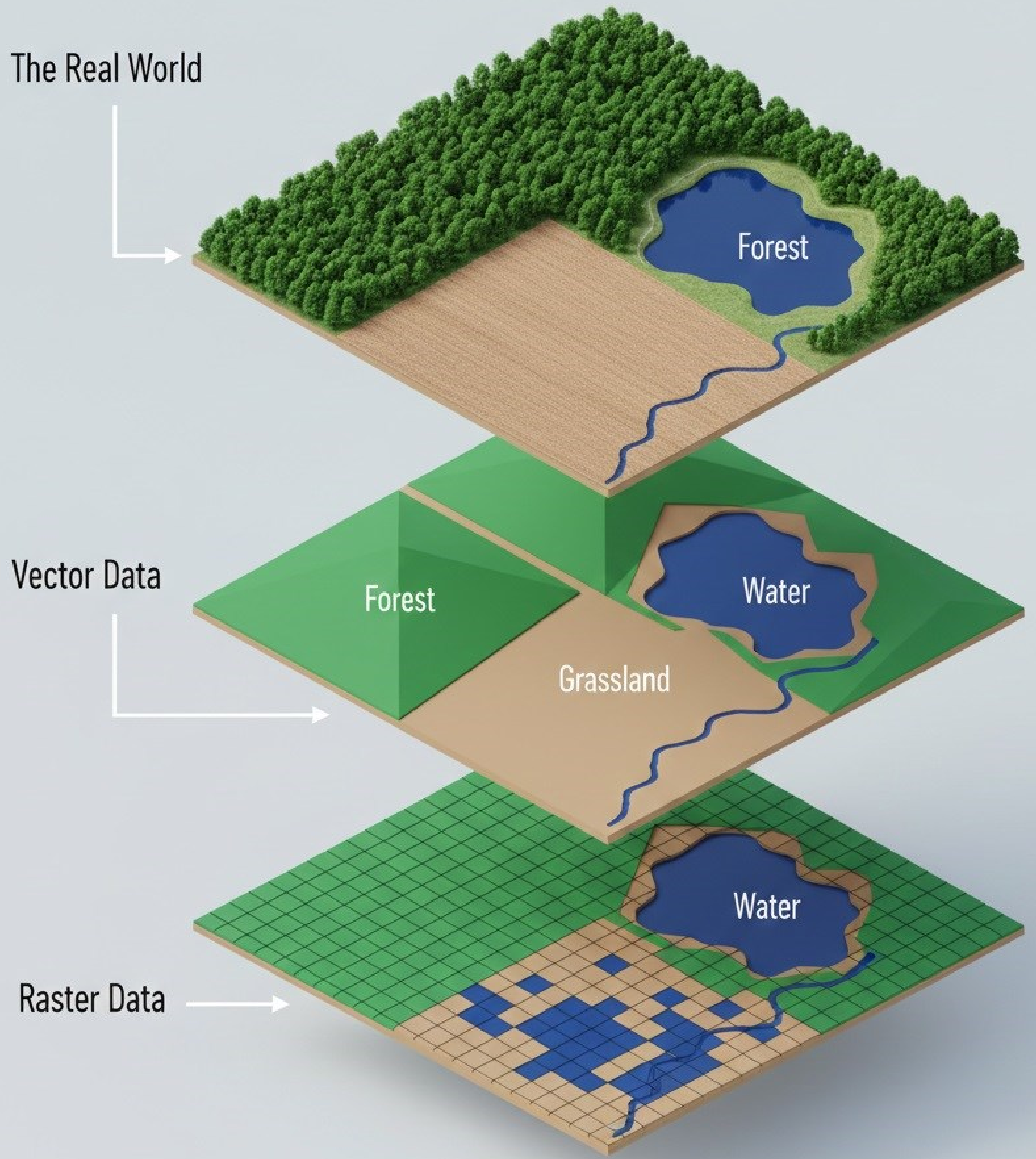


What is Spatial Data?

Definition:
Spatial Data can be represented in two different data format:

1. Vector Data: points, lines, polygons

2. Raster Data: rows and column matrix



What is Geographic Information System (GIS)

A system for

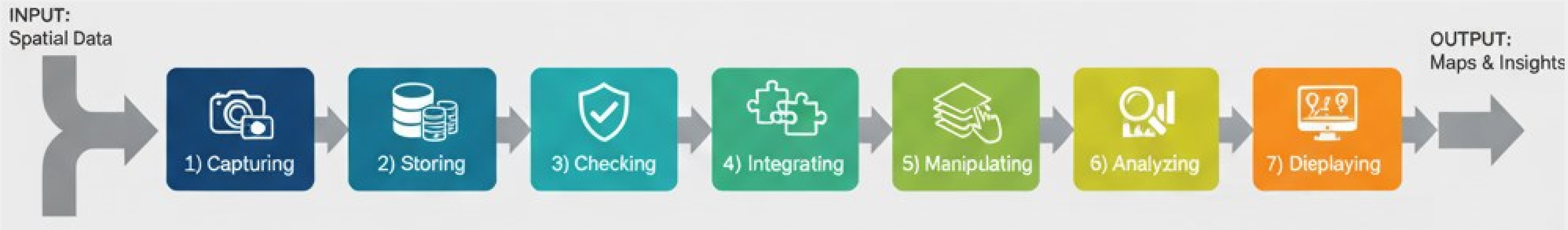
Capturing (1), storing(2), checking (3),

integrating (4), manipulating (5),

analyzing (6) and displaying (7)

spatial data.

What is Geographic Information System (GIS)



1. Capturing Spatial Data

Definition:
The process of collecting geographic information from various sources

Methods:
Remote Sensing - Satellites and aerial imagery - GPS/GNSS - Ground surveys and mobile devices - Digitizing etc

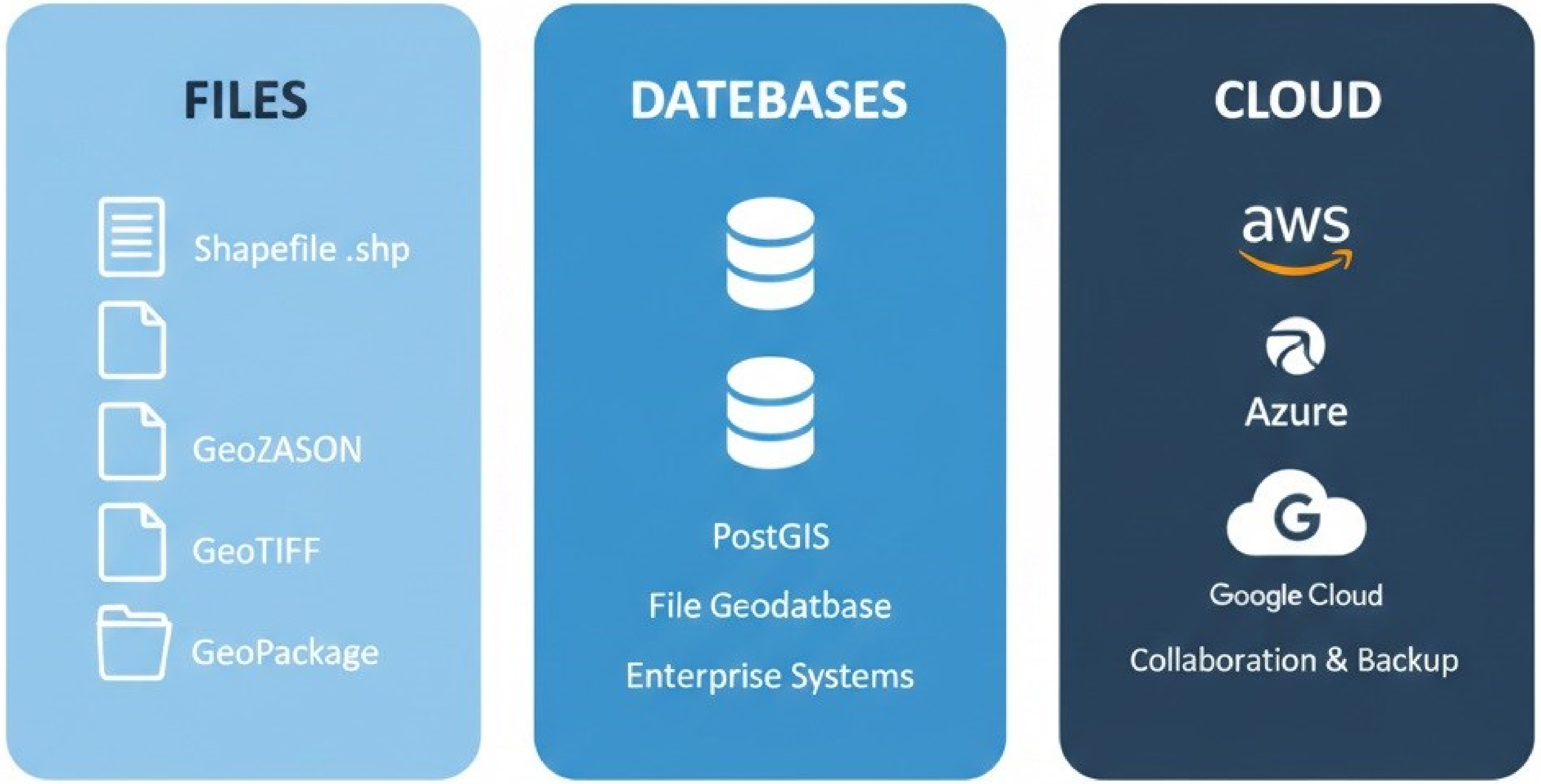
Planning Example:
A transportation planner uses GPS-equipped vehicles to collect road condition data, traffic signals, and pavement marking locations.

2. Storing Spatial Data

Definition:
Organizing and maintaining spatial data in databases and file systems to ensure efficient access, retrieval, and long-term preservation.

