I-24 MOTION data documentation (v1.x)

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System overview

The Interstate-24 MObility Technology Interstate Observation Network (I-24 MOTION) is a new instrument for traffic science located near Nashville, Tennessee. I-24 MOTION consists of 294 pole-mounted high-resolution traffic cameras that provide seamless coverage of approximately 4.2 miles I-24, a 4-5 lane (each direction) freeway with frequently observed congestion. The cameras are connected via fiber optic network to a compute facility where vehicle trajectories are extracted from the video imagery using computer vision techniques. The main output of the instrument is anonymized vehicle trajectory datasets that contain the position of each vehicle on the freeway, as well as other supplementary information on vehicle dimensions and class. The map of the system and the field of view covered by a 6-camera unit (on each pole) can be seen in Figure 1 and 2 respectively. Additional information about the system and links to peer-reviewed articles can be found on the project website.

As the system continues to mature, all trajectory data will be made publicly available at https://i24motion.org/. New versions of the trajectory data will be released as the processing software is continually improved. This data documentation, and all subsequent versions pertaining to new data versions, will be available at https://github.com/I24-

MOTION/I24M_documentation. The project team encourages users of the data to report data questions, improvement requests, issues, and oddities as Issues on the tracker repository at https://github.com/I24-MOTION/I24M_improvement_tracker.

