# CSE 564 Project Report Phase 4

# Team 07

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# 1. Executive Summary (Updated)

## 1.1. Key Aspect 1: Customer Problem

### 1.1.1. Student dissatisfaction

Students at ASU face significant dissatisfaction due to prolonged shuttle wait times and overcrowded buses. These issues result in frustration and discomfort, making it challenging for students to rely on shuttle services for timely transportation.

### 1.1.2. Resources waste

Additionally, the current shuttle system suffers from inefficiencies in dispatching and route design. The lack of real-time information and poor coordination with other transport services further exacerbates these problems, leading to increased travel time and resource wastage.

## 1.2. Key Aspect 2: Proposed Solution

### 1.2.1. Real-time data collection

The ASU Shuttle Dispatcher service introduces real-time shuttle tracking, dynamic scheduling, and improved communication features. By displaying current shuttle locations and providing estimated arrival times, students can better plan their travel and reduce wait times.

### 1.2.2. Dynamic scheduling

Moreover, the system adjusts shuttle schedules based on real-time events and passenger demand, optimizing routes to enhance efficiency. It also facilitates seamless communication between drivers and dispatchers, ensuring timely responses to incidents and schedule changes.

## 1.3. Key Aspect 3: Bring Value

### 1.3.1. Satisfaction improvement

Implementing the ASU Shuttle Dispatcher service significantly enhances the student experience by reducing wait times and overcrowding, thus improving overall satisfaction. The system's real-time updates and dynamic scheduling ensure a more reliable and efficient shuttle service.

### 1.3.2. Cost Saving

The implementation of the ASU Shuttle Dispatcher service also results in significant cost savings. By optimizing shuttle schedules and routes based on real-time data, the system reduces unnecessary trips and ensures efficient use of resources. This efficiency minimizes fuel consumption and maintenance costs, directly lowering operational expenses.

### 1.3.3. Environment friendly

Furthermore, the solution leads to better resource allocation and reduced operational costs. By minimizing unnecessary trips and optimizing routes, the shuttle service becomes more environmentally friendly and cost-effective, benefiting both the university and the community.

# 2. Customer Problem (Updated)

CP2.1. Student Dissatisfaction

CP2.1.1. Long waiting time [1]

The current ASU shuttle system across campuses is found to be inadequate to meet all the students' needs. This is because the number of shuttles running is unable to meet the needs of the students depending on the shuttles. Due to the large number of students who rely on the shuttle buses, there are long queues at the shuttle bus stops. Students must wait for shuttle much longer.

CP2.1.2. Crowded shuttle [1]

During certain peak hours when there are a lot of students travelling across campuses to attend their classes or any special events including career events and other activities, it is often seen that in addition to the long waiting time, when the bus finally arrive at the bus stop, it is crowded and there are no seats left. A crowded environment can make the students uncomfortable and often times, students are unable to board the bus. This results in student dissatisfaction and most students lose their patience in taking the shuttle and end up not attending class.

CP2.2. Lack of Proper Communication

CP2.2.1. Lack of feedback system [1]

A major issue with the current shuttle service is the absence of a formal feedback system for students. Hence the student complaints are neither heard nor addressed promptly. Students may encounter recurring problems, such as long waiting times, overcrowding, and without a proper channel for communication, these concerns are left unresolved. This lack of responsiveness from the shuttle service further compounds frustrations and contributes to a poor student experience.

CP2.2.2. Lack of notification system [2]

The lack of real-time notification is another critical issue that negatively impacts the student experience with the shuttle service.

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[1] T. Arabghalizi and A. Labrinidis, "Data-driven Bus Crowding Prediction Models Using Context-specific Features," ACM/IMS Transactions on Data Science, vol. 1, no. 3, pp. 1–33, Sep. 2020, doi: https://doi.org/10.1145/3406962.

[2] M. W. Raad, M. Deriche, and T. Sheltami, "An IoT-Based School Bus and Vehicle Tracking System Using RFID Technology and Mobile Data Networks," Arabian Journal for Science and Engineering, Nov. 2020, doi: https://doi.org/10.1007/s13369-020-05111-3.

Students are often left unaware of delays or cancellations, as the shuttle service does not provide timely notifications. In the absence of real-time updates. Students may arrive at shuttle stops to find that the service is delayed or cancelled, causing unnecessary waiting and inconvenience. This lack of communication can also make it difficult for students to plan and attend their classes, appointments and other ASU events. This adds to the student frustration with the shuttles.

CP2.3. Inefficient Shuttle Dispatching

CP2.3.1. Lack of responsiveness

The current shuttle service is unable to respond to accidents and other unforeseen incidents quickly. This will cause delays for students who rely on the shuttle for timely transportation. Additionally, the shuttle service is unable to accommodate the surge in demand when there are any ASU events like career fairs etc. This lack of responsiveness can result in students being unable to reach their destinations on time, leading to frustration and a loss of trust in the shuttle service. In these cases, students are left without options, either having to wait for the next available shuttle or seeking alternate and more expensive transportation.

CP2.3.2. Lack of Real-Time Information [3]

A significant challenge for students is the lack of real-time shuttle information. There is no daily schedule for the shuttle published to the students and the students are not shared the information about the number of available seats in the shuttle buses. With no way of tracking the shuttle seat availability or knowing exactly whether the next bus will have seats, students are left waiting uncertainty. This problem is particularly frustrating when students need to plan their travel around class schedules or other important commitments.

The absence of real-time data means that students cannot make informed decisions about whether to wait for the shuttle or seek alternative transportation options. It also leads to inefficiencies, as students may be unnecessarily waiting at shuttle stops and is unable to board the shuttle even after waiting because they don't have accurate information about the seat availability.