Files:
Shapefile, GeoJSON, GeoTIFF, GeoPackage
Databases: PostGIS, File Geodatabase, Enterprise systems
Cloud: AWS, Azure, Google Cloud - enables collaboration and backup

Planning Example:
City of Toronto uses File Geodatabase for zoning, PostGIS for property parcels, GeoTIFFs for aerial photos, and GeoJSON for open data.



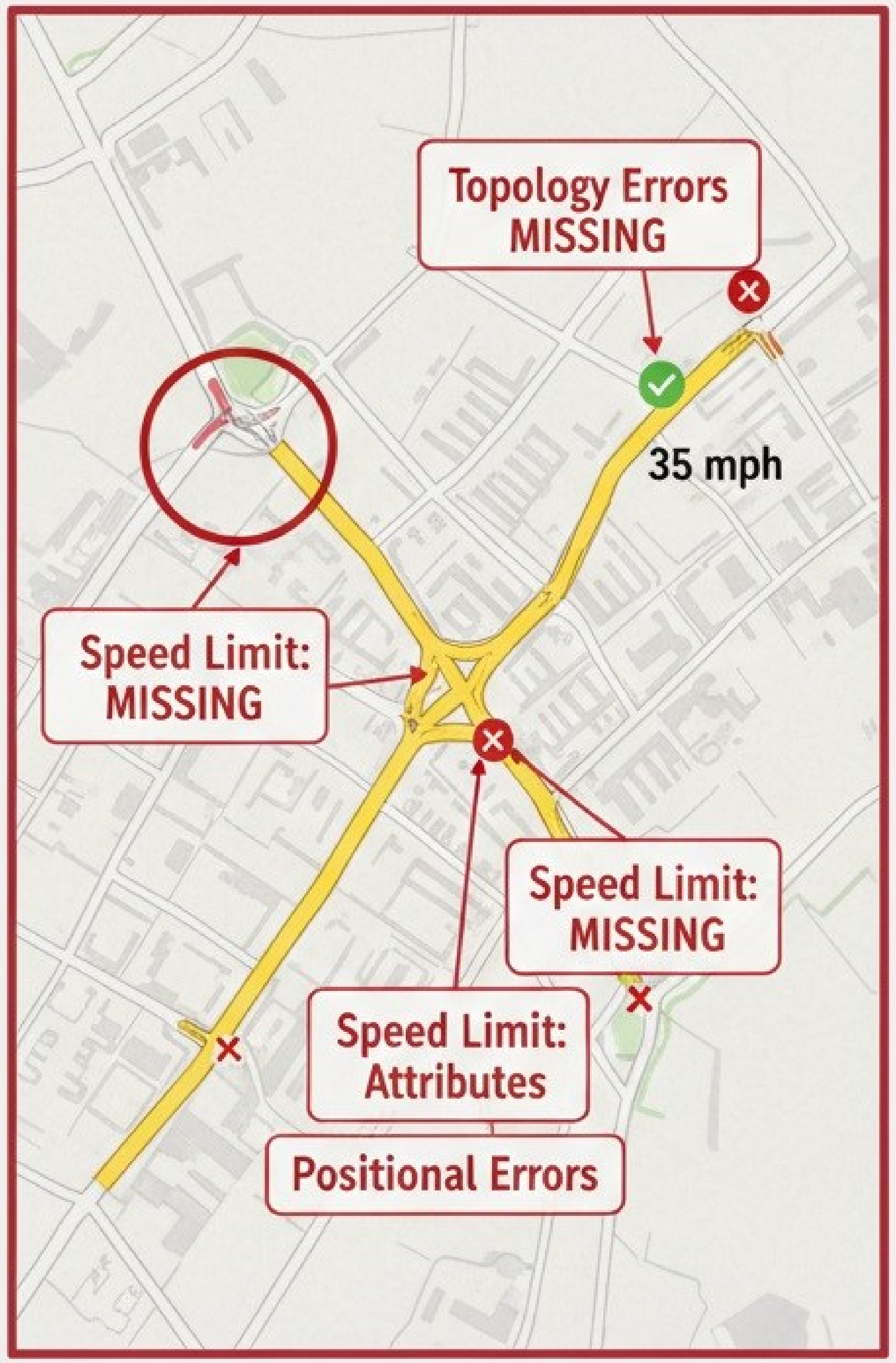
3. Checking Spatial Data

Definition:
Verifying the accuracy and consistency of spatial data to ensure quality and reliability for analysis and decision-making.

Accuracy: Positional coordinates, attribute values, temporal currency
Consistency: Topology errors, coordinate system, format standards

Planning Example:
Transportation planner validates road intersections connect properly, speed limits are complete, and coordinates align with aerial imagery.

BEFORE CHECKING - ERRORS FOUND



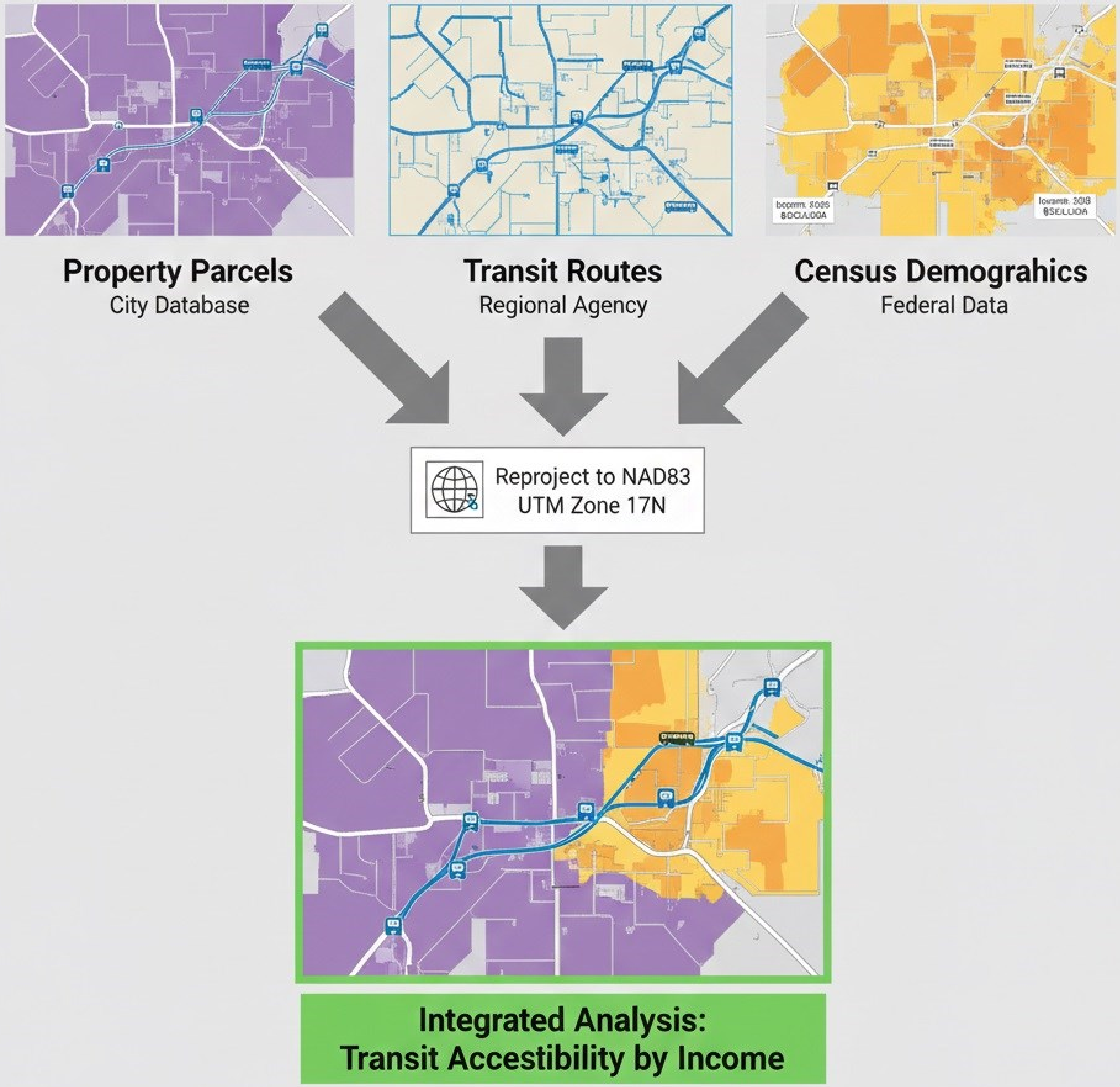
AFTER VALIDATION - QUALITY APPROVED

4. Integrating Spatial Data

Definition: Combining multiple spatial datasets from different sources into a unified system for comprehensive analysis.

Layer Overlay: Stack multiple data layers (zoning, parcels, roads)
Spatial Join: Link attributes based on location relationships
Coordinate Alignment: Reproject data to common coordinate system
Data Merging: Combine datasets with matching geometry or attributes

Planning Example: Planner combines property parcels, transit routes, and demographics by reprojecting to common coordinate system and joining by location to analyze transit accessibility.

