Leveraging High Fidelity GPS 'Trajectory' Data to Identify and Understand Signal Performance Network Wide

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INTRODUCTION

The goal of every network operator is to have a perfectly functioning traffic signal network. Unfortunately, it can be a real challenge to proactively monitor and address problems quickly across the entire network, especially for many public sector operators that are not fortunate enough to have fully connected and functional systems or otherwise limitless budgets and resources to conduct the necessary performance reviews. This paper will highlight how cloud-based software, using GPS trajectory data, can be used to measure and monitor the performance of intersections and corridors. These tools can be used to identify areas in need of improvement and measure the impact of various signal management strategies. These improvements can have real benefits including significant reduction in delay, fuel use, and emissions.

METHODOLOGY

The data being used are probe trajectory data. These data are collected from connected vehicles and include individual waypoint information every few seconds. The waypoint data allow a vehicle to be traced through an intersection, where valuable insights can be extracted and aggregated to understand and improve the signal performance at an intersection (Figure 1). INRIX Signal Analytics sources data purely from high-quality, low ping frequency data providers to produce a series of signal performance measures. The metrics collected at the vehicle level are approach speed, travel time, stops, and entering and exiting heading. The data are processed through the INRIX trips engine, then aggregated at the intersection level to provide scalable metrics at every intersection.

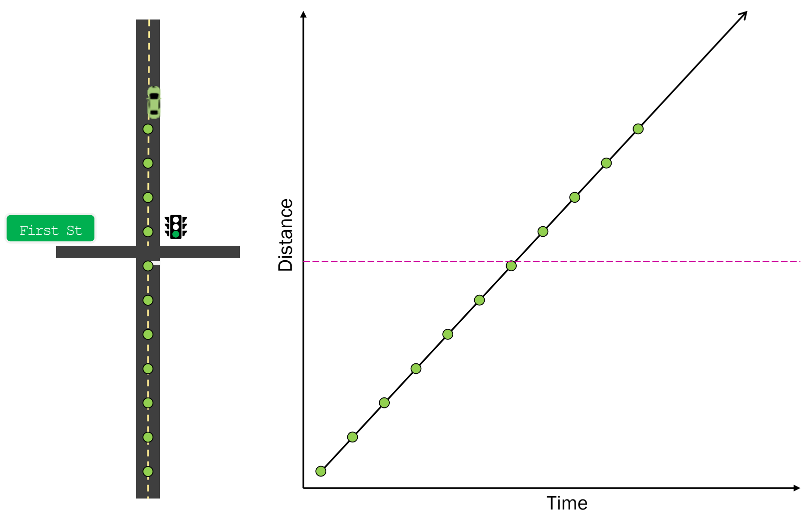


Figure 1. Trajectory Data and Time Space Diagram Example

Leveraging the high frequency waypoint data, a vehicle's journey through the intersection can be characterized. Figure 2 shows examples of three different trips through the intersection. The green vehicle traveled through the intersection in 12 seconds with a constant speed and no stops. It can logically be assumed that this vehicle arrived at an intersection when the signal was green and experienced little to no delay. The yellow vehicle traveled through the intersection in 32 seconds, and slows to a stop prior to the signalized intersection. This vehicle is assumed to have arrived on a red signal and experienced a minor amount of delay (~20 s) as it made the journey through the intersection. The red vehicle traveled through the intersection in 100 seconds, with two observed stops. The vehicle experienced significant delay (~88 s), and because the vehicle had to stop two distinct times, it likely experienced a split failure, or had to sit through numerous cycles at the intersection.

