CTIP TECHBRIEF

November, 2019

Coordinated Technology Implementation Program

# Inductive Loop Signature Technology to Conduct Origin-Destination Studies on Public Lands

## Introduction

To strategically allocate resources to maintain the routes to and facilities at major attractions, it is critical for Federal Land Management Agencies (FLMAs) to understand how their transportation network is utilized by the traveling public and what facilities and roadways are most in demand by visitors. The project described in this technical brief field-tested the viability of using Inductive Loop Signature (ILS) technology for visitor usage and origin/destination data at Kenai National Wildlife Refuge (NWR) in Alaska.

Inductive loops are typically used to count traffic, trigger traffic signals to change, or to raise gates in parking lots. More recently, these systems have been modified to capture the signal strengths over time as vehicles pass over the loop to create a “signature” for each vehicle. This waveform can serve as a crude anonymous identifier of that vehicle.

When used in this way, ILS technology has the potential to help:

- Keep track of seasonal and year-round visitation at different locations;
- Identify major attractions;
- Identify routes and travel patterns, including when a trip occurs and trip travel time;
- Find bottleneck locations and time periods with traffic congestion; and
- Analyze trip purposes.

This project was conducted under the Federal Highway Administration’s (FHWA) Coordinated Technology Implementation Program (CTIP), which selects certain innovative technologies to be fielded in support of FLMAs. On behalf of the U.S. Fish and Wildlife Service (FWS), the John A. Volpe National Transportation Systems Center (Volpe Center) managed the deployment effort and issued a contract to CLR Analytics Inc. (CLR), a developer of ILS technology.

## Executive Summary

**Innovation**

*ILS technology uses the same loops commonly used for detecting vehicles to provide classification and anonymous identification. This technology makes it possible to collect origin-destination (O-D) data in relatively closed spaces such as public lands.*

**Key Results**

*The systems installed at Kenai NWR were able to provide some O-D data, but were adversely affected by the fact that most roads are gravel, and therefore drivers often did not use good lane discipline. The data collected from paved, striped roadways was much more effective.*

**Potential Impact**

*ILS technology has usefulness in providing O-D data, but it is best used in places where the roadways are paved and lanes are well defined. The system deployed at Kenai NWR did produce O-D data, but it needed to be augmented with Bluetooth identification to provide an adequately rich dataset.*

U.S. Department of Transportation

John A. Volpe National Transportation Systems Center

## How it Works

The project team deployed a traffic informatics system to collect vehicle signature data via ILS road loops and travel times and vehicle tracking via Bluetooth classic and low-energy data.

ILS technology uses road loops similar to those used to detect vehicles at traffic signals to anonymously identify vehicles. The loops are installed in pavement cuts or buried in non-paved surface areas as necessary. In this pilot, road loops were modified by CLR Analytics of Irvine, CA, to provide vehicle signatures that could be matched when detected in different locations. By installing a network of these loops throughout an FLMA, the technology can be used to understand some of the travel patterns of visitors within Federal lands.

*Figure 1: ILS installed in pavement*

The ILS network was augmented with a Bluetooth media access control (MAC) address matching module that collects and analyzes Bluetooth classic (permanent MAC address) and low-energy MAC addresses (temporary MAC address), which was used to derive Bluetooth-based travel times and assist in vehicle matching, which is necessary to obtain origin/destination information.

Given the remote nature of the Refuge, the system was also configured with online and offline modes. In locations where cellular service was present, all data were transmitted back to the central server automatically (online mode). In locations where there was not cellular service, all data were stored on a Secure Digital (SD) card and FWS staff collected the data by swapping the SD cards every two to three weeks (offline mode).

After the technology and equipment is used for this pilot, it was donated to the Alaska Department of Transportation to deploy in other locations.

## Installation

The project team selected ten sites, listed in Table 1, and shown in the map in Figure 2, in the Kenai NWR for the study.

