GOING GREEN BY SEEING THE GREENS

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Optimizing the roadway network and signal timings to reduce congestion and ease traffic flow has been the goal of transportation engineers since the advent of the traffic signal. The use of time-space diagrams and adaptive signal systems are some of the hallmark developments used to achieve this goal, however, they have either approached the issue from an infrastructure focus or assuming ideal conditions (e.g., drivers following the speed limit). Modern technology provides both the hardware and communications capabilities to begin integrating and approaching the issue from an end user's perspective, the driver and vehicles themselves.

As part of Transport Canada's Program to Advance Connectivity and Automation in the Transportation System (ACATS), EcoDrive II examined how providing Connected Vehicle (CV) information to drivers could minimize speed variation, improve fuel efficiency and reduce emissions as the driver approaches traffic signals. Building on FHWA research through the Applications for the Environment: Real-Time Information Synthesis (AERIS) program and European green-light optimized speed advisory (GLOSA) work, the concept is to provide the driver with a computed speed that would allow them to successfully pass through an upcoming signalized intersection during the green phase. As shown in Figure 1, there are four possible travel paths for a vehicle through a traffic signal network, where the dashed paths show conditions that can benefit from GLOSA. Using the information, the vehicle's glide path can be optimized to reduce unnecessary fuel consumption if they maintain a speed that will not require them to stop.

The project team involved Carleton University, Traffic Technologies Services (TTS), Thompson Technologies and the City of Ottawa Traffic Department, in addition to Transport Canada.

Project Scope

Previous work investigating the benefits of AERIS Glidepath and GLOSA have primarily focused on research around controlled scenarios with either a single vehicle and traffic signal, or on a limited corridor basis. The City of Ottawa provided an ideal opportunity to investigate the potential benefits of the technology on a citywide basis across a fleet of vehicles. For the EcoDrive II project, the entire 1178 traffic signal network in the city was connected, as shown in Figure 2.

The City of Ottawa uses an adaptive traffic signal timing system which also includes the use of "free mode" signals on low-volume cross streets and crosswalks that trigger only upon vehicle presence. This added extra complexity to the process of generating the predictive signal timing data necessary to calculate a GLOSA value.

A custom-built Android mobile app was developed to communicate with the traffic signal data provider via the cellular network to receive signal timing data and used by the drivers to improve driving efficiency. Seven City field personnel were recruited to support data collection efforts during May and June 2019. A total of 218 person-days of testing data was collected with 23,980 kilometres travelled and 29,393 traffic signals traversed by the test drivers, with 87,569 minutes of data collection occurring during the May 6th to June 28th period.

Technical Background

The basis for providing GLOSA information to a driver is predicated on the availability of real-time information regarding where the vehicle is in relation to the traffic signal and both the status of the signal and amount of time remaining in the current cycle. In locations where traffic signals operate on fixed timing plans, this information is always known and therefore makes availability of the current status at any point of time easy to generate without constant and direct access to the signal controller. Where actuated signals are deployed and signal timing is adjusted based on current traffic conditions, a signal's status shows less consistency and thus enabling the provision of real-time signal status information requires additional infrastructure.

Whenever the signal controller adjusts the timing and status of a signal head, the most current status data is located at the controller level. One solution to gaining access to the latest data is the use of dedicated short-range communications (DSRC) equipment tied into the signal controller at each intersection that can provide a "local broadcast" of the signal timing and phasing (SPaT) data as well as the intersection geometry (MAP) data. However, this can be a costly endeavour if a citywide deployment would be required.

Actuated signals are primarily used in the City of Ottawa, but the system has been designed so that these signals report their real-time status on a second-by-second basis to the central traffic control system. As such, the current status of every signal in the City is known and available from a centralized location in a similar fashion to a fixed timing implementation. This created the opportunity for the use of a cellular-based GLOSA system that could be served from a central or cloud-based application, as shown in Figure 3.

The raw signal controller data was retrieved by TTS from the City of Ottawa's Traffic Control Centre and used to generate predictive signal phase and timing data. The in-vehicle unit (IVU) components then used standard Internet communication protocols used for data exchange, known as REST API. Through that request, the TTS backend identified the specific approach and signal the vehicle was heading towards and provided signal status and timing information.

The in-vehicle unit (IVU) used for the project were designed to use commercial off-the-shelf (COTS) components purchased from local retailers or online, as shown in Figure 4. It was important that the project investigated whether common technology could be used to provide a GLOSA service which would not require new vehicles or expensive equipment to be procured, thus removing potential barriers for adoption by other jurisdictions or being made available to the general public.