The inefficiency of the shuttle system has a direct impact on the environment. Shuttles are often running with low passenger loads during off-peak hours, leading to wasted energy and unnecessary emissions. This inefficient operation contributes to air pollution and increases the overall carbon footprint of the transportation system.

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[3] "Real-Time Bus Arrival Prediction: A Deep Learning Approach for Enhanced Urban Mobility," Arxiv.org, 2024. https://arxiv.org/html/2303.15495v3 (accessed Sep. 22, 2024).'

[4] W. Austin, G. Heutel, and D. Kreisman, "School Bus Emissions, Student Health, and Academic Performance," National Bureau of Economic Research, Mar. 01, 2019. https://www.nber.org/papers/w25641

When shuttles run with fewer passengers, the resources used to operate them, such as fuel and energy, are not being utilized efficiently, making the service environmentally unsustainable. This inefficiency exacerbates the negative environmental effects of transportation, contributing to air quality issues and climate change.

CP2.4.2. Operational Costs [5]

Inefficient dispatching of shuttles leads to higher operation costs for the school. The school may need to deploy more shuttles than necessary, particularly during off-peak hours, or run shuttles that are not filled to capacity. These inefficiencies result in unnecessary fuel consumption, driver wages, and maintenance costs, all of which add up over time. Furthermore, inefficiencies in scheduling and route design can also contribute to higher operational costs, as shuttles may take longer routes or need to make more frequent stops, increasing the overall expense of operating the shuttle system.

To ensure the long-term sustainability of the shuttle service, the school must address these inefficiencies and find ways to optimize operations, such as adjusting schedules based on demand, improving route design, or reducing unnecessary resources.

CP2.4.3. Underutilized Shuttle Capacity [1]

Underutilized shuttle capacity is another waste of resources that contributes to the inefficiency of the shuttle system. During non-peak hours, shuttles often run with very few passengers, wasting valuable resources such as fuel and personnel time. This underutilization not only affects the environment but also impacts on the cost-effectiveness of the shuttle service.

When the service operates with low demand but full staffing, it creates a mismatch between the resources allocated and the actual need, leading to unnecessary costs. The idle capacity of shuttles during these times further adds to the financial burden on the school or institution running the service.

CP2.4.4. Inefficient Scheduling [5]

Scheduling that is not based on actual demand also means that shuttles may be running at half capacity, wasting resources that could be better allocated elsewhere. Inefficient scheduling can lead to longer wait times or overcrowding during peak hours, creating an imbalanced shuttle system that fails to meet the varying needs of students throughout the day.

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[1] T. Arabghalizi and A. Labrinidis, “Data-driven Bus Crowding Prediction Models Using Context-specific Features,” ACM/IMS Transactions on Data Science, vol. 1, no. 3, pp. 1–33, Sep. 2020, doi: https://doi.org/10.1145/3406962.

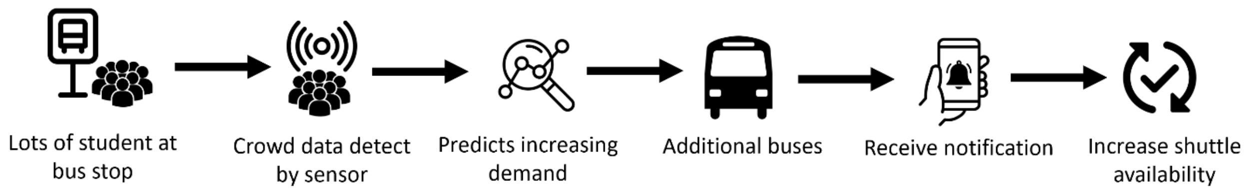
[5] A. Sharma, “Advancing School Bus Routing: A Machine Learning Approach for Enhanced Efficiency, Safety, and Sustainability.” Accessed: Sep. 28, 2024. [Online]. Available: https://www.ijfmr.com/papers/2022/6/16031.pdf

To address these issues, shuttle operators need to adopt a more data-driven approach to scheduling, considering factors like historical crowd data, special ASU events, and class schedules. By adjusting shuttle service based on real demand, the system can become more efficient and cost-effective, providing better service for students while reducing unnecessary waste.

# 3. Concept of Operations (Updated)

CO3.1. Storyboards [6][7]

CO3.1.1. Storyboard 1: Morning Rush Hour

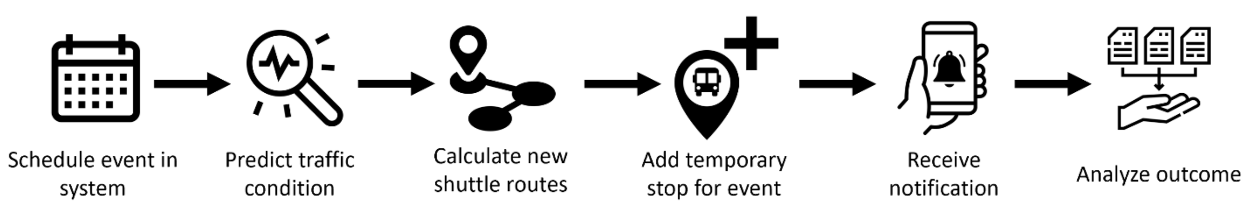



CO3.1.1.1. Detail

Sensors and surveillance are set up at the shuttle bus stop to collect the crowd data. These sensors track the number of people waiting, providing real-time information on passenger demand. This incoming data is then analyzed by crowd prediction algorithms, which process the information to detect patterns and predict the crowd trend. Based on these predictions, the system can anticipate crowds and automatically dispatch additional buses to meet the growing demand.

To keep students informed, the system sends real-time notification about the changes in schedule. This dynamic approach helps manage crowding more effectively by increasing shuttle availability during peak hours, allowing for a more efficient and responsive public transport system. By adjusting resources in real time, the system aims to provide a smoother, more comfortable experience for students while optimizing the shuttle service.