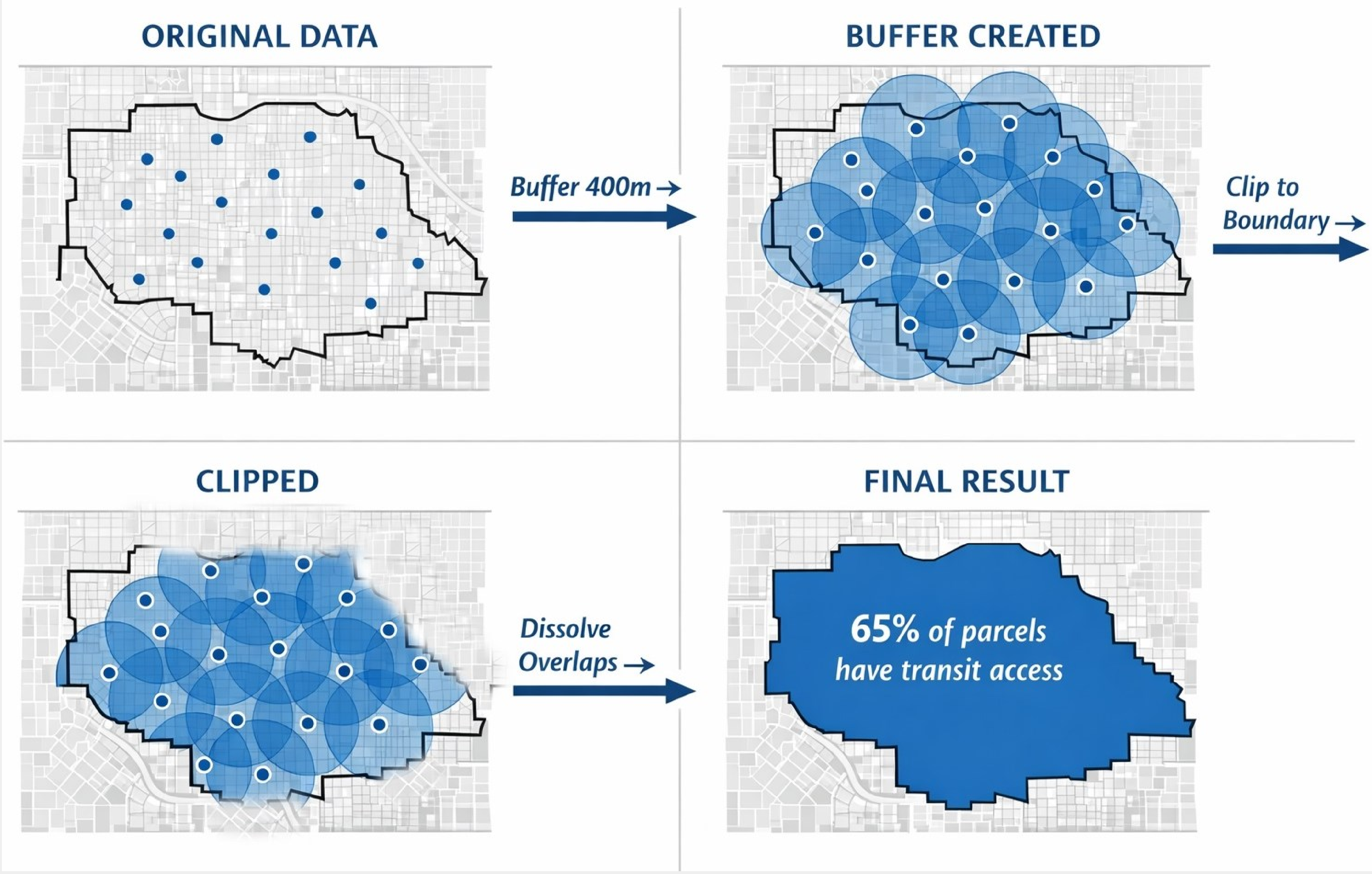


5. Manipulating Spatial Data

Definition: Editing, transforming, and preparing spatial data to meet specific analysis requirements.

Buffer: Create zones around features (e.g., 500m around transit stops)
Clip: Extract data within study area boundaries
Dissolve: Merge adjacent features by common attribute
Split/Merge: Divide or combine features as needed Attribute
Editing: Update data values, add new fields

Planning Example: Planner combines property parcels, transit routes, and demographics by reprojecting to common coordinate system and joining by location to analyze transit accessibility.

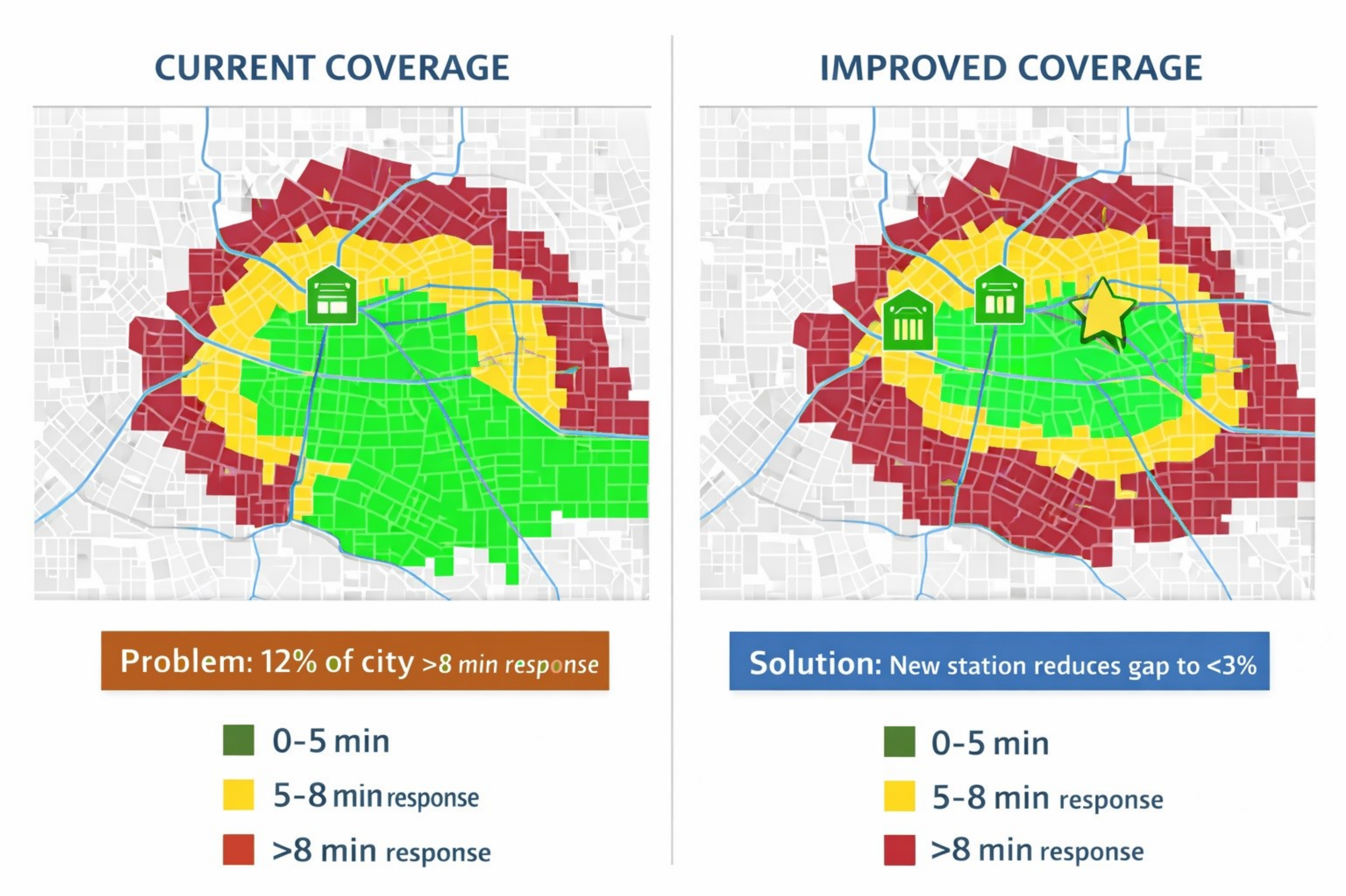


6. Analyzing Spatial Data

Definition: Applying spatial operations to discover patterns, relationships, and insights from geographic data.

Spatial Query: Select features by location (e.g., parcels within flood zone)
Proximity Analysis: Measure distances and nearest features
Overlay Analysis: Combine layers to find spatial relationships
Network Analysis: Find optimal routes, service areas, shortest paths
Hot Spot Analysis: Identify clustering and spatial patterns

Planning Example: planner performs network analysis to find shortest emergency response routes from fire stations, calculates 5-minute service areas, identifies neighborhoods with response times >8 minutes requiring new station..