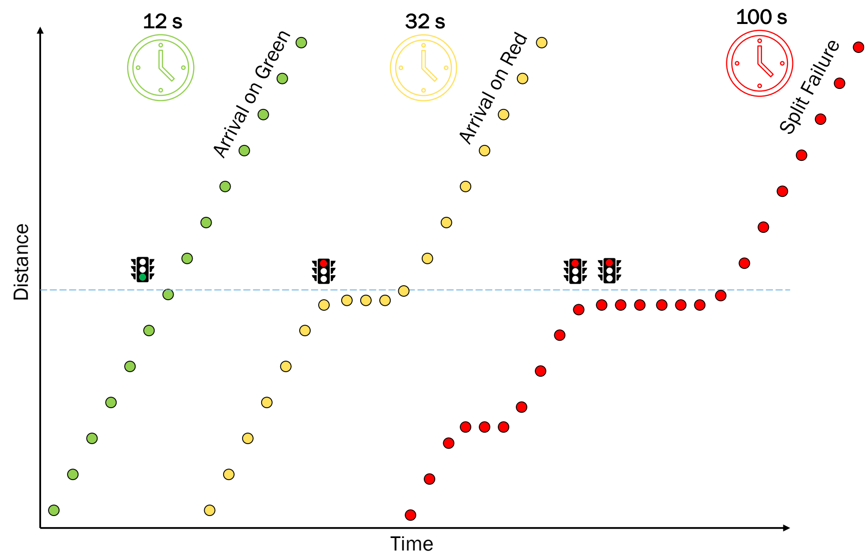


Figure 2. Vehicle Experiences Captured

A series of assumptions were necessary to create performance metrics at the intersection. For each vehicle traveling through the intersection the following assumptions were made:

- The intersection metrics consider an inbound length of 150 meters (~492 ft) prior to the stop bar and an outbound length of 80 meters (~262 ft) past the stop bar. The inbound length is used to determine if a vehicle stopped prior to the intersection. Both the inbound and outbound lengths are used to determine the travel time of the vehicle through the intersection.
- A vehicle is considered to have stopped at the intersection if the speed dropped below 10 kph (6.2 mph) for 2 seconds in the inbound length.
- The reference travel time, used to determine a typical travel time through the intersection, is considered the 5th percentile travel time of all vehicles that did not stop while making the same movement during the selected period.

Figure 3 illustrates the assumptions made above. These assumptions allow us to consider every vehicle observed traveling through an intersection and define the characteristics of that vehicle including:

- **Arrival on Green (AOG)** – Arrivals on green represent a vehicle that did not have to stop at a signalized intersection.
- **Travel Time** – The time a vehicle takes to travel the inbound and outbound length of the movement.
- **Approach Speed** - Maximum speed of a vehicle using waypoint pairs on the inbound length of an intersection.
- **Control Delay** - The difference between the actual travel time for a vehicle to move through the intersection versus the reference travel time.
- **Split Failure** – A split failure is defined when a vehicle is forced to stop more than once at a traffic signal.

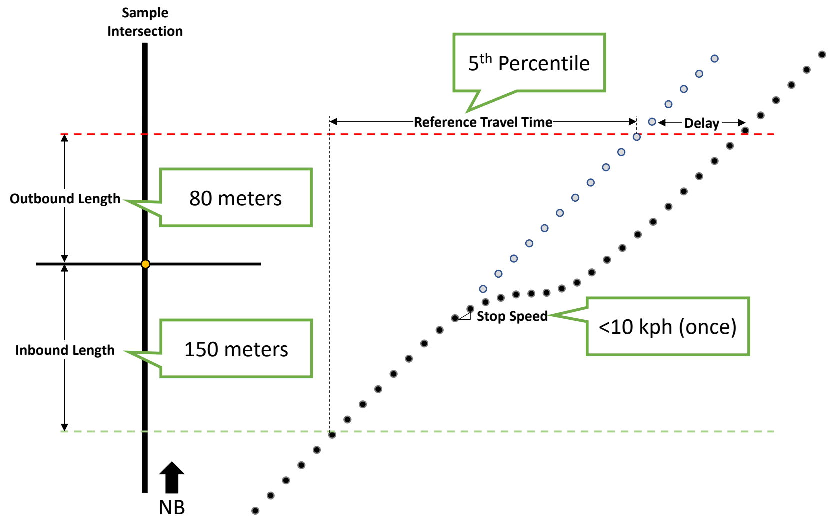


Figure 3. Assumptions for Signal Analytics

A similar methodology can be used to provide travel time statistics using observed end to end trips along defined corridors. Leveraging GPS data from vehicles one can determine the point in time a vehicle passes a start point and an end point. Using those times, a travel time can be measured for each vehicle. Travel Time, Reliability Metrics, and travel time distributions can all be calculated to understand the performance of a corridor.

The metrics created using the trajectory-based approach were compared with traditional detector-based systems in the United States. The results showed that although the metrics were being performed using significantly different approaches (point-based detectors vs. trip-based trajectories) the trends for travel time, delay, arrivals on green, and split failure all aligned.

