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Surtrac for the People:

Upgrading the Surtrac Pittsburgh Deployment to incorporate Pedestrian Friendly Extensions and Remote Monitoring Advances

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FINAL RESEARCH REPORT

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1. Project Overview

This report summarizes work performed and results obtained under the Mobility 21 University Transportation Center project titled: *Surtrac for the People: Upgrading the Surtrac Pittsburgh Deployment to incorporate Pedestrian Friendly Extensions and Remote Monitoring Advances*. This project was initiated with the goal of upgrading the Pittsburgh Surtrac deployment to incorporate recent technical advances that have been made as the Surtrac technology has been further developed and deployed in other cities, ultimately to set the stage for subsequent transfer of responsibility for system operations from Carnegie Mellon University (CMU) to The City of Pittsburgh's Department of Public Works (DPW). The work has been carried out jointly with in-kind support from Rapid Flow Technologies, a CMU spinout company that is the commercial supplier of Surtrac.

The Pittsburgh Surtrac deployment currently includes a network of 50 intersections in the East End of the city (see Figure 1). It has grown incrementally over the past 7+ years, starting with an initial 9 intersection field test in July 2012, then adding 9 more intersections in 2013, 7 more in 2014, 24 more in 2015 and finally 1 last intersection in 2017. At the inception of this project, three different versions of Surtrac, each built on a separate software stack, were running in different portions of this road network. Additionally, none of these initial Surtrac variants provided the ability to synchronize the traffic signals controlled by Surtrac with any pedestrian signals also present at the intersection, and safe and efficient movement of pedestrians has been an important priority with the City of Pittsburgh's Department of Mobility and Infrastructure (DOMI).

Over the past eighteen months, all major objectives of the project have been achieved, resulting in the following accomplishments:

- The Surtrac processor running at each of the 50 intersections has been rebuilt from the operating system up, and Rapid Flow Technologies' current Surtrac Alpine release (henceforth referred to as Surtrac 2.0) has been installed and tested at all 50 intersections. Customized configurations have been developed for those intersections that previously required master/slave coordination with their neighbors, due to their tight spatial proximity to one another.

- As part of the Surtrac 2.0 system, an extension that synchronizes Surtrac decisions to extend or change the current phase with any pedestrian signals at the intersection has been included. We expect this extension to increase the amount of pedestrian walk time at an intersection by upwards of 50% at some intersections.

- Rapid View, a graphical tool for remotely viewing the status and performance of Surtrac controlled intersections, has been configured for use with the Pittsburgh deployment and has been provided to the City of Pittsburgh DPW Signal Shop for their use at their backend traffic management center.

At this point, 20 intersections are actively running Surtrac 2.0, and activation of the remaining

30 intersections is proceeding. Discussions have been initiated between DPW and Rapid Flow Technologies regarding establishment of a support contract for continued Surtrac maintenance at these 50 intersections, and the 150 additional intersections that are anticipated to be added in the next couple of years as part of the City of Pittsburgh "Smart Spines" initiative.