In total, the cost of the IVU was approximately $250 and included a base model mobile phone (Samsung J3 - $200); a Bluetooth on-board diagnostic dongle (OBD - $20) that connects to a vehicle's OBD-II port which reports engine performance data up to every second; and a heads-up display unit that could be placed on the dashboard ($25), along with a cellular data-only plan for requests and receipt of GLOSA data. If monitoring of fuel consumption via the OBD is not required and a driver is able to use their existing mobile phone, the per-vehicle cost is essentially limited to the heads-up unit and data plan.

Given the uniqueness of the EcoDrive II project, the City of Ottawa Traffic Management Branch built a custom Android app to support the in-vehicle equipment, as shown in Figures 5 and 6. This approach was taken to enable future enhancements and allow the City to conduct further research, as well as expand the potential applications this technology could be applied to. The Android mobile app was used for six specific functions which included:

- Getting the phone's current date and timestamp data to be included as part of each new record written to the logfile every second by the app.
- Using the built-in functionality of Android phones to retrieve location information such as the latitude, longitude, GPS speed, and vehicle bearing (based on each new lat-long point recorded) of the vehicle.
- Collecting the OBD data including vehicle speed (km/hr); engine revolutions per minute (RPM); Fuel rate (L/hr) and Mass Air Flow (MAF); Intake Temperature and Intake Pressure; Instantaneous fuel consumption rate (L/100km); Fuel consumed while driving and while idling (L); Driving time and idling time in minutes; Distance travelled (km); and count of hard accelerations and decelerations.
- Making a request for the approaching signal by sending the vehicle's current location and heading, and then processing the responding data sent.
- Updating the Android app user interface to display the current GLOSA data.
- Logging all the above data to a comma-separated file which could be submitted upon completion of the day's activities.

System Considerations

Given that the application was being deployed in a live and operational environment, a number of provisions and system considerations were built into the EcoDrive II app. Safety of the drivers was paramount and limiting the potential for distracted driving through a simple and clean user interface was important. When and how content would be displayed to the driver was equally reviewed, to ensure they would be focused on the traffic signal in crucial decision-making situations.

To effectively use and maximize the benefits of GLOSA, scenario training in advance of deployment was conducted with all drivers. All told, a number of considerations were used during the project, as described below.

- For approaching a green light, the app provided the minimum GLOSA value to reach the stop line before the light switches to red. When the GLOSA value was very small, it indicated that the driver would easily reach the stop line before the phase change. In a fully operational system, this speed value would likely be hidden from the driver to indicate that no recommendation is needed.

- While the GLOSA speed on approach to a green light was a simple task, the more significant challenge was how to effectively handle the potential of vehicle queues at red lights. Since there was no information with regards to the queue length at a red light, the project team developed a pre-set time buffer that would reduce the suggested speed and provide a GLOSA value that would result in the vehicle reaching the stop line at a configurable time **AFTER** the red light switched to green. By adding this buffer, it would allow for some clearance of queued vehicles prior to the vehicle's arrival at the intersection. The configurable value was set to 10 seconds for through travel and 5 seconds for left turn movements.
- On the safety front, at least 5 seconds before any signal phase change, the app screen icons changed to yellow as an indication to the driver that they should pay attention to the traffic signal and not the app display.
- If the vehicle's speed ever exceeded 95 km/hr, the app stopped displaying information to the driver. This was added since the vehicle would likely have been travelling on a highway and there were no signals present on other roadways with a speed limit of that level within the City. When the speed dropped below the threshold, the app would resume making displaying GLOSA data to the driver.
- In addition, the project team sought to reduce the potential for speeding or making recommendations to exceed the posted speed limit, while not wishing to be overly restrictive and preventing the driver from receiving a GLOSA value for testing purposes. Using a local file stored within the app that contained the posted speed limit, and given the drivers were all hand-picked City staff, the app limited the GLOSA speed displayed to slightly above the posted speed.
- The driving profile of the test vehicles were known to include extended periods of idling while conducting traffic inspection or installation work. The log files were designed to separate fuel consumption while the vehicle is moving (e.g., OBD speed > 0) and when the vehicle was at rest (e.g., OBD speed = 0). However, a further level of disaggregation was needed for the idling fuel consumption to separate out idling time while commuting between locations (e.g., at a signal or stop sign) versus while parked. In considering maximum cycle lengths and the likely length of idling, the project team developed a "90-second idle" concept that would only accumulate the fuel consumed under idle for the first 90 seconds after the vehicle came to a stop. The 90-seconds time period would reset every time the vehicle registered any non-zero speed value from the OBD, so a vehicle in stop-and-go traffic conditions would reset the counter after every vehicle moment.