CO3.1.2. Storyboard 2: ASU Events

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[6] P. HORAŽĎOVSKÝ, S. KOZHEVNIKOV and M. SVÍTEK, "Dynamic Public Transport in Smart City using Multi-agent system," 2019 Smart City Symposium Prague (SCSP), Prague, Czech Republic, 2019, pp. 1-5, 2019

[7] S. Lyapin, D. Kadasev and N. Voronin, "Application of Digital Control Approaches in Solving Transport Planning Problems in Road Transport," 2023 5th International Conference on Control Systems, Mathematical Modeling, Automation and Energy Efficiency (SUMMA), Lipetsk, Russian Federation, 2023, pp. 894-898

CO3.1.1.1. Detail

ASU events can be integrated with the Dispatcher system. The registration data to the event can be used to estimate the additional crowd to the destination campus. The new information is used to update the shuttle schedule. On the day of the event, the updated shuttle schedules are notified to students. Students are kept informed through real-time updates about bus stop arrivals and the seat vacancy in each shuttle bus which are delivered via the mobile app & website, allowing them to plan their travel more efficiently.

The system also collects user feedback to improve future planning and make any necessary adjustments to better handle similar events in the future. This proactive approach helps optimize shuttle services and enhances the overall experience for students and event attendees.

CO3.2. Operational Concepts

CO3.2.1. Facility student success

CO3.2.1.1. Optimized bus scheduling

Optimizing bus schedules based on crowd patterns helps ensure that the shuttle service aligns with peak demand times, improving efficiency and convenience for students. By analyzing historical crowd data, the system can generate an optimized shuttle schedule. As a result, more buses are dispatched during peak hours to accommodate the increased demand.

Additionally, the system is designed to respond quickly to incidents such as roadblocks or accidents, making real-time adjustments to bus schedules, further minimizing disruptions and delays.

CO3.2.1.2. Better campus connectivity

The improved shuttle service ensures better connectivity across ASU's campuses, enabling students to arrive on time for classes, meetings, and events. The enhanced connectivity allows students to collaborate across campuses more easily, opening up more opportunities for cross-campus interactions.

Additionally, students can attend ASU events across campuses with greater ease, ensuring they are not limited by transportation constraints. This increased mobility enhances the overall academic experience, promoting inclusivity and participation across the university community.

CO3.2.1.3. Maximize student comfort

One of the key objectives of the shuttle system is to maximize student comfort by minimizing wait times, especially during extreme weather conditions. With more predictable shuttle schedules, students are less likely to experience the stress of unexpected delays or long waiting periods. This reliability encourages greater attendance in classes.

Reducing delays and maintaining consistency in bus schedules also ensures that students have a more seamless experience, improving their overall satisfaction with campus transportation services. By addressing these concerns, the shuttle system directly supports students' academic success and well-being.

CO3.2.2. User Interaction and Feedback

CO3.2.2.1. Intuitive interface

An intuitive interface is important to enhance user satisfaction [8]. The system is designed with an easy-to-use interface that ensures users can navigate through the app effortlessly. This simplicity contributes to a positive experience, as students and staff can access shuttle schedules, real-time updates, and other essential information with minimal effort.

Clear visuals and real-time alerts help users stay informed about the status of shuttles, whether they are on time or delayed. Additionally, the app offers personalization options, allowing users to customize their experience based on individual preferences, such as preferred shuttle routes or alert settings.

CO3.2.2.2. Information sharing for better planning.

The app provides real-time seat occupancy data [9], which helps users make informed decisions about when to board. By tracking and publishing this information, students can better manage their time and avoid overcrowded buses. The system also sends out notifications regarding schedule changes or delays, keeping users updated and reducing uncertainty.

Furthermore, the shuttle system enhances communication with drivers and staff, ensuring that everyone involved in the operation is informed about the status of the service, contributing to a more coordinated and effective shuttle experience.

CO3.2.2.3. Optional Data Collection for Improvement

The shuttle system also collects optional data that can be used to improve service quality and operational efficiency. Students can share their preferred travel windows, allowing the system to better predict demand and optimize scheduling.

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[8] M. N. Islam, "Towards Designing Users' Intuitive Web Interface," 2012 Sixth International Conference on Complex, Intelligent, and Software Intensive Systems, Palermo, Italy, 2012, pp. 513-518,

[9] Vidyasagaran, S. R. Devi, A. Varma, A. Rajesh and H. Charan, "A low cost IoT based crowd management system for public transport", 2017 International Conference on Inventive Computing and Informatics (ICICI), pp. 222-225, 2017.

Drivers can input their availability, helping to ensure that shifts are well-managed and that buses are staffed appropriately. The system also tracks instances where students are unable to board due to crowded shuttles, providing valuable insights into areas for improvement. By gathering and analyzing this data, the system can refine its operations and better respond to user needs.

CO3.2.3. Cost-effective Solution

CO3.2.3.1. Predicts the Right Number of Buses to Minimize Cost

Predicting the right number of buses required for each route is crucial in minimizing operational costs. By detecting and tracking crowd data at bus stops [10], the system can assess real-time demand and predict future crowd sizes based on historical data and trends.

Using artificial intelligence, the system can make accurate forecasts about when additional buses are needed and when fewer buses can be deployed [11]. This predictive capability ensures that the shuttle service operates efficiently, avoiding the waste of resources by dispatching only the necessary number of buses based on demand, thus reducing overall costs.

CO3.2.4. Positive Environmental and Social Impact

CO3.2.4.1. Reduce the Environmental Impact

By optimizing the number of buses deployed, the system helps lower its carbon footprint, minimizing unnecessary emissions from idle or underutilized buses. The system also provides students with carbon footprint data, showing the environmental benefits of using public transport instead of driving individual vehicles. This transparency not only raises awareness about the environmental impact of transportation but also encourages students to make more sustainable choices [12].