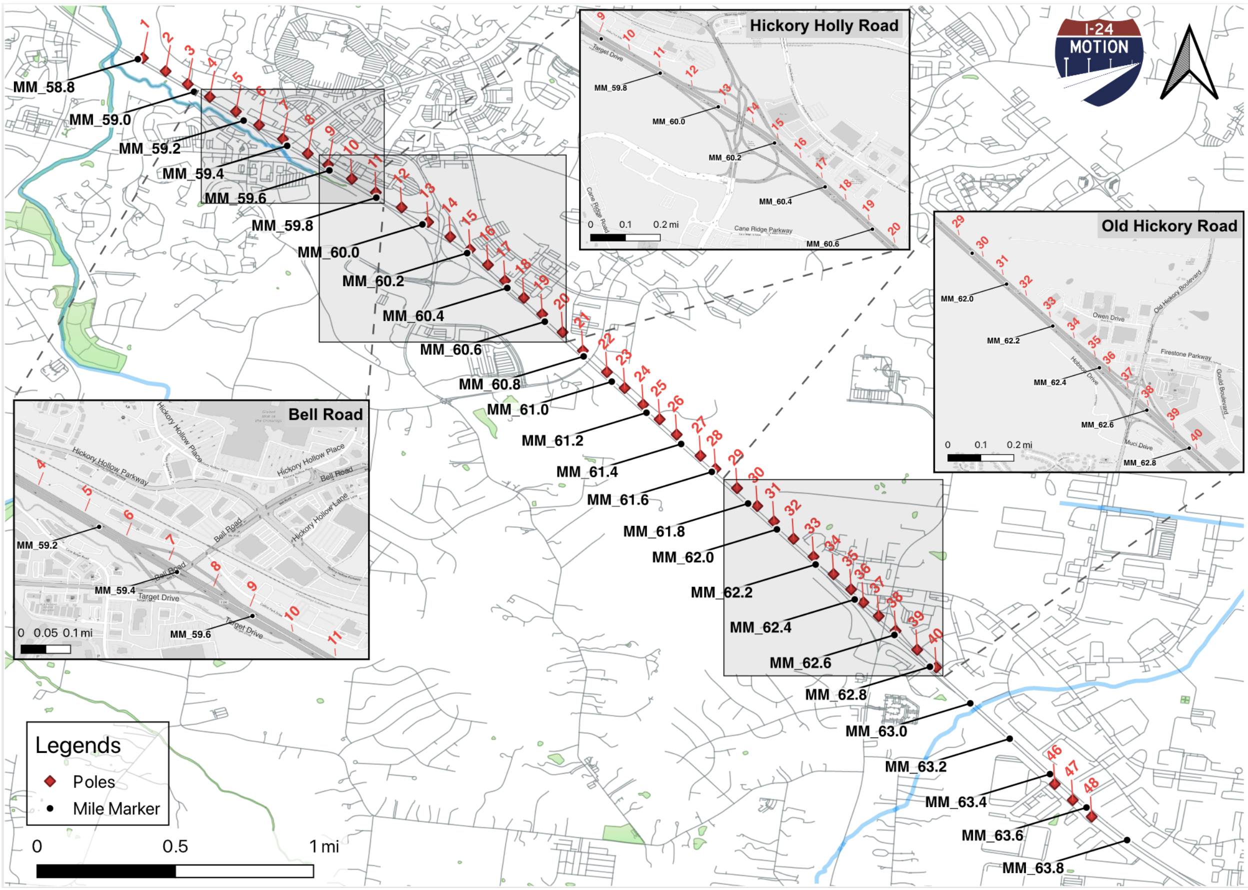

Fig 1. An overview of I-24 MOTION map with pole locations, key landmarks and approximate mile-markers.

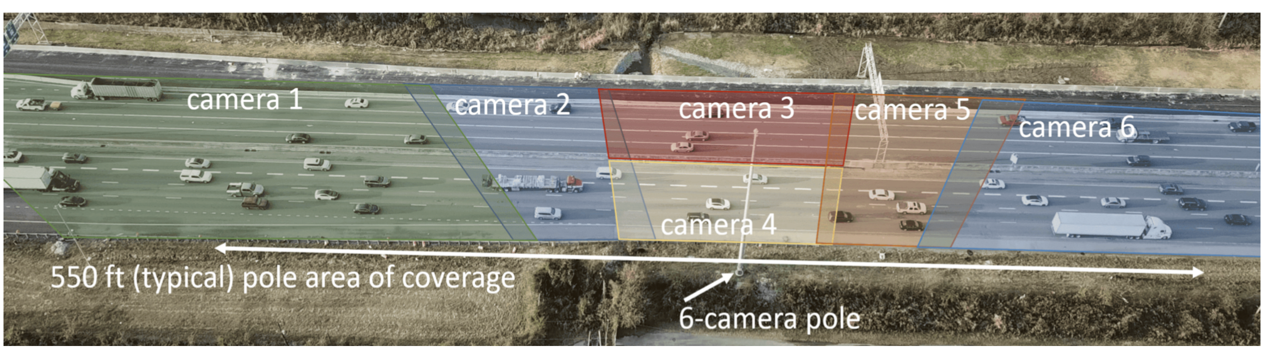

Fig 2. Example camera fields of view for a single 6-camera pole. Each portion of the roadway is covered by at least one camera, with overlaps long enough to allow objects to be tracked between cameras.

Acknowledgements

The I-24 MOTION project and its data are made possible by tireless effort and contributions from a large team at Vanderbilt University, the Tennessee Department of Transportation, and Gresham Smith. The full team listing can be found at https://i24motion.org/team. Data and software contributions were principally made, and continue, by (in alphabetical order) William Barbour, Derek Gloudemans, Junyi Ji, Yanbing Wang, and Gergely Zachár. Many others contributed in countless ways to make the project possible.

Glossary

- EB: eastbound
- MM: mile-marker
- WB: westbound
- WGS84: WGS84 coordinate system with latitude and longitude

Release history

A summary is in the table below:

Version	**Data production began**	**Public release date**	**Description**
Version 1.0	Nov. 2022	Sept. 2023	This is the initial public release version of I-24 MOTION trajectory data.

Data identifiers

Datasets from each run of the system are given unique identifiers. The identifier links to a metadata document that defines all settings that were used system-wide to generate the set of trajectories contained in the dataset. The file for each dataset is named `<unique_identifier>.zip`, but may be organized in a different directory structure.

A listing of data identifiers is not given in this documentation, since it is subject to change. It should, instead, be found on the data listing on https://i24motion.org/.

Trajectory data description

Data schema

Below is an example vehicle trajectory document stored in JSON format.

- The fields marked in red are included in the dataset, but are not currently implemented. They may be implemented in future releases.
- The fields marked in gray are for internal use only.

