Generating a Vehicle Trajectory Database from Time-Lapse Aerial Photography

Transportation Research Record

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ABSTRACT

The advancing art of micro-simulation modeling is driving a growing interest in vehicle trajectory databases. These can be rich sources of travel information, providing origin-destination patterns, path choices, travel times or delays, and lane changing behavior. These metrics have historically been difficult to acquire, and even with the approach of the "big data" era, it remains a challenge to collect high quality, granular vehicle trajectory data.

This paper describes how use of state-of-the-practice time-lapse aerial photography (TLAP), acquired continuously for up to several hours at one-second frame rates, can produce trajectory datasets with high granularity. These surveys involve the use of airborne digital cameras held in stationary positions about one mile above the ground, to record the movement of virtually all highway vehicles in defined study areas.

In this paper, TLAP's differences from similar military imaging capabilities (WAMI) are discussed, to explain how TLAP can be affordable for highway traffic studies. Then local survey design and execution for a Phoenix-area study are presented. Flight and photography survey planning, image alignment, and data extraction methods are discussed; and study output tables and graphics are presented near the end.

It seems likely that "big data" will someday be able to magically supply all of the field data needed for complex analysis or simulation of specific study areas; for now, however, one-second TLAP can provide many of those benefits.

Keywords: vehicle trajectory, origin-destination, aerial photography, bottleneck.

1. INTRODUCTION

Through its highway data management program, The Maricopa Association of Governments (MAG), the designated Metropolitan Planning Organization for the Phoenix metropolitan area, periodically conducts regional bottleneck studies that identify, rank and analyze regionally-significant traffic bottlenecks. The collected information is used at the micro-level to plan specific corridor improvements, as well as at the macro-level to provide broad quantitative datasets for large regional planning studies. Conceived within this framework, the subject study of this paper was to identify the best congestion relief options for MAG's major freeway corridors. First, multiple sub-tasks compiled complete sets of traffic flow metrics for congested freeway corridors; then analysis of speed and traffic volume data resulted in the identification, confirmation and ranking of all regional freeway bottlenecks.

Once congested freeway segments had been identified, full understanding of traffic flow characteristics was needed before identifying possible congestion mitigation strategies. This would be complicated in the Phoenix area by the fact that the region-wide one-mile arterial grid provides numerous alternative route choices for freeway users (freeway segments likewise provide route options for arterial users). Evaluating this relationship is a necessary step to understanding how specific freeway bottlenecks form and persist. For example, one of MAG's most significant congested corridors is I-10 as it passes north and east of downtown Phoenix, between the I-17 interchange to the west and the SR-202L interchange ("Pecos Stack") to the east. MAG planners and engineers have posed questions about this complex area that cannot be answered by analyzing traditional traffic flow or speed data. What are the origins, destinations and routes of relevant trips within this corridor, including travel along the arterial grid? To what degree are road users changing their paths in order to bypass bottlenecks? Is capacity adequately distributed between merging flows to reflect travel demand? And on a micro-level, what lane changing behavior is exhibited on relevant stretches of freeways as congested zones are negotiated? Answering these and similar questions would require detailed analyses of large vehicle trajectory datasets that cannot be produced through the use of any of traditional survey method. Furthermore, reliable and efficient calibration of MAG's micro-simulation models would be needed later, so that proposed operational and planning improvements could be evaluated; accordingly, a comprehensive source of vehicle behavior metrics would also be needed.

2. METHODOLOGY SELECTION

MAG reviewed both established and emerging technologies to find an affordable way to acquire the metrics needed to document complex vehicle movement patterns. MAG learned that relatively new airborne sensing technologies can simultaneously record all visible vehicle movements across relatively large viewing areas -- for example, tanks and jeeps or cars and trucks. Once large archives of this type of aerial imagery have been acquired, almost any vehicle movement metric can be extracted. For highways this includes origin and destination (O-D) tables with routes taken; travel times and speeds, again by route or segment; traffic densities and queue lengths at bottlenecks; weaving and lane changing behaviors; and volume counts at ramps, mainline travel lanes, or for turning movements at intersections. While these technologies have their limitations, no other data collection method was found that can yield this full set of traffic flow metrics.

WAMI vs. TLAP

The military adaptation of this capability is called "*wide-area motion imagery*" (*WAMI), "wide-area surveillance" (WAS), or "wide-area persistent surveillance" (WAPS)*[1]. For transportation planning applications, similar methods have fallen under the generic umbrella of "*one-second time-lapse aerial photography*", hereafter called *TLAP*. Mission differences drive the differences between WAMI and TLAP: military WAMI sensors must downlink and produce ready-to-view imagery in near-real-time for immediate analysis; viewing areas therefore are fixed, typically covering up to 10 square miles at several frames per second. [2] WAMI systems need to be on-station for five or greater hours at a time; some can image in the dark. These capabilities make them heavy to lift (typically 500 to 1500 lbs) and very expensive both to build and maintain in an operational status (specialized aircraft, drones, or balloons are typically used) [3,4]. Unlike WAMI, TLAP for highway planning applications does not need to be delivered in real-time, and extended periods of coverage are not necessary to be useful for some applications. This means that self-contained clusters of lightweight "prosumer" digital cameras (e.g. Canons or Nikons) can be flexibly mounted without stabilization, and deployed on local helicopters that are rented by the hour. Total system weight ranges from 15 to 50 lbs with mount, depending on number of cameras used. Multiple cameras can be individually aimed to cover asymmetrical survey areas or linear survey areas that would extend beyond the fixed fields-of-view of WAMI systems. For example, one hovering helicopter with a multi-camera TLAP system can image linear highways that are up to 6 miles long, with enough resolution to allow end-to-end vehicle tracing. Multiple systems have been affordably deployed on separate aircraft working together, enabling the documentation of vehicle movements across very long study areas. (For example, in 2014 four TLAP-equipped helicopters working in tandem surveyed a 17-mile freeway section in San Antonio, Texas for 90-minute peak travel periods.[5]) Other significant cost savings realized by TLAP are that: 1) the systems are small enough to be shipped as checked airline baggage, allowing them to flexibly move to jobs sites without the cost of ferrying planes and crews large distances; and 2) the alignment of images (which must be done before data extraction can begin) can be accomplished post-flight using software and basic office computers; therefore the complex technologies and heavy equipment needed to align on-the-fly are not needed.