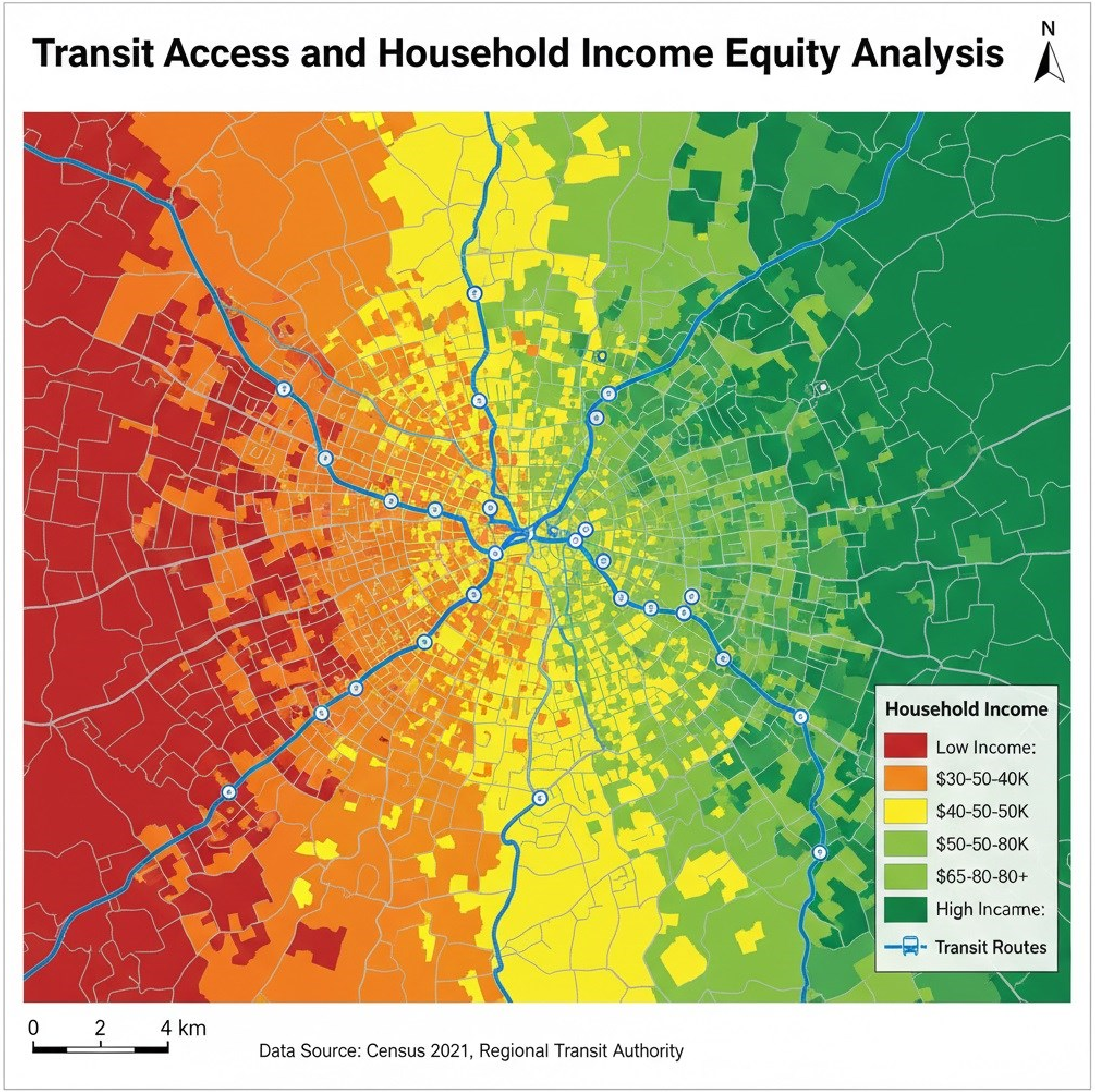


7. Analyzing Spatial Data

Definition: Visualizing spatial data through maps and graphics to communicate findings effectively.

Thematic Maps: Choropleth (color by value), graduated symbols, heat maps
Cartographic Design: Color schemes, legends, scale bars, north arrows
Labeling: Feature names, data values, annotations
Multi-scale Display: Zoom levels, detail hierarchies
Interactive Maps: Web maps, dashboards, story maps

Planning Example: Transportation engineer performs network analysis to find shortest emergency response routes from fire stations, calculates 5-minute service areas, identifies neighborhoods with response times >8 minutes requiring new station..



GIS Software Types

GIS Platform Type	Analysis Power	Capabilities	Example(s)
Geobrowser	Weak	• View and navigate • Basic search • No data upload	Google Maps, Google Earth, Apple Map, OpenStreetMap
Web-based GIS	Medium	• Upload custom data • Customize symbology • Basic analysis • Online sharing	ArcGIS Online, MapBox
Desktop GIS	Strong	• Advanced analysis • Geoprocessing tools • Full data control • Custom scripting	ArcGIS Pro QGIS

Desktop GIS Comparison

Feature	ArcGIS Pro	QGIS
Cost	$100-700/year (student) $7,000+ (professional)	Free, open-source
Platform	Windows only	Windows, Mac, Linux
Performance	Resource-intensive	Lightweight
Tools	Comprehensive - all functions	Most functions, some gaps in advanced analysis
Support	Professional (ESRI direct)	Community forums
Training	Extensive official courses	Community tutorials, variable quality
Industry Use	Industry standard	Growing adoption, especially in non-profits and academia
Best For	Professional work, enterprise environments	Learning, cost-sensitive projects, open-source workflows

GIS as a Foundation for Traffic Simulation

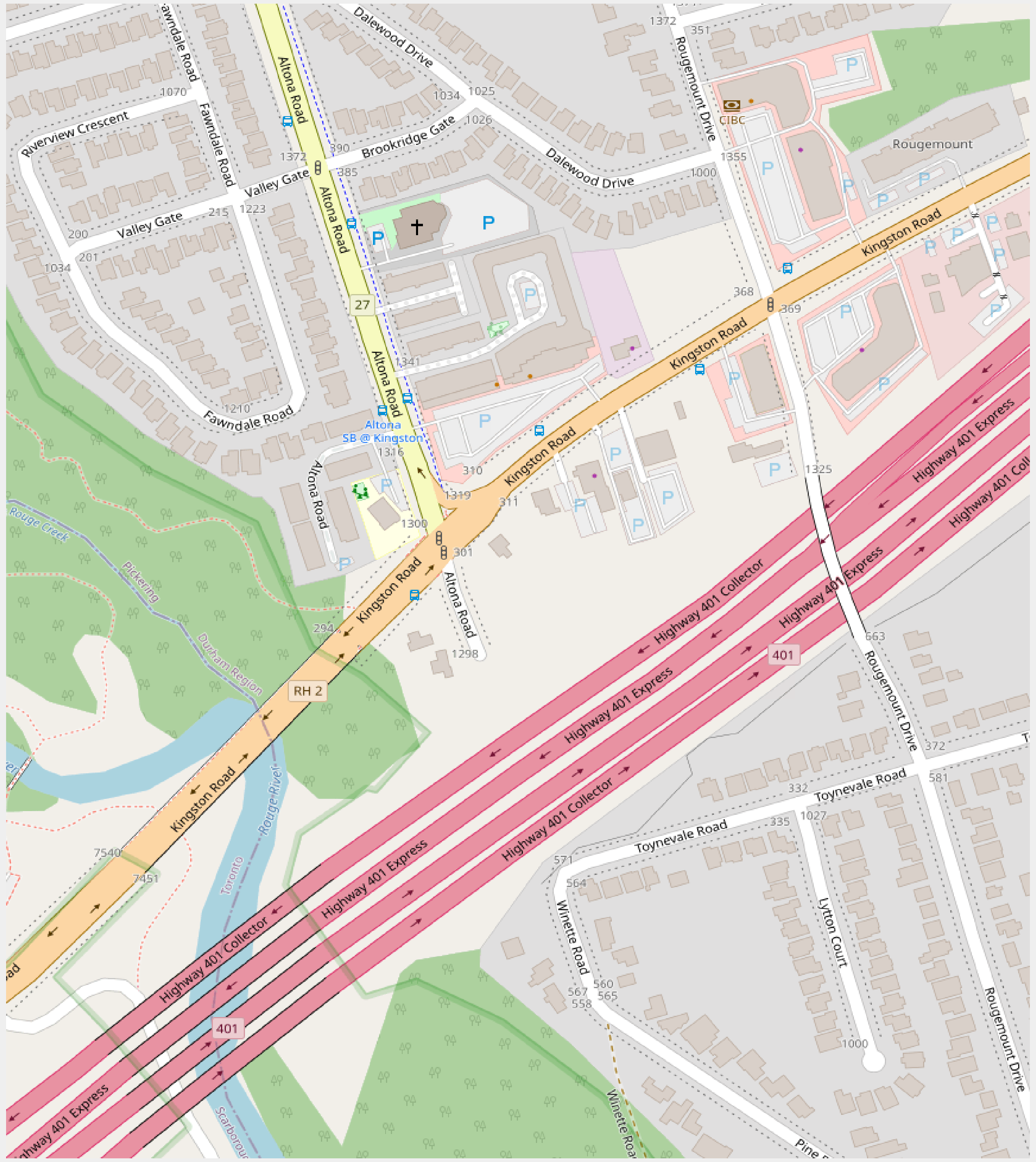
The Challenge:
Creating accurate traffic simulation networks requires precise real-world geometry and spatial context.

GIS Provides:
Base Imagery: Aerial photos and satellite imagery for visual reference
Spatial Reference: Coordinates and scale for accurate network placement
Background Layers: Property boundaries, landmarks for geographic context
Attribute Data: Speed limits, lane counts, signal locations from GIS databases

The Process:
Currently, there is an automatic process of importing GIS into simulation; however, it does not generate road network accurately.

