



# Xtelligent

2021 DOE Vehicle Technologies Office  
Annual Merit Review Presentation

“Next Generation Intelligent Traffic Signals for  
the Multimodal, Shared, and Automated Future”

Andrew Powch | Xtelligent | June 22, 2021 | Project ID: eems069

This presentation does not contain any proprietary, confidential, or otherwise restricted information

# + Overview

---

## Timeline:

---

- Project start date: September 2019
- Project end date: August 2021
- Percent complete: 85%

## Funding:

---

- Total project funding: \$1,000,000

## Partners:

---

- Argonne National Laboratory (ANL)
- City of Greenwood Village, CO
- City of Fremont, CA
- Colorado Dept of Transportation (CDOT)
- Los Angeles Cleantech Incubator (LACI)

## Barriers to achieving objectives:

---

- COVID19-related fluctuations in vehicle movement and congestion causing variations in traffic flows affecting baseline measurements.
- COVID19-related major organizational changes at vehicle location data partners, in particular automotive OEMs, has dramatically affected the availability of high-quality CV data streams.
- General quality of streaming location data is lower than anticipated.
- Real-world complexity and validation required of Proportionally Fair (PF) Adaptive Traffic Control System (ATCS) algorithm on the network-level (beyond intersection-level).
- Computational difficulty of modeling energy efficiency and greenhouse gas (GHG) improvements across cities.



# + Relevance and objective

---

## Relevance:

1. Improve energy productivity of the overall transportation system:
  - Advanced Proportionally Fair (PF) Adaptive Traffic Control System (ATCS) algorithm can dramatically increase systems-level energy efficiency (>50% improvement achieved in PTV VISSIM microsimulations).
2. Improve affordability:
  - Incorporation of location data streams from internet-based sources in combination with PF ATCS can also dramatically increase affordability of transportation systems by avoiding installation of costly physical sensor infrastructure.
3. Research and Develop an ATCS system with true product-market fit
  - 40 yrs of ATCS systems have failed to penetrate U.S. traffic signals market beyond 1-2%
    - Incumbent systems have been cumbersome, expensive, and failed to achieve marketed benefits, frustrating two generations of transportation professionals.

## Objectives:

- Real-world, in-street research of PF ATCS algorithm to improve energy efficiency of transportation network by retiming traffic signals in real-time. Incorporate novel location data streams as inputs to dramatically reduce cost for cities, counties, and states to adopt these systems.
  - Phase I resulted in basic prototype PF ATCS that showed 21% improvement in single-intersections.
  - Phase II focuses on expansion to corridor control, bigger road network, and inclusion of streaming location data.
  - Conduct pre/post data analysis with ANL to validate energy efficiency gain of vehicles on associated streets (initial estimate by ANL = **15% energy efficiency gain** and proportional greenhouse gas emissions reduction)
  - \*Test additional use of streaming location data from connected vehicles and other location data systems.

# + Relevance: Achieved through April 2021

Current quarter

- Achieved:
  - Phase I single-intersection system refactored to function on corridors
  - 55 separate in-road system tests performed to iterate system development
  - Myriad hurdles overcome interfacing with legacy traffic signal controller infrastructure
  - User interface version 1 completed
  - Streaming data providers evaluated and partially integrated.
- Ongoing:
  - Performance testing of full corridor-enabled PF ATCS system (delayed due to COVID19\*)
  - Complete Objective 3. See GANTT →
  - Currently collaborating with Argonne National Laboratory to create data evaluation model
- Incomplete:
  - Objective 4: lack of available high quality location data sources has eliminated objective 4 as a viable option.

Phase II *Proposal* GANTT Chart\*:

| Milestone                                                                                                                                          | Deliverables                                                                                                                                                                                                                                                           | Year 1      |             |             |             | Year 2      |             |             |
|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                                                                                                                                                    |                                                                                                                                                                                                                                                                        | Q1: 09DEC19 | Q2: 09MAR20 | Q3: 09JUN20 | Q4: 09SEP20 | Q5: 09DEC20 | Q6: 09MAR21 | Q7: 09JUN21 |
| Objective 1: Coordinated ATCS Control for Throughput Maximization                                                                                  | Backend design for intersection-to-intersection communication<br>Installation and configuration of each<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                  | ■           | ■           | ■           | ■           | ■           | ■           | ■           |
| Objective 2: Evaluation of Data Streams                                                                                                            | Data quality analysis for each data source<br>OEM(s)<br>TomTom<br>INRIX<br>Waze Connected Citizens Program<br>Xtelligent mobile phone application<br>Other<br>Data source preference hierarchy determination<br>Data source logic implementation for queue calculation |             | ■           | ■           |             |             |             |             |
| Objective 3: Performance Improvement by <u>Supplementing</u> Existing Physical Sensor Data with Connected Vehicle Location Data (V2I using 4g/LTE) | Software/algorithm encoding to incorporate location data on streaming basis<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                                              |             |             |             | ■           | ■           | ■           | ■           |
| Objective 4: ATCS Control Using Connected Vehicle Data <u>Only</u>                                                                                 | Software/algorithm encoding to incorporate location data on streaming basis<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                                              |             |             |             |             | ■           | ■           | ■           |
| Objective 5: Evaluation of Beta/Pilot                                                                                                              | Internal evaluation<br>Independent validation                                                                                                                                                                                                                          |             |             | ■           | ■           | ■           | ■           | ■           |