TLAP Limitation: without automated data extraction, cost effective only for short-period planning studies

As a low-cost cousin to WAMI, TLAP from a single helicopter has continuous coverage period of only two hours on-station; it also lacks a live downlink capability. Furthermore, even today's automated tools (non-classified at least) do not seem to exist that can trace vehicles to the edges of 1-hertz TLAP imagery with acceptable error rates (trees, shadows, buildings, and vehicle concentrations in congestion etc. introduce "puzzles" that humans can solve reliably but not today's computer algorithms.)[6] Therefore, data extraction cannot yet take advantage of economies of scale that comes with automation. Accordingly, the market to date has accepted TLAP as a cost-effective method only for planning studies where complete knowledge of virtually all aspects of traffic movement is desirable, say for the calibration of micro-simulation models during peak demand periods. Still, TLAP surveys to acquire just peak-period highway data require significant investments that have typically totaled between $20,000 and $60,000 (cost can go significantly higher for unusually large or complex survey areas).[7]

Other TLAP Limitations

Helicopter-deployed TLAP systems require clear views to the ground, so intervening clouds can force surveys to be aborted or postponed. Trees, buildings and overpasses on the ground may occlude important highway segments (strategically-placed ground cameras can sometimes cover these gaps). Also, while TLAP systems can image in the dark, the size of coverage areas are substantially reduced if vehicle tracing is needed (~1 square mile). (Inclement weather is also a limitation; however, most planning studies stipulate that pavement be dry when datasets are collected, making this limitation moot.)

3. SURVEY DESIGN AND EXECUTION

After weighing these considerations, MAG concluded that traditional ground sensors or use of any other method could not capture the breadth of traffic flow metrics needed for a state-of-the-art bottleneck evaluation program. MAG contracted with a firm that specializes in TLAP surveys to learn what would be possible with available research funds. MAG then defined the initial study area as a strip of urban real estate approximately 1.25 miles wide, straddling 5.5 miles of I-10 just north of the Phoenix CBD, as shown in Figure 6. The 5 x 1 mile grid formed by McDowell Road to the north, Van Buren Street to the south, 24th Street to the east and 27th Avenue to the west was entirely encompassed by the survey zone limits, meaning that movements of vehicles almost anywhere in this study zone could be traced or counted.

Selection of Survey Times and Dates

This survey aimed to document typical recurring congestion during four hours of typical peak-demand flow, two during the morning and two during the evening commuter travel periods. Because non-recurring events could cause atypical congestion, coverage during two morning and two evening periods was planned (later, the more typical morning and evening periods would be selected for analysis). Several factors were considered in determining the survey time periods and dates: 1) the survey needed to be executed during a peak travel season and when fair weather could be expected; 2) adequate dawn and dusk daylight would need to be present to produce sharp aerial photographs; and 3) two-hour periods of coverage could be expected to show the development, evolution and discharge of bottleneck congestion. Accordingly, sunrise / sunset tables, historical freeway detector data and historical weather data were examined to identify the best month to survey. After deciding that the first three weeks of October would be the most likely period to optimize these three criteria, the most recent (2013) travel time data tables from the National Performance Management Research Data Set (NPMRDS) were studied in detail: I-10 bottleneck travel times (by 5-minute period) were aggregated for 6:00 to 9:00 a.m. and 3:00 to 6:00 p.m. for each weekday in that prior October. Delays were quantified and compared; six candidate days were ultimately selected that could be expected to yield high-but-typical levels of congestion. After coordinating survey logistics with the survey team, October 15th and 16th of 2014 were chosen as TLAP survey dates. Based also on the NPMRDS 2013 tables, morning and evening survey start and stop times were selected: 6:30 to 8:30 a.m. and 3:45 to 5:45 p.m. Lastly, with regard to weather, clear skies below 10,000 ft. almost always prevail in the Phoenix area; this made it unlikely that coverage would need to be postponed to the following week.

Camera Coverage Plans and Test Flights

Each of the two TLAP systems was configured with three cameras to cover an area of about 2.75 by 1.25 miles, from a planned hover altitude of about 4,400 feet above ground[8]. A 4th auxiliary camera was added to the western system to cover the Grand Avenue corridor to the northwest, a major commuter route that was also wanted for analysis. Camera coverage zones were arranged and named A through G as shown in Figure 1. The black rectangle shows the boundaries of the ~5 x 1 mile survey area. Cameras aboard two helicopters were arranged to cover this area; as labeled, the two blue dots indicate the fixed hover points for the WEST and EAST helicopters. Each helicopter would have one vertical camera covering the C and F areas shown above. Camera C would be flanked on both sides by overlapping oblique cameras (areas B and D). Likewise, Camera F would be flanked by Cameras E and G. Lastly, a fourth camera would be added to the WEST system, angled obliquely to the northwest to acquire coverage of Grand Ave to the Thomas Road intersection (area A).

