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SmartSAT: A customizable mobile web application toward improving the efficiency and equitable access of San Antonio's public transit services

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ABSTRACT

SmartSAT is a mobile web application designed to enhance the efficiency and equitable access of San Antonio's public transit services, providing real-time bus arrival predictions, notifying riders of seat availability, and gathering rider's feedback. It aims to leverage technology to deliver an inclusive service with potential impacts for social equality, and enhancement of overall ridership experience. Two studies were conducted to access the impact of SmartSAT on the actual bus arrival times and rider's communte experience. The findings of the arrival times analysis indicated that certain routes exhibited very slow average differences between their actual and schedule arrival times while a couple displayed a big average difference showing significant delayes and deviations from the schedules timetable. The rider experience study found that there is a differential in the feelings of access to the city's public transit system held by poor, working-class, and Latinx communities in San Antonio. These findings suggest the need for regular minitoring and optimazation of the bus schedules to improve the effieiency and inclusive access to the current transportaiton system. The outcomes of the study primarily benefit San Antonio residents, especially for underserved communities, leading to an enhancement of its transit network infrastructure.

Code metadata

Current code version	*V1*
Permanent link to code/repository used for this code version	https://github.com/SoftwareImpacts/SIMPAC-2024-125
Permanent link to reproducible capsule	
Legal code license	*MIT License*
Code versioning system used	*git*
Software code languages, tools and services used	*Python, Django, Cloud Run*
Compilation requirements, operating environments and dependencies	
If available, link to developer documentation/manual	https://github.com/mysmartsat/smartmap
Support email for questions	Jeong.yang@tamusa.edu

1. Introduction

Public transportation connects people to other people to places in jobs, education, health, and social & economic opportunities they need. In recent years, smartphones have become so important as a new normal means in daily life. Smartphone applications have transformed the way that people connect to opportunities using public transportation services. Many public transit systems operate based on the available tools and their core applications often depend on the pre-built third-party software programs created by vendor companies, which makes the transit system difficult to customize in adopting changes. Given the benefits of fast but less costly implementation, a few disadvantages of using the pre-built software include limited functionality, incompatibility, and scalability [1]. The demand for mobility services using smartphone apps is also increasing in urban areas to improve

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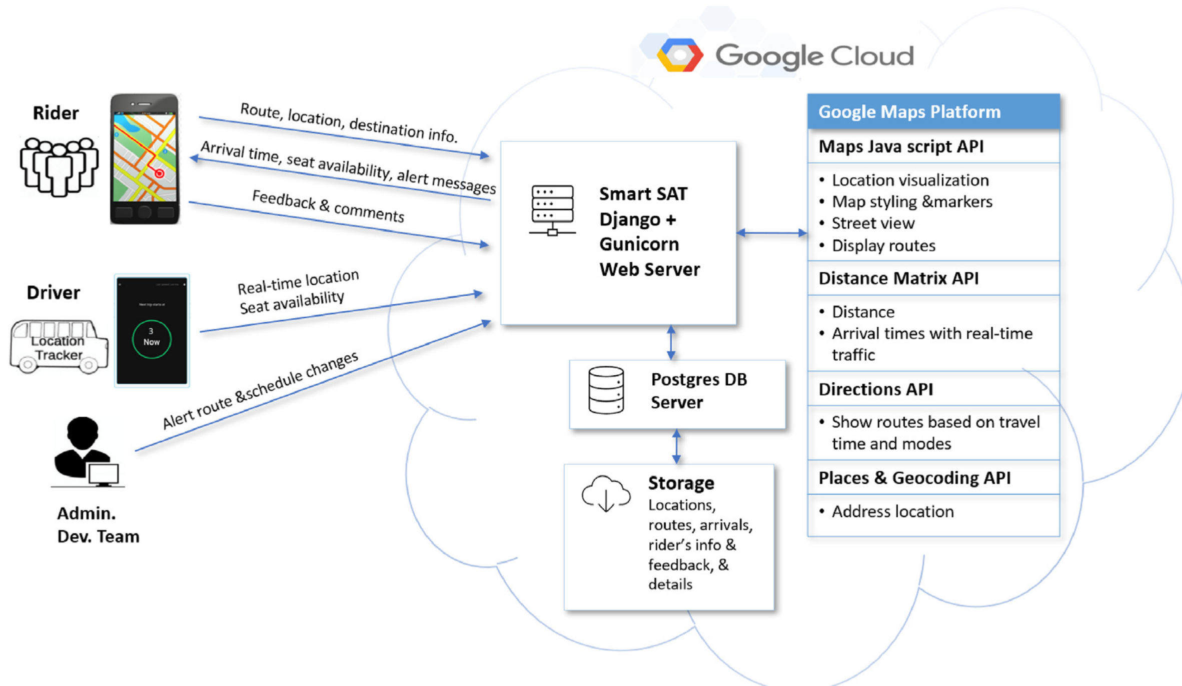


Fig. 1. System architecture [9].

quality services [2–4]. However, providing sustainable quality services of transportation is yet another challenge [1,3].

