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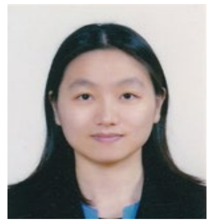
Setting the Wheels In Motion: Reimagining the future of heavy vehicles, roads and freight

INDIVIDUAL VEHICLE RECORD (IVR) SIGNATURE RE-IDENTIFICATION METHODS AND NEW TRUCK TRAVEL ATTRIBUTE RESULTS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Abstract

The FHWA has established an Individual Vehicle Record (IVR) format in the 2022 Traffic Monitoring Guide (TMG)[1] that contains a detailed 5-digit vehicle signature field for reporting unique vehicle signatures. Utilizing these loop signatures, over 100 different types of trucks can be classified. It has been shown that at nearly any traffic detection site with loops in each lane, vehicles can be re-identified. When successfully re-identification of vehicles exists, link-based information along roadways is now available. This can be done between WIM sites and at even non-WIM sites using advanced loop signature cards to obtain loop signatures. This technology is showing promise by providing WIM data to now even non-WIM sites when re-identification techniques are applied along the route. Every time a vehicle is re-identified the travel attributes between sites help show a more complete picture of travel methods along corridors being studied.

Various re-identification and IVR specific methods will be explored that detail how to quantify travel attributes at locations and along routes. Also featured will be the exploration of the re-identified vehicles attributes using IVR and signature-based data to demonstrate how both the new results and knowledge of the link-based data can now provide origin and destination (O & D) information, between site monitoring, WIM sensor tracking, truck travel characteristics, and driver safety measures.

Key Words: IVR, GVW, TMG, WIM, vehicle signatures, loop signatures, re-identification, lane gap, headway, and axle weights.

1. Introduction

The Federal Highway Administration has established in the 2022 Traffic Monitoring Guide (TMG) an Individual Vehicle Record (IVR) format that contains a detailed 5-digit vehicle signature field for reporting unique vehicle signatures. By utilizing loop signatures over 100 different types of trucks and it has been shown that at nearly any traffic detection site with loops, vehicles can be re-identified to now provide re-identification of vehicles and now link-based information along roadways. This can be done between WIM sites and at even non-WIM sites using these signatures to obtain signatures from almost any in-road loop sensor. This re-identification technology is showing promise by providing the richer WIM data to now even non-WIM sites when re-identification techniques are applied to the WIM datasets. Every time a vehicle is re-identified the travel attributes between sites help show a more complete picture of travel methods along corridors being studied.

Various re-identification methods will be explored that detail how to utilize IVR data for an improved knowledge of traffic patterns. Also featured will be the exploration of the re-identified vehicles attributes and how new results and knowledge of the link-based data are now possible.

2. Background Research

An approximate 200 square mile area was studied in Southern California which included 7 directional WIM sites and 10 directional volume traffic data collection sites. The results from this and other loop signature tests provide signature match rates, the detailed vehicle attributes that IVR data provide, and then how the resulting analysis are provided in the following:

A) by site, direction, and lane WIM calibration and sensor monitoring,
B) by site, route, or through corridor vehicle driving distances and actual travel times,
C) unique travel by vehicle commodities - now known with 100+ truck types,
D) truck vehicle and even driver origin and destination information,
E) vehicle actual travel times and average link speeds and
F) other attributes such as vehicle to vehicle in the same lane gap distances.

To ensure the test results were valid and the conclusions were accurate for all 17 monitoring locations a license plate re-identification process was completed. For all 17 locations in Southern California as ground truth for this test, the proof positive results were verified. Vehicle attributes could be independently authenticated for actual re-identification rates using matched license plate results and then different re-identification methods were deployed including using signatures alone, signatures and axle spacing and thirdly re-identification using signatures, axle spacing and axle weights.

Figure 1: Southern California, USA sites studied for loop signature re-identification research through the FHWA sponsored Small Business Innovation Research (SBIR) Phase 2 project.[2]

Source: CLR Analytics Inc. FHWA SBIR Program

The findings from these extensive field test conducted by CLR Analytics Inc. will be provided with field collected results to help guide others when they employ IVR and vehicle signatures. These will include how to track WIM sensor calibration between WIM sites and how to know these values for non-WIM sites by using the re-identified vehicles, weights, and spacings to reidentify vehicles. These results show how to know if WIM sites are properly registering vehicle weights for area wide monitoring. The results highlight how predictive measures of unique vehicle types can be known with different travel corridor origin and destination travel patterns to clearly understand area wide travel characteristics across the network. From a truck and driver safety aspect, the truck travel times and by vehicle gap distances along with distances traveled can be measured to help ensure truck driver compliance with maximum hours per driver daily limits.