Attribute	Type	Description	Unit	Example Value
`_id`	12-byte BSON	Unique ID automatically generated by database	-	63732b74e1fa5a45ae0c2fdd
`timestamp`	[double]	Unix timestamps after correction to reduce synchronization errors	sec	[1668600002.0133328, 1668600002.0533328, …]
`first_timestamp`	double	Min timestamp from all timestamps in the trajectory fragment	sec	1668600002.0133328
`last_timestamp`	double	Max timestamp from all timestamps in the trajectory fragment	sec	1668600007.2098653
`x_position`	[double]	Array of back-center longitudinal position along the road segment in feet. In general, one can convert from `x_position` to mile marker by dividing `x_position` by 5280 ft/mi.	feet	[316800,316801,...]
`y_position`	[double]	Array of back-center lateral position perpendicular to the lane lines in feet. y=0 is roughly the center line on the median strip. Following the right-hand rule, `y_position` on WB are positive, and EB are negative.	feet	[-12,-12,...]
`length`	double	Vehicle length	feet	18.3

`width`	double	Vehicle width	feet	6.4
`height`	double	Vehicle height	feet	5.4
`merged_ids`	[objectId]	Fragments (that have time overlaps) that are combined to this trajectory.	-	[id1, id2]
`fragment_ids`	[objectId]	Fragments (that do not overlap in time) that are combined to this trajectory.	-	[id1, id2]
`starting_x`	double	The first value in `x_position`	feet	123.2
`ending_x`	double	The last value in `x_position`	feet	5763.3
`coarse_vehicle_class`	int	Vehicle class obtained from the object detector. 0 : sedan 1 : midsize 2 : van 3 : pickup 4 : semi 5 : truck	-	0
`direction`	int	1 if eastbound, -1 westbound	-	1
`compute_node_id`	string	The name of the compute server that this fragment is processed on	-	“videonode1”
`local_fragment_id`	[int]	Integer unique to each tracked vehicle per compute_node_ID and configuration_id, generated by the tracker	-	[1,2,3]
`fine_vehicle_class`	int	[not implemented] Vehicle fine class number	-	-1
`road_segment_ids`	[int]	[not implemented] Unique road segment ID. This differentiates the mainline from entrance ramps and exit ramps, which get distinct road segment IDs		[-1]
`configuration_id`	[int]	[not implemented] A unique ID that identifies what configuration was run. It links	-	[1,2,3]

		to a metadata document that defines all the settings that were used system-wide to generate this trajectory fragment		
`flags`	[string]	[internal use only] Array of flags describing the tracking process	-	[“Lost”, “Overlap”]
`x_score`	double	[internal use only] Value of the reconciliation objective function (x) at optimality	-	3.2
`y_score`	double	[internal use only] Value of the reconciliation objective function (x) at optimality	-	2.3
`feasibility`	object	[internal use only] Feasibility score for some metrics	-	“Conflicts”: 1 “Distance”: 0.8

Coordinate systems

We use three coordinate systems to convert positional information between video imagery, WGS84/TN coordinate system and roadway coordinate system. Demonstrated in the figure below, objects in video imagery are mapped to TN system and WGS84 via homography transform estimated from labeled points; they are subsequently mapped to a roadway coordinate system based on spline curve fitting.