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[10] Y. Xie, J. Niu, Y. Zhang and F. Ren, "Multisize patched spatial-temporal transformer network for short- and long-term crowd flow prediction", IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 11, pp. 21548, 2022.

[11] M. Z. Malik, S. Nazir and H. U. Khan, "Artificial Intelligence Based System on Enhancing the Capabilities of Transport System: A Systemic Literature Review," 2023 IEEE Symposium on Industrial Electronics & Applications (ISIEA), Kuala Lumpur, Malaysia, pp. 1-6, 2023

[12] P. HORAŽĎOVSKÝ, S. KOZHEVNIKOV and M. SVÍTEK, "Dynamic Public Transport in Smart City using Multi-agent system," 2019 Smart City Symposium Prague (SCSP), Prague, Czech Republic, 2019, pp. 1-5, 2019

Furthermore, the system tracks the carbon footprint of the shuttle service, allowing for better planning and adjustments to further reduce emissions. The use of minimalist sensors ensures low electricity consumption, helping the system stay environmentally friendly and energy-efficient.

CO3.2.5. Coordination for ASU Events

CO3.2.5.1. Schedule Adjustments

The shuttle system integrates with ASU's event scheduling, providing flexible adjustments to shuttle services to accommodate special events. The system can extend shuttle service hours to ensure that students, faculty, and attendees can easily access campus events, even outside of regular operating times.

The event registration data can be integrated with the shuttle dispatch system to anticipate increased crowds and adjust schedules accordingly. In response to these changes, event-specific notifications are published to users, ensuring that everyone is informed about schedule modifications and that transportation remains smooth and reliable during major campus events.

CO3.2.5.2. Valuable Data Insights for ASU

The data captured by the shuttle system offers valuable insights that can inform future planning and decision-making at ASU. For example, data on shuttle ridership, peak times, and popular routes can be analyzed to identify patterns and improve services. These insights can also be leveraged to optimize class schedules and event planning, ensuring that shuttle services are aligned with academic and extracurricular activities.

# 4. Received Requirements (Updated)

RR4.1 Driver Preferences

To enhance driver satisfaction and operational efficiency, the system should allow drivers to input their preferred work days and hours. This information will be used to create schedules that align with driver preferences whenever possible.

To achieve this, the system should include a driver availability database. This database will store information about each driver's preferred work days and hours, as well as any other scheduling constraints they may have. The scheduling algorithm will then use this information to generate schedules that meet the needs of both the drivers and the university.

In addition to the driver availability database, the system should also include features that allow drivers to manage their own schedules. For example, drivers should be able to request shift swaps, view their schedules in advance, and receive notifications about open shifts. These features will give drivers more control over their work schedules and help to ensure that they are happy with their assignments.

By taking driver preferences into account, the system can help to improve driver satisfaction and reduce turnover. This will lead to a more stable and efficient workforce, which will ultimately benefit the university community as a whole.

RR4.2 School Events

To accommodate the unique transportation needs that arise during school events, the system should allow admins to schedule events and input relevant details. This includes information such as the number of RSVPs, event seating capacity, and the type of event.

The system should also be able to allocate additional resources during events. This could involve adding extra shuttles to existing routes or creating new routes specifically for the event. The system should also be able to dynamically adjust shuttle schedules in response to real-time changes in event attendance.

To facilitate event planning and management, the system should include an events dashboard. This dashboard should display event details, including RSVPs, shuttle resources required, and any other relevant information. The dashboard should also allow admins to update event information in real-time and track shuttle usage during events.

By providing a comprehensive event scheduling and management system, the system can help to ensure that students and faculty have reliable transportation options during school events.

RR4.3 Viewing Shuttle Schedules

RR4.3.1 Students

The schedule view for students should show the number of shuttles assigned for each time slot. This will help students plan their trips and avoid overcrowding on shuttles.
To further assist students in planning their trips, the system should provide real-time schedule access through a user-friendly interface. This interface should display the real-time location of shuttles, estimated arrival times at each stop, and allow students to filter schedules based on their preferences [13].

Additionally, the system should offer "favorite routes" functionality, allowing students to easily access information for their most-used shuttle stops.

RR4.3.2 Drivers

The schedule view for drivers should be at least two weeks in advance and show the schedule on weekly and monthly blocks for readability.

To ensure drivers are aware of any changes to their regular paths, event days should be highlighted in the schedule view. Drivers should be able to click on the event day to find the added stops and their ordering.

Drivers should also be able to access their schedules through the mobile app. This will allow them to view their schedules and any updates in real-time, ensuring they are always on time and informed.

By providing these features, the system can help to ensure that both students and drivers have the information they need to use the shuttle service effectively.

RR4.4 Shuttle Routes

To ensure that drivers can follow their schedules accurately, the system should allow them to view their routes through the app. This includes:

- New and updated routes: Drivers should be able to see any new or updated routes that have been assigned to them. This will help them to stay informed of any changes to their regular routes.
- Location of stops: Drivers should be able to see the location of all stops on their routes, including any newly added stops. This will help them to navigate their routes efficiently.

Stop duration: Drivers should be able to see how long they are scheduled to stay at each stop. This will help them to manage their time effectively and avoid delays.

In addition to the above, the system should also allow students to see where newly added stops are on the map. This will help students and event attendees find and reach their destination on time, especially during events or when there are changes to regular routes.

To further enhance the user experience, the system should provide an abstract map for readability and faster load times. The map should be designed in a way that is easy to understand and use, with clear markings for shuttle stops and routes. This will help users to quickly and easily find the information they need.

Overall, by providing drivers and students with clear and detailed information about shuttle routes, the system can help to improve the efficiency and reliability of the shuttle service.