3. Validation Methodology

Figures 1a - 1c show actual vehicle signatures from three vehicles where loop signature waveforms were obtained at two different locations utilizing two different loop shapes and different loop signatures. These signature curves are generated from each loop as a vehicle pass over the loop. The unique attributes of each vehicle are picked up by the loop induced inductance that measures inductance field changes. Loop signatures are normalized to account for the vehicle speed and loop field strength that is unique to each loop as installed and operated in the road. The overlap and correlation of the spectrums are clearly shown for each vehicle. This shows loop signatures from two different sites which demonstrates how well and repeatable a vehicle loop signature is no matter how large the distance is between locations (in this case they are over 30 miles apart).

Figures 1a through 1c: **iSINC WIM and I-Loop Duo Inductive Vehicle Signature Data Comparison**[2]

Figure 1a (part 1 with truck image and part 2 loop signature waveforms)

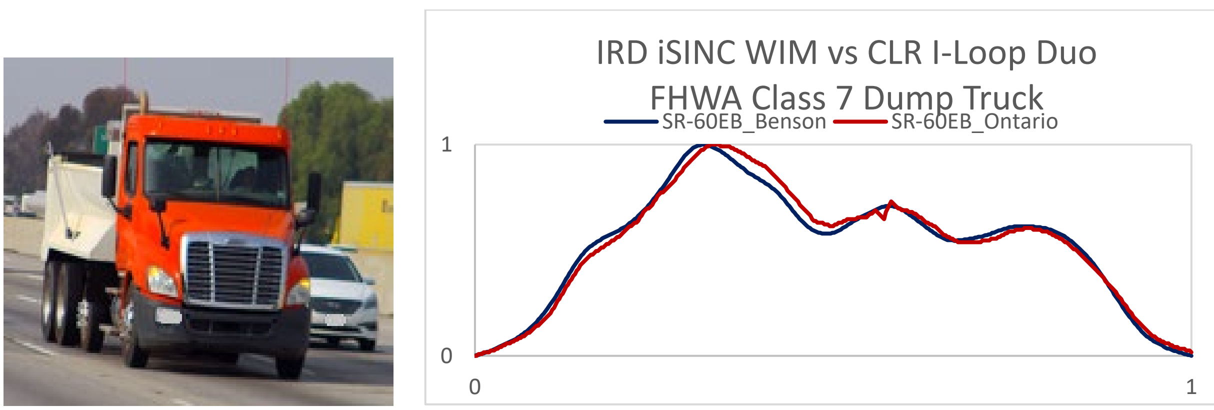


Figure 1b (part 1 with truck image and loop signature waveforms)