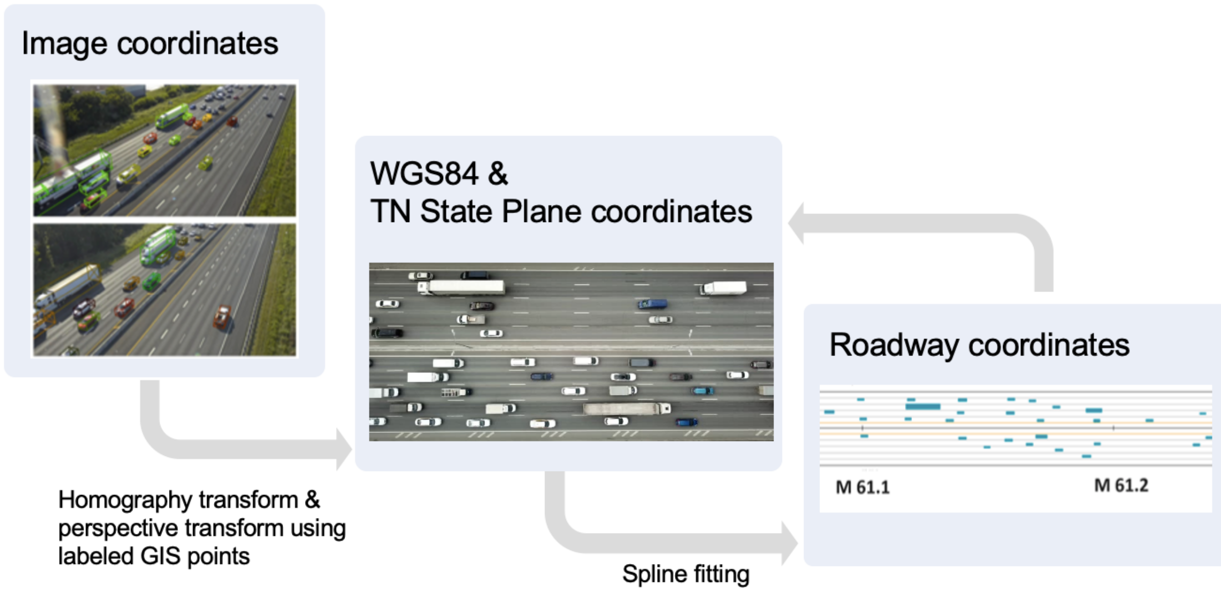

Fig 3. Three coordinate systems utilized in I-24 MOTION system

WGS-84 coordinate system (X_WGS84 and Y_WGS84)

WGS-84 coordinate system is a standard used in cartography, geodesy, and satellite navigation including GPS.

Tennessee coordinate system (X_TN and Y_TN)

The system is defined in US survey feet by state law. The conversion is accomplished by multiplying meters by 39.37/12. It uses a Cartesian 2D coordinate system, with axes easting (X) and northing (Y). The orientations are east and north. The area is bounded by two points (34.98, -90.31) and (36.68,-81.65) in WGS84.

To transform the points in WGS-84 to the TN coordinate system, the following python script can be used, for example.

```
import pyproj
import numpy as np
def TN_to_WGS84(points):
    wgs84=pyproj.CRS("EPSG:4326")
    tnstate=pyproj.CRS("epsg:2274")
    out = pyproj.transform(tnstate, wgs84, points[0],points[1])
    return out
```

```
TN_to_WGS84([34, -90.31])
Result: (677677.1774127262, 263824.98320697015)
```

Roadway coordinates

The roadway coordinate system is natively in a curvilinear 2D system, with the primary (x) axis aligned along the interstate roadway median and the secondary (y) axis defined locally perpendicular to the primary axis (see Figure 4). This means that x is roughly equivalent to station or mile marker along the roadway, while y gives lateral or lane-position data. A second-order spline defines the x-axis in global (state plane) coordinates. (Control points for the center-line in state plane coordinates are included in metadata). This allows for the direct conversion of roadway coordinates into state plane coordinates, with a trivial conversion from state plane coordinates to GNSS WGS84 coordinates. Both coordinate directions are stored natively in feet. The positive x-direction is defined in the eastbound direction (direction of increasing mile-marker as defined by the Interstate 24 mile markers).