RR4.5 App User Interface

RR4.5.1 Students

This involves integrating essential schedule information directly onto the map page, including estimated arrival times (ETAs) and departure times for shuttles at each stop.

The map itself should be designed for readability and quick loading times. This can be achieved by using an abstract representation of the surrounding areas, with detailed routes shown only within the campus.

Additionally, the interface should offer features such as real-time shuttle tracking, the ability to filter schedules based on time and busyness, and the option to save favorite routes for quick access.

RR4.5.2 Drivers

Drivers should be able to easily view their schedules, routes, and any updates or changes in real-time.

The interface should also allow for clear communication between drivers and dispatchers, with features such as incident reporting and assistance requests.

General Usability

The app should have an intuitive layout with clear instructions and helpful information. It should also be designed to be accessible to users with disabilities, ensuring inclusivity for all members of the university community.

To further enhance usability, additional features such as a "dark mode" for nighttime visibility and the option to toggle between different map views (e.g., shuttle route view vs. campus view) could be implemented.

RR4.6 Delay Notification

RR4.6.1 Students

Personalized Notifications: Students should receive notifications about delays only if these delays affect their inputed schedules. This ensures that students receive relevant information without being bombarded with unnecessary notifications.

- Informative Content: Delay notifications should include updated ETAs and departure times, allowing students to adjust their plans accordingly.
- Customizable Settings: To further personalize the notification experience, students should be able to adjust the timing of notifications and prioritize specific routes for immediate delay notifications.
- Alternative Route Suggestions: When delays occur, the system should suggest alternative routes to help students find the quickest available option.

RR4.6.2 Drivers

Personalized Notifications: Drivers should receive notifications relevant to their schedule through the app. These notifications should be personalized to each driver, ensuring they only receive information about changes that affect their shifts.

Informative Content: Notifications should include details about specific route changes, new stop orders, and time adjustments.

Prioritized Alerts: Alerts should be prioritized based on urgency, ensuring drivers are immediately informed of critical changes like route alterations or significant delays.

Notification Log: To allow drivers to review past alerts and stay updated on changes that may have occurred during off-hours, a notification log should be maintained.

By providing timely and relevant notifications, the system can help both students and drivers stay informed about delays and other changes, improving the overall efficiency and reliability of the shuttle service.

[13] "Cognitive Psychology and Emotions in User Interface Design," TeaCode, accessed Oct. 20, 2024. [Online]. Available: https://teacode.io

# 5. Derived Requirements

DR5.1 Shuttle Scheduling

The system should automatically generate shuttle schedules based on data analysis and predictive algorithms, using machine learning to forecast demand and optimize resource allocation. This involves incorporating factors such as historical ridership data, real-time passenger demand, and even external data sources like weather and traffic conditions. The system should be able to simulate multiple scenarios to test potential schedules against different constraints, ensuring the most efficient and effective transportation plan.

While the system automates schedule creation, administrators should have the ability to approve, modify, or override these schedules for special events or unexpected situations. This ensures human oversight and the flexibility to adapt to unforeseen circumstances. The system should also prioritize environmental impact by maximizing shuttle utility, reducing idle times, and minimizing unnecessary mileage. This could involve optimizing routes to reduce fuel consumption and emissions, and dynamically adjusting schedules based on real-time demand to prevent empty shuttles from running.

To enhance connectivity and convenience for students, the system should align shuttle schedules with local transportation services. This could involve integrating with local transit APIs to access real-time schedules and adjust shuttle timings accordingly.

DR5.2 Data Collection

The system should collect real-time data from sensors to inform scheduling decisions and make adjustments based on actual demand. This could involve using sensors on shuttles to track passenger numbers, as well as utilizing GPS data to monitor traffic conditions and adjust schedules accordingly. Students should also be able to input their schedules to improve the accuracy of shuttle scheduling. This data can be used to identify peak demand periods and adjust shuttle frequency or routes to better meet student needs.

DR5.3 Driver Scheduling

Drivers should receive timely notifications about schedule changes, delays, or other relevant updates. This could involve in-app notifications, SMS messages, or email alerts. The system should allow drivers to set preferred work days and hours, improving driver satisfaction and operational stability. This could involve a self-service portal where drivers can input their availability and preferences, and the system should prioritize these preferences when creating schedules.

DR5.4 Event Scheduling

During events, the system should allocate additional resources to accommodate increased demand. This could involve adding extra shuttles to routes or creating temporary routes to event venues. Administrators should be able to add details about scheduled events to aid in planning and resource allocation. This could involve an event management module within the system where administrators can input event details such as date, time, location, and expected attendance.

DR5.5 User Interface

Both students and drivers should have easy access to real-time shuttle schedules through a user-friendly interface. The app should feature an abstract map for readability and faster load times, with detailed routes shown only within the campus. This could involve decluttering the map by only showing major roads and landmarks outside the campus area, while providing detailed routes within the campus.

DR5.6 Notifications for Delays and Changes

Students should be notified of shuttle delays that affect their inputted schedules, including updated ETAs and alternative route suggestions. This could involve push notifications with the updated arrival times and a map interface highlighting alternative routes. Drivers should receive personalized alerts about changes relevant to their schedules, such as route alterations, new stop orders, and time adjustments. This ensures that drivers are always aware of any changes that may impact their work.

# 6. Architectural Design

AD6.1 Functional Requirements [14][15]

AD6.1.1 Functional Requirement: Real-time shuttle tracking (Highest priority)

AD6.1.1.1 Description

This service displays the current location of shuttles on a map, providing users with a visual representation of the shuttles' positions. It also provides estimated arrival times for each stop, helping users plan their journeys more effectively. Users can track the shuttle's progress along its route, ensuring they are well-informed about the shuttle's status.

AD6.1.1.2 Point 1

This feature helps users see where the shuttles are in real-time, making it easier for them to decide when to leave for the bus stop. The map update frequency is high enough to provide a smooth and accurate tracking experience.