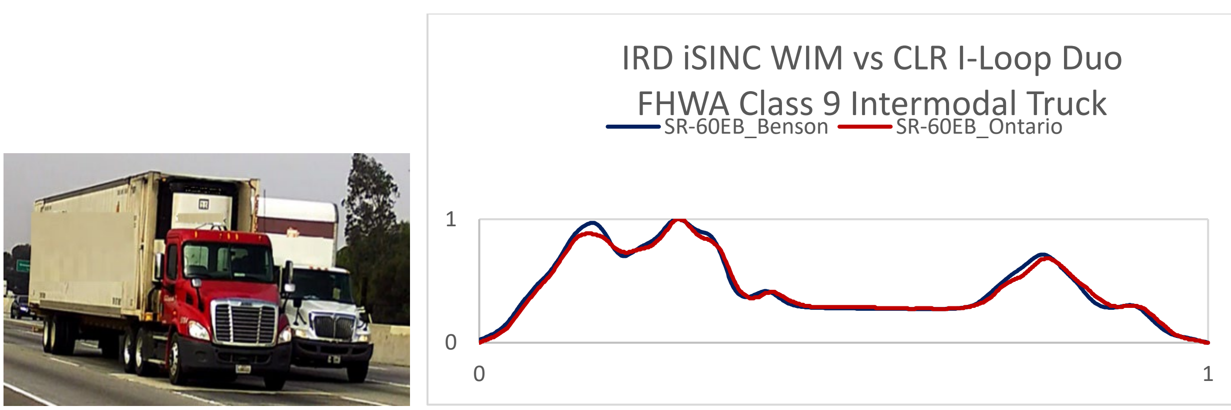
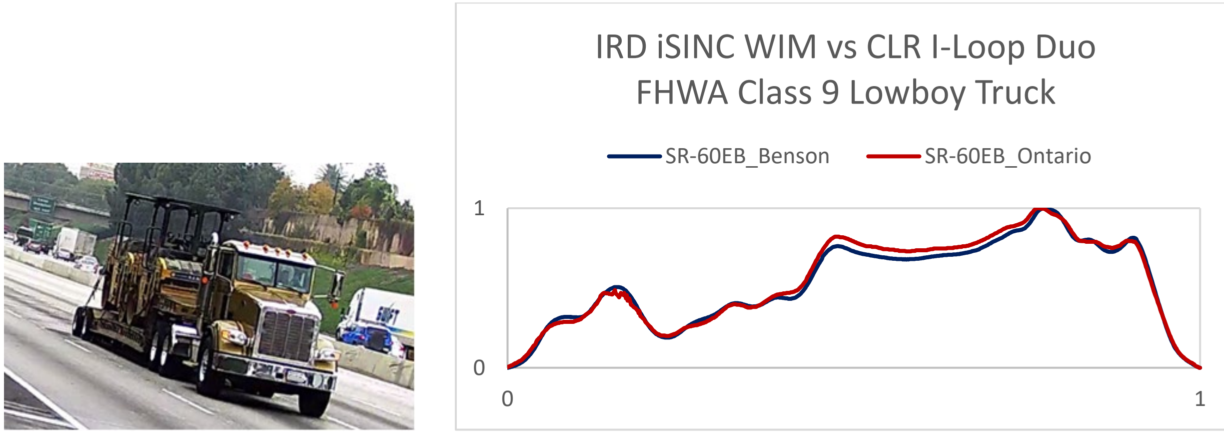


Figure 1c (part 1 with truck image and loop signature waveforms)



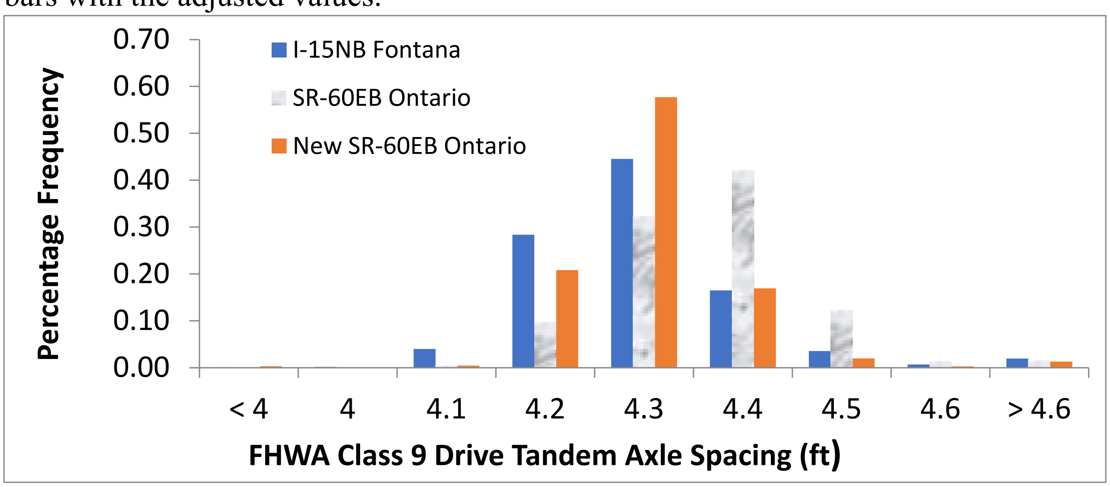
Source – CLR Analytics Inc. FHWA SBIR Program

The first SBIR phase 1 work used two individual video recorders where the full vehicle view and the license plate view were used for proof positive vehicle ground truthing. See figures 1a through 1c for three of these vehicles shown here as an illustration of the signature re-identification capabilities. Then in the FHWA SBIR phase 2 at various locations over the 200+ square mile (322 square kilometer) study area, verification of the license plate results were checked between locations. This provided a proof positive of the same license plate at one location and then when found at the next location verification was complete. Vehicle loop signatures then were analyzed and the system to match the results was compared with the license plate proof positive results.