EXAMPLES

Typically, traffic signals with faulty detectors, configuration, or equipment mean the system is not working optimally and the full benefits of enhanced signal systems are not being realized. It has traditionally been difficult to understand the performance of an entire network of signals or corridors due to the cost of detection and communication at intersections. Proactive steps can now be taken by leveraging the latest development in cloud-based software to identify and prioritize areas of concern. Examples of common signal issues that can be identified include:

- Detection failure
- Poor signal progression
- Poor signal phasing and timing
- Excessive delay and split failures

These issues can be identified through various examples from a trajectory-based signal analytics tool. The example in Figure 4 shows an intersection in Cologne, Germany. Any intersection can be selected in the map view (callout ‘i’). This will display an intersection diagram showing every movement. Each movement can be selected (callout ‘ii’) to display an even closer look at metrics being collected at the intersection. Any of the metrics previously defined can be viewed using the metrics dropdown (callout ‘iii’). The detail panel will highlight the number of observations by hour and colour those observations based on their interaction at the signal. For example, at 7 AM the week of July 17th, 2022 (callout ‘iv’), over 190 vehicles were observed on the westbound through movement and 55 of those vehicles did not stop at the intersection.

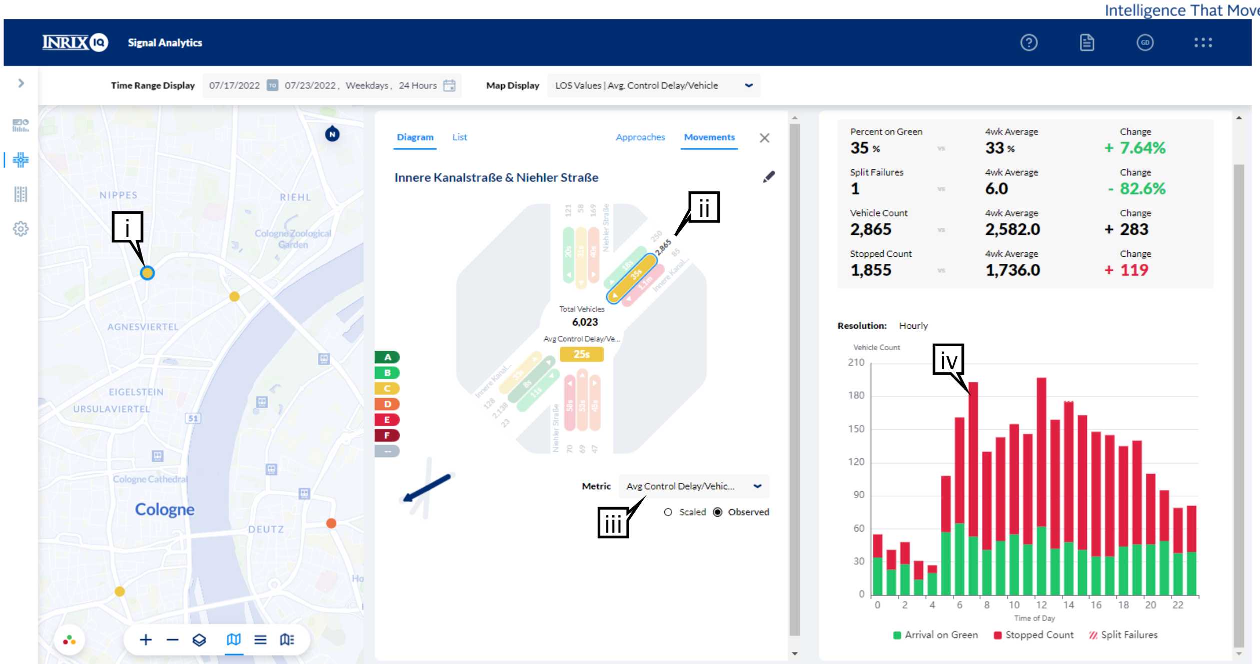
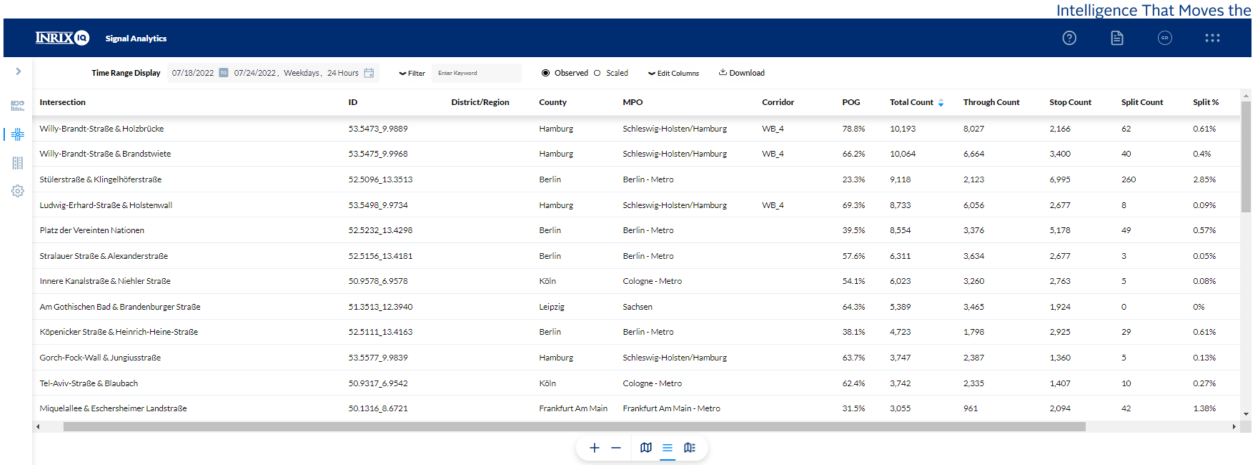