Providing accurate information of real-time bus arrivals and bus capacity is critical to reducing rider's wait time. Knowing arrival times at bus stops in real-time can allow riders to adjust their travel to minimize the waiting time and to reduce the travel time [5,6]. The development of such a system that provides critical information can benefit society by potentially improving rider experience and increasing their ridership and public transit share [6]. However, riders' waiting time at bus stops and irregular bus arrival information are often missing when historical data is used in analyzing the demand of mobility service on public transportation to find problems of improving services [3]. According to the research [7], commuters on public transportation in most American cities have disproportionately lower incomes than commuters who use automobiles. Transit agencies use surveys to evaluate commuters' perceptions, but the surveys lack collecting important data from low-income residents on complex mobility experiences [7]. To address these, some smartphone apps have been developed to collect residents' GPS-tagged and Quality of Service (QoS) data. However, these apps often fail to collect critical information to characterize complex trips, but also lack privacy protection and decision support systems [7]. Many cities also adapt their transportation resources to support the community during the coronavirus pandemic to help essential workers get to work more easily [8].

Many efforts have been made to address the above issues: Providing real-time tracking of metro buses in urban areas by automatically detecting bus-stops, and accurately predicting bus arrival times using historical and real time location data [6]; Making good travel time predictions for routes with the bus GPS data using artificial neural networks [8]; California's Orange County Transformation Authority (OCTA) launched the Transit app in 2020 to provide real-time bus capacity so riders can check enough available seats. During the COVID, OCTA limits the number of passengers on buses: up to 15 passengers for a regular 40-foot bus and up to 20 passengers for a 60-foot bus [10,11]; The LA County Metropolitan Transportation Authority also partnered with the Transit to improve customer experience by providing accurate real-time bus arrival information [11,12]. The NSF sponsored Pitt Smart Living project developed a platform integrated information system to increase the utilization and improve quality service of public transportation with real-time information of arrival and utilization of relevant options of public transit [13,14]. AC Transit for the Bay Area in California support services of providing real-time bus arrivals and bus capacity and accepting rider's feedback is [15]. Google Maps provides route options in various modes of transportation, including driving, transit, and walking, also targeting a broad range of users including visitors and travelers [9]. Google Maps provides real-time information on bus arrivals but only for major stops. It also provides general options for user feedback on crowdedness, temperature, and accessibility.

SmartSAT is a mobile-web application customized for the San Antonio (SA)'s Metropolitan Public Transit, VIA. Its purpose is to contribute to adress the above-mentioned challenges and to make the critical service available in the SA community. The analysis results of the "Who is Rider" pre-COVID survey in 2019 indicate: 61% of typical VIA riders are Hispanic or Latino and 20% Black or African American; 72% of the riders are employed in full time and utilize VIA 5–7 days a week; 67% of them live at or below the federal poverty level making less than $25,000 per year; 58% of the riders do not have any motor vehicle in their household [2]. The 2019 US Census Bureau for the city of San Antonio reported: 64.25% of the population are Hispanic or Latino and 7.0% Black or African American alone, and 17.8% people in poverty [5]. Providing public transportation service is critical to Black or African Americans and those who live at the poverty level, in particular. Aligned with the needs, the objectives of SmartSAT are to: (1) Decrease riders' wait time and reduce their overall travel time, (2) Enhance rider's satisfaction and overall quality of ridership experience, and (3) Provide reliable transit with convenient and equal access to get to places of employment, education, health, business, and services.

2. Software architecture and functionalities

The application is designed to build a platform that easily adapts to the changes of functional requirements and plans for expansion and long-term goals. It intends to provide greater compatibility and reusability with other programs and devices by building its infrastructure on clouds. The application has contributed to research with some outcomes in the peer-reviewed scholarly publications [9,16–19].

2.1. Architecture

Fig. 1 presents an architecture of the SmartSAT system [9]. The application has been developed on a Django and Gunicorn web server that is deployed on Google Cloud's serverless platform, Cloud Run, using a Docker container [9,17,20]. The containerization offers some benefits, including easy portability, optimized resource utilization with cost, and quick development lifecycle [21]. Django is a Python web framework that follows the model-template-views architectural pattern and works relational databases. Django is hosted on a Gunicorn server being run by Cloud Run. It is connected to a PostgreSQL instance created in Google Cloud. User data, bus data, and route data such as associated bus stop locations and scheduled times are stored in the PostgreSQL instance. When a user interacts with a map, data is communicated with the server via AJAX executions. AJAX is an asynchronous tool that requests a URL in the background allowing the user to interact with the map without having to reload the page. We created special URLs where our server handles requests from AJAX executions on the front-end. Google Maps Distance Matrix API is used to calculate transit distance and duration between the coordinates of a bus and the coordinates of a given bus stop. The API also considers real-time traffic situations when calculating arrival times at selected stops. Other APIs such as Maps Java Script API, Directions API, and Places & Geocoding API are used for various map-related displays on the map. All interfaces respond to different screen sizes of devices and different browsers and yet run well on any mobile phone, tablet, laptop, and desktop. Its design goals are to make it easy to connect riders, drivers, and management/development teams, whichever phones or devices and browsers they use.