4. Results

A) By site, direction and lane WIM calibration and sensor monitoring,

Figure 1: Two California WIM sites showing before adjustment in marbled gray bars and orange bars with the adjusted values.[2]

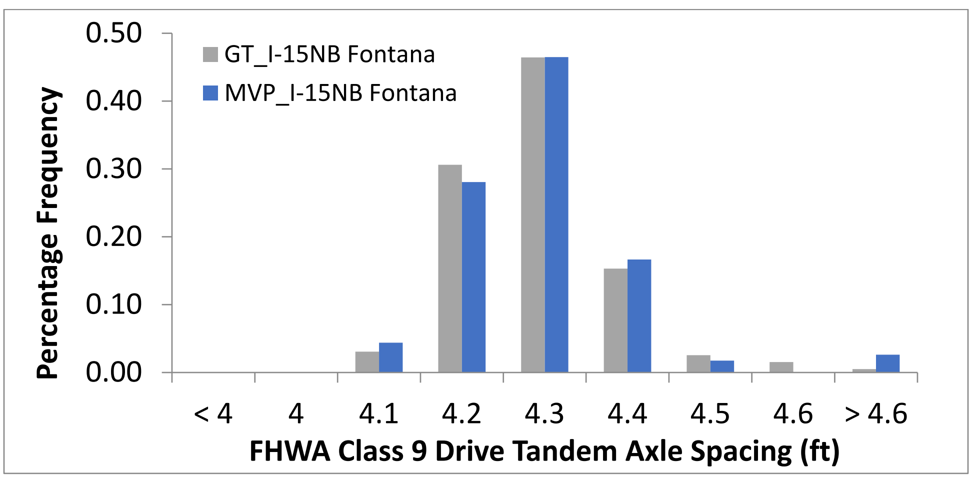


Source – CLR Analytics Inc. FHWA SBIR Program

A location in Southern CA shows the tandem axle spacing for 200 vehicles and how the site (on state route 60 east bound) showed higher than expected tandem axle spacing distances. By using the Interstate 15 locations, adjustments to the spacings were made to fix the known issue (spacing of axles were not correctly being measured in the one lane) with the tandem axle spacings between WIM sites. By re-identifying 200 plus trucks utilizing vehicle signature data the differences in measurements were detected and corrective measures were applied that fixed the state route 60 east bound location axle spacings so its values are properly measuring - shown with the orange bars in figure 1.

In figure 2, a WIM on Interstate Route 15 show accurate ground truth (GT) spacing results from tandem spacings (calibrated WIM spacing) as compared to the tandem spacing lengths obtained from loop signature vehicle class results. The tandem axle spacings of trucks as classified and measured by the WIM (GT) vs. what the class and determination of the tandems are from vehicle signatures (designated as MVP in the figure) are shown for the site on I-15 in figure 2. As an example of success, the correlation shows very similar results. Since loop signatures work to properly identifying vehicles at one site this can then be used at different sites. This confirms how re-identification methods, using vehicle signature can be used to track the calibration between sites of not only axle spacing but other WIM attributes as well. The improved by vehicle class accuracy from loop signatures demonstrates how now even between sites, measurement comparisons can be made as vehicles are re-identified using vehicle loop signatures. Once re-identified, now the attributes of those vehicles can be easily shared between sites. This permits the rich data from WIM sites to be transferred to volume, speed and/or class sites as each vehicle is re-identified.