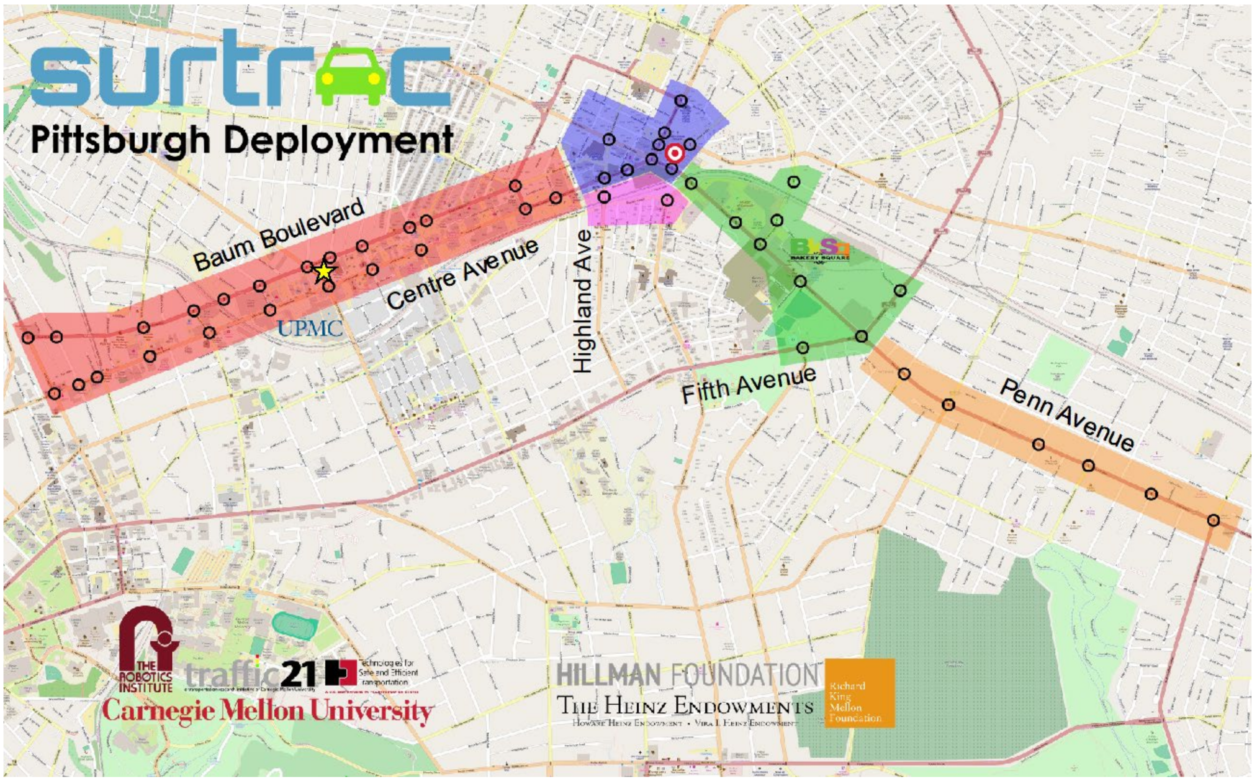

Figure 1: Pittsburgh's Surtrac Deployment.

In the remainder of this report, we describe the enhancements made to the Pittsburgh Surtrac deployment in more detail, and its current status.

2. Pedestrian Friendly Walk Times

One of the principal new features incorporated into the Surtrac 2.0 release is a mechanism for synchronizing the pedestrian walk signals at the intersection (if they exist) with the traffic signal phases that are dynamically determined by the system. When Surtrac was originally deployed in Pittsburgh, pedestrian walk signal durations were set to the intersection's respective minimum time constraints. Consequently, whenever the timing plans generated dynamically in real-time by Surtrac to match actual traffic demand exceed these fixed phase minimums, pedestrian walk signals incorrectly communicate "don't walk" to waiting pedestrians when in fact the traffic signal in the crossing direction is still green. The result is that pedestrians are often given substantially less time to "legally" cross (as dictated by pedestrian walk signal displays) than is actually available.

To better understand the issue, Figure 2 graphically depicts the constraints associated with programming pedestrian walk signals. The signal repeatedly cycles through three display states: *walk*, *flashing don't walk*, and *don't walk*. Each cycle proceeds according to the following timing constraints:

- Fixed walk period - When the corresponding traffic signal phase begins, the pedestrian walk signal enters the *walk* state for a fixed time interval, correspondent with the minimum green time constraint in force at the intersection.
- Variable walk period – Subsequent to the fixed walk period, there is an additional variable walk period before the signal state transitions to *flashing don't walk*. The length of the variable walk period is the one parameter that can be dynamically adjusted in real time.
- Flashing don't walk period – Upon transition of the pedestrian signal to *flashing don't walk*, it stays in this state for a fixed, pre-specified period of time, designed to convey to the pedestrian that the crossing phase is about to end.
- Don't walk period – Once the *flashing don't walk* period expires, the pedestrian signal transitions to the *don't walk* state, and stays in this state until the beginning of the crossing phase on the next traffic signal cycle.

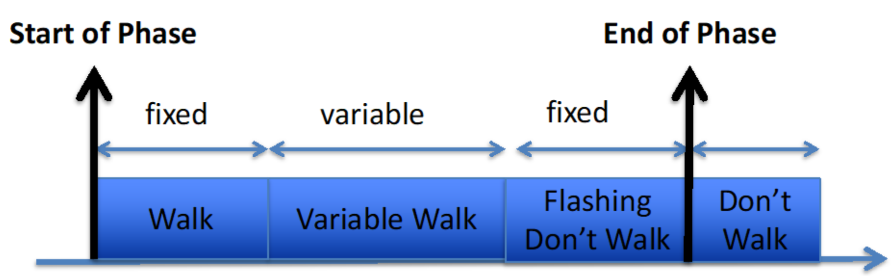

Figure 2: Pedestrian signal cycle

For conventional fixed timing plans, the variable walk period in each direction is simply set to its predetermined value, and the pedestrian signals are preprogrammed once in advance. However, synchronization with Surtrac controlled intersections is more complex. Once the minimum green time is reached on any given phase, Surtrac continuously recomputes its timing plan and every 1-2 seconds it issues a new command to the hardware controller to either (1) stay in the same phase or (2) switch to the next phase. Thus, the simple strategy of simply extending the pedestrian signal's variable walk time each time a new command is issued to the controller to extend the current phase will not work. Upon receipt of a switch to the next phase command, the controller will immediately transition the traffic signal to the next phase and a message to the pedestrian signal to end the variable walk period will not leave enough time to execute the *flashing don't walk* period, and compromise pedestrian safety. In essence, Surtrac's second-by-second decisions on phase durations give it too much adaptive flexibility and this flexibility must somehow be curtailed to enable safe pedestrian crossing.