Figure 4. Signal Analytics in Cologne, Germany

Scale is the real benefit of trajectory-based metrics. Every intersection in a region, state, or country can be measured the same way. There are no dependencies on detection, communication, or equipment in the field. Every intersection can be ranked and prioritized every day, week, or month based on any of the previously defined metrics. Trends can be understood to identify any significant deviation. These deviations can be acted upon, and the resulting improvements can be quantified and documented. Traditional recurring timing adjustments can be prioritized or deprioritized based on the actual observed performance of an intersection or corridor. Times when data collection would typically be costly or deemed unimportant, like seasonal or weekend periods, can be monitored with the same level of granularity as the busiest peak periods.

An example of a simple system wide report for a select number of intersections in Germany for the weekdays of July 18th, 2022 is shown in Figure 5. A prioritization study that would have likely taken months to identify poor performing intersections can now be addressed in seconds leveraging the power of trajectory-based data in the cloud. Another benefit is a network wide visualization like the one shown in Figure 6. It shows all of the signalized intersections in Austin, Texas, USA colored based on the level of service (LOS) of the PM peak periods in April 2022.



Intersection	ID	District/Region	County	MPO	Corridor	POG	Total Count	Through Count	Stop Count	Split Count	Split %
Willy-Brandt-Straße & Holzbrücke	53.5473_9.9889		Hamburg	Schleswig-Holsten/Hamburg	WB_4	78.8%	10,193	8,027	2,166	62	0.61%
Willy-Brandt-Straße & Brandstwiete	53.5475_9.9968		Hamburg	Schleswig-Holsten/Hamburg	WB_4	66.2%	10,064	6,664	3,400	40	0.4%
Stülerstraße & Klingelhöferstraße	52.5096_13.3513		Berlin	Berlin - Metro		23.3%	9,118	2,123	6,995	260	2.85%
Ludwig-Erhard-Straße & Holstenwall	53.5498_9.9734		Hamburg	Schleswig-Holsten/Hamburg	WB_4	69.3%	8,733	6,056	2,677	8	0.09%
Platz der Vereinten Nationen	52.5232_13.4298		Berlin	Berlin - Metro		39.5%	8,554	3,376	5,178	49	0.57%
Stralauer Straße & Alexanderstraße	52.5156_13.4181		Berlin	Berlin - Metro		57.6%	6,311	3,634	2,677	3	0.05%
Innere Kanalstraße & Niehler Straße	50.9578_6.9578		Köln	Cologne - Metro		54.1%	6,023	3,260	2,763	5	0.08%
Am Gothischen Bad & Brandenburger Straße	51.3513_12.3940		Leipzig	Sachsen		64.3%	5,389	3,465	1,924	0	0%
Köpenicker Straße & Heinrich-Heine-Straße	52.5111_13.4163		Berlin	Berlin - Metro		38.1%	4,723	1,798	2,925	29	0.61%
Gorch-Fock-Wall & Jungiusstraße	53.5577_9.9839		Hamburg	Schleswig-Holsten/Hamburg		63.7%	3,747	2,387	1,360	5	0.13%
Tel-Aviv-Straße & Blaubach	50.9317_6.9542		Köln	Cologne - Metro		62.4%	3,742	2,335	1,407	10	0.27%
Miquelallee & Eschersheimer Landstraße	50.1316_8.6721		Frankfurt Am Main	Frankfurt Am Main - Metro		31.5%	3,055	961	2,094	42	1.38%