Project Findings

The focus of the EcoDrive II project was to evaluate the potential benefits of GLOSA and collect data both with and without GLOSA being displayed to the drivers. Engine performance and fuel consumption data was collected throughout the eight-week testing period, but GLOSA data was alternatingly hidden/shown to the driver during the first five weeks of the data collection period each week. Due to the variability of weather and temperatures during May and June in Ottawa, this method was chosen to enable comparative analysis of fuel consumption should drivers use the heater or air conditioning. The final three weeks of the testing period always provided GLOSA data to the drivers and yielded an opportunity to evaluate if there were incremental benefits and changes in driver behavior from longer term use of GLOSA.

An analysis that included all data gathered during the testing period quantified the “real world” savings that an organization could expect from GLOSA with vehicles performing normal duties. This analysis looked at the overall fuel consumption (including idling while at a work site), only while the vehicle was in motion, and a “90-seconds of idle” which only considered the first 90-seconds of idling fuel consumption after the vehicle came to rest and thus encompassed idling at stop lights and filtered most other idling fuel consumption.

During the data collection period, a total of 23,980.3 kilometers were driven by the test vehicles, with a total of 4,660.05 litres of fuel consumed, as shown in Table 1. This yielded an overall fuel consumption rate of **19.432 L/100km** during the data collection period. Given the large amount of time and variation in the time vehicles spent idling during GLOSA and non-GLOSA weeks, the “drive time” fuel consumption was examined. A total of 3896.86 litres were used while moving and 763.19 litres while at rest, which yielded a “driving only” fuel consumption rate of **16.25 L/100km**.

This baseline information was then used to break down fuel use into weeks when the driver was presented GLOSA information on the user interface and weeks where the GLOSA information was not presented. A savings in the fuel consumption rate was found when GLOSA data was presented to the pool of drivers of approximately ***2.5%, or about 0.48 L/100km*** (non-GLOSA of 19.754 versus GLOSA of 19.274)***.*** When only fuel consumed while driving was considered, there was ***almost a 3 percent*** reduction (non-GLOSA of 16.579 versus GLOSA of 16.087), with individual drivers seeing results of between zero and over fourteen percent.

To determine the scale of potential savings from GLOSA for typical municipal operations, the project team believed that an analysis of the overall fuel savings achieved by the fleet during their normal daily operations when comparing Week 1 versus Week 6 would also be valuable. This analysis respected the use of the “90-second idle” criteria to filter out non-driving related idling. Vehicles during Week 1 consumed 374.5L of fuel over 2127km of travel, while they consumed 669.7L of fuel while driving 4005.9km during Week 6, as shown in Table 2. This amounted to a savings of ***five (5) percent or 0.883 L/100km***.

To analyze the specific influence of GLOSA data availability on fuel savings, the project team further excluded all travel periods where GLOSA data was not available (e.g., highways, local roads, signals where GLOSA was not reporting values, etc.), as well as used only the 90-seconds of idle after each time a vehicle came to a stop. In isolating the dataset exclusively to areas of GLOSA availability, the study found that GLOSA could influence drivers and yield fuel savings of slightly more than 7 percent, when comparing Week 1 of the data collection (without benefit of GLOSA) versus Week 6 where the drivers were shown GLOSA information in the Android app. The average fuel consumption showed an improvement of 7.6% reduction in L/h fuel consumption and 7.8% reduction in L/100kms for all seven vehicles and all road types.

The team also reviewed fuel model curves and computed the average speed of the analyzed data to verify to ensure that the data was comparing similar datasets. For example, knowing the typical Consumption vs. Speed curves of internal combustion engines, there is a convex shape to the curve, such that the L/100km fuel consumption rate is much higher at lower speeds, and this pattern was verified in the collected fuel data. In the Week 1 versus Week 6 comparisons, the average OBD speeds were 33.32 and 32.63 km/hr, respectively, suggesting that there would be a negligible effect of differing vehicle speeds from having GLOSA.

The study found that providing GLOSA information to drivers in order to reduce fuel consumption was impacted by four key factors which included (1) acceptance of the technology and the willingness of the driver to adjust their driving habits; (2) existing traffic volumes; (3) road class the vehicle was travelling on; and (4) weekly tasks.