GIS as a Foundation for Traffic Simulation

GIS



Simulation

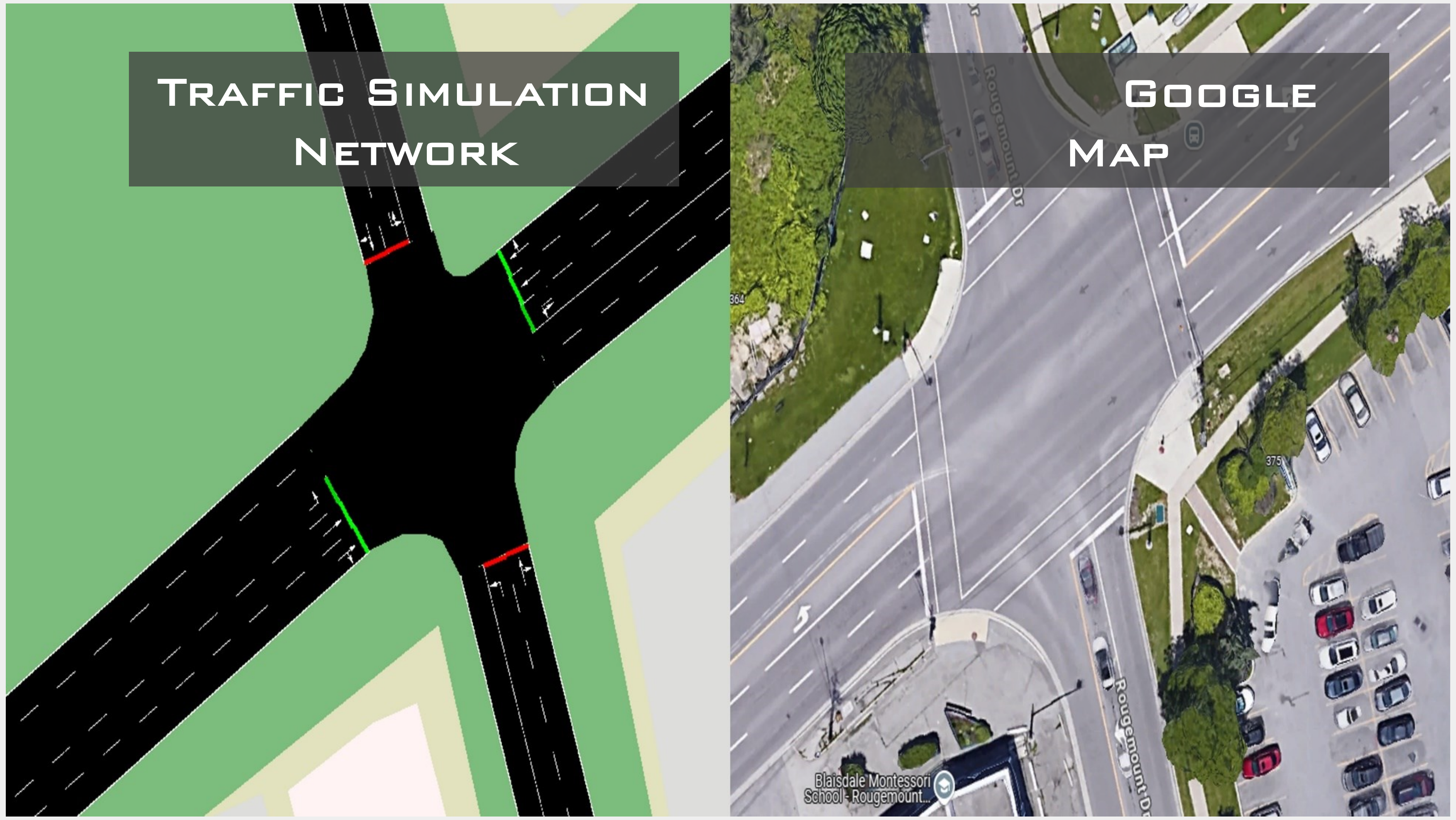
GIS as a Foundation for Traffic Simulation

Planner:

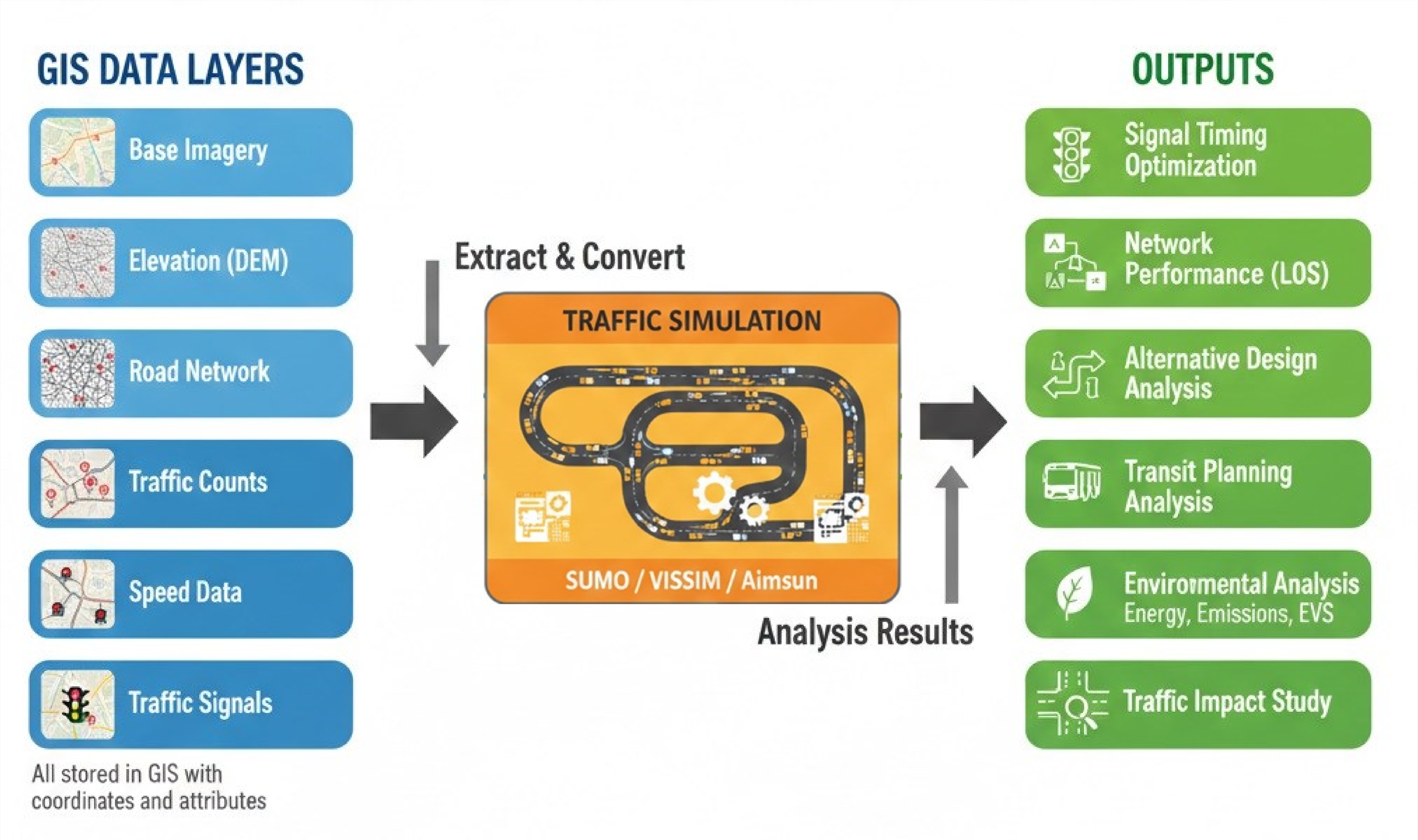
Import GIS imagery into simulation as georeferenced background, then manually trace and build road networks matching real-world geometry, ensuring accurate representation.

Why:

- ✓ Simulation results depend on network accuracy
- ✓ Understanding geometry impacts traffic flow patterns
- ✓ Real coordinates enable proper distance and speed calculations
- ✓ Visual verification against imagery ensures quality



GIS Data Layers to Simulation



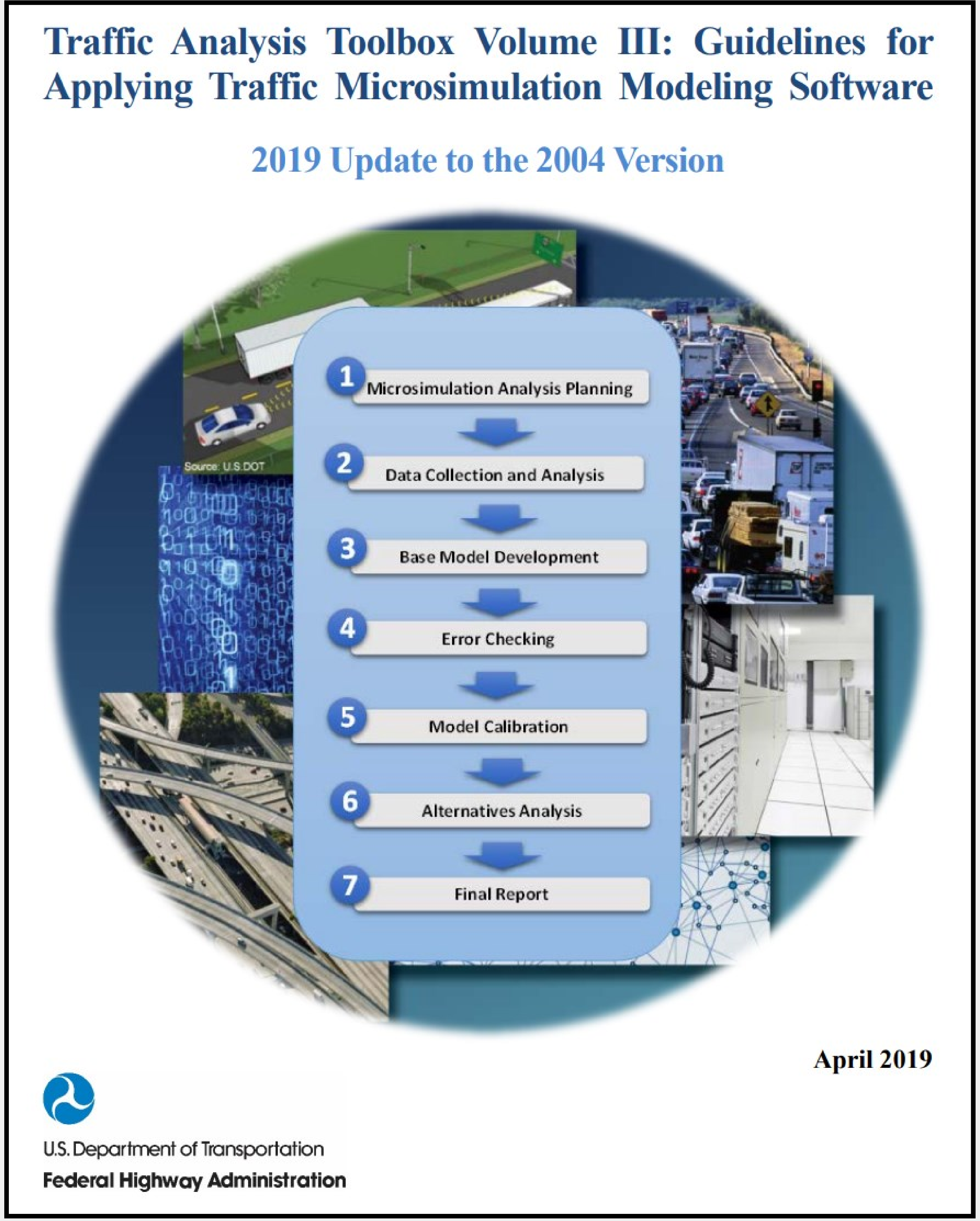
GIS Data Layers in Simulation

https://youtu.be/rEOmc2tJ9WY

Network Elements Required for Simulation

- ✓ Road Geometry Data (Number of lanes, Lane width)
- ✓ Operational Data (Speed limits, Lane restrictions)
- ✓ Traffic Control Data (Traffic Signals, Stop/Yield Control))
- ✓ Traffic Demand Data (Traffic Volumes & Speed)
- ✓ Vehicle and Driver Characteristics (Vehicle Length/Width)