2.2. Functionalities

The application serves as the main connection point among riders, drivers, and administrators in these ways: (1) A rider uses the app to choose a route and ride from a bus stop and a destination stop and receives real-time bus arrivals, (2) A bus driver monitors seats and notifies availability to the system when there are very limited seats with 3, 2, 1, or 0 seats available. (3) The development team and administrators deploy emergency alerts, and schedule changes instantly notified riders through their phones. (4) Rider's feedback and comment on commute experience are collected through a well-designed survey questionnaire. Toward these, the major functionalities of the application include:

- Real-time bus arrivals at stops for piloting six VIA bus routes
- Seat availability alerts with limited seats (<= 3)
- Instant alert messages on important schedule and route changes
- Multiple routes display in an admin view
- Feedback collections from riders on their commute experience

Real-time bus arrivals at stops: This functionality has two components: (1) The real time location broadcast of the bus and (2) Updating the estimated arrival time in the maps User Interface (UI). For the real time location broadcasting, a bus driver is entitled access to a webpage in which they shall be able to select a route from a list of valid bus routes and enable the sending of their bus location to the server. navigator.geolocation.watchPosition method is used to obtain location data, which is given as latitude and longitude coordinates. The watchPosition function also provides other data including approximate speed, the accuracy of the location coordinates, and heading. We bundle all this data together JavaScript. This bundled data is sent to the server in JSON format via an AJAX call. Updating an estimated arrival time on an ahead stop in the google maps UI mainly relies on the corresponding object in the buses table in the database. This also consists of three parts: (a) Updating the bus markers on the map, (b) Showing the real-time arrival details on selecting a particular route, and (c) Drawing the route polyline based on the current bus location. To update the bus markers on the map, when a rider selects a route from the radio buttons, a JavaScript function is executed that makes an AJAX call which sends to the server the ID number of the bus route that is currently selected in the dropdown. When a rider clicks a bus stop marker in the map, an estimated or scheduled arrival time data is displayed in a small window above the marker, showing the real-time arrival details on the selected stop on the particular route (Fig. 2. (a), (b), (d)) The functionality involves drawing the polylines on the map based on the current location of the bus. A required color is configured for each route polyline in the database. The polyline drawing details are loaded and stored using Google Map's DirectionsService API. In summary, the complete list of events happening in order to show the updated arrival time in an info window is as follows.

- User clicks on a bus stop (This will open an info window for that bus stop. Each info window has a callback function that is called when the info window is opened. This callback function is responsible for showing the arrival time in the info window. This callback function is invoked every 5 s to get the updated arrival time from the server).
- The front-end code sends an AJAX request to the server to get the arrival time for the bus stop (This is the call back method mentioned in the previous step).
- The server code checks if there is an active bus on the route.
- If there is an active bus on the route, then the server code calls the Google Distance matrix API passing the current location of the bus and the location of the bus stop to get the estimated travel time.
- The server code returns the estimated travel time to the front-end code.
- If there is no active bus on the route, then the server code returns the scheduled arrival time of the bus to the front-end code.
- The front-end code displays the arrival time in the info window.

Bus capacity with limited seats: This feature allows the rider to see how many open seats are available on a bus. This is indicated by the color of the bus's icon on the map. Green means there are more than 3 seats available. Yellow means there are less than 3 seats available. Red means there are no seats available. This is described in a collapsible legend box on the bottom right-hand corner of the map as shown in Fig. 2(c). A simple UI has been implemented for bus drivers to update the status of their seat availability shown in Fig. 2(e). The bus driver shall use these buttons to indicate their seat availability status at any time they wish while they are broadcasting their location. When a bus driver begins their location broadcast, their bus icon shall appear on the map as the green bus icon by default. No action is required of the driver for this to happen, it is done automatically.

Instant alert messages: A page was created in which riders may view announcements made. Currently announcements shall be created only in the admin site (by administrators). When an announcement is created, it simultaneously will appear on the announcement page (viewable to the public) and is sent out to registered riders as an SMS text message. Twilio service is used to make SMS text messages. Valid riders are those with a non-empty phone number. Phone numbers are collected when a person registers a profile with the application. When necessary, an admin can also create a profile in the admin site, which has by default an empty string phone number.

Multi-routes display in an admin view: The purpose of the multi-routes display in the admin view is to enable administrators with a comprehensive oversight of all routes, allowing them to monitor and track the real-time locations of buses simultaneously. Fig. 3 presents the view showcasing a comprehensive presentation of all currently active routes within the selected route category. These are organized under the selection menu located on the left side of the interface upon logging

Algorithm 1 Algorithm to update the content for InfoWindow Object on bus stop marker
Input: *'route' and 'bus_stop_id'*
Output: The estimated and scheduled arrival times are updated

```
Initialization :
for every 5 seconds do
  if An InfoWindow is Open then
    Call getEstimatedArrivalAJAX with input parameters.
    if data then
      if data['est_arrival'] is not empty then
        if est_arrival is equal to defaultTimeString then
          scheduled_arrival ← defaultTimeString
        end if
        est_arrival ← data['est_arrival']
      else
        est_arrival ← defaultTimeString
      end if
      if data['scheduled_arrival'] is not empty then
        scheduled_arrival ← data['scheduled_arrival']
      end if
    else
      scheduled_arrival ← defaultTimeString
      est_arrival ← defaultTimeString
    end if
    Invoke method to Update the Active Info Window Content with latest Details
  end if
end for
return None
```