*Table 1 - ILS Installation Sites*

| Site # | Site | Road Surface | Roadway Owner |
|---|---|---|---|
| 1 | Swanson River Road Refuge Boundary | Gravel | FWS |
| 2 | Dolly Varden Campground | Gravel | FWS |
| 3 | Swanson River Road (Industrial Traffic) | Gravel | FWS |
| 4 | Swan Lake Road | Gravel | FWS |
| 5 | Keystone Drive South West Access | Gravel | FWS |
| 6 | Keystone Drive North Lot | Gravel | FWS |
| 7 | Keystone Drive South East Access | Gravel | FWS |
| 8 | Keystone Drive Boat Ramp | Asphalt | Borough of Kenai |
| 9 | Kelly Peterson Access | Gravel | FWS |
| 10 | Upper Skilak Access 2 | Asphalt | State of Alaska |

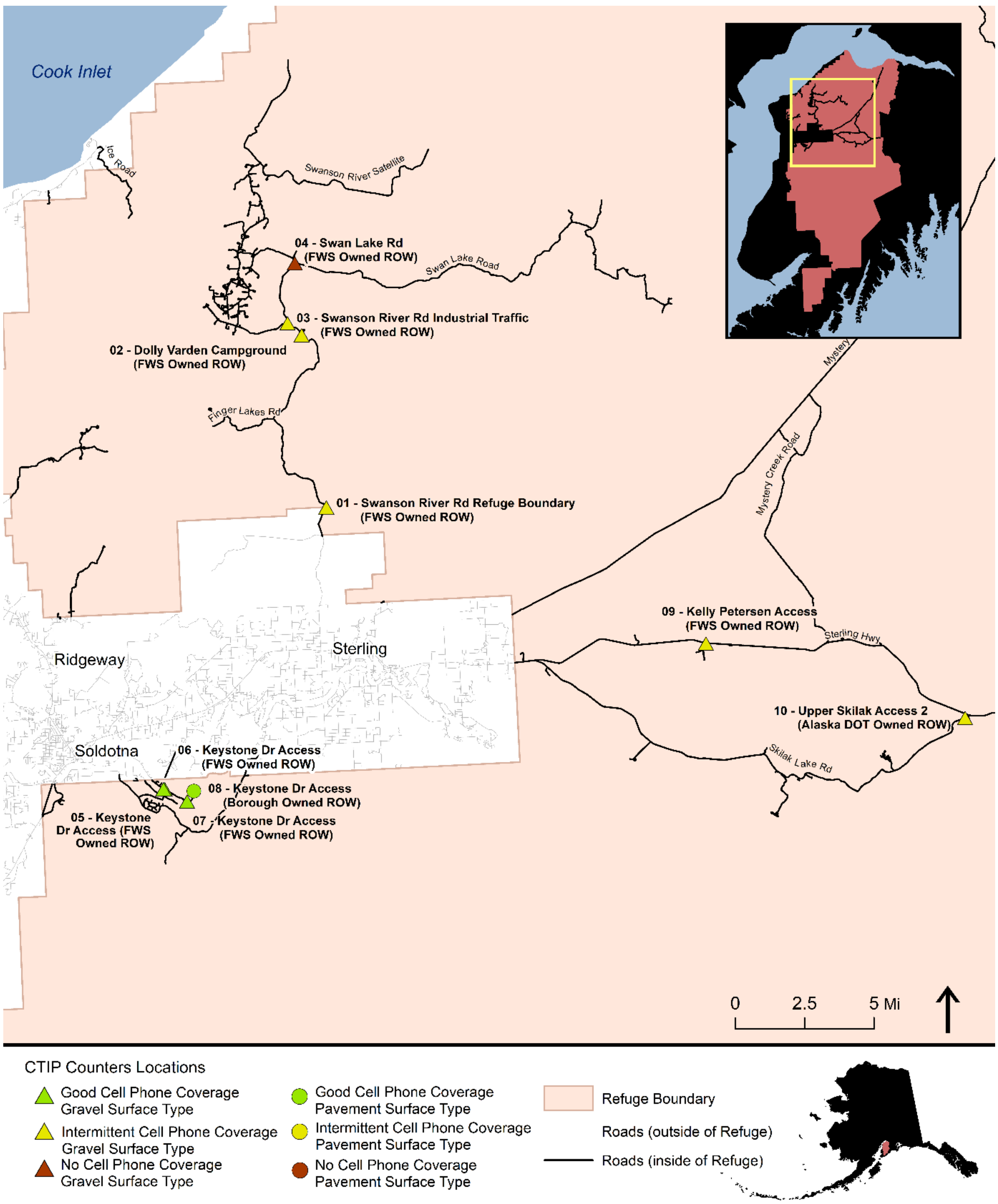


*Figure 2. Map Showing ILS Deployment Sites in Kenai NWR*

In order to acquire origin/destination data, the project team placed separate loops on the inbound and outbound lanes. A total of 20 loops were installed at the ten locations in May 2019 (with data collected through September 2019). One location on Keystone Drive was a parking area with two entry/exit points. The three-person team from Volpe, FWS, and CLR, was able to complete the installation of the system in six days.

In order to install the inductive loops in the gravel roadways, a trenching machine was rented locally, and the loops were buried with a layer of sand, then covered with gravel. Two of the roads were paved with asphalt, and loops were cut into the pavement using a radial saw that was also rented locally. Figure 3 shows installation of the loops on both types of roadways. The project team worked closely with Alaska Department of Transportation and the Bureau of Kenai as they each owned roads in which the technology was being deployed.

*Figure 3 - Installation of Inductive Loops in Gravel and Asphalt Roadways*

**System Components**

The system was composed of the following components in the field:

- A single ILS loop per lane, with either a preformed direct-burial loop (at seven sites with the gravel pavement) or a saw-cut loop (at the two sites with asphalt pavement);
- A Bluetooth dongle, which detects Bluetooth classic and low-energy devices and collects MAC addresses and broadcasts data;
- A Phoenix Traffic Counter, which collects vehicle signature data when a vehicle passes a loop;
- A system hub, which is a small Linux-based industrial computer with cellular communication capability. It collects and processes vehicle signature and Bluetooth data and stores these data locally and/or transmits the data to the central server;