To overcome this problem, an extension aimed at advance estimation of the end of the phase was developed and incorporated. The basic approach is as follows. Each time Surtrac generates a new timing plan, the plan is examined to determine its prediction of when the next phase change will occur. Whenever, this prediction falls below the time required for the mandatory *flashing don't walk* period (plus some small epsilon), we take that as an indication that the controller should tell the pedestrian signal to start *flashing don't walk*. Of course, this is in no way guaranteed to be a good prediction of when Surtrac will actually (later) decide to end the phase – one of the virtues of a real-time adaptive signal system is that it can change its mind (e.g., as a large platoon of vehicles enter into its predictive view). To hedge against sensing uncertainty and the potential unreliably of a single prediction, a parameter is introduced that can be set to instead rely on the last n predictions (e.g., require 2 consecutive predictions to be below the above threshold before initiating *flashing don't walk*.

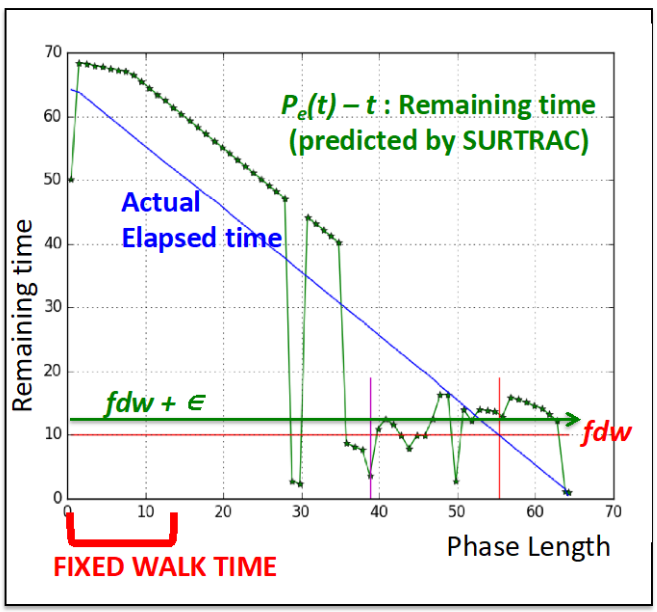

Figure 3: Determining when to initiate flashing don't walk period

More precisely, let $P_e(t)$ be the predicted phase end time in the timing plan generated by Surtrac at time t, let *fdt* be the fixed flashing don't walk duration, and let n be the number of consecutive predictions below threshold required to trigger *flashing don't walk*. Then the controller will trigger the flashing don't walk period at the pedestrian signal when the following condition becomes true:

$$\forall\ P_e(i),\ i=t, \ldots, t-n+1\ (\,P_e(i) - i < fdw + \varepsilon\,)$$

This scheme is graphically depicted in Figure 3.

