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A toolkit for measuring connected vehicle project benefits

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Abstract
We propose a practical and robust toolkit for evaluation of connected vehicle (CV) programs which can produce quantifiable data and related analysis necessary to determine the cost effectiveness of CV deployments. This toolkit will improve the rigor of CV program monitoring and provide stakeholders a mechanism for calibrating CV investments against real-world results. To demonstrate how the toolkit can be applied, we select two possible areas of study from an ongoing Panasonic Vehicle to Everything (V2X) deployment in Orem, Utah, which includes measurement of Bus Mobility and Emergency Vehicle Mobility benefits. The methodologies and data sets we suggest in this toolkit are broadly suitable for a range of related CV topics and could readily be applied to research into snowplow mobility, for example, or could be further extended to freight mobility or related use cases with minor modifications.

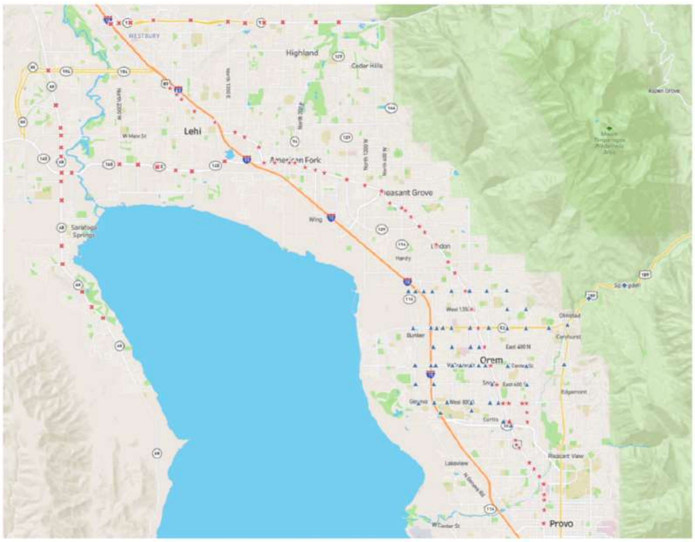
Keywords: V2X EFFICACY, TSP, EVP

About the Orem V2X Enclave project

In partnership with the Utah Department of Transportation (UDOT), Panasonic's Smart Mobility Office has embarked on a deployment of V2X communication technology in and around Orem, Utah ("the Orem V2X Enclave"). This project is part of the larger UDOT Connected Vehicle Ecosystem and is designed to add scale to Utah's V2X capabilities. Current project phases are focused on connected intersection preferential treatment (CIPT) applications such as transit signal priority (TSP), emergency vehicle preemption (EVP), and snowplow signal preemption. The research methodology proposed in this paper was developed to quantify the practical benefits of UDOT's V2X investments by analyzing defined vehicles and routes near a dense, live deployment to understand real-world impact.

The technology deployment includes a total of 134 roadside units (RSU) as well as 151 vehicles equipped with onboard units (OBU) that are expected to drive around the Orem V2X Enclave deployment locations and the nearby surrounding area. The team selected most RSU installation sites within an approximate 11-square-mile area of Orem City proper as well as at signalized intersections along a main bus route that connects Lehi, UT, to Provo, UT, via seven bus stations/stops (UTA Bus, 2021), that are frequently traversed by vehicles of interest. In addition, several common snowplow routes are equipped near the Orem V2X Enclave to serve snowplow preemption requests during adverse weather conditions. Figure 1 illustrates the geographical reach of the RSU deployment and the proximity of the Orem V2X Enclave (represented by blue icons) to the CIPT-specific deployment locations (represented by red icons). The OBUs are targeted to be installed in a variety of public works vehicles, many of which include public transit buses, fire trucks/response SUVs, ambulances, and snowplows that operate throughout the project area.

Many of these vehicles will also have access to signal priority and preemption functionality through V2X applications, which are capable of triggering CIPT functionality at any connected intersection in the Orem V2X Enclave or surrounding CIPT deployment. Of note, but not addressed with detail in this proposal, human machine interface (HMI) devices will also be installed in select vehicles to enable driver messaging. This will provide more opportunity for future research designs to be added to this toolkit.