AD6.1.1.3 Point 2

This feature gives users the confidence to plan their journeys, reducing waiting times and uncertainty. The system uses real-time data to calculate the most accurate arrival times possible.

AD6.1.2 Functional Requirement: Dynamic Scheduling (Next highest priority) [14][15]

AD6.1.2.1 Description

The shuttles are scheduled to maximize student comfort and minimize waiting time. This system adjusts shuttle schedules based on real-time events and passenger demand, ensuring that the shuttle service is responsive to actual conditions. It optimizes shuttle routes to minimize travel time and maximize efficiency, which is crucial for a smooth and effective transportation experience.

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[14] Maiti, Richard Rabin, et al. "Using OCR to read handwritten texts in search for NFRs in Agile Software Engineering." Journal of Software Engineering Practice 3.2 (2019): 1-10.

[15] Rocha, Álvaro, and João Álvaro Carvalho. "Influence of the Information System Function Maturity in the Approach to the Requirements Engineering." New Perspectives on Information Systems Development: Theory, Methods, and Practice. Boston, MA: Springer US, 2002. 205-215.

AD6.1.2.2 Point 1

This feature allows the shuttle service to be flexible and adaptive, improving overall user satisfaction. Real-time adjustments help in managing unexpected delays or increased demand efficiently.

AD6.1.2.3 Point 2

This reduces travel time, making the shuttle service more efficient and convenient for users. The system continuously analyzes route performance and makes necessary adjustments to ensure optimal routing.

AD6.1.3 Functional Requirement: Driver Communication (Next highest priority)

AD6.1.3.1 Description

The solution enables efficient and seamless communication with shuttle operatives. It facilitates communication between drivers and dispatchers, which is essential for managing operations smoothly and effectively. Providing drivers with updated schedules and route information ensures they are always aware of their assignments and any changes.

AD6.1.3.2 Point 1

This feature ensures that any issues or changes can be communicated quickly and effectively, reducing operational delays. Efficient communication helps in managing incidents and maintaining smooth operations.

AD6.1.3.3 Point 2

This ensures that drivers are always aware of their assignments and any changes, improving overall service efficiency. Real-time updates help drivers navigate their routes more effectively and respond to any changes promptly.

AD6.2 Non-Functional Requirements

AD6.2.1 Non-Functional Requirements: Performance (Highest priority)

AD6.2.1.1 Description

Ensures fast loading times for real-time tracking and schedule updates. The system handles a large number of concurrent users and data requests efficiently, ensuring a smooth user experience. It maintains responsiveness during peak usage periods, preventing delays and ensuring that users can access the service without interruptions.

AD6.2.1.2 Point 1

Fast loading times are critical to providing a seamless user experience, allowing users to access real-time information without significant delays.

AD6.2.1.3 Point 2

The system is designed to manage high traffic volumes, ensuring that it can accommodate numerous users simultaneously without performance degradation. By maintaining high responsiveness during peak times, the system ensures continuous accessibility and usability, even during high-demand periods.

AD6.2.2 Non-Functional Requirement: Reliability (Next highest priority)[14][15]

AD6.2.2.1 Description

Provides accurate and up-to-date information, ensuring users can rely on the system for their transportation needs. The system minimizes downtime and ensures continuous service availability, providing a dependable service. It also implements error handling and recovery mechanisms to quickly address and resolve any issues that may arise.

AD6.2.2.2 Point 1

Reliability is ensured by consistently providing users with accurate and current information, which is essential for planning and decision-making.

AD6.2.2.3 Point 2

Minimizing downtime is crucial for maintaining user trust and service reliability, ensuring that the system is available whenever needed. Effective error handling and recovery mechanisms help maintain system stability and reliability by quickly addressing and resolving issues.

AD6.3 Reused Components[15]

AD6.3.1 Real-Time Shuttle Tracking and Passenger Notification (Highest priority)

AD6.3.1.1 Description

The dynamic scheduling feature of the ASU Shuttle Dispatcher maximizes efficiency and minimizes passenger wait times by adjusting schedules based on real-time events and passenger demand. It optimizes shuttle routes through continuous data analysis, allowing for real-time route adjustments to ensure the most efficient travel paths. Additionally, the system notifies users of schedule changes, keeping passengers informed and reducing the inconvenience of unexpected adjustments.

AD6.3.1.2 Point 1

By displaying the current location of shuttles on a map, the system provides a visual and dynamic representation of shuttle movements. This real-time tracking feature updates frequently to give users a precise and up-to-date view of where each shuttle is, reducing uncertainty and improving planning.

AD6.3.1.3 Point 2

The provision of estimated arrival times at each stop uses real-time data and advanced algorithms to predict when a shuttle will reach a given stop. This feature enhances user convenience and allows passengers to better manage their time by avoiding unnecessary waits.

AD6.3.2 Dynamic Scheduling and Passenger Notification (Next highest priority)

AD6.3.2.1 Description

The dynamic scheduling feature of the ASU Shuttle Dispatcher maximizes efficiency and minimizes passenger wait times by adjusting schedules based on real-time events and passenger demand. It optimizes shuttle routes through continuous data analysis, allowing for real-time route adjustments to ensure the most efficient travel paths. Additionally, it notifies users of any schedule changes, keeping passengers informed and reducing the inconvenience of unexpected adjustments.

AD6.3.2.2 Point 1

Adjusting shuttle schedules based on real-time events and passenger demand ensures that the shuttle service is responsive to actual conditions. This dynamic approach allows the system to accommodate sudden changes, such as increased passenger numbers or road closures, maintaining service efficiency.

AD6.3.2.3 Point 2

Optimizing shuttle routes involves continuously analyzing traffic conditions, passenger demand, and other factors to find the most efficient paths. This optimization reduces travel time and fuel consumption, enhancing the overall sustainability and reliability of the service.