After the two preliminary camera plans were completed, the contractor deployed to Phoenix to assemble systems and conduct test flights. Adjustments were made to camera aiming angles, and test photos were examined for issues that may have been missed earlier. Below, test photos are shown in Figure 2; the blue lines identify 27th Ave (vertical, far left); McDowell Road (across top); Van Buren Street (across bottom); and Central Ave, the centerline of the survey area (vertical, far right). Full-resolution image detail inside the red rectangle is shown in Figure 3.

Airspace Coordination

Because of the proximity of the survey area to Sky Harbor International Airport, charts indicated that air traffic control (ATC) permission would be required to conduct these survey flights. Accordingly, coordinations were made with the ATC managers, resulting in assurances that the proposed operations were high enough to be safe, and therefore would be permitted under most runway configurations.

Supplementary Coverage by Ground Cameras

Because travel through the I-10 tunnel between 3rd Street and 3rd Avenue could not be photographed from above, ground cameras were positioned to capture high-resolution oblique views of the traffic streams entering and exiting the tunnel. As shown in Figure 4, these images would be available later to positively establish the identities of specific vehicles while both entering and exiting the tunnel.

Survey Execution and Data Obtained

Survey operations for record were conducted on Wednesday and Thursday, October 15 and 16, 2014. Two helicopters were flown for each survey period as planned, with on-station durations of approximately 2-hours each. Start and stop times were 6:45 to 8:45 a.m. and 3:45 to 5:45 p.m. Also as planned, two ground cameras were operated concurrently at the I-10 tunnel.

Each of the nine cameras (7 airborne and two on the ground) acquired one digital photograph per second for all four of the two-hour surveys periods. This means that, altogether, about 260,000 high-resolution digital photographs were acquired during the two-day period. Furthermore, concurrently with aerial survey operations, traditional ground-sourced traffic data were either directly pulled from the ADOT Freeway Management System (FMS) database (for freeways), or collected by pneumatic tubes (for ramps). All of these data were time-stamped, for easy synchronization with the TLAP photography. Lastly, in order to watch for traffic incidents and other non-recurring congestion, real-time internet traffic reports were monitored during all four survey periods.

4. IMAGE PROCESSING AND DATA EXTRACTION

The purpose of image processing was to tightly-align 260,000 digital photographs in order to enable the efficient tracing of vehicles and extraction of vehicle counts and any other desired metric. Alignment was done using special software and the consultant's proprietary process. The basic steps were first to align all 7,200 digital photographs from each camera for each 2-hour survey period, and then to "trim" the edges like a virtual stack of playing cards. Next, digital "photo-boards" were assembled using one image from each camera acquired at the same instant. As these were produced, tight alignment was maintained from one second to the next, so that later during vehicle tracing activities, the images could be advanced while the backgrounds remained fixed. As illustrated in Figure 5, one pair of photo-boards was produced for each second of survey coverage: each western board was comprised of simultaneous images from Cameras A through D. The associated eastern board was assembled from concurrently-acquired images from Cameras E, F, and G. Figure 5 also provides a visualization that shows that as each board was created, precise alignment was maintained with all other boards. Approximately 7,200 copies of each photo-board (one per second) were created for each two-hour survey period.

Vehicle Sampling and Tracing for O-D, Path and Speed Tables

The data extraction task first focused on freeway traffic in order to demonstrate the effectiveness of the methodology before addressing arterials. Beginning with the westbound direction in the evening period, vehicles would be traced from all origins to all destinations, producing a trajectory database that would produce not just O-D tables, but travel time profiles and lane changing behavior. (Later, when completing the traces of these vehicles along the arterial grid, detailed route information would also be contained in the database.) As a lower priority or on an as-needed basis, other metrics were also left for later -- ramp or mainline volumes, intersection turning movement counts, queue lengths, or freeway traffic densities & LOS, all of these potentially profiled for the duration of each survey period.

Setting up for a vehicle tracing order starts with defining the survey boundaries beyond which vehicles would not be traced, and then coding all significant external and internal origins and destinations. Then the sampling strategy must be decided: hypothetical "assignment lines" (AL's) need to be drawn across active travel lanes to define exactly where vehicles will be chosen for tracing. There are three basic ways to place AL's: 1) co-locate one AL with each origin, so vehicles only need to be traced forward (most common strategy); 2) co-locate AL's with destinations, so vehicles only need to be traced backward (to origins); or 3) place AL's in mid-segment locations so vehicles must be traced both backward to origins and forward to destinations ("select link" analysis). Survey objectives sometimes dictate combinations of these strategies; however, care must be taken later to properly balance results using volumes prior to aggregating into final O-D tables.

As shown in Figure 6, the designated analysis zone featured one five-mile freeway segment (I-10); one freeway/freeway interchange at each end; a half-mile tunnel in the center (with no out-of-sight ramps); and one freeway/arterial diamond interchange on each side of the tunnel. Six origins (yellow boxes) and six destinations (blue boxes) were defined in each direction. With regard to the sampling plan, a hybrid of the three selection strategies was adopted: assignment lines were drawn across the eastbound and westbound travel lanes on the ingress sides of the tunnel; this "select link" strategy would assure that only vehicles that could first be passed successfully through the tunnel would be traced forward and backward, so that labor time would not be wasted tracing vehicles from distant origins or destinations, then learning that some would be "lost" inside the tunnel. Because this time-saving strategy would not capture users who did not travel through the tunnels, AL's were also drawn across the two exit ramps (eastbound and westbound) upstream of the tunnel, and across the two entrance ramps downstream of the tunnel. Therefore, with these six assignment lines, all combinations of O's and D's through the survey zone would be sampled.