- A cellular antenna (for online sites), which is an outdoor antenna mounted on top of the cabinet;
- A USB hub, which is used to connect the system hub with the traffic counter and the Bluetooth dongle;
- A 45-Watt solar panel, charge controller, and 12-volt 40 AH battery; and
- A cabinet to house the equipment.

## Project Costs

The approximate costs associated with conducting this effort are shown in Table 2 below.

*Table 2 - Cost of Deploying ILS System in Kenai NWR*

| Expense Category | Cost |
|---|---|
| **Equipment – Contractor-provided** | $34,587 |
| **Equipment – GFE** | $12,821 |
| **Labor – CLR Configuration of Components** | $11,636 |
| **Labor – CLR Data Analysis and Reporting** | $33,980 |
| **Labor – Volpe**[1] | $33,500 |
| **Travel** | $9,077 |
| ***Total*** | *$135,601* |

## Data Collection and Analysis

The project team evaluated the data collected for effectiveness and accuracy based on traffic count, vehicle classification, vehicle tracking, and origin destination information. Ground-truth video data was also collected to evaluate system performance.

The team found that the traffic flow at all sites was lower than expected due to the Swan Lake fire that started on June 5, 2019. The campsites at the Kelly Peterson Lake were reserved for firefighters and all traffic data collected at site 8 beginning July 10, 2019, were related to the vehicles used by firefighters. CLR was tasked with analyzing the data and producing the results.

Early on, the team discovered some anomalies with the gravel road loops. For some reason, perhaps due to ground instability or variations in loop depth, portions of the signatures from the gravel road loops had unexpected spikes that adversely affected efforts to match signatures captured by other loops. The loop manufacturer suggested that future installations should use more sand, and the buried loop be affixed to a wood frame to help it maintain shape and depth uniformity.

CLR developed a software update that helped compensate for the distortion and other noise generated by the gravel road loops. But there was an additional challenge that emerged as the data was further analyzed: drivers on gravel roads tend to drive toward the center when no opposing lane traffic is present. CLR was able to recognize this phenomenon due to the frequent simultaneous inbound and outbound detections.