Figure 5. Signal Analytics Network Summary in Germany

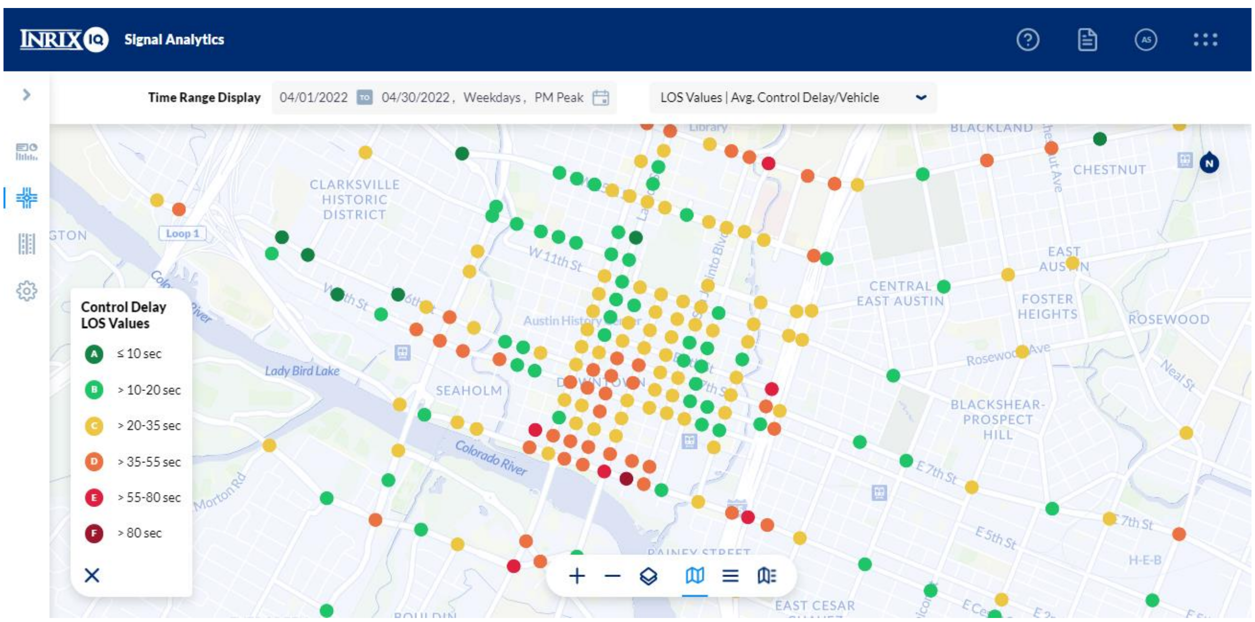


Figure 6. Citywide map of signalized intersections in Austin, Texas, USA

Corridor priority projects can also be turned from a significant effort to collect and organize data to a few clicks on the screen. Figure 7 shows an example of a set of corridors in the Portsmouth, UK area. The NB corridor (callout 'i') is selected and metrics are shown for the week of March 14th, 2022. Additional metrics are shown for the corridor (callout 'ii') including average travel time and some reliability metrics. Additionally, the change in the metrics relative to the previous four weeks can also be seen. The power of the corridor tool is the ability to view the travel time over time (callout 'iii'). This can be used to identify the peak periods, or if significant delays on a corridor require attention. Similar to the intersections tool, the scale is important. Every corridor in a network can be measured and compared without the need for equipment or data collection.