\*Delays due to COVID-19 are further discussed later in presentation



# + Approach: Summary of overall technical approach

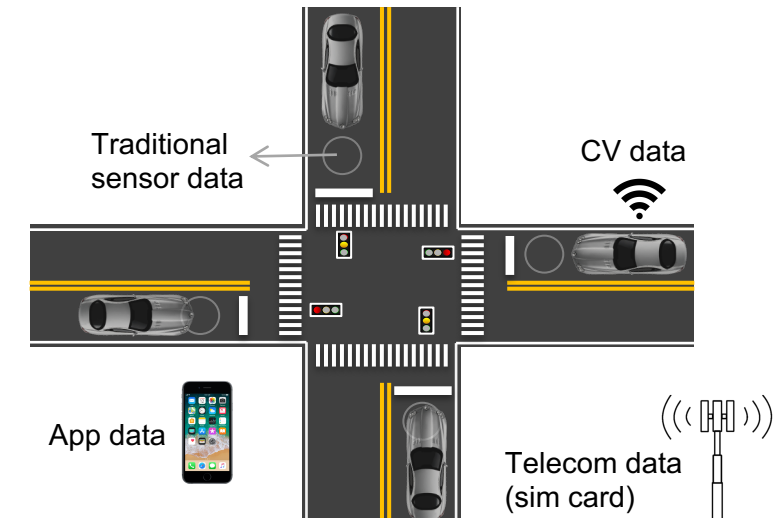
## Three steps:

- 1 Integrate Proportionally Fair algorithm (PF) into a live Adaptive Traffic Control System (ATCS) across corridors and grids, using traditional physical vehicle detection sensors. Test performance against baselines.\*
- 2 Augment step 1 with streaming vehicle location data from Connected Vehicles (CVs), cellular devices, or other systems to improve system awareness of vehicle locations and improve performance. Test performance against baselines.
- 3 Remove traditional physical sensor data stream and rely solely on streaming location data. Test performance against baselines.\*\*

## PF ATCS algorithm basics

- Inspired by well-regarded controllers from communications networks
- Sets each phase's green time allocation in proportion to its share of aggregate demand
- Practical for real-world use:
  - Does not require turning ratios
  - Only requires aggregate phase queue length
  - Does not need downstream queue lengths

## Vehicle presence detection data types



\*Delays due to COVID-19 are further discussed later in presentation

\*\*This objective has been impacted by the lack of usable streaming location data streams.

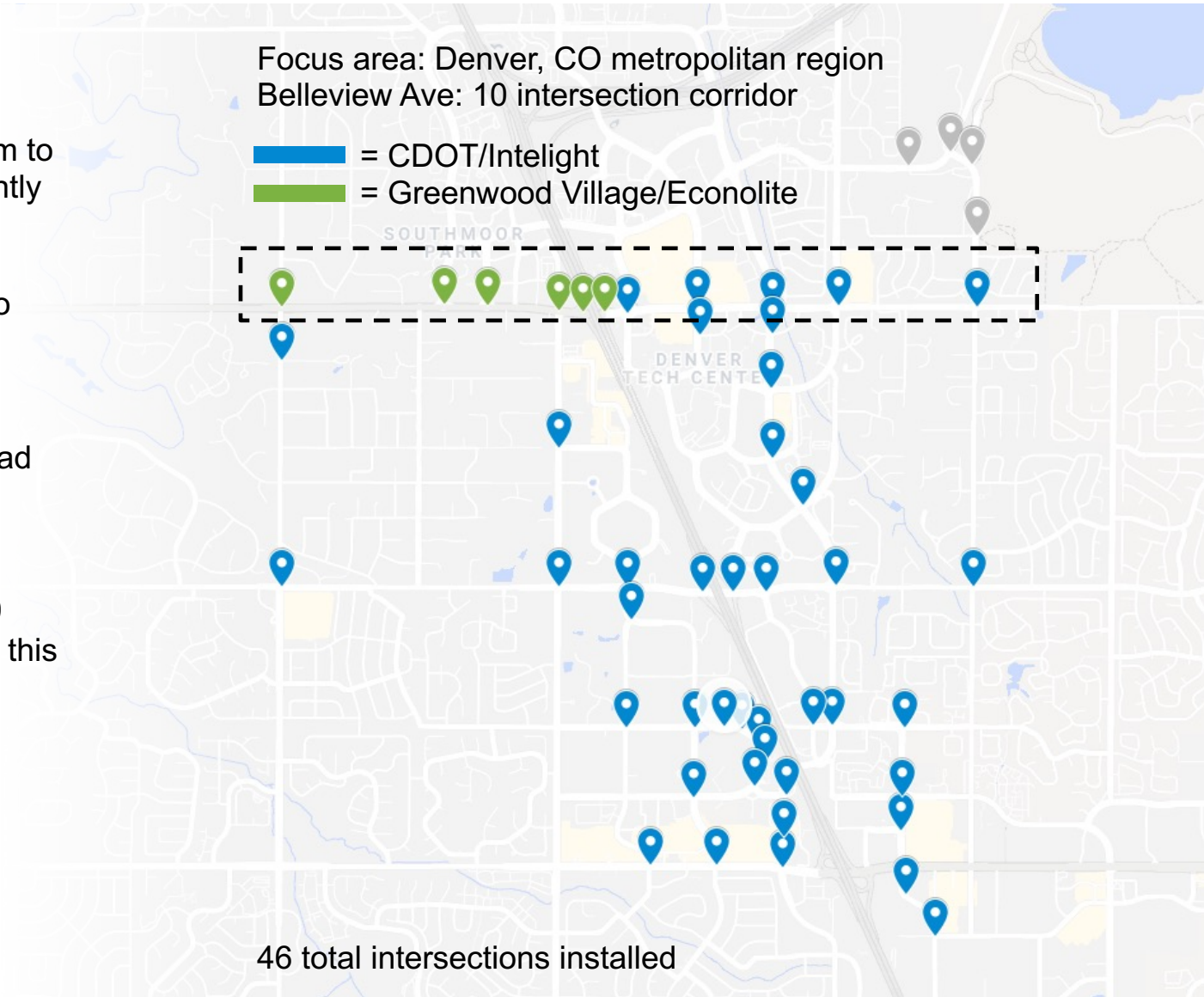
# + Technical accomplishments and progress: ATCS update