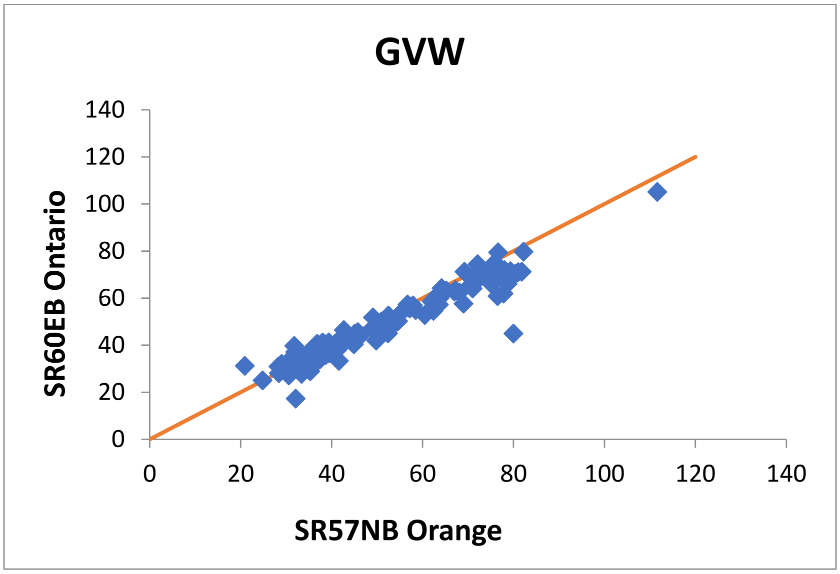
Figure 2: California Interstate 15 north bound showing accurate tandem spacing results from ground truth and loop signature-based class results.[2]



Source – CLR Analytics Inc. FHWA SBIR Program

Utilizing two WIM locations, figure 3 shows the gross vehicle weight (GVW) verification performed between California sites along state route 60 east bound and state route 57 north bound. In this case you can see the overall GVW between the two locations for the 330 plus trucks that were re-identified using vehicle signatures during the study period. As shown, there is a very high correlation, and this is to be expected as both locations are bending plate technology which tend to produce reliable GVW results. Because the vehicle signature match rate was so accurate, you see similar GVW results for each site compares rather well as a check of GVW validation method.

Figure 3: California WIM sites checked using gross vehicle weight on state route 60 east bound (Ontario) as compared to state route 57 north bound (Orange).[2]

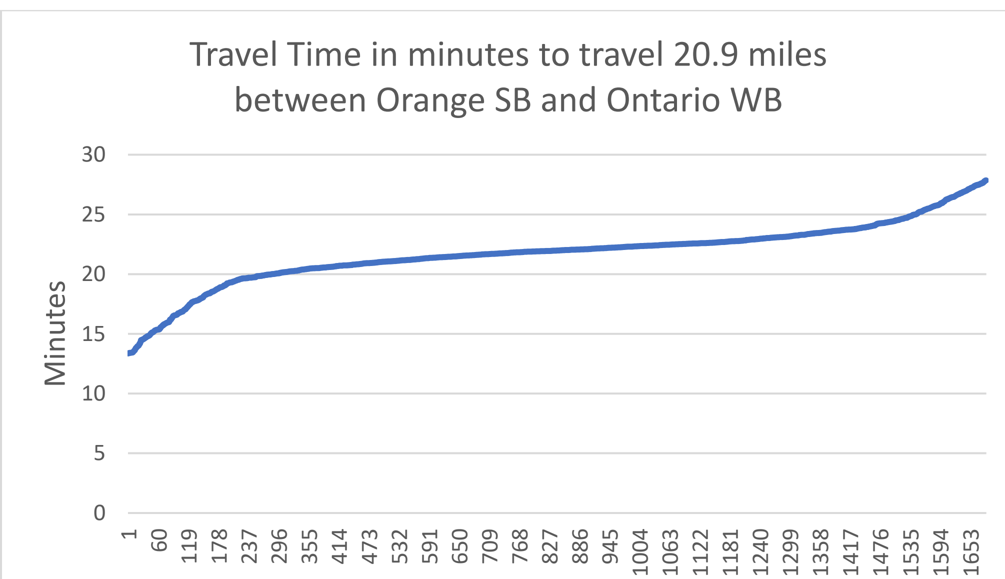


Source: CLR Analytics Inc. FHWA SBIR Program (GVW in kips=1,000 lbs.)

B) By site, route or through corridor vehicle driving distances and actual travel times,

Using over 1,680 re-identified vehicles between two vehicle signature sites (State Route 60 [Orange WB] to State Route 57 [Ontario SB]) the actual travel time range is known between these two sites. The lowest travel time was 13.4 minutes for the 20.9 miles (33.6 km). The largest travel time was 27.8 minutes for the 20.9 miles (33.6km). Figure 4 shows all of the values recorded so the dynamic range and extremes can be studied.