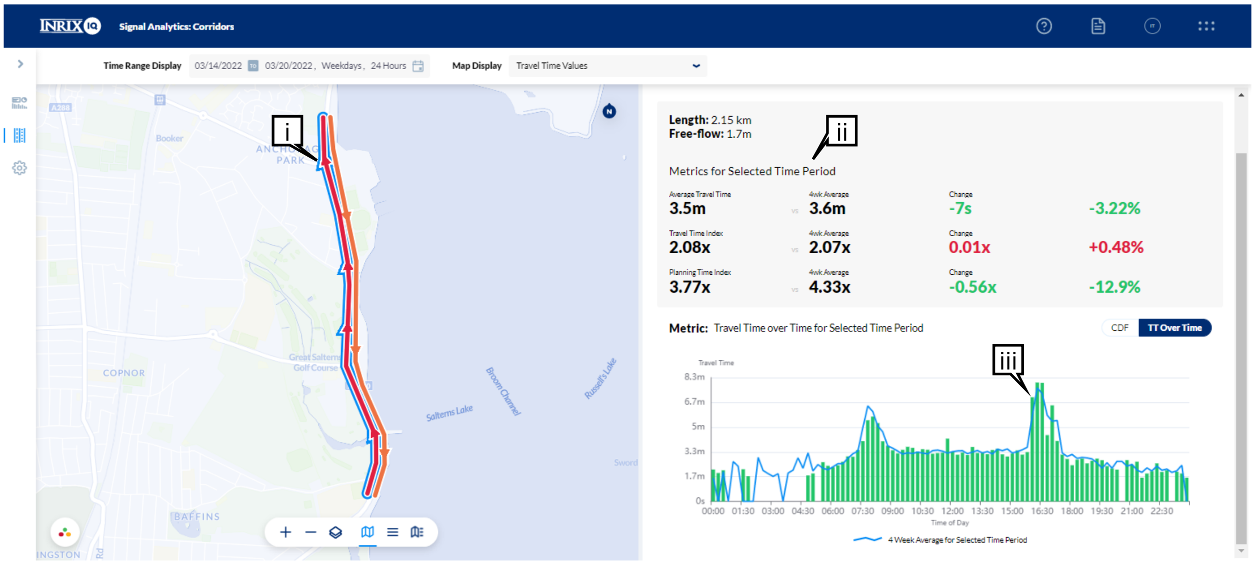


Figure 7. Signal Analytics: Corridors in Portsmouth, UK

USE CASES

The ability to quickly, accurately, and cost-effectively evaluate intersection and corridor performance systemwide opens a breadth of possible use cases. Current use cases include:

- Identify where signal retiming needs are most urgent
- Ranking intersections or corridors by a variety of performance metrics
- Identifying sudden changes in performance of an intersection or movement, to flag for further examination (sensor failure, timing mistake, etc.)
- Guiding the prioritization of traffic signal investments
- Quantifying the impact of various traffic signal management strategies and technologies
- Testing new signal strategies
- Adopting Transportation System Management and Operations (TSMO) strategies for traffic signals
- Understanding the reliability and performance of a corridors
- Identifying time of day plan changes based on performance
- Understanding the impact of special events or work zones

These use cases can directly lead to a decrease in congestion, reduced fuel consumption, and lower vehicle emissions. Compared to traditional traffic engineering methods, GPS-based signal analytics offer a few key benefits:

- Cost reduction – elimination of the need for costly physical infrastructure
- Work reduction – reduce time consuming data collection and analysis
- Quick access to data – near real time access to valuable metrics and insights
- Scalability – granular insights at every intersection and corridor in your network
- Cloud-based – easy access for all users, no hardware or software, little to no IT involvement

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CONCLUSION

Research has evidenced that a well performing traffic signal network makes overall traffic congestion better, with delay savings of between 10 and 20 percent delivered by efficient use of technologies which monitor and ensure correctly timed signals. Moreover, not only are delay savings captured but also the associated reduction in air pollution. So much so, that DfT recently awarded 39 councils in England with a share of £15 million worth of funding ensure traffic signals are working in the most effective manner. Tools leveraging GPS based trajectory data can provide a cost effective and scalable alternative to traditional detection-based performance measure systems.

In summary, given the ease of monitoring traffic signal performance without investing in equipment, the primary benefits of a GPS-based signal analytics solution are:

- Significant time and cost savings vs deploying additional people and infrastructure
- Reduced emissions from enhanced traffic flow and environmental benefits of improved air quality
- Improved safety and quality of driver experience from reduced split failures, improved travel times, and increased level of service