Deployment	Application	RSUs
Orem V2X Enclave	◆ BSM Collection, TIM Broadcast	2
	▲ CIPT (General), BSM Collection, TIM Broadcast	50
CIPT	▲ CIPT (General), BSM Collection, TIM Broadcast	1
	✖ CIPT (Snowplow), BSM Collection, TIM Broadcast	32
	★ CIPT (Transit Bus), BSM Collection, TIM Broadcast	49
Total		134

Deployment	Vehicle	OBUs
Orem V2X Enclave	Non-CIPT	80
	CIPT Snowplows, Fire Response, Ambulances	20
CIPT	CIPT Transit Buses	34
	CIPT Snowplows	17
Total		151

Figure 1: Illustration of RSU deployment in the Orem V2X Enclave

Proposed methods for measuring V2X project efficacy

We propose key research questions which can be used to quantify the benefits of connected vehicle technology on vehicle mobility and indirect impacts on the environment. We apply these mechanisms in this paper specifically to measure Bus and Emergency Vehicle Mobility outcomes.[1] However, our methodology and suggested data sources could be extended to other lines of investigation to suit future projects. We also briefly propose relevant avenues of qualitative investigation.

Current research questions

The following research questions directly correlate to the core issues stakeholders will investigate when selecting among competing project ideas for allocation of limited funding. We separate these research inquiries into sections to clarify our proposed approaches to studying the outcomes.

1. Bus Mobility (BM)
    - BM.1 – Do buses requesting prioritization (TSP) receive it?
    - BM.2 – How does bus prioritization (TSP) impact schedule reliability?
    - BM.3 – Does bus prioritization (TSP) reduce bus intersection stops or idle time?
    - BM.4 – If so, what is the estimated cost savings in terms of fuel consumption?
2. Emergency Vehicle Mobility (EVM)
    - EVM.1 – Do emergency vehicles requesting preemption (EVP) receive it?
    - EVM.2 – Does emergency vehicle preemption (EVP) improve incident response time?

[1]These questions will build on a prior TSP study sponsored by UDOT (*see* Schultz et al., 2020).

Data

The following table provides an aggregate view of the data which we target for our study.

Table 1: Description of data[2].

Data Type	Description
Basic Safety Message (BSM)	Packet of data containing information about a vehicle's state and location
Signal Request Message (SRM)	Message sent by a vehicle to an RSU to request signal priority or preemption at an intersection
Signal Status Message (SSM)	Message sent by an RSU in an intersection that an active request for priority or preemption has been received
Signal Phase & Timing (SPaT)	Message communicating the current signal phase of an intersection by lane
MAP	Message communicating the geometry of an intersection
Automatic Vehicle Location (AVL)	Provides transit vehicle schedule, route, and ridership statistics
Route Details	Contextualizes the locational and schedule information as well as time of day details (e.g., peak time travel)
Vehicle Parking/Equip. Facility	Information on where vehicles station and/or replenish supplies
Vehicle Operator	Randomized driver ID to determine a driver change without identifying the actual driver
Dept. of Energy Fuel Costs	Time-relevant Orem, Utah, cost per gallon from the U.S. Dept. of Energy
Weather (NOAA/NWS)	Indicates or estimates road weather conditions at the time of operation

Procedure(s) – buses

We begin outlining the procedure by describing our approach for Bus Mobility research. Our approach for emergency vehicles directly follows the section. It is important to note that we identified two methods to answer the research questions. The first utilizes secondary data, while the second considers primary data. This distinction is important for many agencies facing significant resource constraints which may impact how research is designed and what type of data collection is possible. Our work attempts to reduce research costs by proposing two paths of opportunity in quantifying the impacts of CVs. Although both paths are rooted in primary research, the first path – utilizing secondary data – may be less resource intensive. The alternate path – utilizing primary data – is more resource intensive but offers a controlled approach.[3]

Utilizing secondary data

The benefit of using secondary data is that it alleviates the need for a researcher to do first-hand data collection for a study. We propose a series of questions and procedures that are sequential in design.

BM.1 - Do buses requesting prioritization (TSP) receive it?

We believe it is important to start with an analysis into the frequency of TSP events occurring in a deployment. This analysis helps to set context as well as prepare data for the subsequent studies. We start by examining the journey along one bus route, using a combination of BSM, SRM, SSM, SPaT, and MAP

[2]BSM, SRM, SSM, SPaT, and MAP data collected by Panasonic North America.
Route details, vehicle parking/equipment facility, and vehicle operator data are sought from UDOT/UTA/Orem.
AVL data is publicly available at www.rideuta.com.
Fuel cost data from U.S. Department of Energy's Fuel Economy website at www.fueleconomy.gov/feg/gasprices.
NOAA/NWS weather data available at www.weather.gov/documentation/services-web-api.