Technology Acceptance

Despite technology being ever-present in today's world, not everyone is comfortable or willing to adopt new technology. This is especially true when it is combined with driving activities, such as with GLOSA, where periodic monitoring of the advisory speed by the driver is required. The EcoDrive II project's test drivers spanned a wide range of ages and area of travel in the City and, as a result, each driver adopted the technology to a different degree.

The oldest driver indicated they rarely used the data to adjust their travel habits and this resulted, as expected, in no change in their fuel consumption, whereas the youngest and most engaged driver fully adopted the technology, so much so, that they offered to continue collecting data over the summer in order to continue having access to the system. This engaged driver saw benefits of a 14.4% reduction in fuel consumption, and this scale of savings could be what is possible if an autonomous vehicle would have its travel speed managed by the network, as shown in Table 3.

Existing Traffic Conditions

The capability of a driver to adjust their speed to match the advisory GLOSA speed is dependent on the existing traffic volume, with greater flexibility in being accommodative under lighter traffic service levels, as shown in Table 4. This is demonstrated by the time of day analysis of our highly engaged driver results that had off-peak hours indicating a savings up to 18.0%. The lunch period for this driver showed savings of 13.6% and morning peak hours of only 9.8%, which is consistent with increased traffic volumes during those periods. Note that specific analysis of whether the travel during these times were with or against the peak direction of travel were not performed.

Road Classification

The effect of GLOSA when used on roadways with different classifications was also investigated. Results show that GLOSA had a greater influence on collectors than roadways classified as arterials. The fuel consumption reduction in L/100kms was found to be 6.8% for arterials versus 16.5% for collectors. This difference was partially attributed to the absence of traffic congestion on collectors and thus the ability to adjust one's travel approach speed more dramatically towards a traffic signal. In addition, signal timings would show preference towards traffic on the arterial (or higher-class roadway), thus reducing the potential benefits from GLOSA on arterials.

Weekly Tasks

As part of regular municipal operations, there is a variation in weekly tasks that staff are required to undertake, and their locations of travel or times of travel may change. This will impact their ability to achieve savings on a regular basis. For EcoDrive II, some of the test drivers were assigned a different set of tasks daily and travelled to different parts of the City each day, while others had more contained regions to cover each day. Similarly, some of the drivers occasionally assisted in hauling portable variable message signs around the City, which changes the vehicle fuel consumption dynamics and was not a repeatable activity during this project and.

Environmental Benefits and Savings

The EcoDrive II project used the OBD data to determine fuel consumption and calculate GHG emissions, with fuel consumed being converted to GHG by using emission factors. Two different fleet types and sizes were considered to estimate the potential saving of fuel consumption and GHGs on an annual basis across a municipal fleet. The savings found from both the isolated GLOSA analysis and overall travel analysis provided a positive indication in the potential for the technology to reduce fuel consumption and reduce greenhouse gas (GHGs) emissions.

For example, a fleet of 450 gasoline engine and 450 diesel engine light duty vehicles would result in approximately 121,500 litres of combined gasoline and diesel fuel per year as a result of GLOSA, each saving approximately 0.3 L/hr of fuel (about 0.5L/100km). For a fleet of 650 heavy duty diesel trucks, approximately 351,000 litres of fuel could be saved annually, with these heavier vehicles each saving approximately 1.2 L/hr.

The reduced fuel consumption would result in 140,655 kg of CO_2 equivalent saved from each group of the 450 light duty gasoline and diesel vehicles (281,310 kg in total), and 961,817 kg of CO_2 equivalent saved from the 650 diesel trucks.

In reducing fuel consumption, the financial benefits to a jurisdiction with fleets as previously described become significant. For example, approximately $137,900 annually could be saved from the 450 light duty gasoline vehicles ($65,000) and the 450 diesel light duty vehicles ($72,900) at current fuel prices. If the 650 heavy duty diesel trucks are included, another $421,200 could be saved annually in fuel expenses.

Of course, there are other spin-off financial benefits available that are harder to quantify at this time as a result of reduced CO_2 equivalent emissions, from improved health of residents to ease demands on our health care system, and to lower pollution in the lakes and rivers that will ease required clean-up and climate change impacts to offset.

Summary

The EcoDrive II project demonstrated the opportunity that a cellular-based vehicle-to-infrastructure deployment of GLOSA could generated in a real-world municipal fleet environment and the potential benefits for fuel savings and reduced emissions. With savings of approximately ***five (5) percent or 0.883 L/100km***, and greater savings for highly engaged drivers, both financial and environmental benefits were demonstrated from use of the technology.