PDF:
https://ops.fhwa.dot.gov/publications/fhwahop18036/fhwahop18036.pdf



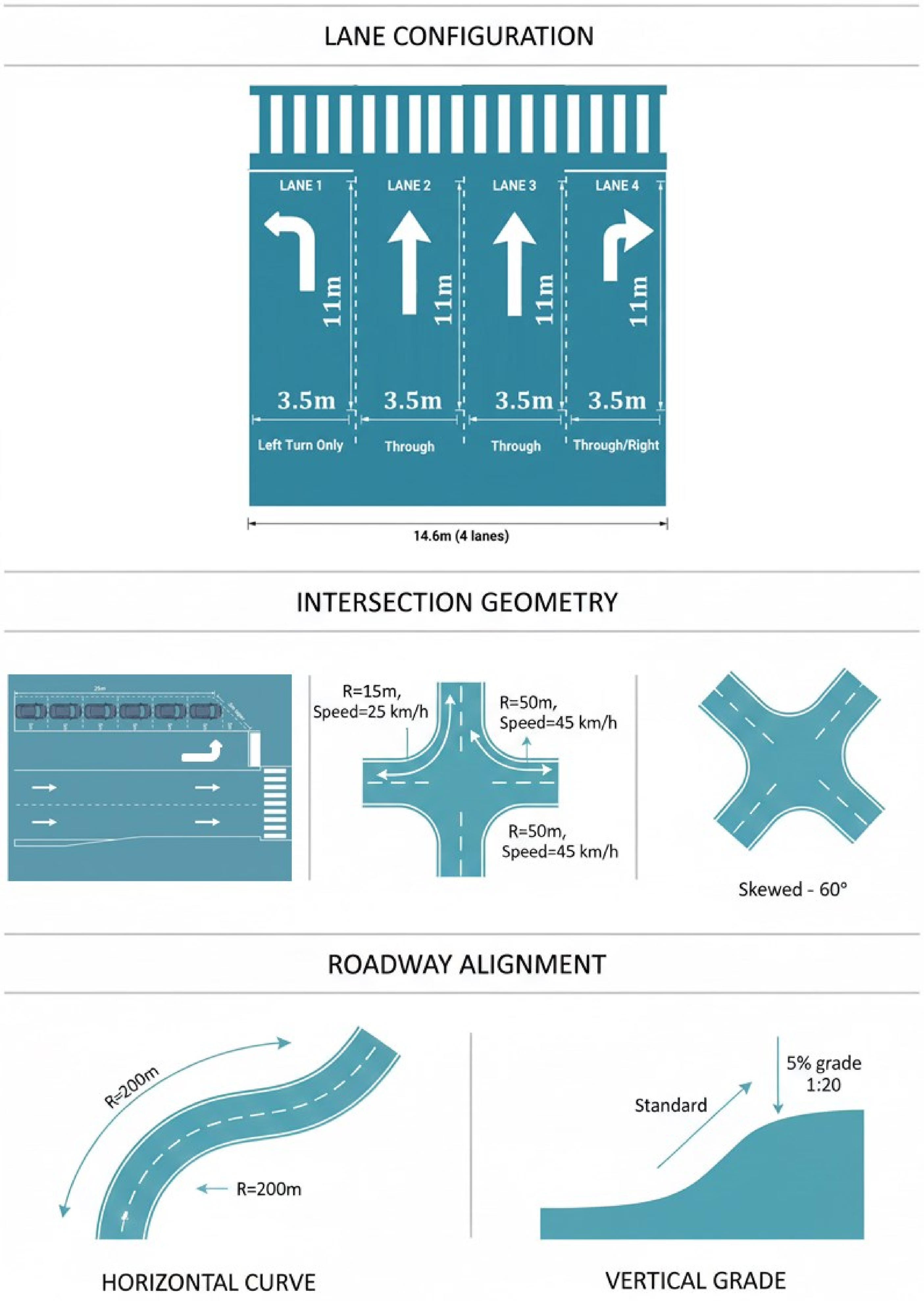
Road Geometry Data

Definition: Physical characteristics of roads and intersections.

Lane Configuration:
Number of lanes per direction
Lane width (standard: 3.5-3.75m)
Lane assignment (through, left-turn, right-turn, shared)

Intersection Geometry:
Storage Lane Capacity
Turn radii (affects vehicle speed)
Intersection angles (90° vs skewed)

Roadway Alignment:
Horizontal curves (how much the road turns)
Vertical slope (going uphill or downhill)



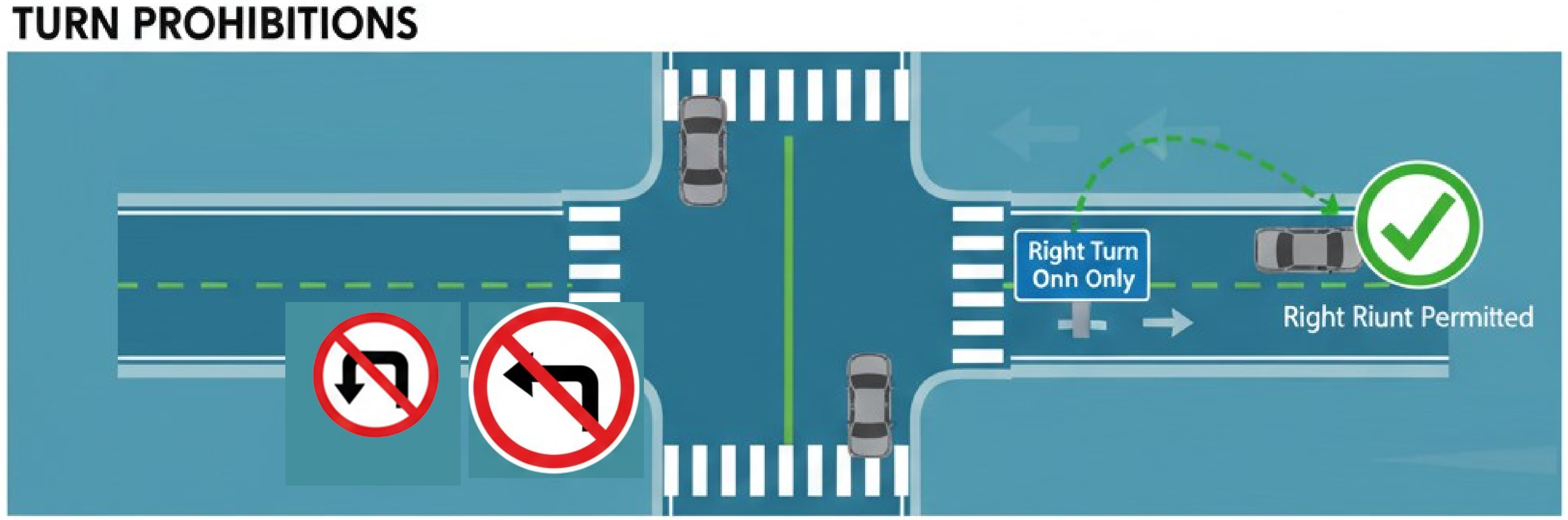
Operational Data

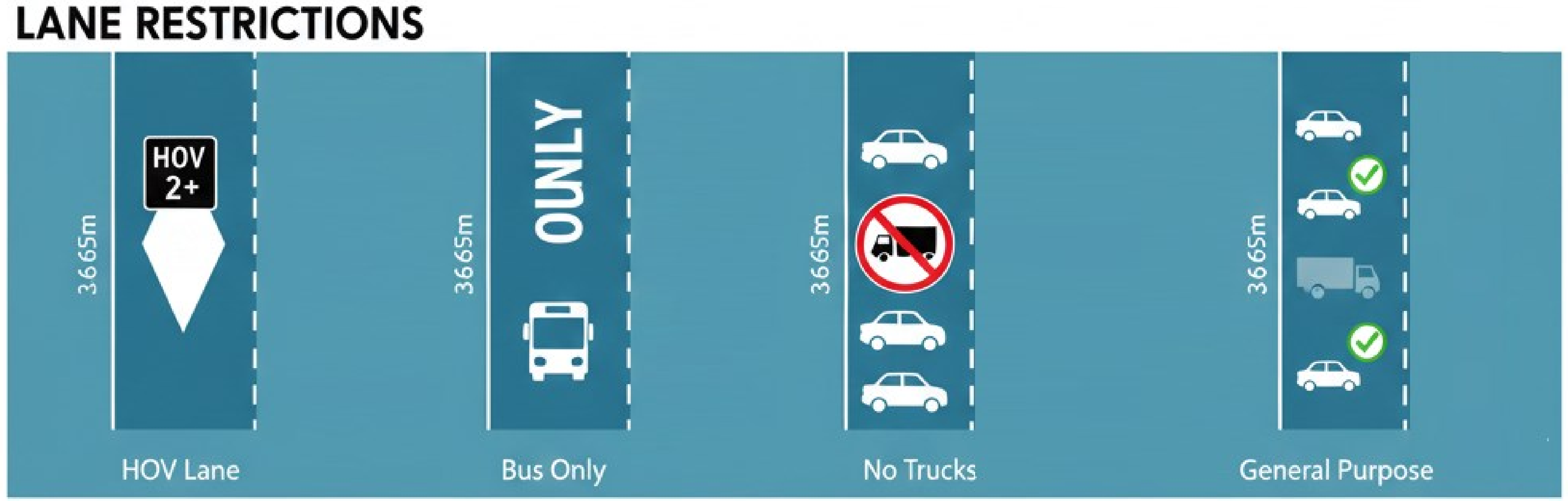
Definition:
Rules and regulations that govern how vehicles can use the road network.