The study period was extended to compensate for the diminished dataset. CLR included both classic and low-energy Bluetooth MAC address data collection from vehicle radios, cell phones, and other devices that may be inside passing vehicles. Not all vehicles have Bluetooth devices, and the low-energy MAC addresses are dynamic, changing every few minutes, which limits its usability in some cases. But together with the imperfect ILS data, CLR was able to produce a richer origin/destination dataset for the portion of Kenai NWR where vehicles are known to travel between recreation sites.

[1] Includes labor for project and contractor management and oversight, labor to procure and install equipment, and time to develop all project deliverables.

While CLR demonstrated that ILS technology could be used to both count and classify vehicles, it was its ability to anonymously identify vehicles so they later can be matched as part of an origin/destination study that was of key interest to both transportation and public lands agencies.

**Challenges and Lessons Learned**

*Loop installation*

The vehicle signature data quality plays a major role for reliable vehicle classification and tracking performance. The installation of saw-cut loops on the asphalt pavement is preferred to installation in gravel surfaces since vehicle signatures collected from saw-cut loops have higher quality in general.

The team found that the installed direct-burial loops under the gravel surfaces were unable to provide quality signature data. The likely causes are that the loops may move after being installed and/or loops are not installed with the uniform depth under the ground. The suggested mitigation includes: 1) closely follow the direct-burial loop installation instructions and use enough sand to encase the loop; 2) use a wood frame to hold the loop in a fixed shape and depth; and 3) use four to six turns of loops in order to generate signatures with higher magnitudes that render the waveforms more distinctive.

The installation was designed for an approximately six-month lifespan. If the installation is intended to be more permanent, additional installation requirements may need to be considered.

*Driver behavior*

The project team witnessed many instances of poor lane discipline and occasional wrong-way driving on the gravel roads and in the parking lots. To detect this behavior and thus improve the accuracy of the data, instead of installing loops side by side on entrance and exit lanes, it would have been better had we installed the loops with an offset. With this setup, wrong-way drivers would trigger each loop in its driving direction first and then the loop in the wrong-lane second, which will generate the loop activation time offset. The loop activation time offset can then be utilized to identify the wrong-way driving vehicle and generate reliable directional counts. If the clearance of the entryway is too wide for vehicles to consistently drive within the lane, the loop offset installation may not be effective. In these conditions, the team suggests adding a signpost in the middle of the entryway to indicate the proper direction of travel and promote traffic separation. Such behavior was not observed on paved roadways with a centerline.

*Reliability of cellular data communication*

The system operation and monitoring tasks can be accomplished by field personnel if no cellular connectivity is available, but it requires more resources. In this project, some sites were installed in locations without cellular signal coverage. The project team found that offline sites are more prone to experiencing problems than sites with communication for online system monitoring. Without cellular coverage, it became necessary to collect the data manually, which is not only laborious, but the process of shutting down the system, swapping out the SD cards, and restarting the system sometimes resulted in failed reboots or other mistakes which led to periods of no data collection. Therefore, it is preferred for the system to be installed at a location with cellular signal coverage to improve system reliability and to enable live status checks and frequent data downloads.

*Wildfires*
During the test period, a wildfire burned through parts of Kenai NWR. During this time, sites 1-4 were periodically closed to visitors, and site 9 (Kelly Peterson) was dedicated as a rest facility for firefighters. It also reduced visitation to other parts of the refuge during this normally busy part of the season. This condition limited the size of the dataset that could be analyzed.

*Systems calibration and testing*
It is important to allow sufficient time for system operation testing. The system test involves testing of the loops and refining detection parameters based on field observation with vehicles present. However, most sites in this pilot project had low traffic volumes, especially during the installation period. Under such conditions, it was inefficient to conduct system operation testing using the team's vehicles with limited staff available in the field. It therefore took more time to detect issues and it was difficult for the project team to identify any issue that rarely occurred and even more challenging to rectify given the distances involved.