Algorithm 2 Algorithm to get the estimated travel time for the selected bus stop
Input: *'route' and 'bus_stop_id'*
Output: The estimated and scheduled arrival times for the bus stop

```
Initialization :
busStop ← The bus stop instance for the given route and bus_stop_id
busStopCoord ← Lattitude and Longitude for the given buS stop.
bus ← Get the bus object for the given route
day_of_week ← Get the letter code for todays date.
next_arrival ← Get the bus stop's next scheduled arrival time from the database.
if next_arrival is not None then
  result['scheduled_arrival'] ← String representation of scheduled arrival time.
end if
if bus is None then
  return result
end if
busCoord ← Get Lattitude and Longitude for the bus
travelDuration ← Get the Estimated Travel time between the locations busCoord and busStopCoord by calling the Distance Matrix API.
if duration in travelDuration then
  result['est_arrival'] ← Estimated travel time in text form.
end if
return result
```

into the system with a role of an administrator. This capability is not accessible to regular users such as riders or drivers.

Feedback collections on commute experience: To collect data on ridership experiences and the impact of SmartSAT, we deployed instruments for data collection: Phase I (Fig. 4 left) involves user experience survey to assess rider's interpretation of and engagement with in their overall use of the current VIA transit system (https://tamusa.co1.qualtrics.com/jfe/form/SV_7WF9vwgK7BUyoxE). Phase II (Fig. 4 right) investigates how the use of SmartSAT has aided riders in timeliness of arrival to work, school, and other important events (https://tamusa.co1.qualtrics.com/jfe/form/SV_0NT7LynF4lUNuNo). This will look at how they understand the information provided in SmartSAT to have increased their accuracy of predicting their arrival at these important events relative to their past experiences without SmartSAT.

3. Illustrative examples

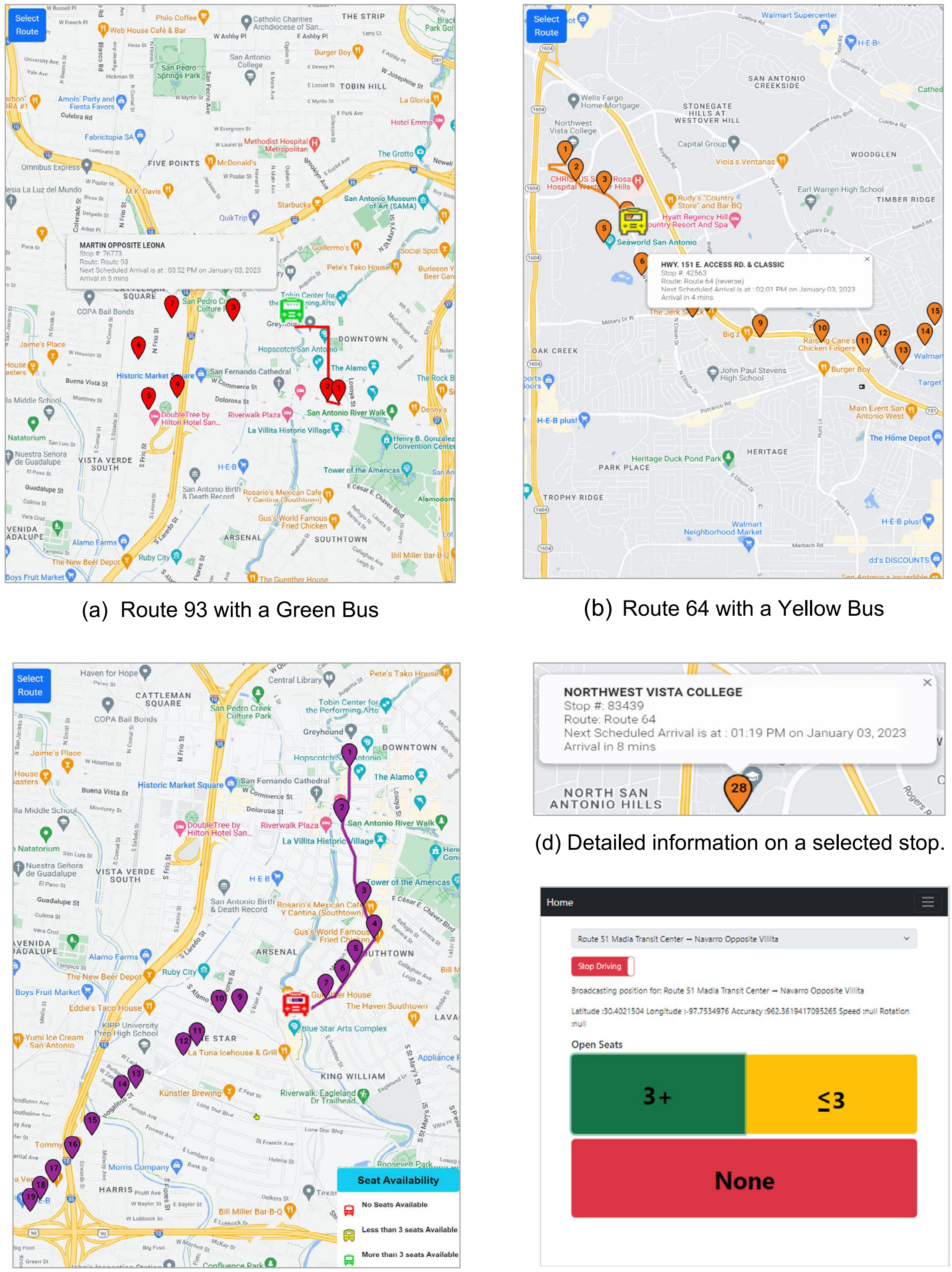
Fig. 2 provides illustrative examples to showcase the major functionalities of SmartSAT, displaying the screenshots of routes 93, 64, and 51 captured during the field test. The routes, 93 and 64, are categorized as 'Express Service' type, which is designed for commuters traveling on expressways. Route 51 is categorized as fixed 'Metro Service' type, operating every 30 or 60 min and running more frequently in the morning and afternoon. The bus icon in green indicates that there are currently enough seats available on the bus. When the bus has limited seats such as lower than 3, the driver can easily click on a button in yellow (<3 seats) or red (no seat available). Riders get informed about the seat availability through the changed color of the bus on the route in the map. The color of the bus icon is to ensure riders being aware of the seat situation before getting on board.