As of April 2021, Xtelligent has implemented its PF ATCS system to operate in both corridors and single intersections. We are currently testing, alternating a baseline week with an ATCS week while iterating to maximize performance levels. A user interface to maximize commercialization potential of the technology has also been built with Xtelligent's non-SBIR funding.

Although working with the “standardized” NTCIP Management Information Base (MIB) to interact with existing controllers, myriad differences exist between each controller manufacturer's interpretation of this standard.

Performance testing was significantly delayed due to COVID-19 related traffic volume reductions, though these have resolved at this point.

11 intersections are also installed in Fremont, CA and are being tested concurrently with the Colorado evaluation





# + Technical accomplishments and progress: post-COVID

Initial results from testing when COVID traffic levels restored:

In August 2020 the COVID19 related reductions in traffic volumes began to lessen, and we were able to finally begin testing the PF ATCS. At the time, the baseline control the agencies were using was “free” mode, where no coordination is enforced, and intersections are allowed to cycle through their phases according to preset minimum and maximum greentimes, and traffic demand as determined by the presence of a 3 second gapout. **The PF ATCS performed 26% better.**

To analyze this data, Xtelligent analyzed a 5-day baseline of data, and compared the average hourly performance data between baseline and ATCS weeks. The specific metric we used was “flushtime,” which we define as the time it takes the initial queue to cross into the intersection. By taking the sum of flushtimes for major and minor phases per hour, and comparing to the PF ATCS result, we are able to determine which control system has, in aggregate, shorter queue lengths. When normalized for differences in traffic volumes, the control system that has shorter queue lengths is minimizing congestion across the network.

Figure: sum of flushtimes (seconds) per hour for major phases:

| 8/3 - 8/7 Baseline (Free mode) |       |       |       |       |       |          |       | 8/10 - 8/14 PF ATCS |        |        |        |        |        |          |       |     |
|--------------------------------|-------|-------|-------|-------|-------|----------|-------|---------------------|--------|--------|--------|--------|--------|----------|-------|-----|
| Phase                          |       |       |       |       |       |          |       | Phase               |        |        |        |        |        |          |       |     |
| Hour                           | 3-Aug | 4-Aug | 5-Aug | 6-Aug | 7-Aug | Stddev % | Avg   | Hour                | 10-Aug | 11-Aug | 12-Aug | 13-Aug | 14-Aug | Stddev % | Avg   | Δ   |
| 9                              | 6,369 | 5,886 | 6,281 | 6,093 | 6,343 | 3%       | 6,194 | 9                   | 4,370  | 4,251  | 4,148  | 4,452  | 4,492  | 3%       | 4,343 | 30% |
| 10                             | 5,951 | 6,373 | 6,633 | 6,554 | 6,619 | 4%       | 6,426 | 10                  | 5,135  | 5,408  | 4,808  | 5,522  | 5,105  | 5%       | 5,196 | 19% |
| 11                             | 6,934 | 6,857 | 6,906 | 6,801 | 6,674 | 2%       | 6,834 | 11                  | 4,775  | 4,915  | 4,930  | 6,011  | 5,082  | 10%      | 5,143 | 25% |
| 12                             | 6,581 | 6,528 | 6,739 | 6,813 | 6,960 | 3%       | 6,724 | 12                  | 4,343  | 4,892  | 4,952  | 5,353  | 4,834  | 7%       | 4,875 | 28% |
| 13                             | 6,300 | 6,210 | 6,447 | 6,531 | 6,810 | 4%       | 6,460 | 13                  | 4,604  | 4,759  | 4,885  | 4,693  | 4,933  | 3%       | 4,775 | 26% |
| 14                             | 7,088 | 7,590 | 6,929 | 7,089 | 7,446 | 4%       | 7,228 | 14                  | 4,948  | 5,493  | 5,691  | 5,172  | 5,517  | 6%       | 5,364 | 26% |
| 15                             | 8,654 | 8,007 | 7,972 | 8,256 | 8,251 | 3%       | 8,228 | 15                  | 5,972  | 6,412  | 5,835  | 6,578  | 5,635  | 7%       | 6,086 | 26% |

26% improvement achieved on major phases, with no reduction in performance on minor phases

# + Technical accomplishments and progress: corridors

After successfully testing against a free mode baseline, Xtelligent urged its agency partners to restore TOD coordination to provide for a more robust baseline for testing. In early 2021, Xtelligent was finally able to begin iterative testing against a TOD baseline.