[3]Primary data are generated firsthand by the researcher. Secondary data have already been collected for another reason.

data to segment results into two groups: 1) requested TSP and received it ("Requested/Received"), and 2) requested TSP and did not receive it ("Requested/Not Received"). To develop this data, we will review all signal request messages from project buses at each RSU-equipped signalized intersection along the project bus route. Where available, the result of a request will be obtained from an analysis of SSMs sent by the traffic controller through the RSU. Where SSMs are not available or incomplete, the result of a request will be estimated using SPaT messages but may extend to traffic signal performance measurement data.

This bifurcation of the data will establish a starting point for future studies investigating situational factors that differentiate a bus requesting and receiving TSP from a bus requesting but not receiving TSP. We recommend pursuing a root cause analysis, as the identification of these factors might be influential to study outcomes. For instance, this process may reveal that non-granted TSP requests are related to competing prioritization signals, higher priority requests, the recency of previously granted requests at the intersection, the amount of time the bus is running behind schedule, and/or the queue of vehicles at the intersection.

BM.2 - How does bus prioritization (TSP) impact schedule reliability?
Using the segmentation approach in BM.1, we propose further analysis to research the extent to which TSP impacts schedule reliability. For this study, we define schedule reliability as an on-time departure[4] from a bus stop/station. Our hypothesis is that buses that can request and are granted TSP at 100-76% of signalized intersections in a one-route bus journey will have a higher frequency of on-time station departures (±5 minutes) compared to all other frequency groups of requested and granted buses (i.e., requested and granted 75-51%, 50-26%, and 25-1% of the time). Figure 2 is a hypothetical illustration of this comparison. We propose to quantify outcomes at the bus route level rather than at individual bus station/stops due to unknown but predicted variance in the number of equipped intersections that precede each bus station/stop. Subsequent work may focus on association/correlation analyses to delve into factors that are associated with realized variances among TSP bus groups.

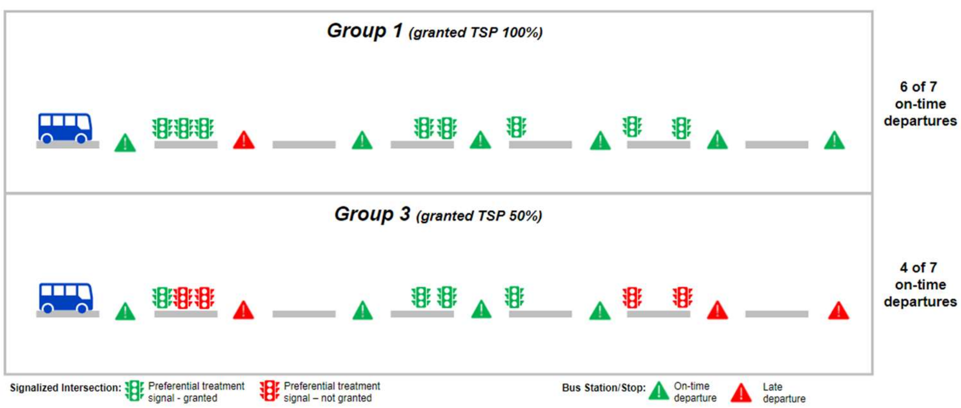


Figure 2: Hypothetical illustration for research question BM.2

BM.3 - Does bus prioritization (TSP) reduce bus intersection stops or idle time?

[4]We suggest using on-time departures rather than on-time arrivals to better calibrate results to real-world passenger expectations. Most transit agencies have guidelines which limit buses from leaving early, and passengers will typically only experience on-time or late departures (never early departures). Travel time reliability improvements, therefore, only have practical impact when they enable a bus to leave on-time more regularly (which is only a sub-set of bus arrival time). Following this recommendation precludes measuring early arrivals (but late departures from other causes) which provide no practical benefit to transit users.