Sampling Rates and Work Flow Breakdown

While the industry is striving to improve automated vehicle tracing tools, MAG's contractor reported that it had not yet found any such tool that could achieve satisfactory accuracy rates. Accordingly, vehicle tracing would need to be a manual process, constrained by a labor budget. A tool was needed to decide what sampling rate for each AL would optimize confidence levels without exceeding the overall labor budget. From experience, the contractor knew that labor hours could be estimated as 4 times the cumulative travel time of all vehicles traced; and that cumulative travel time could be projected for each AL using the volume, sampling rate, and expected speed and tracing distance of the average vehicle. These factors were assembled into **Table 1,** with a cost-efficient goal set at 95% confidence level with 10% margin of error, the sample rate of each AL by time period can be determined. Then the sampling rate for each AL could be further adjusted to optimize MOE within the direct labor (DL) budget.

Once optimized, **Table 1** listed how many samples would be needed for each 15-minute period for each AL. (Note that that the first and last 15-minute sub-periods of each 2-hour flight were reserved to allow completion of traces that began or ended during other periods.)

Vehicle Tracing Procedures and Output Database Tables

Vehicle tracing for the two tunnel assignment lines started with using the photo sets from the ground cameras to select vehicles as they entered the tunnel; and then re-identify them at the tunnel exits. (In order to avoid various types of sampling bias, vehicles from different lanes and of different classification types were chosen across all lanes, based on the flow rate of each lane and the sampling frequency from **Table 1**.) Using synchronized time-stamps, all vehicles successfully passed through the tunnel were then identified in the TLAP photo-boards. Tracing was then done both upstream and downstream to find origins and destinations. For the four assignment lines that did not involve the tunnel, vehicle selection involved simply choosing vehicles based on the appropriate sampling rate from **Table 1,** and then tracing them forward to their destinations (for the on-ramp AL's), or backward to their origins (for the exit-ramp AL's).

As each vehicle was traced, the time-of-day (to the second) that it crossed its origin and destination lines were recorded into the origin / destination / travel time database; the number of lane changes en route were also documented (see **Table 2** below).

5. PRESENTATION OF THE FINDINGS

O-D percentage, travel time by O-D pair, and lane change frequency are the outputs derived to date from the tracing database. Sample graphics summarizing various aspects of these outputs are presented below.

Based on the westbound I-10 tracings, O-D "arc" diagrams at 4:00-4:15 p.m. and 5:00-5:15 p.m. are presented in **Figure 7**. The thickness of each colored arc represents the volume of a specific origin-destination pair; and each band around the periphery represents those origins and destinations. This figure illustrates how O-D patterns in the study area varied one hour apart. **Figure 8** shows how the travel time measurements of the major freeway-to-freeway O-D pairs changed from the early congestion stage to the peak congestion condition. From 4:00 p.m. to 5:00 p.m., travel times increased while becoming more unreliable (reliability evidenced by the degree of scattering in each plot). **Figure 9** summarizes the frequency of lane changes in the study area. It was found that close to 80% of the traffic made lane change at least once; about 37% made lane changes at least three times; and almost 1% made lane changes for 8 or 9 times. It was also determined that the highest concentrations of lane changes occurred where traffic from L202 and SR51 merged with I-10.

6. CONCLUSION

Vehicle trajectory data provides rich vehicle travel behavior information such as its origin-destination, path choice, lane change, and travel time. Despite the growing interest of such data, it has always been challenging to collect vehicle trajectory data from field. In this paper, a new vehicle trajectory data collection effort based on TLAP survey is introduced and discussed in different aspects of survey planning, survey execution, data processing, and data analysis. As expectations increase for the utility of well-calibrated micro-simulation models, this study addresses an emerging need to acquire ever more granular and accurate sets of vehicle trajectory data. It describes how high granularity traffic flow metrics have been extracted from second-by-second archives of time-lapse aerial photography, for movement along an urban freeway and (soon) the parallel arterial routes. In this manner, a foundation for advanced micro-simulation modeling and bottleneck analysis has been produced. As an important component of MAG's bottleneck study program, the results obtained from this effort is invaluable while addressing many planning and operational issues associated with severely congested areas. This paper demonstrates a successful example of obtaining vehicle trajectory data from a comprehensive bottleneck area to better understand its severe congestion problems.

The era of big data is arriving, and it suggests that perhaps someday a data source will exist that will allow researchers, planners and designers to submit a request and receive an archive of vehicle trajectories in any specified study area, recorded at the highest levels of granularity: where did every active vehicle on a highway network come from, where did it go, and what route did it take? What delays did it encounter, where, and what were the causes of those delays? Until then, extracting metrics today from wide-area time-lapse aerial photography can give us some of those benefits.

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[6] A conclusion of one of the authors, Mr. Jordan, who between 2011 to 2015 has been unable to locate a vendor of a non-classified auto-tracing tool that can provide satisfactory accuracy rates using 1 hertz TLAP imagery over wide areas.

[7] Skycomp has performed 64 TLAP surveys since inception of the service in 2011; virtually all have been for planning studies of peak-demand morning, midday or evening travel periods.

[8] In Phoenix, 4,400' above ground level corresponds to 5,500' above sea level. This is the highest altitude that the preferred helicopter model (R-44) can reliably sustain a fixed-altitude stationary hover (given that air density decreases with altitude).