Early testing on a coordinated baseline as of April 16, 2021 has not yet demonstrated improvement in line with expectations, but the following substantial changes are being implemented and tested in the next three months:

## Changes being implemented:

1. Setting configurable preferences for coordination flow to accommodate real-world requirements.

2. Incorporating queue storage constraints to prevent spillbacks

3. Incorporate configurable “max recall” setting when local vehicle detection is unreliable

4. Experiment with use of greentime utilization as the PF input instead of initial queue flushtime.

## Practical reason:

1. Agency-configured coordinated phase may be fixed for phases 2 and/or 6, but actual demand is for a protected-left phase 1 to service a freeway on-ramp.

2. Optimal split and cycletime may conflict with available queue storage capacity and cause unsafe spillbacks.

3. Unreliable detection causing early gap-outs even with heavy traffic present.

4. Flushtime, representing queue length, is most aligned with existing PF research, however real-world comparison to overall greentime utilization as input is worthwhile

First test activations resulted in little improvement, but several substantial opportunities for improvement are being implemented and tested at the time of this presentation submittal.

# + Technical accomplishments and progress: data update

- COVID 19 heavily impacted partners' internal operations and timelines
- Key variables for each data stream are % penetration, % accuracy, data latency, and ease of partnership.
- Due to non-disclosure agreements, names must remain obscured.
- Preferred data streams would be #10, #1-4 and #5.

• Difficulty of aggregating sufficient high quality location data sources for general use suggests near-term opportunity is limited to more detailed use cases like freight, buses, emergency vehicles, etc.

|           | Data partner              | % Penetration (of vehicles) | Accuracy | Latency               | Partnership potential | <b>Status</b>                                                |
|-----------|---------------------------|-----------------------------|----------|-----------------------|-----------------------|--------------------------------------------------------------|
| <b>1</b>  | Connected Vehicles: OEM 1 | <1%                         | 2m       | 30 sec                | Medium                | COVID reprioritizations delayed past grant timeline          |
| <b>2</b>  | OEM 2                     | <1%                         |          |                       | Medium                | COVID reprioritizations delayed past grant timeline          |
| <b>3</b>  | OEM 3                     | 0-5% <sup>1</sup>           |          |                       | High                  | App requirement is not realistic for commercial use          |
| <b>4</b>  | OEM 4                     | ~4%                         |          |                       | High                  | Low penetration and high cost: not a viable source for now   |
| <b>5</b>  | Telecom 1                 | 30%                         | 100m     | >1 min <sup>2</sup>   | High                  | Committed partner, but no site overlap                       |
| <b>6</b>  | Data Aggregator 1         | 10%                         | ~50m     | 1-15 min <sup>3</sup> | Medium                | High latency and "smoothed" data is not high potential       |
| <b>7</b>  | Data Aggregator 2         |                             |          |                       | Medium                | High latency and "smoothed" data is not high potential       |
| <b>8</b>  | Data Aggregator 3         |                             |          |                       | Medium                | High latency and "smoothed" data is not high potential       |
| <b>9</b>  | Xtelligent's App          | 0%                          | 2m       | 1s                    | High                  | App requirement is not realistic for commercial use          |
| <b>10</b> | Map Provider              | >20%                        | 2m       | TBD                   | Medium                | Large organization; timeline to focus on this effort is long |

<sup>1</sup> Requires installation and connection of OEM's or 3<sup>rd</sup> party smart phone app