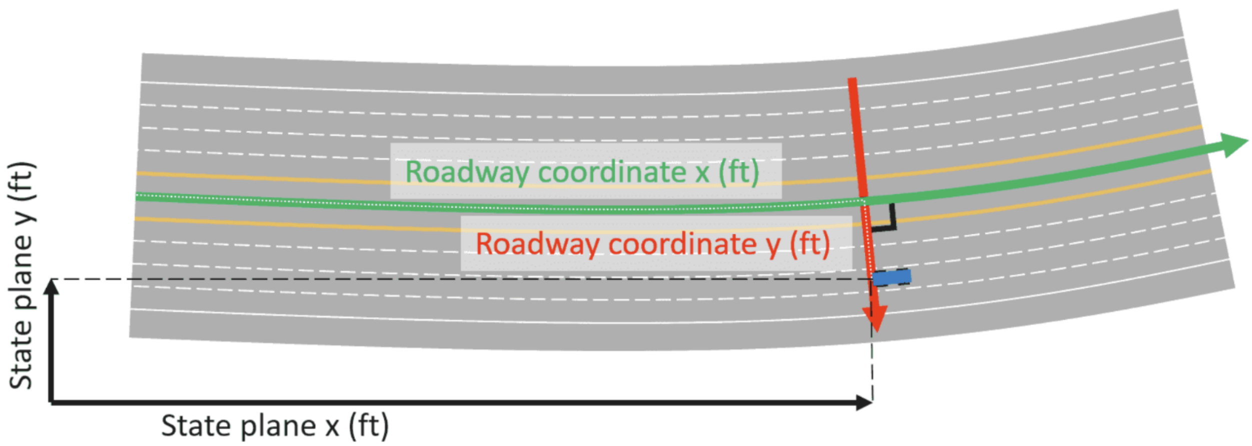

Fig 4. Spline-curvilinear x-axis (green) and locally perpendicular y-axis (red) for roadway coordinates. State plane coordinates are shown in black for comparison. Position of the vehicle can be expressed either in state plane coordinates (black dashes) or roadway coordinates (white dots).

For data version 1.x, the x-coordinates are offset such that the x-coordinate for MM60 corresponds exactly to 5280 × 60 = 316800 ft. (Other mile markers are approximately but not exactly located in this way (e.g. MM 61 ≈ 5280 × 61 = 322080 ft). Adopting the right-hand rule convention, the y-coordinate is negative on the EB side of the roadway (vehicle is moving in increasing x-direction), and positive on WB.

Lane delineation

Determining lane location/number for a trajectory is currently best accomplished using the lateral position of the vehicle. This lateral position is known to have deficiencies in v1.0 of the data and this is a scheduled enhancement in the next release. For now, we recommend using the column *y_position* (ft) in the dataset and the following approximate lateral ranges to identify the lane information.

For trajectories in direction *-1*:

- 12 - 24, lane 1 (HOV lane)
- 24 - 36, lane 2
- 36 - 48, lane 3
- 48 - 60, lane 4

Known artifacts

We observe some data artifacts due to hardware and software issues in the early versions of I-24 MOTION. Some examples can be seen from the time-space diagram below:

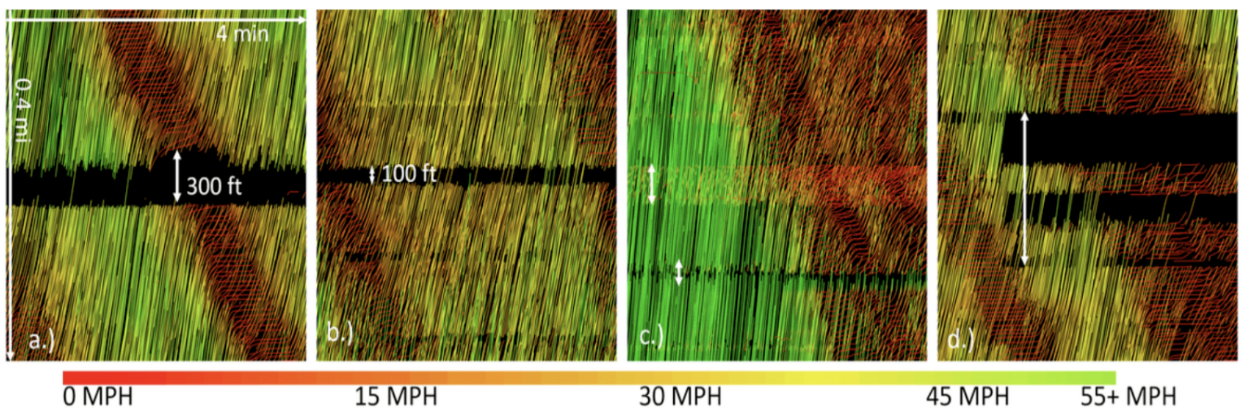

Fig 5. Example artifacts: For all figures, horizontal scale = 4 min. and vertical scale = 0.4 mi.