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LIST OF TABLES

TABLE 1: Sampling Rate and Work Volume Estimation Worksheet for Westbound AL's

	PM			max dist	avg dist		avg	15-min			travel	trace		Conf. Level	Margin of Error - MOE (%)
AL	Start	End	Site (WB)	to trace	to trace	Speed	trav time	vol	freq.	samples	time (min)	time (min)	DL (hr)		
1	3:45	4:00	Tunnel	3.7	2.6	22	7.0	1691	8%	0	7.0	27.8	0		
1	4:00	4:15	Tunnel	3.7	2.6	21	7.5	1705	8%	136	7.5	30.1	68	95%	8.1
1	4:15	4:30	Tunnel	3.7	2.6	18	8.6	1485	8%	119	8.6	34.3	68	95%	8.6
1	4:30	4:45	Tunnel	3.7	2.6	12	13.1	1273	8%	102	13.1	52.3	89	95%	9.3
1	4:45	5:00	Tunnel	3.7	2.6	8	19.4	1009	8%	81	19.4	77.7	105	95%	10.5
1	5:00	5:15	Tunnel	3.7	2.6	10	15.4	1206	8%	96	15.4	61.5	99	95%	9.6
1	5:15	5:30	Tunnel	3.7	2.6	14	11.0	1229	8%	98	11.0	44.1	72	95%	9.5
1	5:30	5:45	Tunnel	3.7	2.6	10	15.0	1147	8%	0	15.0	60.2	0		
2	3:45	4:00	off ramp 7th st	1.2	0.8	22	2.3	340	14%	0	2.3	9.0	0		
2	4:00	4:15	off ramp 7th st	1.2	0.8	21	2.4	341	14%	48	2.4	9.8	8	95%	13.1
2	4:15	4:30	off ramp 7th st	1.2	0.8	18	2.8	362	14%	51	2.8	11.1	9	95%	12.7
2	4:30	4:45	off ramp 7th st	1.2	0.8	12	4.2	359	14%	50	4.2	17.0	14	95%	12.7
2	4:45	5:00	off ramp 7th st	1.2	0.8	8	6.3	388	14%	54	6.3	25.2	23	95%	12.5
2	5:00	5:15	off ramp 7th st	1.2	0.8	10	5.0	378	14%	53	5.0	19.9	18	95%	12.5
2	5:15	5:30	off ramp 7th st	1.2	0.8	14	3.6	369	14%	52	3.6	14.3	12	95%	12.5
2	5:30	5:45	off ramp 7th st	1.2	0.8	10	4.9	398	14%	0	4.9	19.5	0		
3	3:45	4:00	on ramp 7th ave	0.9	0.6	22	1.7	305	14%	0	1.7	6.8	0	95%	
3	4:00	4:15	on ramp 7th ave	0.9	0.6	21	1.8	322	14%	45	1.8	7.3	5	95%	13.6
3	4:15	4:30	on ramp 7th ave	0.9	0.6	18	2.1	352	14%	49	2.1	8.3	7	95%	13.0
3	4:30	4:45	on ramp 7th ave	0.9	0.6	12	3.2	337	14%	47	3.2	12.7	10	95%	13.3
3	4:45	5:00	on ramp 7th ave	0.9	0.6	8	4.7	325	14%	46	4.7	18.9	14	95%	13.3
3	5:00	5:15	on ramp 7th ave	0.9	0.6	10	3.7	335	14%	47	3.7	15.0	12	95%	13.3
3	5:15	5:30	on ramp 7th ave	0.9	0.6	14	2.7	334	14%	47	2.7	10.7	8	95%	13.3
3	5:30	5:45	on ramp 7th ave	0.9	0.6	10	3.7	321	14%	0	3.7	14.6	0		

TABLE 2: Vehicle Tracing Database Example

Folder Name	Time (entering Tunnel)	Time (exiting Tunnel)	Veh Type	Veh Color	Note	Origin	Destination	O-Time	D-Time	TT sec	TT min	Lane Change
Veh160004	16:00:04	16:01:46	PC	Red		L202	I-10	155241	160547	786	13.1	+1
Veh160012	16:00:12	16:02:54	PC	White	Chrysler 300	I-10	I-10	155506	160618	672	11.2	0
Veh160018	16:00:18	16:02:36	HT	White	EGL871	I-10	I-10	155520	160543	623	10.4	0
Veh160028	16:00:28	16:03:00	PC	White	before a black sedan	I-10	I-10	155541	160632	651	10.9	0
Veh160034	16:00:34	16:04:00	LT	White	with a trailer	I-10	I-17N	155602	160827	745	12.4	-1
Veh160038	16:00:38	16:03:28	SUV	White	Chrysler	16th St	I-10	155825	160625	480	8.0	+3
Veh160051	16:00:50	16:04:39	Van	color	USA flag	I-10	I-17N	155637	160840	723	12.1	-1
Veh160054	16:00:54	16:04:26	SUV	White	with driver-side sun visor laid down, chevy	L202	I-10	155327	160844	917	15.3	+1
Veh160102	16:01:02	16:03:42	PC	White	has a roof	SR51	I-10	155543	160704	681	11.4	+3
Veh160103	16:01:03	16:03:22	PC	white	convertible	L202	I-10	155534	160709	695	11.6	+2
Veh160106	16:01:06	16:03:18	PC	Yellow		SR51	I-10	155546	160706	680	11.3	+4
Veh160114	16:01:14	16:03:12	MT	White	a white MT with red Ryder logo	I-10	I-10	155632	160616	584	9.7	0
Veh160125	16:01:25	16:03:25	SUV	white	RAV4	SR51	I-10	155622	160658	636	10.6	1,1,1,1,1
Veh160136	16:01:36	16:03:31	Van	white	ladder in top	I-10	I-10	155630	160703	633	10.6	-1,-1
Veh160145	16:01:45	16:03:31	PC	white	Camry toyota	L202	I-10	155600	160710	670	11.2	1,1,1,1,-1
Veh160152	16:01:52	16:03:31	SUV	white	highlander toyota	I-10H	19th Ave	155520	160522	602	10.0	-1,-1,-1,-1,-1
Veh160202	16:02:02	16:05:24	LT	White	a white pick-up with some red equipment in the trunk	L202	I-17N	155620	160821	721	12.0	1,-1
Veh160226	16:02:26	16:04:32	LT	white	CAT pickup	L202	I-10	155644	160808	684	11.4	1,1
Veh160232	16:02:32	16:04:40	PC	grey	Chrysler	I-10	I-17N	155702	160816	674	11.2	-1,-1,-1,+1,-1