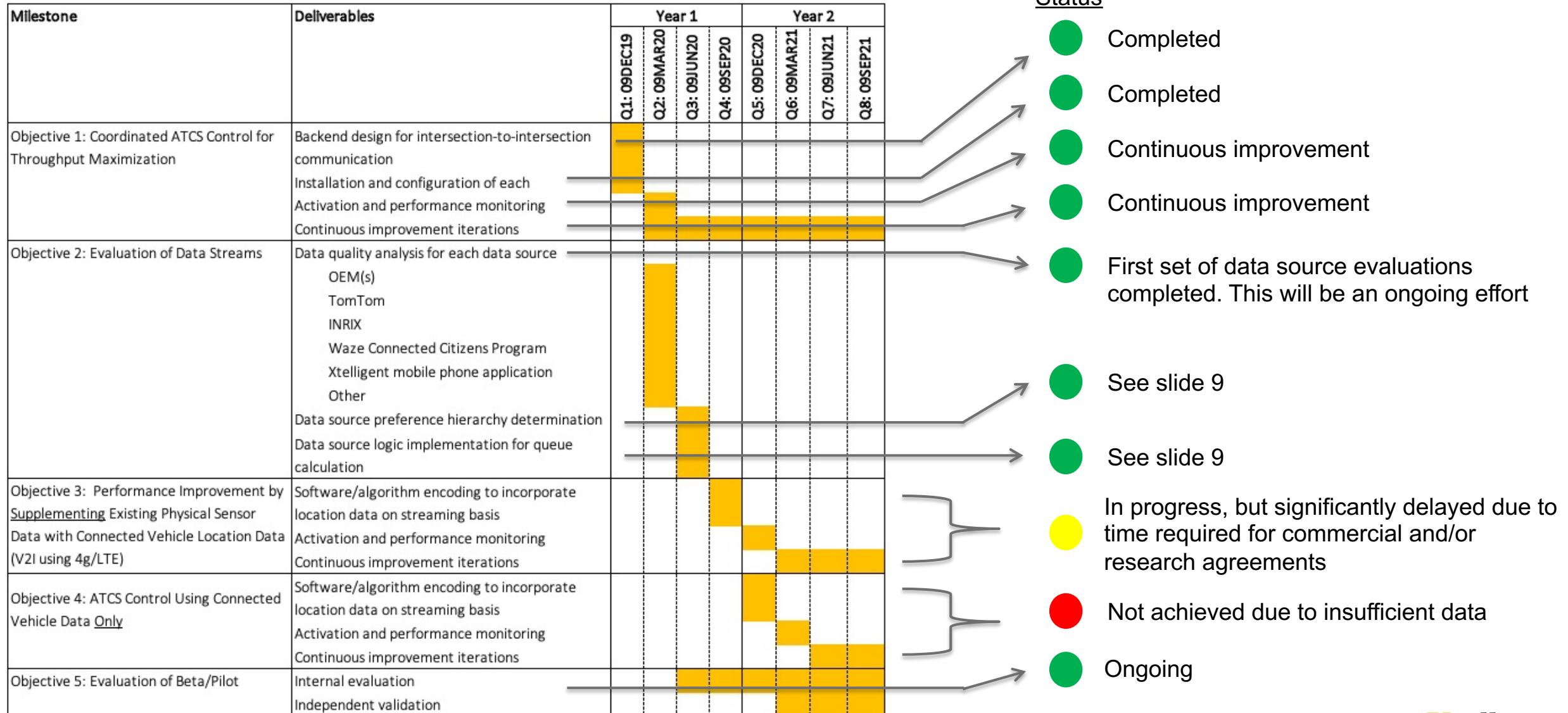
<sup>2</sup> Improved 4X since last year, but geographic regions with this service available are few

<sup>3</sup> Varies according to location and frequency of data points on specific links. Aggregators provide "smoothed" data to agencies, whereas we seek the raw data feed.