a) Missing pole causes a wide horizontal band of missing data.
b) Overpass causes a narrow horizontal band of missing data. In some cases post-processing can successfully stitch trajectories through this occlusion.
c) Homography error causes multiple trajectories corresponding to the same vehicle, or else results in a narrow band with no coverage.
d) Packet drops cause bands of missing trajectory data with a discrete start and end. Post-processing only partially fills in this data.

We intend to continue addressing each of these artifacts in later releases.

Auxiliary information

Auxiliary information can be found alongside distributed data from https://i24motion.org/. A description of the file contents is provided here, since it applies to all datasets in this version.

Mile markers

The file `mile_marker_layer.csv` records the location of some key mile-marker signs, in both WGS84 and State plane coordinates.

Field name	Description
MM†	Approximated mile-marker
X_WGS84	The longitude of a location, according to the WGS84 coordinate system
Y_WGS84	The latitude of a location, according to the WGS84 coordinate system
X_TN	The easting coordinate in the TN state plane coordinate system.
Y_TN	The northing coordinate in the TN state plane coordinate system.

† **Notice:** do not use mile-markers for distance calculation. Mile-marker signs are known to be installed with a margin of error. To get an accurate result, please refer to the coordination system in WGS-84 or Tennessee state plane coordinate system.

Poles location

The file `pole_layer.csv` records the location of each pole, in both WGS84 and TN state plane coordinates:

Field name	Description
Pole-number	The index of each pole from 1 to 40 (I-24 MOTION), and 46-48 (the validation system). The trajectory data is collected from cameras hosted on pole 1 to 40.
X_WGS84	The longitude of a location, according to the WGS84 coordinate system
Y_WGS84	The latitude of a location, according to the WGS84 coordinate system
X_TN	The easting coordinate in the TN state plane coordinate system.
Y_TN	The northing coordinate in the TN state plane coordinate system.

Ramps and landmarks

The I-24 MOTION testbed covers three major interchanges: Bell Road, Hickory Hollow Pkwy and Old Hickory Blvd, with on and off ramps on the main corridor leading to and exiting from them (see Fig 6).