*Hardware and software issues*
The original software was designed as an online system and the offline operation mode was a customized option developed for this project. The team found that the software related to the offline operation was not bug-free and the following two issues occurred: 1) missing data or system lockup occurred after the Kenai NWR staff picked up data, which can be solved by adding a power switch to the system; and 2) system reboot failure, which was caused by the hardware watchdog of the system hub. Both issues can be addressed in future system installments.

**Results**
*Traffic counts over time*
The project captured traffic counts over time. For example, at the oil field (Figure 4) the data shows that north bound traffic peaks between 4 and 5 AM when oil field workers go to work, and south bound traffic peaks between 5 and 6 pm when oil field workers and other visitors drive back home.

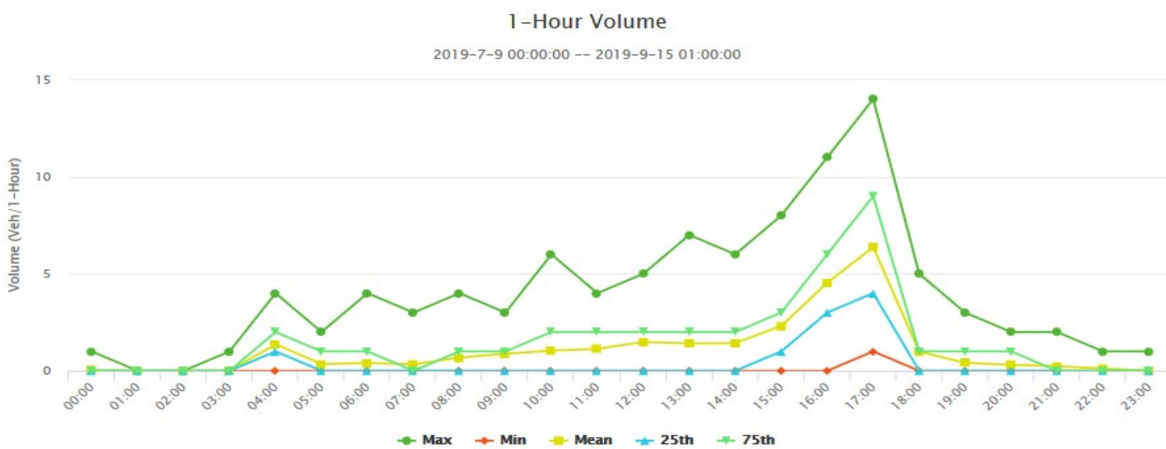


*Figure 4 - Hourly Traffic Counts at Site 3 Entering the Refuge from the Oil Field*

At a fishing pier (Figure 5), travel patterns show a seasonal peak in late July, which corresponds with salmon season. The busiest day was July 23, 2019.