4. Impacts

Studies were conducted to assess the impact of SmartSAT: (1) a study on the analysis and evaluation of actual bus arrival times and (2) a study on the commute experience of riders. From the data collected in field tests on routes 30, 53, 64, and 93, the first study focused on the analysis of the difference between VIA's scheduled and actual bus arrival times. From the analysis, we learned that monitoring and evaluating bus arrival times are important to improve the adherence to schedule. Such insights can help transit authorities optimize their bus schedules, reducing delays therefore rider's overall wait times. The rider experience study was focused on understanding the experiences of bus riders in public transportation, from collecting data on experiences with bus use, such as transfers, wait times, and perceptions of bus arrival times. Despite rider's reliance on Google Maps and other technologies, percent expressed a need for a new app to be made available. There is a significant gap between existing technology for accessing bus information and the bus user's desire for an improved means of accessing public transit information in San Antonio.

4.1. Study on bus arrival times

A preliminary study was conducted with the public data dataset of San Antonio buses [22] to evaluate their adherence to the scheduled times [18] by comparing classical and deep learning models and their ability to accurately predict bus adherence. The analysis of data showed that different routes and specific parts of the day show variations in how well they stick to their schedules. The study found that some characteristics such as part of the day, the direction of the bus, and its location can significantly impact delays in bus arrival and departure times [18]. While certain routes experience these, others have less issues. This implies a possible relationship between the time of day and infrastructure challenges.



(a) Route 93 with a Green Bus
(b) Route 64 with a Yellow Bus
(c) Route 51 with a Red Bus
(d) Detailed information on a selected stop.
(e) A touch-screen interface for seat availability in a driver view.

Fig. 2. Illustrative examples in a rider view.

The follow-up study was conducted with the actual data collected from the field test [21]. The study focused on the analysis of the difference between VIA's scheduled and actual bus arrival times. The actual arrival times were collected by tracking the GPS locations of the buses on four different routes: Route 30 (downtown of SA to east), Route 93 (downtown of SA to north), Route 64 (downtown of SA to west) and Route 51 (downtown of SA to south) – the representation of three routes in Fig. 2. The results demonstrated that the best routes in adherence to the schedule are Route 30 and Route 30 Reverse. These routes have extremely low average differences between actual and scheduled arrival times (0.0021 and 0.0035 min, respectively). The buses on these routes are highly punctual and tend to adhere closely to the scheduled timetable. The worst Routes in Adherence to Schedule were Routes 93 and 51. Route 93 has the highest average difference