Under this question, we propose to dig deeper into the data to investigate the number of times a vehicle stops or the idle time spent (in seconds) at each intersection to determine if there are group differences in 1) the number of stops and 2) the time spent idle. We hypothesize that buses which request and are granted TSP have fewer complete stops at intersections than buses that request but are denied TSP. Relatedly, such buses have less idle time at intersections than buses denied TSP. We will evaluate descriptive statistics to calculate the average number of complete stops at equipped intersections during the entire route journey by these TSP-granted segments. We will also employ a between-group comparison using a one-way ANOVA to determine if there is a statistically significant difference between the TSP-granted groups.

BM.4 - If so, what is the estimated cost savings in terms of fuel consumption?
With an understanding of the stop and idle times for the buses (and any differences that may exist), we next propose analyzing the cost impact of these differences. For the fuel expense due to a bus stop, we propose this is a function of time spent (in seconds) under a high acceleration post-stop event multiplied by gallons of fuel consumed and dollar cost per gallon of fuel. We use acceleration post-stop because it accounts for significant fuel usage (U.S. Department of Energy, n.d.). We will employ a similar calculation to determine the cost impact of time spent idle (in seconds) at the intersection. Below are proposed calculations for complete stops and idle time.

$$Fuel\ Expense\ (STOP) = seconds\ in\ high\ acceleration \times \frac{gallons\ of\ fuel\ consumed}{second\ of\ high\ acceleration} \times \frac{cost}{gallon}$$

$$Fuel\ Expense\ (IDLE) = seconds\ of\ idling\ at\ 0mph \times \frac{gallons\ of\ fuel\ consumed}{second\ of\ idling\ at\ 0mph} \times \frac{cost}{gallon}$$

Utilizing primary data
As discussed above, the creation of primary data first-hand by a researcher can be much more cost intensive in terms of time, personnel, preparation, and execution. However, the benefit of primary data is that the study is designed with the exact research intent in mind. This provides researchers with the ability to better control extraneous variables that could have an (unknown) impact on the study conclusions. Where primary data can be generated, a key question is "*How does bus prioritization (TSP) impact schedule reliability?*" in a controlled experiment. Note that BM.3 and BM.4 as presented in the former section are still applicable using a similar methodological approach; we do not repeat them here. This section solely focuses on the revised method for BM.2.

BM.2 - How does bus prioritization (TSP) impact schedule reliability?
To understand TSP impact on schedule reliability with primary data, we propose a quasi-experimental design that examines differences between a treatment and control bus group. Each bus will complete its normal route journey multiple times, targeting approximately 28 total observations per group[5]. The treatment vehicle will be a CIPT-enabled bus (a.k.a. TSP ON); the control vehicle will be a CIPT-disabled bus (a.k.a. TSP OFF). A bus will begin a one-route journey from an originating bus station (either Provo or Lehi in our Utah project). The treatment vehicle will travel the route first, requesting TSP at each signalized intersection encountered if the criteria are met for TSP to be granted. The control vehicle will travel this route second, *without* the ability to request TSP at an intersection. We propose running two test journeys each day for each group, one on-peak and one off-peak (four bus runs total a day) for a total of fourteen days or until the proposed number of observations is reached. Each iteration of the route journey will

[5]Power analysis will help to determine a suitable sample size for this proposed study once logistics are finalized (Lenth, 2006-9).

alternate which bus group goes first. The distinct journeys should be spaced enough to minimize the undue influence of disrupted traffic flows caused by a recent prioritization of another bus. It is important to match the treatment and control groups as best as possible on factors that may account for variance in the outcome (e.g., on-peak time, off-peak time, route direction). Once data are collected, we propose examining the number of on-time bus stop departures between the treatment and control groups using an independent samples t-test. Figure 3 is a hypothetical illustration of this evaluation.