LIST OF FIGURES

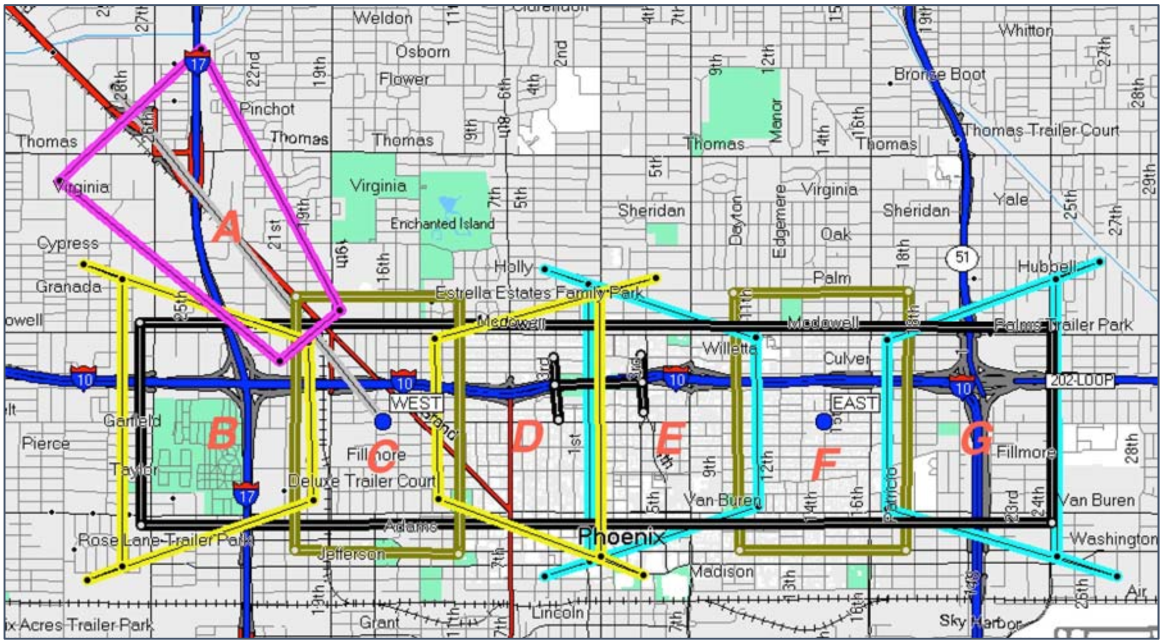

FIGURE 1: Survey zone and final camera plans

FIGURE 2: West helicopter photo set taken during a test flight on October 13th, 2015; cameras B, C, and D are shown, from left to right

FIGURE 3: Test flight crop shows full-resolution image detail of the area inside the red rectangle shown in Figure 2

FIGURE 4: Crops from ground cameras show how specific vehicles could be identified both entering (left) and leaving (right) the I-10 tunnel under Central Ave

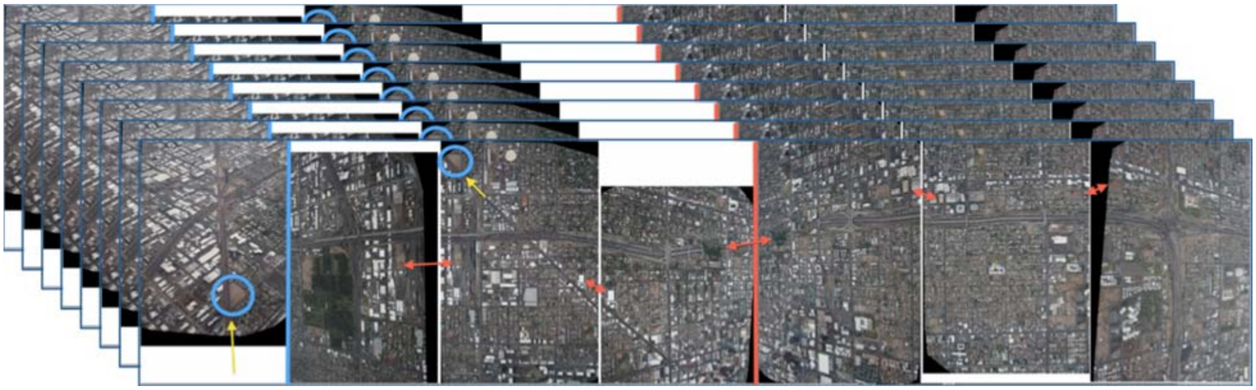

FIGURE 5: A visualization of 8 tightly-aligned, 1-second photo-boards; red arrows show overlapped regions of adjacent photos