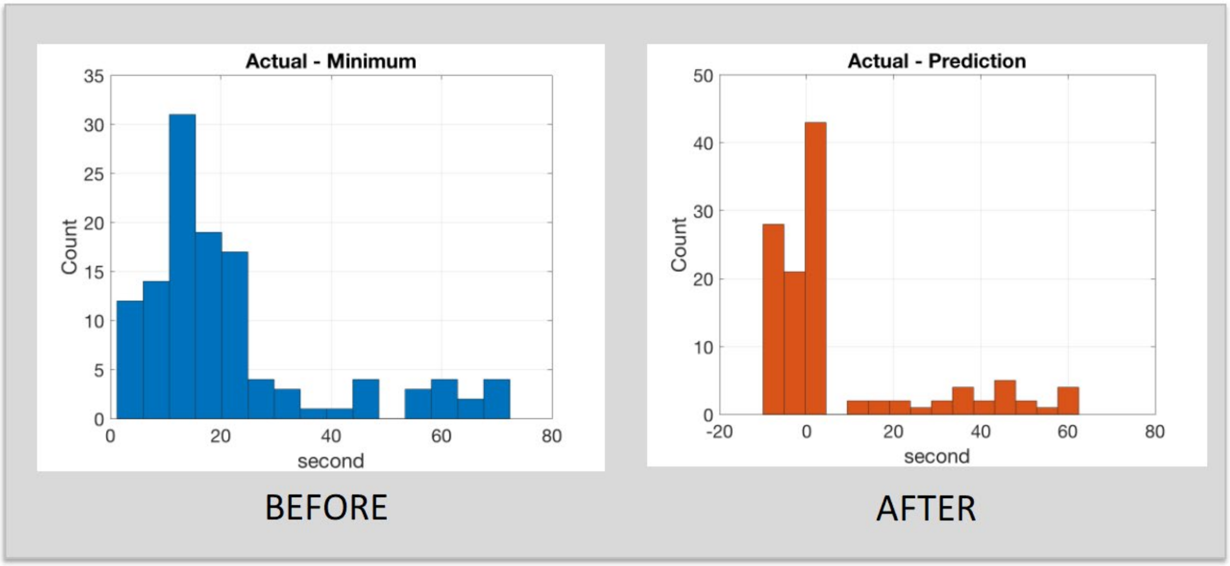

Figure 4: Distribution of cycle mismatches between the traffic signal and pedestrian walk signal at the intersection of Penn Avenue and East Liberty Boulevard (data taken 8:00AM – 10:00AM on August 31, 2017)

Note that under this basic approach, there is no guarantee that Surtrac will actually end the current phase at precisely the same time as the flashing don't walk period ends. As indicated above, it is possible that the system will perceive new approaching vehicle platoons and decide to instead extend the current phase further. In this case, the solid *don't walk* signal will still appear prematurely, but the intuition is that the amount of pedestrian crossing time that is lost is substantially less than before. Figure 4 shows results from some initial testing of the mechanism at the intersection of Penn Avenue and East Liberty Boulevard showing the distribution of cycle mismatches between the traffic signal and the pedestrian walk signal (assuming just a single below threshold prediction will trigger *flashing don't walk*). In this test, the number of cycle mismatches ≤ 10 seconds increased from 18% to 70%.

A second variant of the above scheme is also defined for use in more pedestrian dense areas where greater precision with respect to synchronization with pedestrian walk times is desired at the expense of some potential increase in vehicle delays. In this case, when the triggering condition is satisfied, the predicted traffic phase end is also locked in, and Surtrac (re)planning is suspended until the next phase starts.

3. Remote Monitoring

A second feature provided in the Surtrac 2.0 release is a recently developed remote monitoring tool called Rapid View. Rapid View provides a web-based interface for accessing information about the performance of Surtrac-controlled intersections. Most basically, it provides status information on the current operational status of various traffic control devices and processes at the intersection (e.g., whether Surtrac is in control of the intersection, running in the background for testing purposes in shadow mode, or disabled), and generates email alerts when error conditions in the network are detected (e.g. a detector is malfunctioning). Figure 5 shows the top-level graphical display for the Pittsburgh deployment.