AD6.3.3 Data Collection and Analysis and User Feedback Mechanism (Next highest priority)

AD6.3.3.1 Description

The data collection and analysis feature gather essential metrics on ridership, wait times, and other key factors to understand user patterns and improve the shuttle service. By analyzing this data, the system can optimize scheduling, dispatching, and resource allocation to better meet passenger needs. Additionally, it generates reports and visualizations to track performance, aiding administrators in making data-driven decisions and enhancing service quality.

AD6.3.3.2 Point 1

Data collection involves monitoring various aspects of shuttle usage, including the number of passengers, average wait times, and peak usage periods. This data provides valuable insights into how the shuttle service is being utilized and helps identify opportunities for improvement.

AD6.3.3.3 Point 2

Using the collected data, the system can make informed decisions about scheduling, dispatching, and resource allocation. This ensures that resources are used efficiently, improving the reliability and responsiveness of the shuttle service.

AD6.3.3.4 Point 3

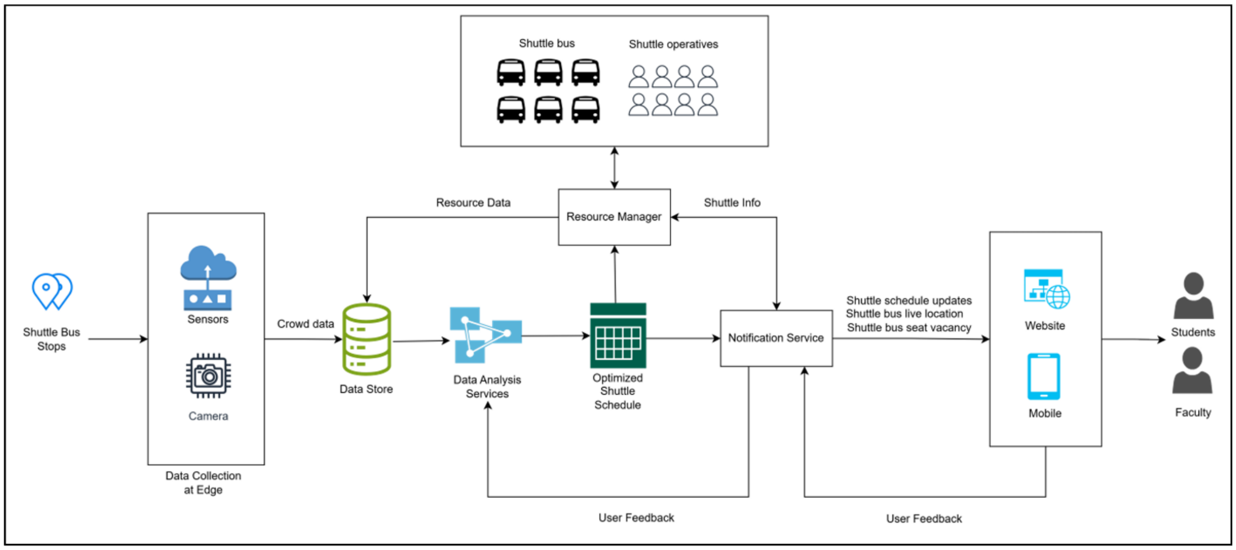
Generating reports and visualizations allows administrators to track performance metrics over time. These tools provide a clear overview of the system's efficiency and effectiveness, helping to identify trends and areas that require attention or improvement.

[14] Maiti, Richard Rabin, Aleksandr Krasnov, and Deanna Marie Wilborne. "Agile software engineering & the future of non-functional requirements." Journal of Software Engineering Practice 2.1 (2018): 1-8

[15] Rocha, Álvaro, and João Álvaro Carvalho. "Influence of the Information System Function Maturity in the Approach to the Requirements Engineering." New Perspectives on Information Systems Development: Theory, Methods, and Practice. Boston, MA: Springer US, 2002. 205-215.

# 7. Detailed Design

## DD7.1 Design Element: Process View (Highest priority)[10][11]




### DD7.1.1 Description

The process view summarizes the main parts of the ASU Shuttle Dispatcher system, providing an overview of how different modules interact to ensure efficient operation. This view includes the Data Collection Module, Resource Manager, Data Transformation Module, Data Analysis Module, and Notification Service.

The Data Collection Module is responsible for gathering sensor data and surveillance data to track the crowd. This module plays a crucial role in providing real-time information on passenger density and movement, which is essential for optimizing shuttle routes and schedules.

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[10] Y. Xie, J. Niu, Y. Zhang and F. Ren, "Multisize patched spatial-temporal transformer network for short- and long-term crowd flow prediction", IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 11, pp. 21548, 2022.

[11] M. Z. Malik, S. Nazir and H. U. Khan, "Artificial Intelligence Based System on Enhancing the Capabilities of Transport System: A Systemic Literature Review," 2023 IEEE Symposium on Industrial Electronics & Applications (ISIEA), Kuala Lumpur, Malaysia, pp. 1-6, 2023