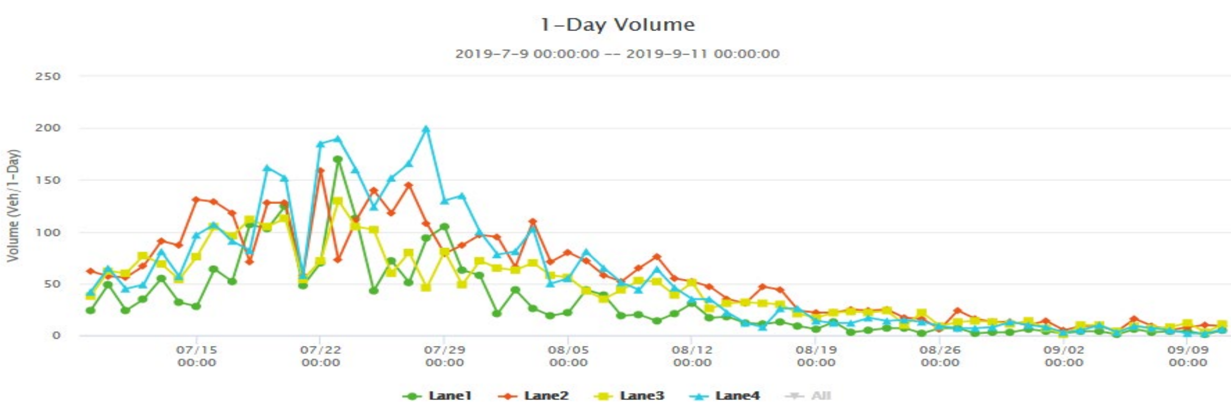


*Figure 5 - Daily Traffic Counts at Keystone Drive South (Site 5) Fishing Pier*

*Vehicle classification*

The results showed that inductive loop signature data can be used to classify vehicles. At Sites 1-3, there was a broad variety of vehicles, including single-unit trucks and vehicles pulling trailers, making these ideal for conducting the vehicle classification study. Virtually all traffic traveling to sites 2-4 pass through Site 1. Site 3 leads to a commercial oil field which is comprised largely of trucks. The Dolly Varden Campground (Site 2) has traffic which has a surprisingly similar percentage of trailered vehicles (campers) or motor homes. These percentages are shown in Table 3. (Note: Site 4 encountered several technical difficulties during the test period resulting in an incomplete dataset, so this data was not used.)

Table 3 - *Classification of Vehicles at Sites 1-3*

| Vehicle Category | Site 1 – Swanson River Road Refuge Boundary | Site 2 – Dolly Varden Campground | Site 3 – Oil Field |
|---|---|---|---|
| **Passenger Car & Pickup Truck** | 33.8% | 32.9% | 32.7% |
| **Bus & Single-unit Truck** | 57.8% | 58.2% | 56.7% |
| **Single & Multi-unity Trailer Truck** | 7.9% | 8.1% | 10.1% |
| **Unclassified** | 0.6% | 0.9% | 0.5% |
| ***Total Count*** | *2,422* | *581* | *1,378* |

*Travel times*

The route between the Kenai NWR boundary (Site 1) and the Oil Field (Site 3) was the focus for the travel time study (Figure 6). The study showed an average speed of 30 mph, with the trip taking 18.6 minutes to complete the 9.3-mile trip (orange line in Figure 6). The speeds ranged between 25 and 50 mph, with the trip time ranging between 11 and 22 minutes. The study shows there is little correlation between travel time and time of day. Note that some vehicles travel slower on the gravel road than do others and it is not possible to account for the possibility that drivers may stop along the way.