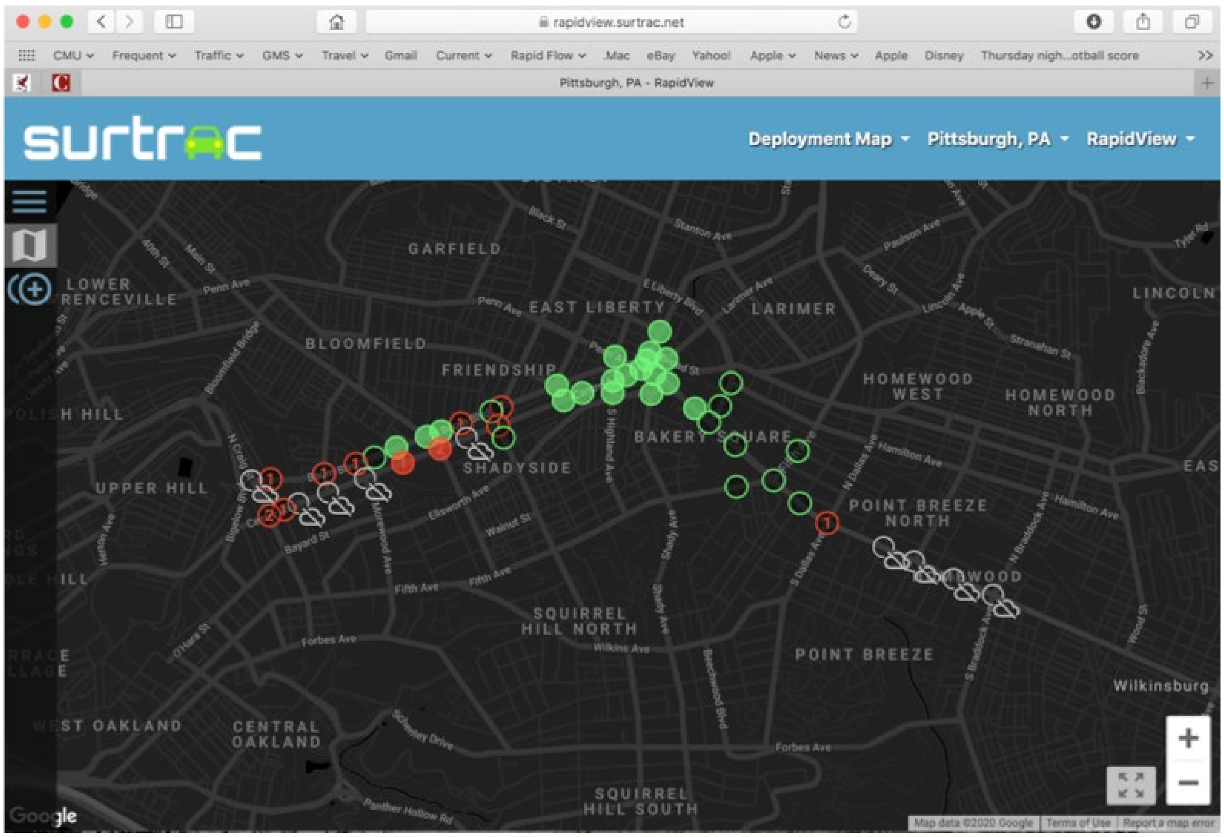

Figure 5: Rapid View remote monitoring interface

More detailed information about a particular intersection is accessible from this display by clicking on the intersection of interest on the map. Figures 6-9 illustrate the types of information that are available, in this case for the intersection of Penn Avenue and Centre Avenue in the heart of East Liberty. The basic information has been selected in Figure 6, and summarizes the current operational state of the intersection.

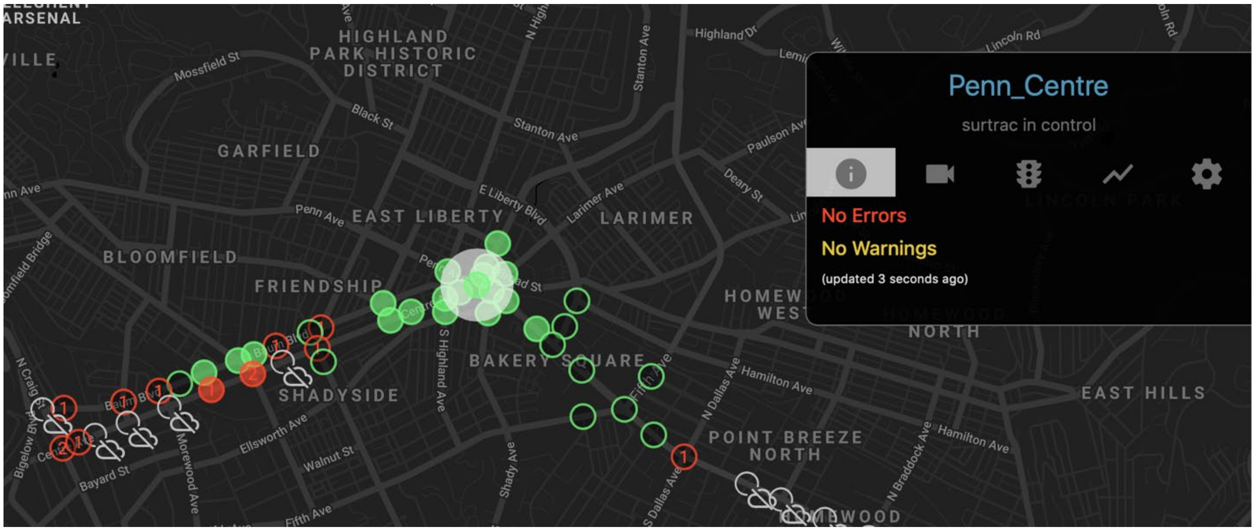

Figure 6: The intersection information tab

Selection of the camera icon (shown in Figure 7) provides a real-time video feed of traffic approaching the intersection from different directions (for those intersections that are using cameras for detection).