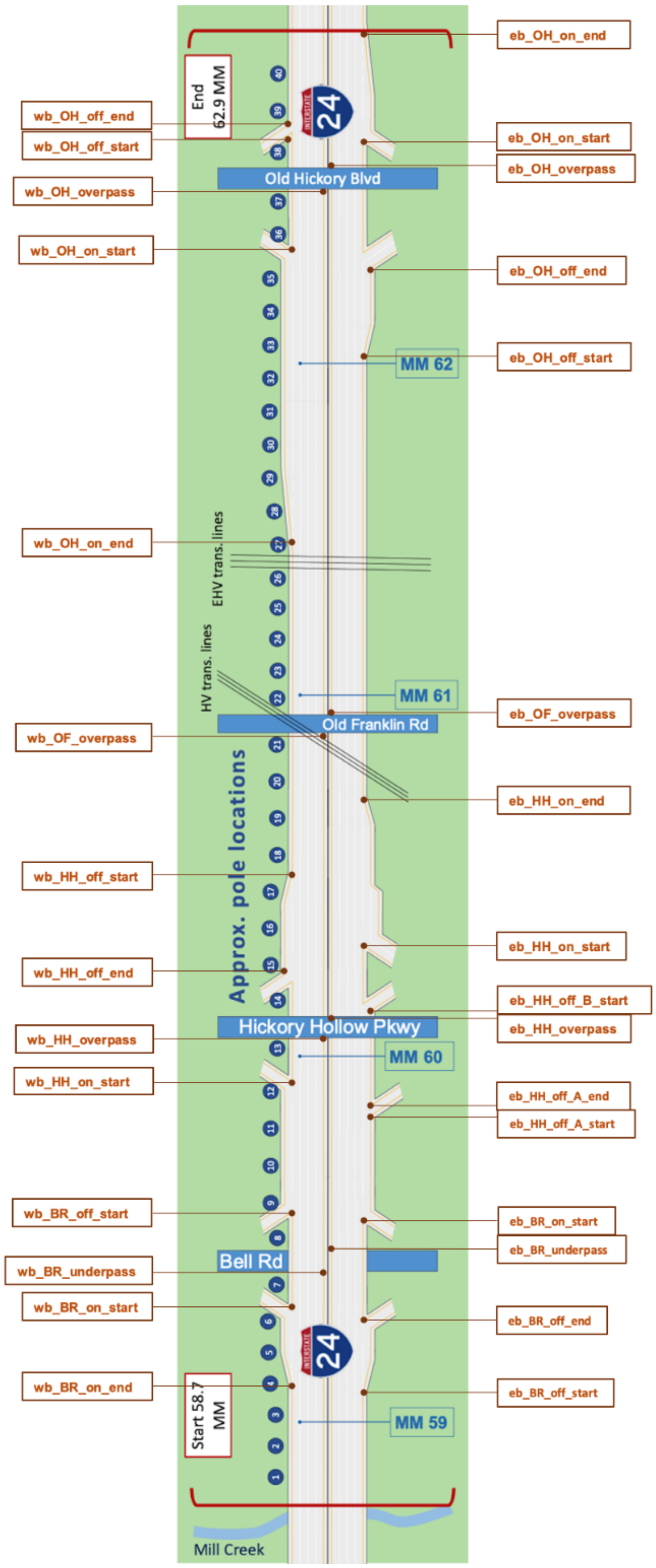

Fig 6. Diagram of the I-24 MOTION instrument, spanning from MM 58.8 to MM 62.8. Camera poles (blue circles) are spaced at roughly 550-foot intervals. The system spans three overpasses and one underpass, as well as three interchanges with 13 entrance/exit ramps.

The locations of ramps and interchanges are recorded in `ramp_and_landmark_layer.csv.` The table below describes each field in the `.csv` file.

Field name	Description
Direction	eb: eastbound, wb: westbound
Landmark name[†]	Landmark name follows the format <a>_<b>_<c>_<d>_<e> for ramp points, where: a: direction, “eb” or “wb” b: abbreviation of the intersection name. BR: Bell Road, HH: Hickory Hollow, OF: Old Franklin, OH: Old Hickory c: ramp type, either “on” or “off” d: increasing letters to distinguish multiple on/off ramps at the same intersection. (optional) e: either “start” or “end” of ramps. For on-ramps, “start” is the point the ramp intersects with the main corridor, and “end” would be the point the ramp completely merges with the corridor, and vice versa for off-ramps. The name follows the format <a>_<b>_<f> for overpasses, where: a: direction, “eb” or “wb” b: abbreviation of the intersection name. BR: Bell Road, HH: Hickory Hollow, OF: Old Franklin, OH: Old Hickory f: either “overpass” or “underpass”
MM	The approximate mile-marker corresponding to each landmark. Note that MM is an approximation of roadway location and should not be used for distance calculations.
X_WGS84	The longitude of a location, according to the WGS84 coordinate system
Y_WGS84	The latitude of a location, according to the WGS84 coordinate system
X_TN	The easting coordinate in the TN state plane coordinate system.
Y_TN	The northing coordinate in the TN state plane coordinate system.

[†] **Notice:** due to the lack of standard naming convention especially for complicated roadway geometry, we suggest users to look up the landmarks on the illustration diagram (Fig 6) along with GPS locations to confirm their interpretations.

Grade and elevation

The grade and elevation information is stored in `grade_elevation.csv`. The raw measurements are obtained from the State [of Tennessee LiDAR program] and processed to generate grade and elevation functions for the roadway section of interest.