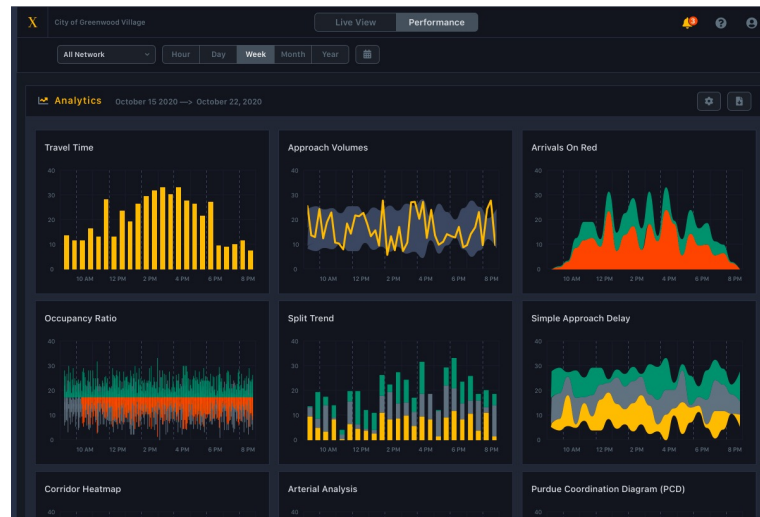
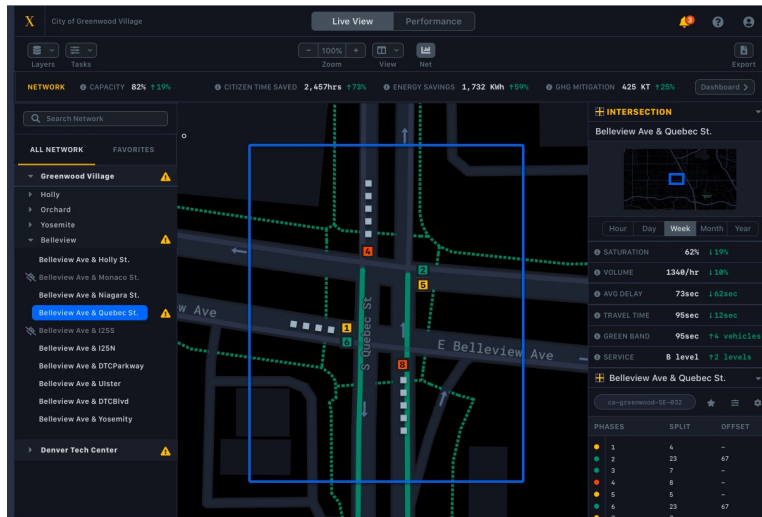
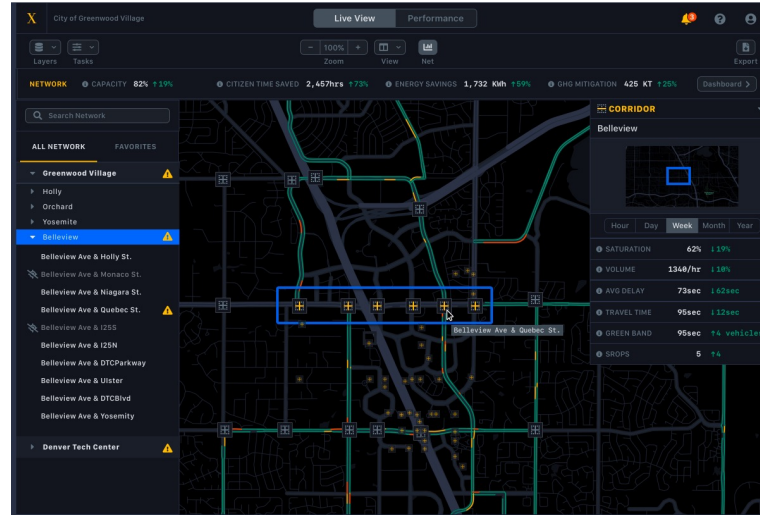
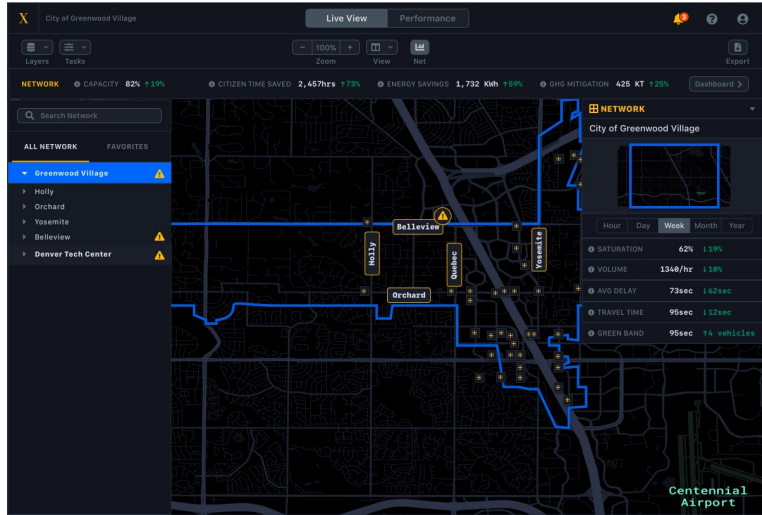
# + Technical accomplishments and progress: snapshot

Phase II *Proposal* GANTT Chart:



# + Technical accomplishments and progress: user interface

Although not undertaken with grant funding, the development of a working user interface has been undertaken and is a critical component to the eventual commercialization of this technology. It is also critical to provide continuous reporting of performance, energy productivity, and other key metrics to departments of transportation.



- Focus on performance evaluation, transparency, and accountability
- Network-level, corridor-level, and intersection-level metrics
- Existing ITS metrics reflected to provide familiarity and immediate usability
- Potential to integrate with DOE-funded MEP (Mobility Energy Productivity) and F-MEP (Freight Mobility Energy Productivity) metrics
- Connected and automated vehicle integration

# + Responses to previous year's reviewer comments

---

**1** Comment: *“One significant item that is not included in the current approach is the use of a robust traffic simulation model. A traffic simulation model that accurately represents the Proportionally Fair (PF) Adaptive Traffic Control System (ATCS) algorithm and the data types and latencies of data provided from the potential data partners could be used to investigate the impact of various market penetration levels and data sources (either single data sources or data sources in combination). This could also be used to identify targeted performance levels for the system. This type of evaluation capability would provide for a much more robust project and could eventually be used by those local agencies who may consider implementing such a system.*

Response: We agree that robust traffic simulation models can be a strong tool when evaluating potential control methodologies. The PF algorithm had been already been evaluated using PTV VISSIM, and we specifically sought to now provide a real-world analysis of its efficacy. The added complexity has been very challenging, but we believe it an important step to true validation.

---

**2** Comment: *“Some clarifications in a few of the project details would be helpful, such as a clearer and more complete definition of green-time utilization and slack time. It is clear that these are inverse terms, but a detailed definition of green-time utilization and its calculation would be helpful. A clearer and more complete description of the proposed corridor that is being instrumented for testing would also be helpful.*

Response: We define green-time utilization as the percent of green time where vehicles are occupying the stop bar detection sensor. Slack time would be the inverse: the percent of green time where no vehicles occupy the detector.