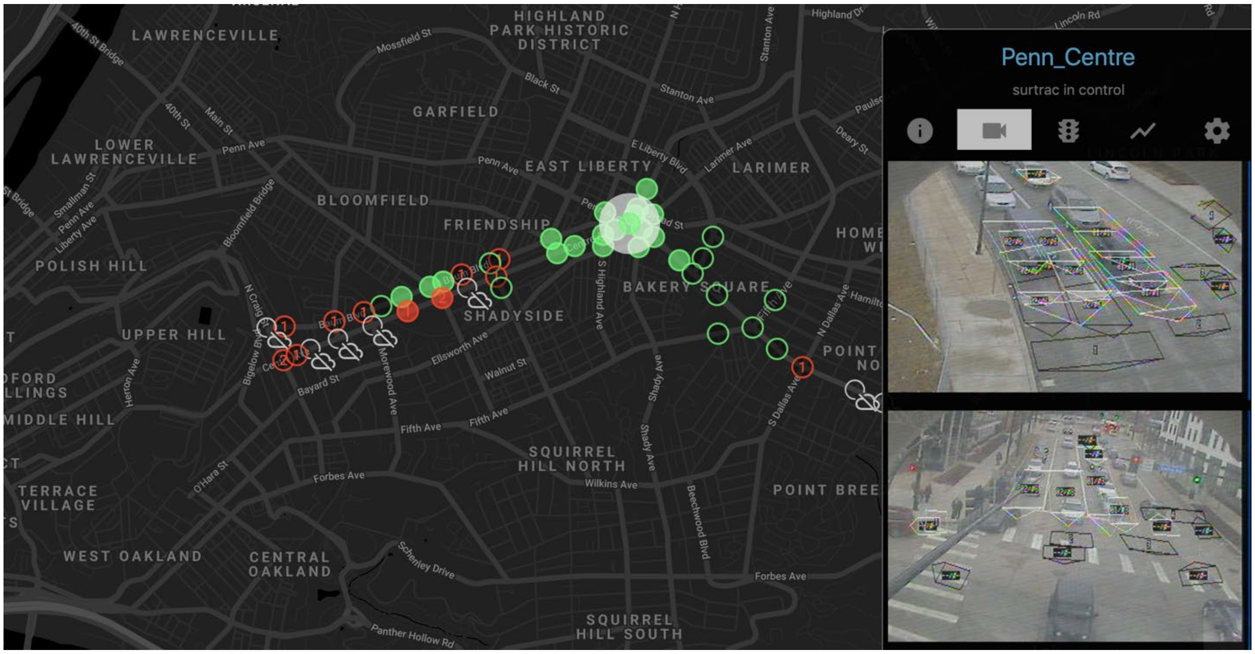

Figure 7: Real-time video streaming of approaching traffic

Selection of the traffic signal icon (shown in Figure 8) gives real-time information on the state of the traffic signal at the intersection. In the example displayed in Figure 8, we can see that the intersection of Penn and Centre is currently servicing phase (2,6) – bi-directional east/west vehicle flows – and relevant parameters are displayed.

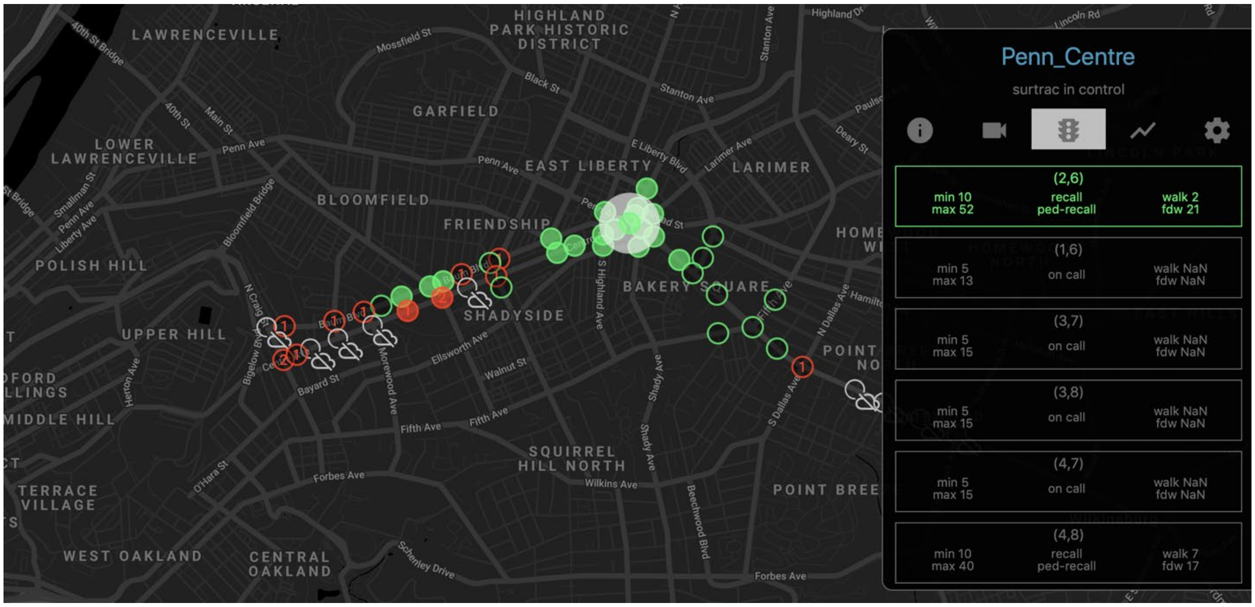

Figure 8: Current traffic signal state.