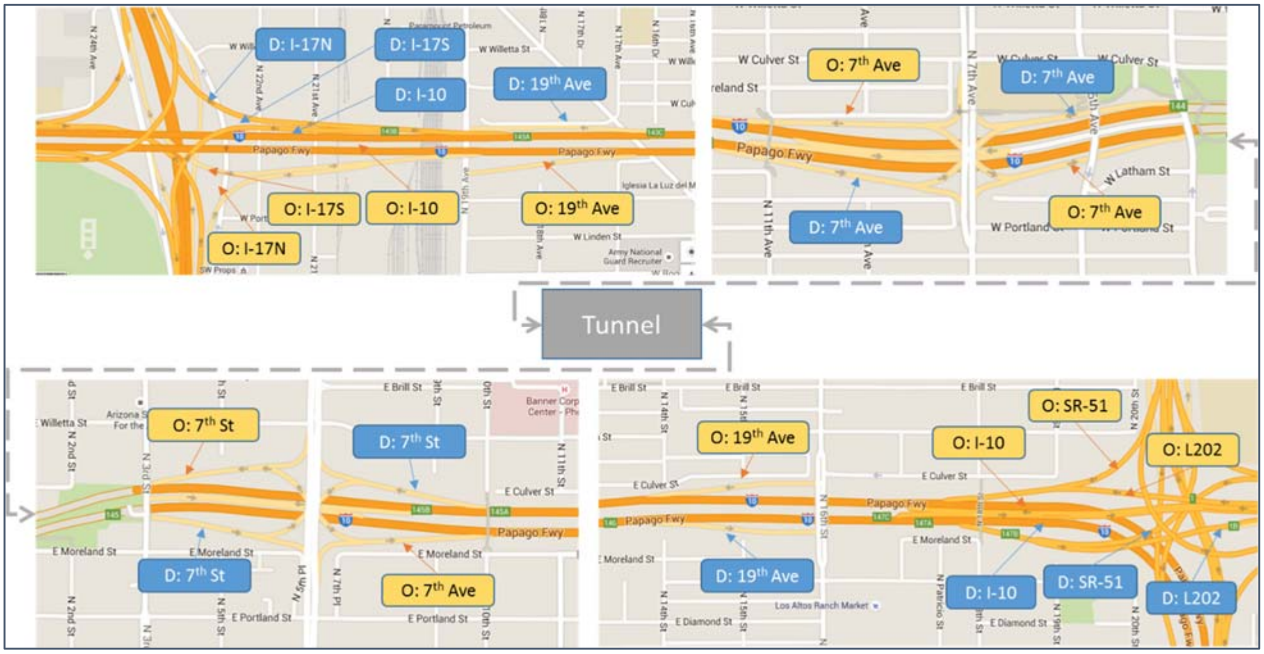

FIGURE 6: Study area with Origin and Destination definitions

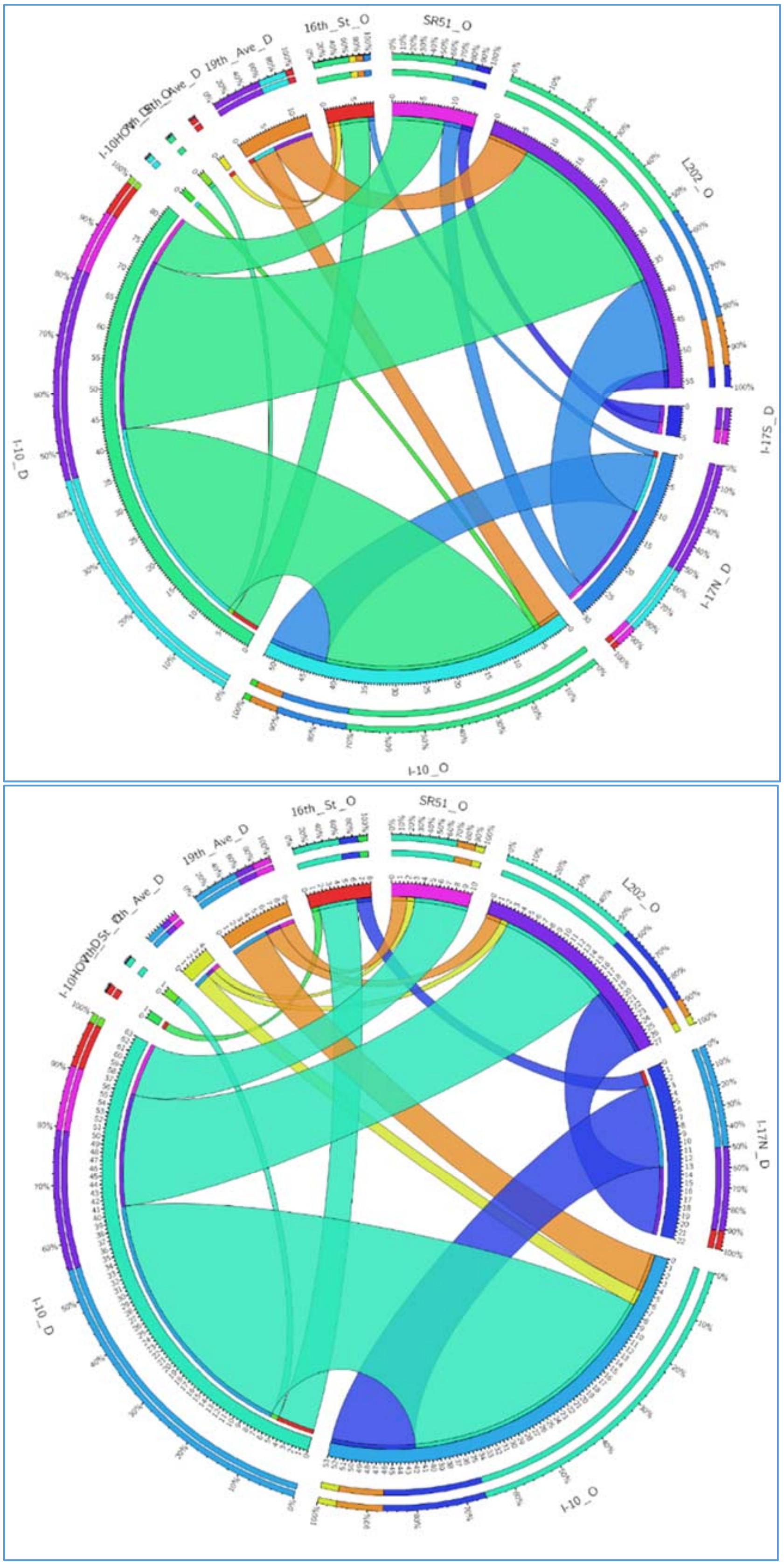

FIGURE 7: O-D "arc" diagrams from 4:00 - 4:15 p.m. (upper) and 5:00 - 5:15 p.m. (lower)