---

**3** Comment: *Risks include “restoration of traffic volumes to “normal” levels and commitments of data partners. Of these risks, the lack of commitment of data partners is probably the higher. If sufficient data partners are not participating, the project will not have sufficient market penetration so that the traffic volumes will not be representative of traffic on the network. This would make the traffic-signal timing non-responsive to the traffic in the scenario where no infrastructure-based data collection is used*

Response: Agreed. While COVID19 related traffic volumes have mostly restored, though with more volatility than normal, the lack of available high-quality location data partners has become a reality and has impaired the project team's ability to incorporate streaming, internet-based location data into its system. We still see a very compelling future where these data streams are available for general use, but in the near-term more specific use cases like freight priority and transit priority using cellular data over 4g/LTE can be studied more readily.



# + Collaboration and coordination with other institutions

- Project requires complex collaboration with city engineers, city IT network administrators, and traffic signal controller manufacturers. This collaboration has continued strongly as evidenced by our achievements thus far.
- Argonne National Laboratory is a subcontractor for final data analysis to estimate energy efficiency gains achieved by this ATCS approach as well as corresponding GHG emissions reductions. Data evaluation is currently ongoing as the end of the grant period of performance nears.
- Fremont, CA is pilot site #1
- CDOT + Greenwood Village, CO is pilot site #2
- Long Beach, CA is in final stages of MOU to become site #3 despite COVID related delays
- Majority of the key transportation agencies across LA, San Bernardino, and Riverside counties are now supporting the project





In Focus

# TRI-CONNECT

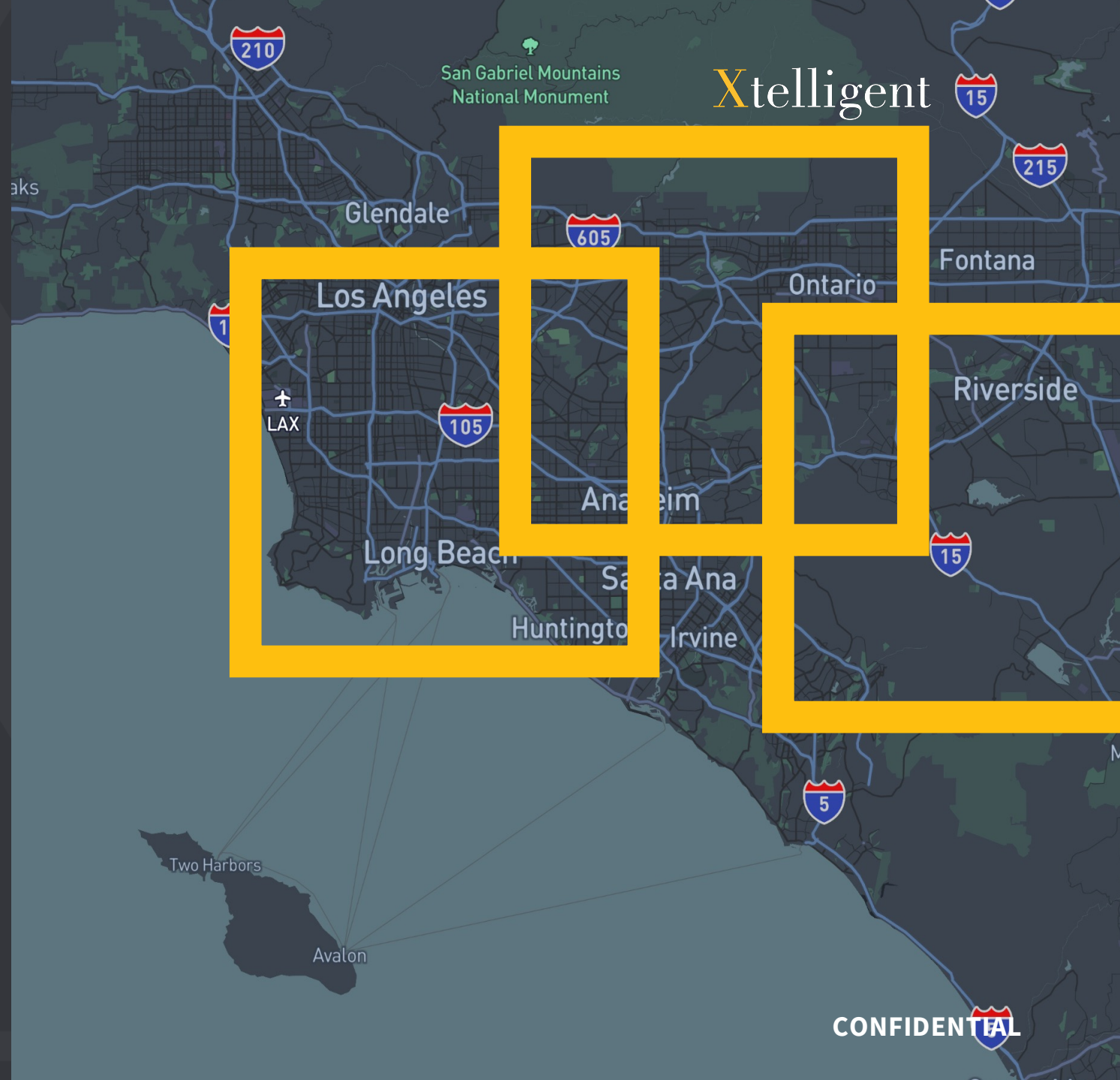
The tri-county concept brought together regional public, private, and nonprofit partners to facilitate clean and coordinated freight movement