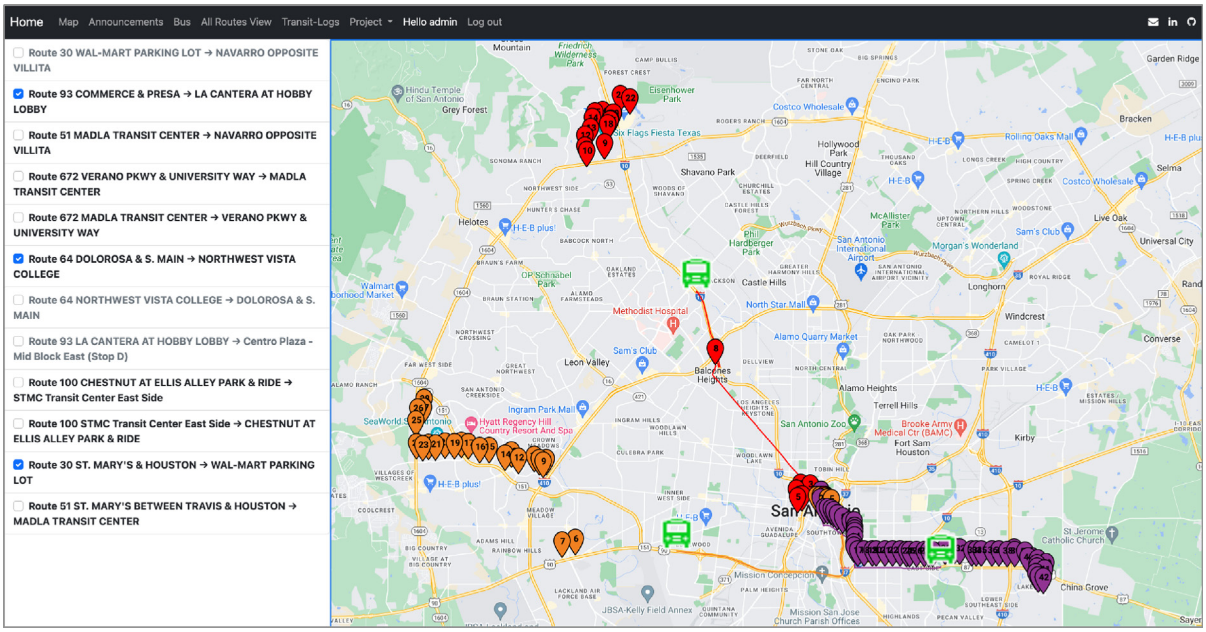


Fig. 3. Multi-routes display in an admin view.

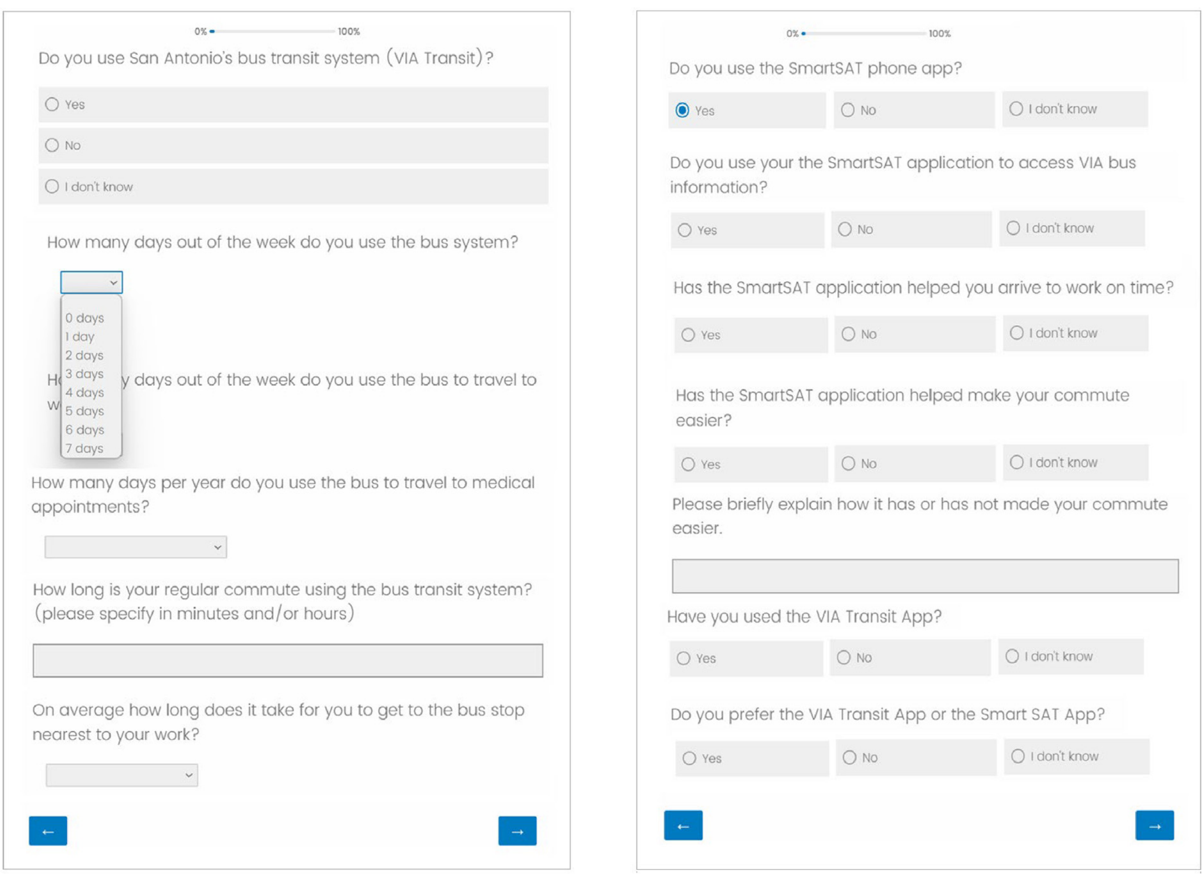


Fig. 4. Survey questions on rider experience: Phase 1 (left) and Phase 2 (right).

between actual and scheduled arrival times (4.85 min). Buses on this route tend to experience the most significant delays or deviate the most from the scheduled timetable.