Figure 4: California measured travel times between State Route 60 east bound (Ontario) to State Route 57 north bound (Orange).



Source: Steven Jessberger

C) Unique travel by vehicle commodities are now known with 100+ truck types.

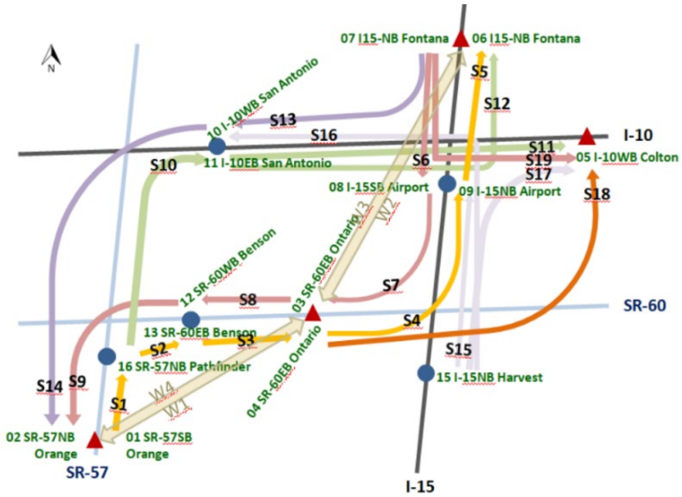
For any location utilizing loop signatures the unique travel by vehicle commodities are now known for over 100+ different truck types so the numbers and travel patterns are available for the following types of trucks: logging trucks, refrigerated trucks, intermodal vehicles, tanker trucks, box trucks, low boys, recreational vehicles, buses, vehicles pulling trailers and so on with along roadway data available from location to location. With IVR research across the United States there now are over 8 states utilizing and collecting detailed loop signature data. As more sites are added to the loop signature list, more is known about the unique vehicles that traverse roadways. The library of vehicles with the correct signature and 5-digit code as detailed in the FHWA 2022 Traffic Monitoring Guide (TMG) IVR format provides additional insights of the local travel patterns with over 100+ unique types of vehicles that can now be classified from one loop in each traffic detection the lane. The classification library is expected to also include magnetometer signatures and will include data from every state in the United States of America at some point.

D) Truck vehicle and driver origin and destination information,

Part of the FHWA SBIR research on re-identification of vehicles studied the ability to provide vehicle origin and destination over a large test area. For the FHWA SBIR phase 2 project the California District 8 provided access to 7 WIM sites and 10 dual loop volume sites across the area shown in Figure 1 (mentioned earlier). Two cameras were placed at each location to obtain license plate results. Manual review of video from each location provided proof positive of the same vehicle traversing each location when the license plates were manually read from the recorded videos. At the same time loop signatures were being recorded at each of the 17 locations. Ground truth license plate results were then compared to the re-identification results between sites with signature matching to determine if vehicles could be truly tracked into and around a large corridor. Checking between WIM sites was designated as a W and a number (see figure 5) and then between loop only locations a S and number. Figure 5 details all of the combinations studied in the SBIR research. Table 2 lists the site to site being checked with a section ID and the results showing the re-identification. For Table 2 the CV means the common vehicle obtained from the ground-truth results, which means a vehicle crossed both upstream and downstream stations. In Table 2 the matched vehicle pairs (MVP) mean the re-identified vehicles were generated by the vehicle reidentification algorithm.

For example, there are say 1,000 and 1,200 vehicles (respectively) observed (human ground truth matched) at the downstream and upstream stations, but the number of CVs is only 200 pairs. However, the re-identification method will try to match all 1,000 and 1,200 vehicles obtained at the downstream station and thus the number of MVPs can be smaller, equal to, or greater than the CVs. To help in understanding the 3 different types of outcomes they are detailed. The pairs may be less due to vehicles leaving the travel stream and thus they won't be re-identified again. The pairs may be the same as the travel stream remained constant and very few vehicles left or entered the traffic stream. This also would mean the matching using signatures produced likely accurate matches. The matched pairs may be more due to where the system thinks it is a matched pair and incorrectly sees some of the 1,000 vehicles as matched when these may not be correct matches. From the upstream site the system might match 1,195 vehicles to the downstream site to the previous site and thus it would have a higher match rate.