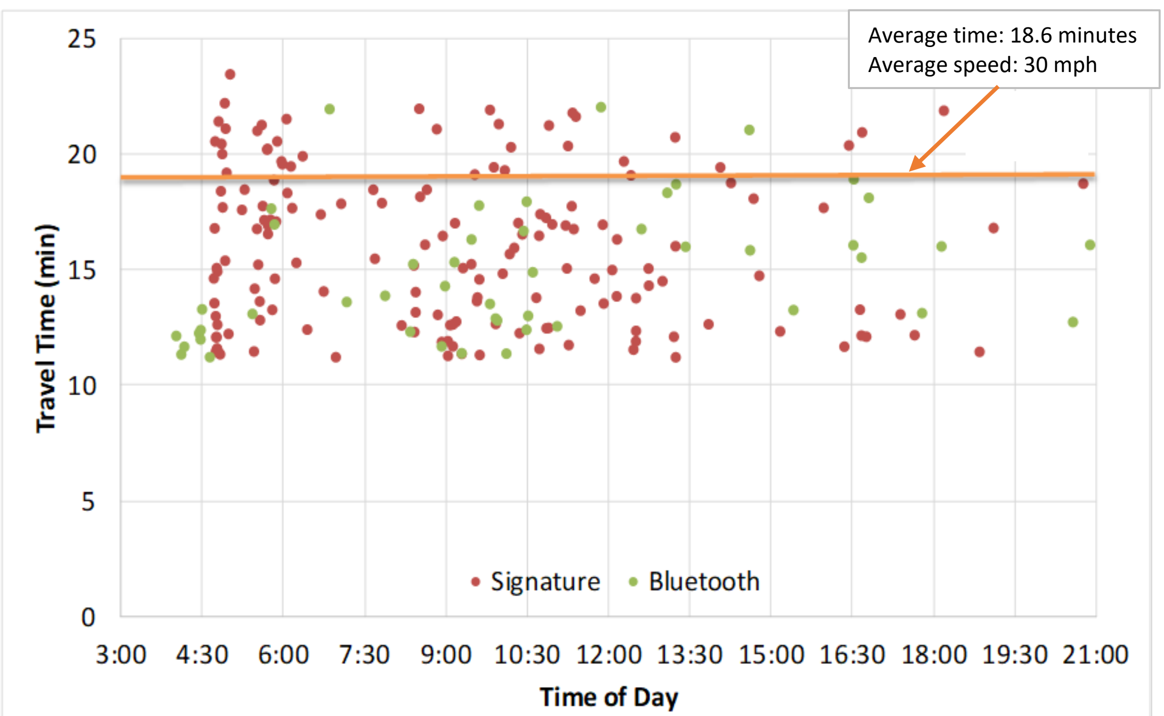


*Figure 6 -Travel Times by Time of Day*

*Origin/Destination*

CLR studied the flow of traffic between the four sites in the northern part of Kenai NWR, which are:

- Site 1: Swanson River Road (Refuge Boundary);
- Site 2: Dolly Varden Campground;
- Site 3: Swanson River Road (Industrial Traffic); and
- Site 4: Swan Lake Road.

CLR used data collected between August 9 and August 11, 2019. Due to technical problems with the equipment at Site 4 during this time, this site could not be included in this analysis. CLR used ILS technology and Bluetooth to compile the data. Unfortunately, the Bluetooth antenna at site 2 (Dolly Varden) was too close to the main road and wrongly matched vehicles that were not entering site 2, but merely passing by. That data, shaded in yellow with an asterisk in Table 4, was pared down manually using Bluetooth/ILS matches collected at Site 1.

As the data shows, the vast majority of traffic in this part of the Refuge travels between Site 1 and Site 3 (The Refuge boundary and the oil field). This is indicative of the extensive traffic that services the industrial oil facility, an amount that dwarfs the recreational traffic visiting other sites in that part of the Refuge. When a subset of the data was ground truthed using video footage, 46.1% of the data points were matched as pairs.

*Table 4 - Origin/Destination Data Totals*

| Match Type | Site 1→ Site 2 | Site 2→ Site 1 | Site 1→ Site 3 | Site 3→ Site 1 | Site 2→ Site 3 | Site 3→ Site 2 | Total |
|---|---|---|---|---|---|---|---|
| **Bluetooth only** | 122* | 151* | 127 | 143 | 45 | 63 | 651 |
| **Signature only** | 11 | 45 | 160 | 207 | 7 | 2 | 432 |
| **Signature & Bluetooth** | 35 | 61 | 210 | 263 | 10 | 9 | 588 |

## Conclusion

This pilot project demonstrated that ILS technology can be used to collect a set of comprehensive traffic data from FLMA lands where data are limited or do not exist. The data collected included traffic count, vehicle classification, vehicle tracking and O-D, and travel times, which were processed and then utilized to analyze travel patterns at the study sites.

ILS provides the potential for acquiring a low degree of anonymous vehicle identification that is sufficient for developing the datasets required for these types of studies. The data can become more extensive when augmented with Bluetooth identification, which also only provides identification for a small percentage of vehicles, but does serve to enhance the dataset.

ILS is not currently an automated technology. While CLR has developed algorithms to aid in this process, there is still extensive manual interpretation of data and “judgement calls” based on similarities of waveforms, timelines and traffic density. If anonymity in data collection were not important, there are other technologies that can accomplish these tasks with greater precision and with less human involvement. But as with any activity that involves the tracking of members of the public, the ability to collect identification data while preserving anonymity is important, and ILS provides a way to accomplish this.

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To strategically allocate resources to maintain the routes to and facilities at major attractions, it is critical for Federal Land Management Agencies (FLMAs) to understand how their transportation network is utilized by the traveling public and what facilities and roadways are most in demand by visitors. This project field-tested the viability of using Inductive Loop Signature (ILS) technology at nine sites ($~135k) for visitor usage and origin/destination data at Kenai National Wildlife Refuge (NWR) in Alaska.

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