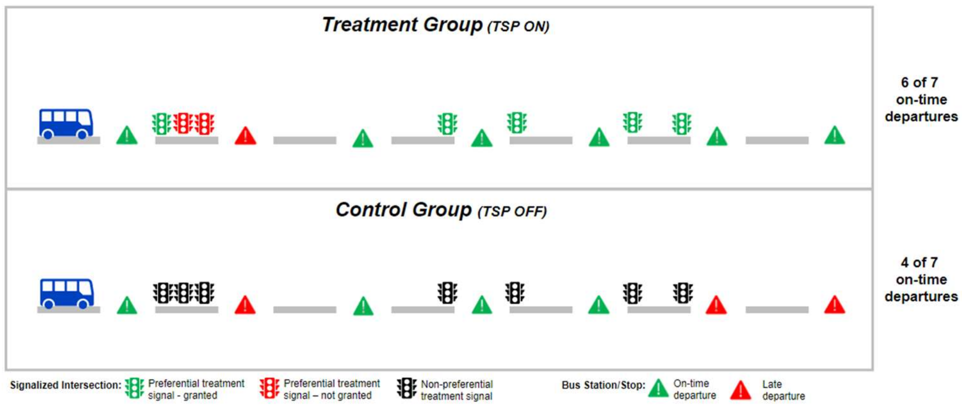


Figure 3: Hypothetical illustration of research question BM.2

Procedure(s) – emergency vehicles

We next turn our attention to assessing emergency vehicle mobility in a V2X environment. As a reminder, the Orem V2X Enclave project seeks to improve emergency vehicle operations using signal preemption (EVP). Prior research has found that using traffic signal preemption can 1) reduce time to traverse an intersection, and 2) reduce response time to the scene of an incident (NHTSA, 2006). Although these benefits have been pervasively demonstrated elsewhere, we are not aware of research proving these outcomes for EVP granted via V2X deployments. Because the technology deployment in the Orem V2X Enclave is still relatively small and does not yet cover the entire route of dispatched vehicles, we designed a methodology which uses a pseudo-environment where we simulate or estimate response times[6]. We believe this can apply to any similarly limited deployment of EVP technology.

As with the research procedures for buses, we separate our lines of inquiry into questions which are answered with secondary data and those requiring the collection of primary data. The mobility and response time of emergency vehicles are evaluated across two key questions: 1) Do emergency vehicles requesting EVP receive it, and 2) Does EVP improve incident response time?

Utilizing secondary data
The benefit of using secondary data is that it eliminates the need for a researcher to do first-hand data collection for a study. For applicable projects, we propose the following procedures to evaluate emergency vehicle-related mobility outcomes.

[6]Incident sites and routes will not always be fully contained within the targeted technology deployment area. An emergency vehicle may encounter anywhere from 0 to multiple equipped intersections. This unknown presents a challenge not realized for bus mobility evaluations in our data, as the latter travel along predictable, pre-assigned routes.

EVM.1 - Do emergency vehicles requesting preemption (EVP) receive it?
We suggest starting research with an analysis of the frequency at which EVP is granted in the deployment region. This is especially relevant to an emergency vehicle inquiry as there are many factors outside of project control which may affect the granting of EVP (e.g., jurisdictional rules, situational roadway factors, or network factors). This question is exploratory to provide contextual insights to project operations.

We propose including all requests for EVP from CIPT-enabled emergency vehicles at project signalized intersections. For our research, we include a balanced mix of firetrucks and ambulances which will operate throughout CIPT-equipped signalized intersections. Upon segmenting the data into "Requested/Received" and "Requested/Not Received," we propose a root cause analysis to examine differences in outcomes at each intersection. As with buses, this segmentation will serve as a starting point for subsequent research questions that are dependent on this split of the data. Future work may include association/correlation analyses to identify factors associated with realized variances among EVP emergency vehicle groups.

EVM.2 - Does emergency vehicle preemption (EVP) improve incident response time?
Using the segmentation approach from EVM.1, we propose further analysis to assess how EVP impacts incident response time (defined as time to traverse an intersection [in seconds] from the point of entering the signal MAP to the point of reaching an egress lane). We propose to quantify outcomes at the intersection level, as a full route is unknown or may include non-CIPT-equipped intersections. We hypothesize that emergency vehicles that request and are granted EVP will traverse the intersection faster than a comparison group. We will include all requests for EVP at all signalized intersections from CIPT-enabled emergency vehicles entering the targeted intersections in the Orem V2X Enclave. We control variance in intersection size and vehicle density at the intersection by including a multiplier to the base value of the traversal time.

Upon deriving the "time to traverse an intersection" statistic, we propose two methods to analyze whether EVP has a positive impact. The first method examines differences between the segmented groups listed above (i.e., "Requested/Received," "Requested/Not Received"). The second method is to compare the statistic for the "Requested/Received" group only and determine if the resulting statistic exceeds a statistically determined critical value which would demonstrate improvements over non-EVP emergency vehicle intersection traversal time. Specifically, we will calculate if "Requested/Received" emergency vehicles' time to traverse an intersection outperforms an industry average (as an example, 10 seconds).