Route 51 also has a relatively high average difference (3.89 min), indicating a notable delay in bus arrivals compared to the scheduled times. The notable delays on these two routes occurred during the evening part of the day at specifically identified times, from 4 pm to 6 pm, which could imply that traffic could contribute to the delays. Some routes demonstrated variability in Arrival Times. For example, Route 93 Reverse has the highest standard deviation (2.07 min), indicating

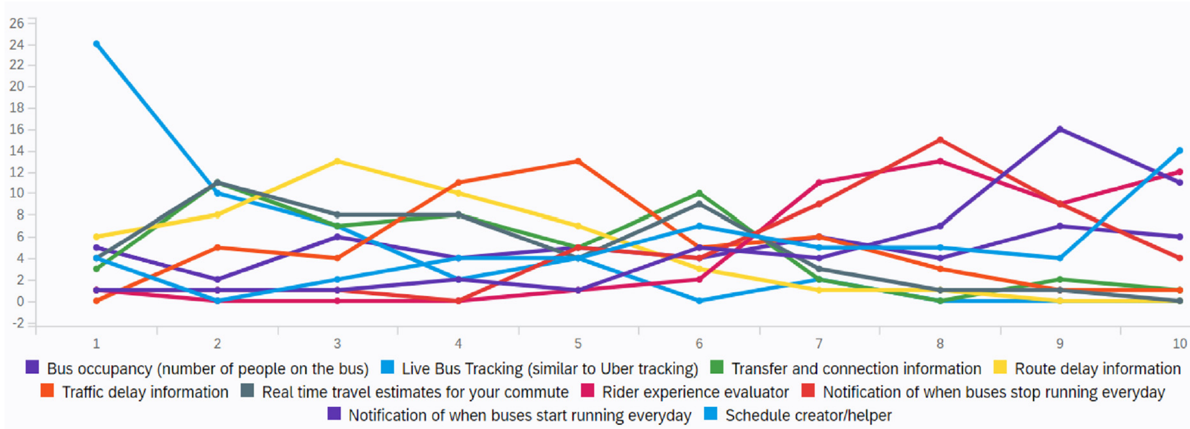


Fig. 5. Desired service with a smart phone app to improve the use of VIA transit.

a higher variability or inconsistency in the difference between actual and scheduled arrival times. Buses on this route may experience more fluctuation in their arrival times compared to other routes. Results also reported the routes with Minimal Delay. Route 64, along with Route 30 and Route 30 Reverse, has an average difference close to zero, indicating minimal delay or even instances of buses arriving earlier than scheduled. These routes demonstrate a high level of adherence to the schedule. From the analysis, we learned that monitoring and evaluating bus arrival times are important to improve the adherence to schedule. Such insights can help transit authorities optimize their bus schedules, reducing delays therefore rider's overall wait times.

4.2. A study on commute experience

To address the question on 'How do racial/ethnic and class-stratified communities in San Antonio access buses?', the survey was initiated with ongoing data collection, interviews initiated with the data collection on bus ridership experiences, access to buses, and city space. Data was collected for the phase one survey with 101 responses and 7 interviews. The results show that respondents have significant use of Google Maps and smart phones to access bus information and buses generally, 93.1 percent of respondents use internet-enabled smart phones to access their bus information, with 57.14 percent of respondents selecting Google as their first choice for accessing bus transit information [19]. Additional results show that Latinx and poor/working-class communities in San Antonio feel as though they have decreased or limited engagement with buses relative to other communities throughout the city. With a majority using Google as their first choice for bus information, 21.43 percent also use the existing transit phone app to access bus information. Despite this reliance, 82.14 percent expressed a need for a new app to be made available [19]. This means there is a significant gap between existing technology for accessing bus information and the bus user's desire for an improved means of accessing public transit information in San Antonio. The study also found that there is a differential in the feelings of access to the city's public transit system held by the poor, working class, and Latinx communities in the city of San Antonio.

Specifically, on the question of 'What would you like for this smart phone app to include as a service to improve your use of VIA Transit?' by ranking it in order of preferred improvements, 1 = Most preferred improvements to 10 = Least preferred improvements (Fig. 5), 48.98% of the respondents showed the preferred service "Live bus tracking" as their top choice, followed by "Route delay information" (26.53%) and "Transfer and connection information" (22.45%). Overall, the results indicate a strong desire for improving the current transit service

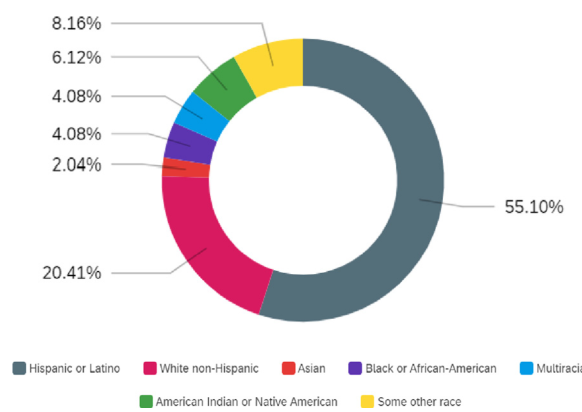


Fig. 6. Race/ethnicity.