Finally, selection of the statistics tab (shown in Figure 9) produces visualizations of recent behavior and performance trends at the intersection, including recent phase durations by cycle (over the last *n* cycles), recent vehicle wait times along each approaching edge (expressed as rolling averages), and vehicle counts along each edge (also expressed as rolling averages).

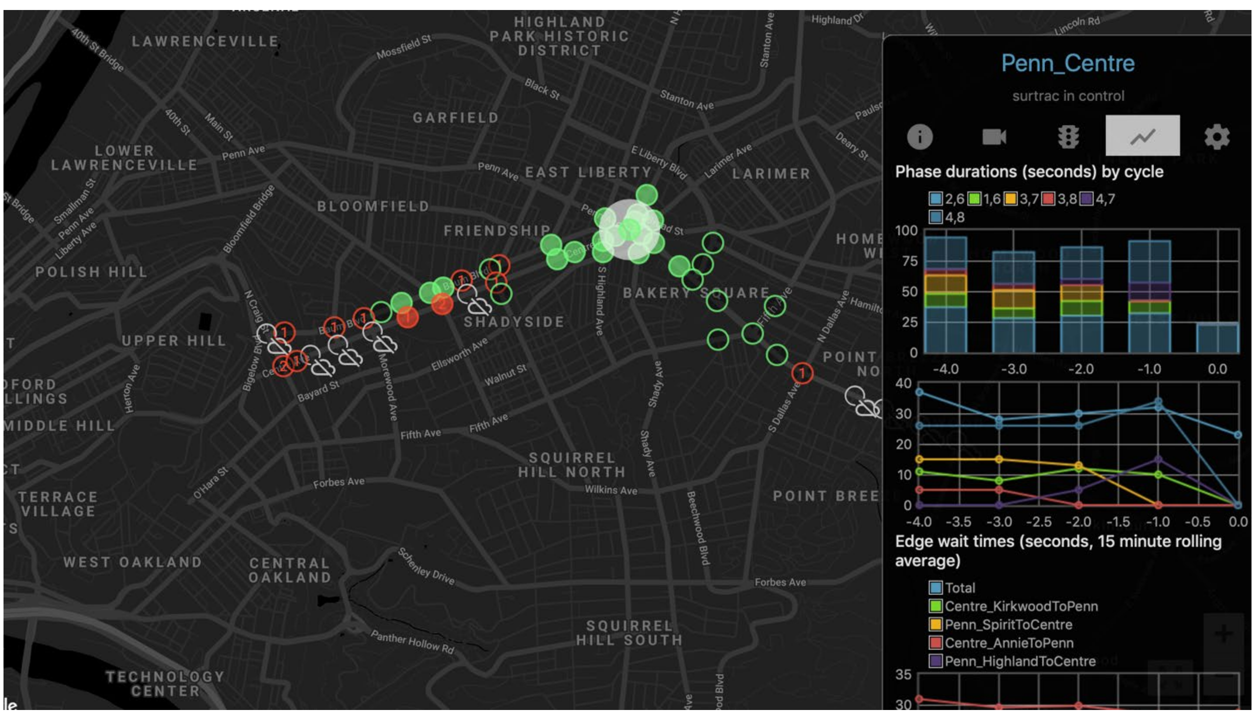

Figure 9: Measurement of recent traffic flow behavior at the intersection

4. Other Algorithmic Improvements

The Surtrac 2.0 release also incorporates a number of more recent improvements to the core Surtrac optimization algorithms. These improvements include:

- Use of downstream congestion information – To better address circumstances when the volume of traffic on the road network approaches saturation (and the intersection control problem becomes less of a scheduling problem and more of a problem of managing queues), local and downstream queue length information is used as a basis for weighting clusters associated with different intersection phases, and a softmax function is introduced that increasingly biases intersection scheduling decisions toward managing queues (i.e., favoring phases that have the largest queues) as congestion increases. Details, along with comparative performance results, can be found in [Hu and Smith 2017a, 2017b].

- Use of higher fidelity predictive models of traffic flows – The Surtrac 2.0 release incorporates modeling extensions that remove several restrictive assumptions that were made in prior versions and improve the system's core ability to minimize cumulative delay. These include use of a richer, lane based model of approaching traffic, and separate consideration of the cluster sequences associated with different compatible movements in a given phase. Some comparative performance analysis of these types of modeling extensions can be found in [Goldstein and Smith 2018].