Figure 5: map view of the traffic sites studied and the different WIM to WIM and site to site combinations listed.[2]



Source: CLR Analytics Inc. FHWA SBIR Program

Between each site, the common vehicle (CV) rates were determined and are listed in table 2. Also listed in table 2 are the matched vehicle pairs that were found from the inductive signature curves being matched between traffic site locations. The higher the match rates, the better able agencies will know more information along route segments (links). High rates of matching will also improve the implied results of WIM data being applied between sites (either WIM to WIM for calibration and sensor health or from WIM to non-WIM for implied results).

Table 2 of Southern California, USA sites studied for loop signature re-identification with different site to site combinations of vehicle matching rates listed (W1 through W4 and S1 through S19).[2]

Section ID	# of Trucks	# of valid CVs	# of MVPs	CV %	MVP %
W1	5,334	1,024	888	19.2%	86.7%
W2	2,036	282	204	13.9%	72.3%
W3	4,994	280	331	5.6%	118.2%
W4	3,167	965	959	30.5%	99.4%
S1	3,815	3,536	2,562	92.7%	72.5%
S2	5,565	1,329	1,621	23.9%	122.0%
S3	5,334	4,085	3,723	76.6%	91.1%
S4	1,404	415	638	29.6%	153.7%
S5	2,030	900	924	44.3%	102.7%
S6	2,002	961	1,041	48.0%	108.3%
S7	4,994	461	908	9.2%	197.0%
S8	5,121	3,744	3,101	73.1%	82.8%
S9	3,167	1,246	1,395	39.3%	112.0%
S10	4,148	633	1,184	15.3%	187.0%
S11	3,766	1,367	1,544	36.3%	112.9%
S12	2,036	185	653	9.1%	353.0%
S13	3,838	134	687	3.5%	512.7%
S14	3,167	451	979	14.2%	217.1%
S15	1,404	449	616	32.0%	137.2%
S16	3,838	51	731	1.3%	1433.3%
S17	3,766	188	731	5.0%	388.8%
S18	3,766	340	1,123	9.0%	330.3%
S19	3,766	169	716	4.5%	423.7%

Source: CLR Analytics Inc. FHWA SBIR Program

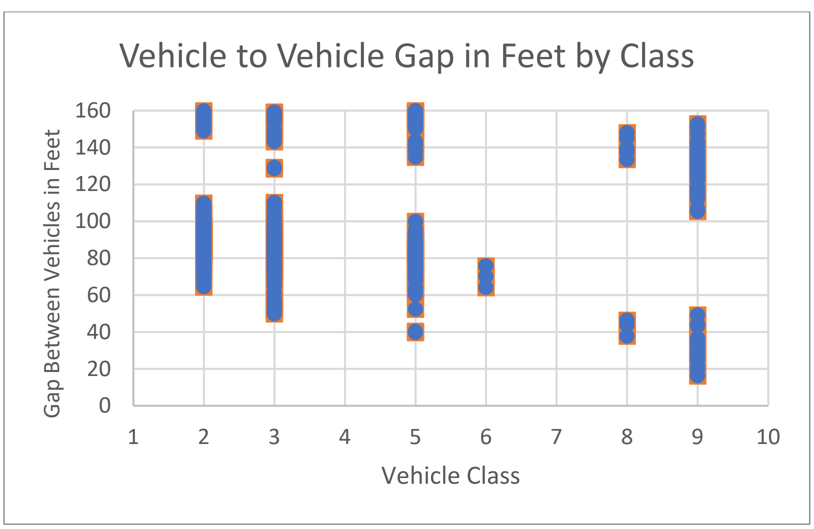
E) Vehicle actual travel times and average link speeds.

Utilizing item B above in figure 4 the average travel speeds between sites can also be calculated with re-identified vehicles. The lowest travel time (fastest speeds) was 13.4 minutes from figure 4 for the 20.9 mile (33.6 km) distance between sites. This result yields an average travel speed for the fastest vehicle of 93 mph (150 kmph)! The largest travel time was 27.8 minutes for the 20.9 miles (33.6km) distance which yields an average speed of 45 mph (72 kmph). These lower travel speed values can provide a measure of actual congestion along routes. These are actual field measured travel times, instead of relying on estimated values, which permits for calibration of other travel time models and systems.

F) Other attributes such as vehicle to vehicle in the same lane gap distances.