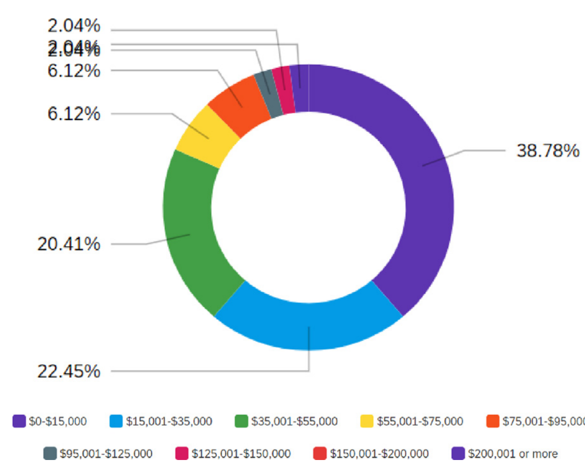


Fig. 7. Household income.

for real-time tracking and delay information with interests in other supportive services.

The demographics of the respondent's breakdown with 55.10% of the respondents identified as Hispanic or Latina, 20.41% White non-Hispanic, 6.12% American Indian or Native America, 2% Black or African American and some other race (Fig. 6). Regarding the household income distribution (Fig. 7), the largest group, 38.78% of them reported their household annual income of $0-$15,000, 22.45%

has incomes between $15,001-%35,000, and 20.41% within $35,000-$55,000, which indicates 81.63% are from lower-income of less than $55,000.

Overall, the analysis of data has yielded clear indications that for our predominantly Latinx and predominantly working class, a significant portion earning at or less than the annual median income for San Antonio, respondents there is significant difficulty in using and accessing public transit [19]. The reasons are numerous but based on our survey 52% of respondents using the bus to commute to work for three or more days with the remaining using it less than two days per week [19]. Such high usage of the bus indicates significant reliance upon the VIA transit system and issues of technology, with 94.4% using their smartphones and a majority of respondents using Google Maps to access bus information, we see that technology is significantly impacting their experiences with the public transit system. Most of the respondents live on the north side of the city and commute across the city to either the Westside or Southside of San Antonio. This results in a majority of respondents having commute times of greater than one hour (61%). Ultimately leading to greater difficulty in their daily lives as they are expected to be on time for work, school, and other activities. Generally, this illustrates that within these Latinx and poor and working-class communities, there is a significant difficulty in gaining access to bus information and certain areas of the city spaces because of longer commute times and issues with accurate technology.

5. Conclusion, limitation, and future work

The major contribution of this paper is the development of the SmartSAT that is a customizable mobile web application for San Antonio public bus transit, providing real-time bus arrivals, seat capacity information, service change or update alerts, and a mechanism for riders to provide feedback on their experiences. The objective of the application is to enhance public transportation services and improve the commuting experience for a diverse group of riders in San Antonio. Toward this, two research studies were conducted to assess the impact of SmartSAT on the analysis of actual bus arrival times and the commute experience of riders. From the data collected in field tests on piloting routes, the first study focused on the analysis of the difference between VIA's scheduled and actual bus arrival times. The findings indicated that certain routes exhibited very low average differences between their actual and scheduled arrival times, while a couple displayed a big average difference that showed significant delays and deviations from the scheduled timetable. Furthermore, some routes experienced small average delays in the afternoon, but the delays significantly increased in the evening. These findings suggest the need for regular monitoring and optimization of the bus schedules to improve the efficiency of the current SA transportation system.

The rider experience study was focused on understanding the experiences of bus riders in public transportation, from collecting data on experiences with bus use, such as transfers, wait times, and perceptions of bus arrival times. The study found that there is a differential in the feelings of access to the city's public transit system held by poor, working-class, and Latinx communities in SA. From the results of analyzing the data from the phase one survey, we constructed Phase two survey instruments and, thus plan to begin collecting data to determine whether or not the implementation of our new app will improve rider experiences with the transit system. Additionally, the study would also look into insights on whether using SmartSAT app can increase the amount of people that take the public transportation service.

This work has limitations on the datasets collected from four routes only from the field test on a weekday. They do not necessarily represent the data for all routes and different days of running buses. From the findings of the studies on bus arrival times, future research can be pursued with quantitative evaluation by gathering riders' feedback on those routes with below 50% on-time arrival rates. Due to the limited data collected, however, further analysis with larger data and different time frames would be needed to validate the findings. Additional parameters such as traffic conditions, rush hours, days on weekend and other external variables can also be involved in the future analysis.

CRediT authorship contribution statement

Young Lee: Data curation, Software, Visualization, Writing – review & editing. **Jeong Yang:** Conceptualization, Data curation, Funding acquisition, Investigation, Supervision, Writing – original draft. **Mohammad Al-Ramahi:** Investigation, Resources, Writing – review & editing. **Daniel Delgado:** Data curation, Investigation, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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