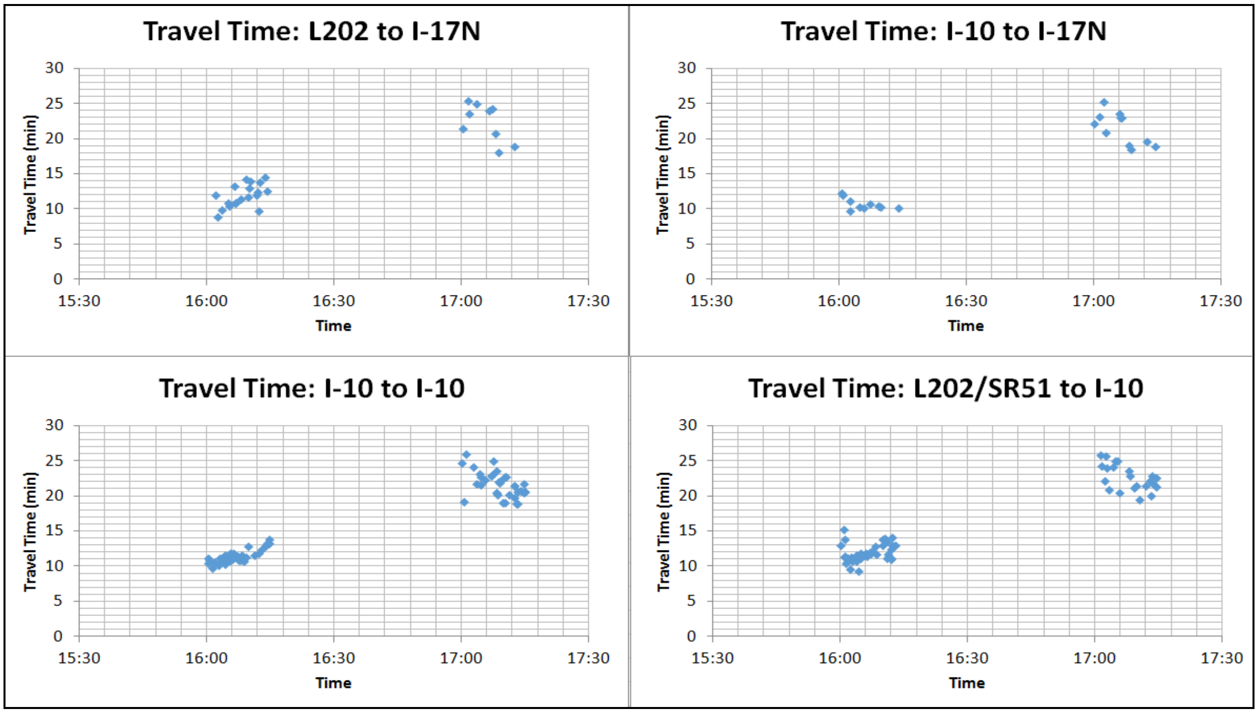

FIGURE 8: Travel time of major O-D pairs, for two 15-minute periods of westbound travel

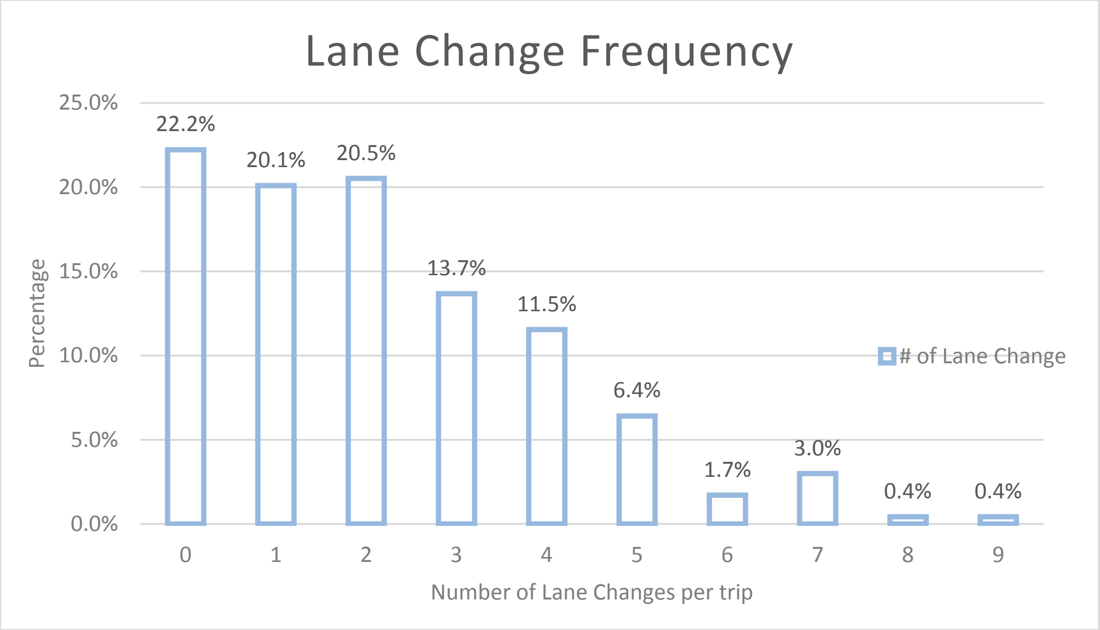

FIGURE 9: Lane change frequency in percentage