Researchers utilized individual vehicle record data provided by the FHWA Long Term Pavement Performance (LTPP)[3] program collected in Missouri, USA. This data has a time stamp to a 1/100th second. Researchers in the paper published through the Transportation Research Record displays how the gap between vehicles could be obtained to show how closely vehicles are following each other that are in the same lane. The calculated gap in Figure 6 was calculated from the Missouri DOT IVR data. By using the time stamp of each vehicle to the 1/100th second and then removing the total vehicle length between each vehicle time stamp the actual gap was obtained between vehicles. Together with WIM GVW data safety researchers can use of IVR results to provide additional information that normally is not obtained from traffic counting devices. In this Figure 6 you can see those vehicles with an under 160 feet (48.8 meters) following distance over a one-day period for a WIM site in Missouri, USA. This time between vehicles is an advanced byproduct of IVR data and can be made available from any IVR data collection site (portable or permanent). Safety planning along roads would greatly benefit from knowing this type of data from any traffic counting site where IVR data is stored.

Figure 6: Graph of vehicle to vehicle spacing (lane gap) in feet for Missouri IVR data.[4]



Source: Steven Jessberger (FHWA)

Future Work, Discussion and Conclusions

The FHWA led pooled fund TPF-5(520) titled "Improving Traffic Detection Through New Innovative i-LST Technology Demonstration Pilot" will research the re-identification of vehicles along corridors. The objective of this research contains loop signature technology (inductive Loop Signature Technology: i-LST) over various corridors across the United States to demonstrate application of signature data and comprehensive data collection methods.

Advanced IVR quality assurance methods employed when either the data is field collected and quality control practices for when the data is office checked need to be developed. These methods can involve individual vehicle checks or by vehicle type summary results by day of week. Quality control methods to employ on individual vehicle data include methods to make sure any measured value is accurate and that includes pavement temperatures, time stamps, axle spacings, vehicle lengths and axle and/or wheel path weights. These IVR checks performed on each vehicle or groups of vehicles are not yet widely used in the traffic industry.

Advancements in the model predictions from historical match rates between sites will help improve future match rates and work to reduce the incorrect false matches that can take place. By reducing how many signatures to try and match from, using advanced models, the "system" performance matching results should improve.

Acknowledgements

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Match Rates																	
FHWA Vehicle Class	**SR57 SB Orange Station 103**							**Total**	**I-5 SB Irvine Station 15**								**Total**
	Hour								**Hour**								
	8	**9**	**10**	**11**	**12**	**13**	**14**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
1	3	3	1	3	3	0	1	14	1	8	5	7	3	6	7	2	39
2	1247	1081	936	879	926	905	993	6967	2453	2628	2117	2268	2465	2806	3072	1007	18816
3	204	230	205	225	208	203	242	1517	458	650	522	523	516	497	539	176	3881
4	3	6	4	0	1	3	2	19	18	24	4	4	3	12	11	1	77
5	124	173	173	172	159	160	158	1119	163	241	222	222	184	207	142	44	1425
6	30	40	50	59	42	40	38	299	19	32	32	33	33	25	20	2	196
7	5	4	0	4	3	5	0	21	16	38	40	16	15	17	12	3	157
8	12	29	19	27	18	29	22	156	15	18	20	23	17	14	9	3	119
9	340	325	362	369	367	337	272	2372	124	199	214	145	169	131	141	43	1166
10	1	2	2	1	1	2	2	11	0	1	1	0	0	0	1	1	4
11	18	21	12	15	16	11	3	96	11	4	7	5	6	11	1	2	47
12	1	0	2	2	2	0	2	9	0	2	0	0	0	0	0	0	2
13	0	0	0	0	0	2	1	3	0	2	0	0	0	0	0	0	2
14	9	5	9	12	5	6	2	48	5	21	15	14	11	13	13	3	95
15	1	0	0	0	1	3	0	5	1	1	2	0	1	0	2	0	7
97*	29	30	18	39	21	29	29	195	72	115	139	139	158	144	140	57	964
99*	4	4	15	5	1	5	16	50	92	169	110	84	92	121	97	30	795
Total	2031	1953	1808	1812	1774	1740	1783	12901	3448	4153	3450	3483	3673	4004	4207	1374	27792

97*: WIM or Signature data error
99*: unable to ground-truth vehicle class and/or license plate due to occlusion