- Learning-based optimization of model parameters – Finally, although not directly incorporated into the Surtrac scheduling engine, a reinforcement learning technique has been developed for establishing model parameters such as maximum phase duration constraints that best fit the traffic demand patterns of a given deployment. The technique is applied to a microscopic traffic simulation model of a prospective deployment, and the parameters that are derived are then incorporated into the intersection configuration files that get loaded in the field as part of the deployment. For details, please refer to [Hu and Smith 2020].

For information on current efforts to integrate the current Surtrac 2.0 release with sensing received directly from connected and autonomous vehicles see [Smith 2020].

5. Surtrac 2.0 Upgrade Status

The following accomplishments have been made toward completing the planned upgrade of the Pittsburgh Surtrac deployment to the Surtrac 2.0 release:

- A new software stack has been installed on all 50 Surtrac processors in the field. This includes (1) a more recent version of the Linux operating system necessary to run Rapid View, (2) the CHEF configuration management tool now used to remotely install and configure new versions of Surtrac, and (3) the Surtrac 2.0 release.

- Configuration files have been generated for all 50 intersections and distributed to respective Surtrac processors in the field.

- Extensions to the Surtrac 2.0 release have been made to enforce "master/slave" constraints between neighboring intersections in close proximity to each other. These constraints were supported and necessary in the original version of Surtrac that was installed in Pittsburgh, but had never previously been needed for deployments in other cities and hence was never added to the re-engineered Surtrac 2.0 release.
- Intersections have been brought online and tested incrementally, starting with the original core intersections in the heart of East Liberty and subsequently working both east along Penn Avenue toward Point Breeze and west along Baum Boulevard and Centre Avenue toward Oakland.
- Detection zones have been checked at intersections as they have been brought online and recalibrated as necessary to match changes that have occurred in traffic patterns (e.g., the opening of Spirit avenue onto Penn Avenue across from the target Department store, the introduction of bike lanes along Negley Avenue where it crosses Baum Boulevard and Centre Avenue).

As mentioned at the outset of this report, 20 intersections are currently operational and actively controlling traffic on a daily basis. Another 12 intersections are currently running in shadow mode (i.e., running in the background but not actually controlling traffic) to confirm that they are functioning properly, and it is expected that these intersections will be put into active mode in the near future. Activation of the remaining intersections is currently blocked waiting for repairs to malfunctioning communication radios and adjustment of selected detection devices, both of which require the assistance of City of Pittsburgh DPW personnel and equipment. Rapid Flow Technologies is in communication with DPW about these issues, and we expect the entire 50 intersection Surtrac 2.0 traffic network to be up and running within the next month or so, depending on weather. In the meantime, the Rapid View remote monitoring tool has been installed in the DPW Signal Shop, and training in its use has been provided to DPW personnel. Rapid Flow Technologies and the City of Pittsburgh Traffic Engineer are currently in discussions regarding transfer of responsibility for maintaining the system from Carnegie Mellon University to Rapid Flow.

Associated Publications

Goldstein, R. and S.F. Smith, "Expressive Real-Time Intersection Scheduling", *Proceedings 26th Annual Conference of the Association for the Advancement of Artificial Intelligence*, New Orleans, LA, February 2018.

Hu, H-C and S.F. Smith, "Learning Model Parameters for Real-Time Traffic Signal Optimization", *Proceedings 30th International Conference on Automated Planning and Scheduling*, Nancy France, to appear, June 2020.

Hu, H-C, S.F. Smith and R. Goldstein, "Cooperative Schedule-Driven Intersection Control with Connected and Autonomous Vehicles", *Proceedings IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019)*, Macau, China, November, 2019.

Hu, H-C and S.F. Smith, "Bi-Directional Information Exchange in Decentralized Schedule-Driven Traffic Control", *Proceedings 29th International Conference on Automated Planning and Scheduling*, Berkeley CA, July 2019.

Hu, H-C, and S.F. Smith, "Coping with Large Traffic Volumes in Schedule-Driven Traffic Signal Control" *Proceedings 27th International Conference on Automated Planning and Scheduling*, Pittsburgh, PA, June 2017.

Hu, H-C and S.F. Smith, "Softpressure: A Schedule-Driven Backpressure Algorithm for Coping with Network Congestion", *Proceedings 27th International Joint Conference on Artificial Intelligence*, Melbourne, Australia, August 2017.

Smith, S.F., "Smart Infrastructure for Future Urban Mobility", *AI Magazine*, 41(1), Spring, 2020.