Speed Controls:
Posted speed limits (km/h)

Movement Restrictions:
Turn prohibitions (no left turn, no U-turn)
Lane restrictions (HOV lanes, bus-only lanes, truck restrictions)

SPEED CONTROLS





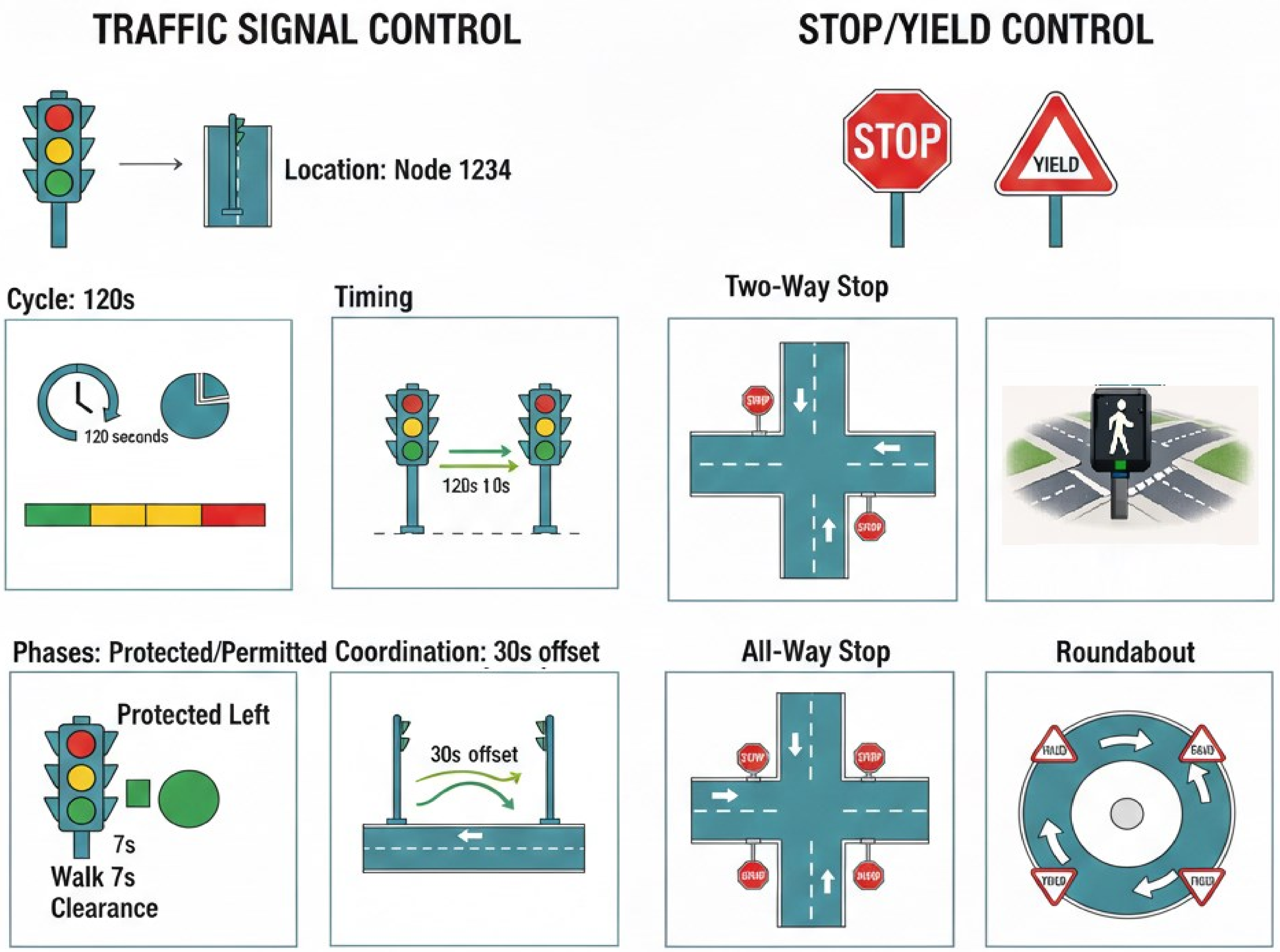
Traffic Control Data

Definition: Devices and systems that regulate vehicle and pedestrian movements at intersections and along corridors.

Traffic Signals:
Signal locations (node IDs)
Cycle length (e.g., 120 seconds)
Phase timing (green, yellow, red durations)
Phase sequence (protected vs permitted turns)
Coordination (offset between signals)
Pedestrian phases and clearance times

Stop/Yield Control:
Stop signs (all-way vs two-way)
Yield signs
Priority intersection rules
Priority rules at roundabouts

Pedestrian Crossings:
Crosswalk locations
Pedestrian signals and timing
Crossing distance/time



Traffic Demand Data

Definition: Real-world traffic measurements used to define simulation inputs and validate model accuracy.

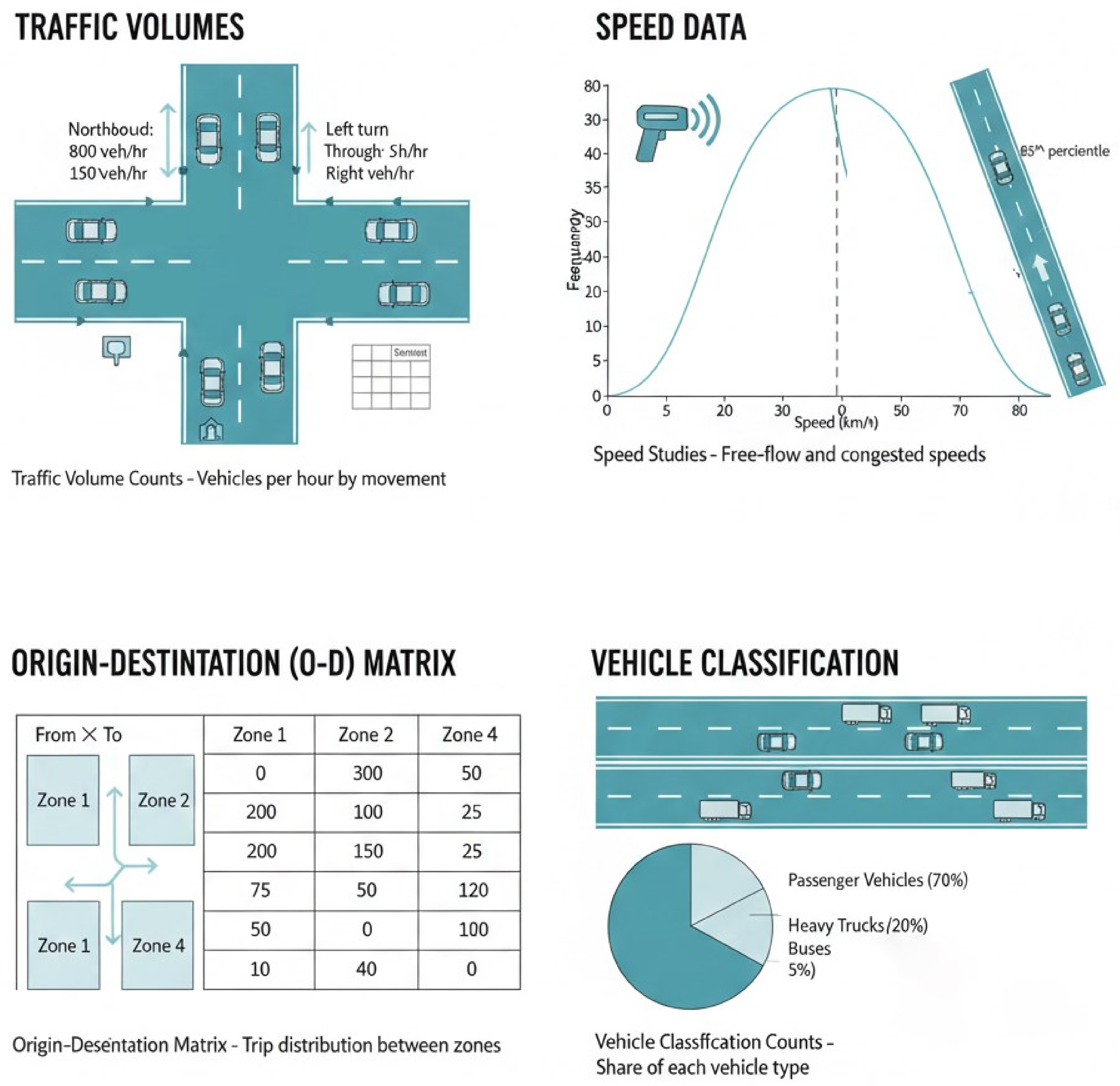
Traffic Data:

Traffic volumes

Speed data

Origin-Destination matrices

Vehicle classification



Vehicle and Driver Characteristics

Vehicle characteristics:

Length

width

Acceleration

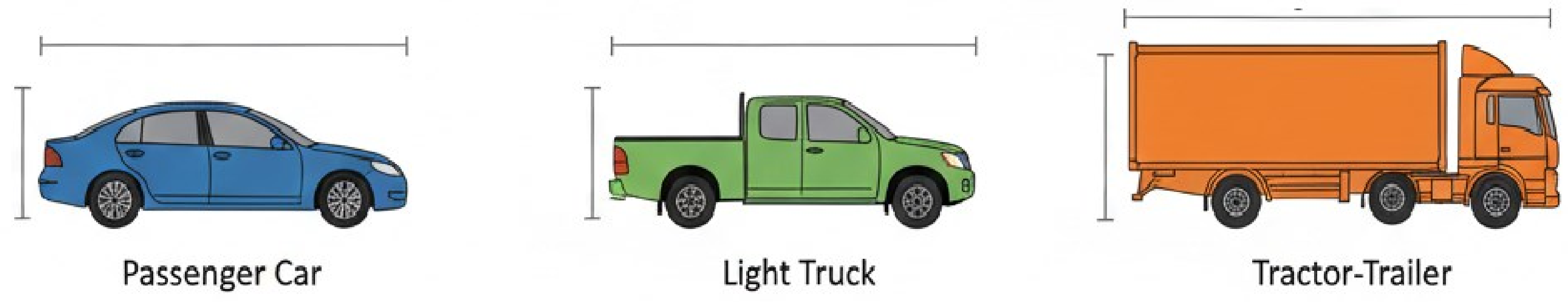
deceleration

Driver Characteristics:

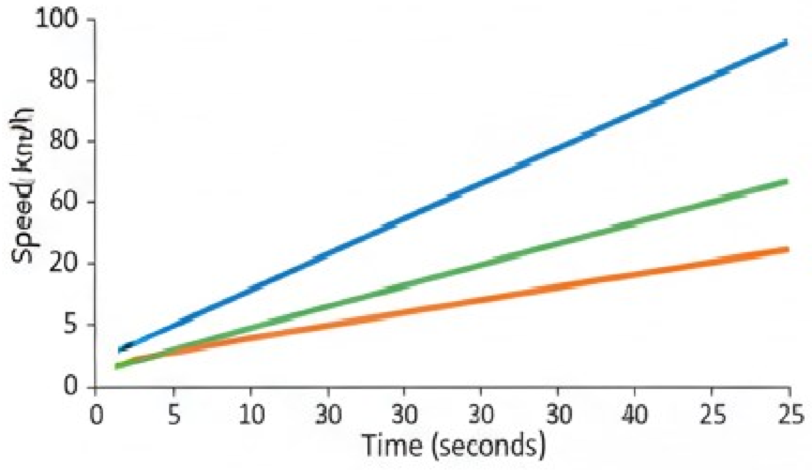
Lane-changing

car-following models

VEHICLE DIMEISIONS

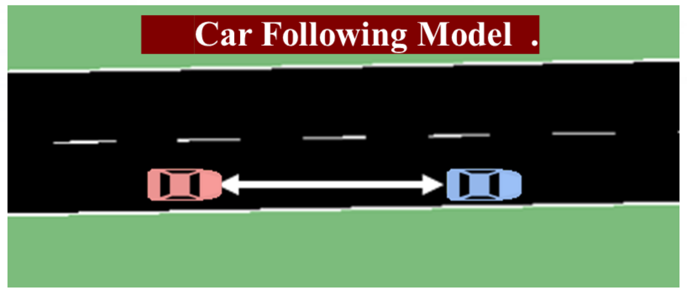


ACCELERATION PERFORMANCE

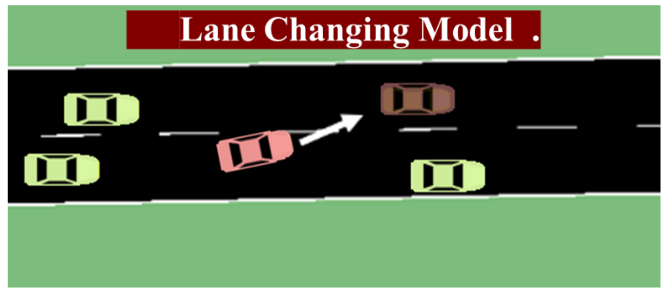


Driver Characteristics

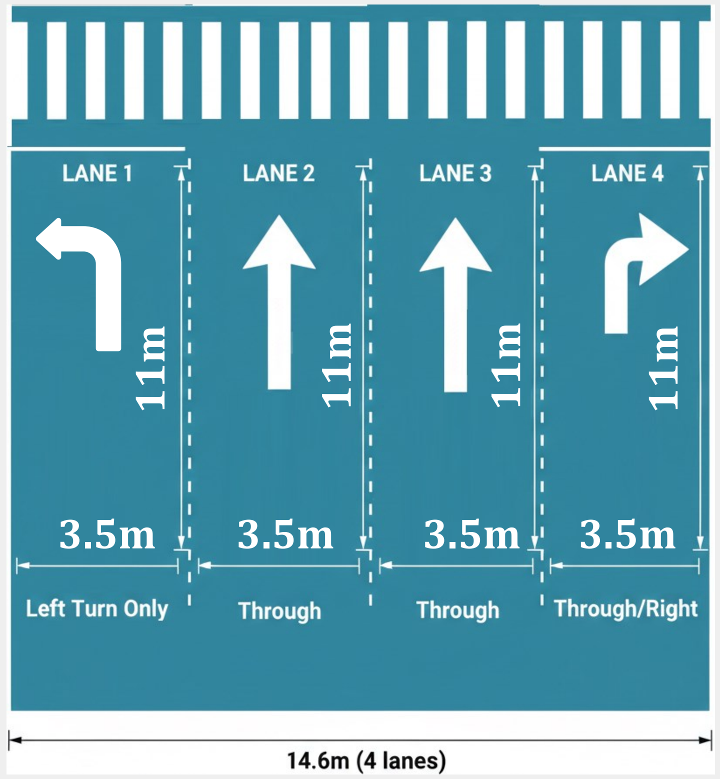
Longitudinal Movement

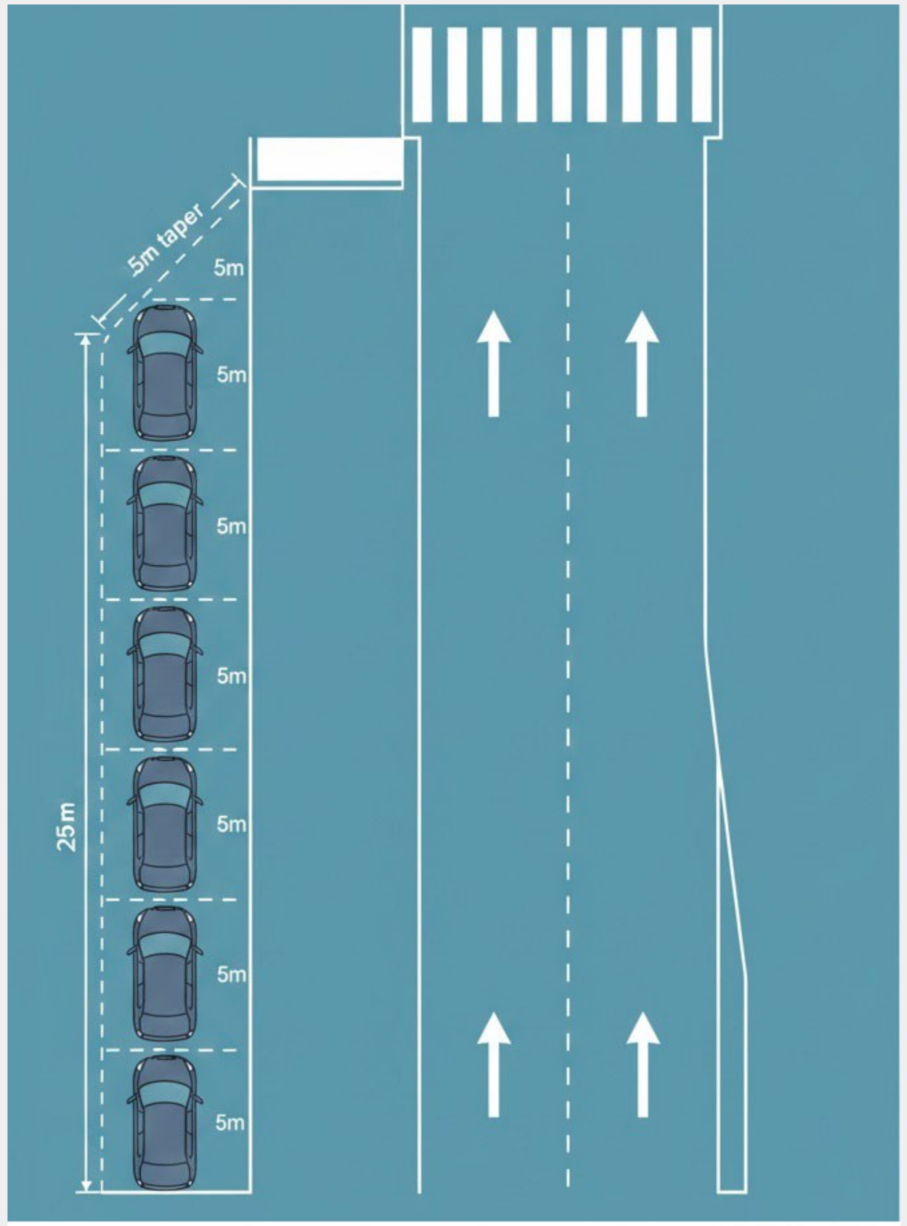


Lateral Movement



Lane Configuration and Intersection Geometry





Left-Turn Storage Lane - Capacity Analysis