Utilizing primary data
Focusing solely on time to traverse an intersection has its limitations. For instance, it does not determine impact to total response time. There exists, however, a significant limitation in aligning an emergency response route to a route equipped with CIPT-equipped signalized intersections, which makes this type of analysis difficult to pursue without a controlled study. Thus, an approach using primary data could add value to the study proposed above. We present an option for such a study below.

EVM.2 - Does emergency vehicle preemption (EVP) improve incident response time?
Using a quasi-experimental approach, we propose identifying a common route of travel for emergency vehicles within the project area, where the travel time is approximately 10 minutes from dispatch to arrival[7]. After identifying this route, we suggest preparing a scenario in which one CIPT-enabled emergency vehicle ("treatment") and one CIPT-disabled emergency vehicle ("control") is dispatched from a specified start

[7]Prior research has suggested that 7-8 minutes is the average response time for emergency medical services (Mell et al., 2017).

point to a destination ("the incident site"). The dispatching of emergency vehicles will occur in pairs. The first pair, fire trucks/response SUVs in our project, will travel the predetermined route on a specific day of the week at a specific time of the day. The treatment vehicle will travel this route first, requesting EVP at each signalized intersection it encounters. The control vehicle will travel this route second, *without* the ability to request EVP at signalized intersections. These distinct dispatches will occur one week apart to minimize variance in day of the week travel and to potentially reduce additional bias that may be introduced by disruption to traffic flow if occurring on the same day at a similar time. This process will be repeated for each pair of emergency vehicles to collect data on time to arrival at the incident site. We hypothesize that CIPT-enabled emergency vehicles that request and are granted EVP at 1+ intersections while travelling to the incident site will have faster arrival times (in seconds) than CIPT-disabled emergency vehicles that arrive at the same incident site. We will analyze differences in average time to arrival at the "incident site" using independent samples t-tests. Results may be stratified by vehicle type if sample size permits.

Proposed qualitative assessments and further study areas

In addition to studies of TSP and EVP effectiveness, our work with UDOT suggests several areas of potential study into both the quantitative and qualitative outcomes for V2X deployments. For example, detecting a crash, incident, or roadway condition early allows DOT traffic operators to post a traveler information message downstream to alert oncoming drivers. This could be via an in-vehicle system (an HMI) or traditional message boards. In either case, such warnings are anticipated to have subsidiary impacts such as reducing the number of secondary incidents (crashes into crashes, for example).

Conclusion

The targeted studies in this toolkit only represent one subset of possible benefits of connected vehicle technology. It is our hope that the identified methodologies are useful in serving as idea generation mechanisms for others who want to show value of their V2X investments, present and future.

References

1. Lenth, R. V. (2006-9). *Java applets for power and sample size [computer software]*. Retrieved June 7, 2021, from http://www.stat.uiowa.edu/~rlenth/Power.
2. Mell, H. K., Mumma, S. N., and Hiestand, B. (2017). Emergency medical services response times in rural, suburban, and urban areas. *JAMA Surgery*, 152(10), 983-984.
3. National Highway Transportation and Safety Administration (NHTSA). (2006). *Traffic signal preemption for emergency vehicles: A cross-cutting study*. Retrieved May 14, 2021, from https://www.gtt.com/wp-content/uploads/Traffic-signal-preemption-for-emergency-vehicles-A-cross-cutting-study.pdf
4. Schultz, G.G., Sheffield, M.H., Bassett, D., & Eggett, D.L. (2020). *Impacts of changing the transit signal priority requesting threshold on bus performance and general traffic: A sensitivity analysis*. Retrieved March 1, 2022, from https://rosap.ntl.bts.gov/view/dot/54889
5. United States Department of Energy. (n.d.) *Techniques for Drivers to Conserve Fuel*. Alternative Fuels Data Center. Retrieved Feb. 24, 2022, from www.afdc.energy.gov/conserve/behavior_techniques.html
6. Utah Transit Authority. (2021). *Route 850-State St. map schedule* April 2021. Retrieved May 13, 2021, from https://www.rideuta.com/-/media/Files/Rider-Tools/Route-Schedules/2021/April/850schedule_Apr2021.ashx