Benefits include:

- Improved freight movement in busiest freight corridor in the U.S.
- Reduced GHG to combat Climate Change
- Reduce vehicle pollution to improve public health outcomes in disadvantaged communities

Partners include:

- LA / San Bernardino / Riverside Counties
- UC Riverside / USC
- Port of Long Beach
- Automotive and logistics industry partners



CONFIDENTIAL

## + Remaining challenges and barriers

---

- COVID-19 impacts to traffic volumes have resolved, but the business impacts to potential streaming location data partners like automotive OEMs has been significant. These businesses are still managing major strategic shifts, personnel changes, and cash loss due to COVID-related supply chain constraints. Their ability to engage on small research projects like this has been impacted and will continue to be in the foreseeable future. As a result, our ability to complete real-world testing with streaming location data inputs has been sharply curtailed.
- As expected, no “slam-dunk” streaming location data provider found yet. This will eventually require careful fusion of location data from multiple internet-based APIs (CVs, apps, telecoms, etc.). Or, in the near term, more specific use cases with higher streaming location data coverage such as freight priority, transit priority, and advanced emergency vehicle preemption may be best suited as inputs.
- Commercialization into transportation agency purchasing market involves longer purchasing cycles, requirement for track-record, and entrenched players. This SBIR funding is critical to supporting Xtelligent to establish required track record for potential commercialization of the PF ATCS.

# + Proposed future research

“Any proposed future work is subject to change based on funding levels.”

Phase II *Proposal* GANTT Chart:



| Milestone                                                                                                                                   | Deliverables                                                                                                                                                                                                                                                           | Year 1      |             |             |             | Year 2      |             |             |             |
|---------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                                                                                                                                             |                                                                                                                                                                                                                                                                        | Q1: 09DEC19 | Q2: 09MAR20 | Q3: 09JUN20 | Q4: 09SEP20 | Q5: 09DEC20 | Q6: 09MAR21 | Q7: 09JUN21 | Q8: 09SEP21 |
| Objective 1: Coordinated ATCS Control for Throughput Maximization                                                                           | Backend design for intersection-to-intersection communication<br>Installation and configuration of each<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                  | █           | █           | █           | █           | █           | █           | █           | █           |
| Objective 2: Evaluation of Data Streams                                                                                                     | Data quality analysis for each data source<br>OEM(s)<br>TomTom<br>INRIX<br>Waze Connected Citizens Program<br>Xtelligent mobile phone application<br>Other<br>Data source preference hierarchy determination<br>Data source logic implementation for queue calculation |             | █           | █           | █           |             |             |             |             |
| Objective 3: Performance Improvement by Supplementing Existing Physical Sensor Data with Connected Vehicle Location Data (V2I using 4g/LTE) | Software/algorithm encoding to incorporate location data on streaming basis<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                                              |             |             |             | █           | █           | █           | █           | █           |
| Objective 4: ATCS Control Using Connected Vehicle Data <u>Only</u>                                                                          | Software/algorithm encoding to incorporate location data on streaming basis<br>Activation and performance monitoring<br>Continuous improvement iterations                                                                                                              |             |             |             |             | X           | X           | X           |             |
| Objective 5: Evaluation of Beta/Pilot                                                                                                       | Internal evaluation<br>Independent validation                                                                                                                                                                                                                          |             |             | █           | █           | █           | █           | █           | █           |

| Tasks                                                                                   | Completion Date          |
|-----------------------------------------------------------------------------------------|--------------------------|
| Continuous improvement with post-COVID traffic volumes restored                         | End of grant             |
| Choose top 3 data sources and determine logic to integrate with traditional sensor data | Done                     |
| Design and implement hybrid system                                                      | End of grant             |
| Test efficacy as compared to PF ATCS using traditional sensors                          | End of grant or deferred |
| Deferred due to low availability of quality location data streams (see slide 9)         |                          |
| Evaluation with Argonne National Laboratory                                             | End of grant             |



# + Summary

---

- Since the 2020 Annual Merit Review, Xtelligent has fully implemented its solution into both single intersections and corridors and achieved improvements in traffic metrics of approximately 25%. However, significant additional work is underway to match and exceed these performance levels against a robust time of day (TOD) coordinated system.
- Data evaluation to fully understand the PF ATCS efficacy in improving the energy productivity of the transportation system is currently underway with Argonne National Laboratory.
- Streaming location data integration has been heavily, indirectly impacted by COVID through the business disruptions felt at data partners' businesses. As a result, Xtelligent will not be able to test the full integration of this data within the grant period of performance but remains committed to pursuing this as location data becomes more readily available.
- Xtelligent is committed to increasing energy productivity of transportation networks through its novel, PF ATCS controller optimization algorithm, while simultaneously and materially reducing the cost of such systems to transportation agencies