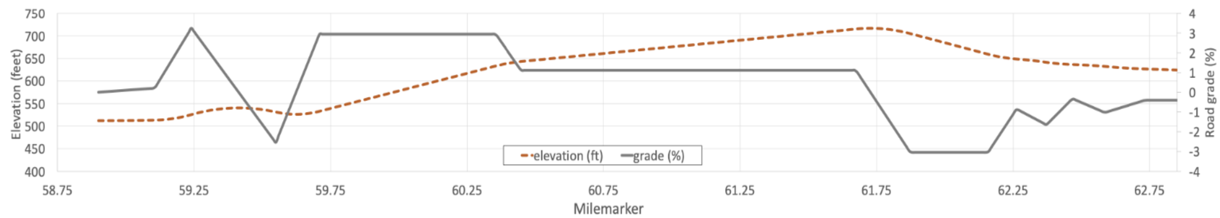

Fig 7. Elevation and road grade along the freeway. Grade is measured in the eastbound (diagram left to right) direction and was determined by differentiating the best-fit second-order piecewise polynomial elevation function.

The table below describes each field in the `.csv` file:

Field name	Description
MM	Mile-marker on I-24. Note that users should be careful when using mile-markers, since the sign installation and resulting GIS points are known to have a margin of error.
elevation	The elevation in feet processed from aerial-based lidar measurements, conducted and published by the State of Tennessee (https://lidar.tn.gov). The data is processed with second-order polynomial fit.
grade	The grade (%) is obtained by differentiating the elevation polynomial to attain the piecewise linear grade function. This approach is consistent with the road design constraint for this roadway of allowing only constant or linear grade in the roadway profile.

Time space diagrams

We may provide up to three versions of time-space diagrams for each dataset. The space-time diagram is generated such that the x-axis is the timescale and the y-axis is distance traveled. An example is provided in Fig 8.

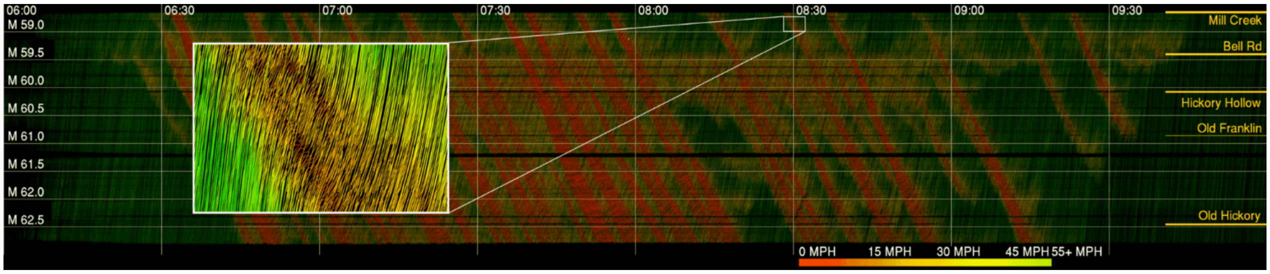

Fig 8. Time-space diagram for four hours of I-24 W morning rush hour traffic on Nov 25, 2022, generated from I-24 MOTION vehicle trajectories. x-axis: time of day (HH:MM); y-axis roadway postmile (mi). Postmile decreases for travelers in the westbound direction.

Each version differs by resolution and scale. Details are as follows:

Folder name	Resolution	Scale	Description
`time-space_large_traj`	~30000 x ~6000 pixel	4 foot/px, 12/25 second/px (except for Nov 25, 2022: 2 foot/px, 33/25 second/px)	Large scale time-space diagrams, trajectories are represented with colored lines.
`time-space_large_pos`	~30000 x ~6000 pixel	4 foot/px, 12/25 second/px (except for Nov 25, 2022: 2 foot/px, 33/25 second/px)	Large scale time-space diagrams, each car position is represented as a colored pixel.
`time-space_mid_pos`	~20000 x ~4000 pixel	6 foot/px, 18/25 second/px	Mid-scale time-space diagrams, each car position is represented as a colored pixel.