DD7.2 Design pattern or technical description

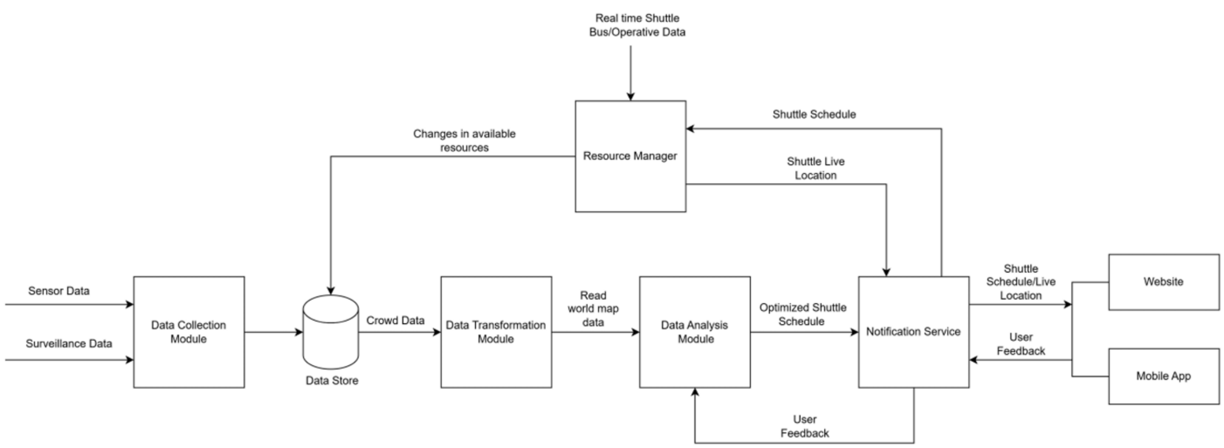
A suitable design pattern for this system could be the Observer Pattern. This pattern is ideal for a scenario where various components of the system (observers) need to be updated in real-time whenever there is a change in the system state (subject). In this context, the Notification Service acts as the subject, and modules like the Resource Manager and Data Analysis Module act as observers.

The Data Analysis Module predicts crowd trends to generate optimal shuttle schedules. By analyzing historical and real-time data, this module can forecast passenger demand and adjust shuttle schedules accordingly, improving the overall efficiency and reliability of the shuttle service.

DD7.3 Rationale

The Observer Pattern is beneficial in this context because it allows for a decoupled and scalable system where changes in one part of the system can be propagated to all dependent components without direct coupling. This design pattern enhances the system's flexibility and maintainability.

DD7.4 Design Element: Physical View (Next highest priority) [16]




DD7.5.1Description

The physical view summarizes the hardware and infrastructure aspects of the ASU Shuttle Dispatcher system, providing an overview of the physical components and their roles in supporting the system's operations.

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[16] S. T. Kouyoumdjieva, P. Danielis and G. Karlsson, "Survey of non-image-based approaches for counting people", IEEE Communications Surveys & Tutorials, vol. 22, no. 2, pp. 1305-1336, Second quarter 2020.

DD7.6 Design pattern or technical description

A suitable design pattern for this system could be the Client-Server Architecture. This pattern is ideal for separating the concerns between the client (e.g., mobile apps, websites) and the server (e.g., cloud-hosted application). It enables scalable, maintainable, and efficient system operations.

The shuttle dispatcher service application is hosted in the cloud. Hosting the application in the cloud provides scalability, reliability, and ease of access, allowing the system to handle large volumes of data and users without performance issues.

The application collects crowd and resource information to optimize the shuttle schedule. By gathering and analyzing data on passenger density and shuttle availability, the system can generate schedules that improve efficiency and reduce wait times.

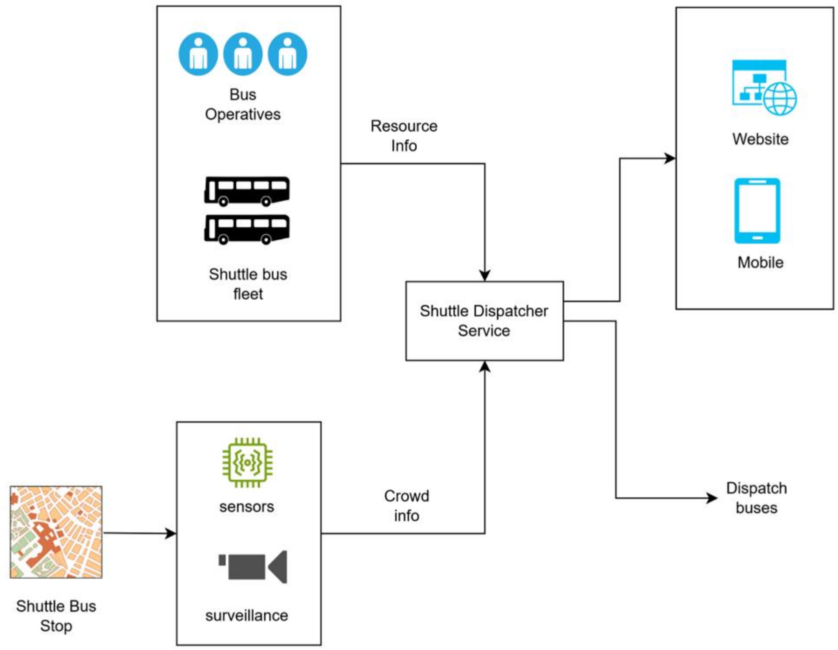
DD7.7 Rationale

The Client-Server Architecture is beneficial as it allows for centralized management and distribution of resources while ensuring that client applications can be lightweight and responsive. This architecture supports the scalability and flexibility needed for the ASU Shuttle Dispatcher system.

The shuttle buses are dispatched according to the optimized shuttle schedule generated. This ensures that the buses operate efficiently, minimizing delays and maximizing passenger satisfaction by adhering to the most effective routes and times.

The updated schedules and shuttle tracking are enabled via websites and mobile apps. These platforms provide users with real-time information on shuttle locations and schedules, enhancing the convenience and usability of the shuttle service.

DD7.8 Design Element: Scenario View (Next highest priority) [9]




DD7.8.1 Description

The scenario view summarizes user interaction and smart scheduling, aiming to provide a better experience for students and faculty using ASU shuttles. This view highlights the steps from waiting at the bus stop to receiving optimized schedules based on real-time data and user feedback.

DD7.9 Design pattern or technical description

A suitable design pattern for this system could be the Model-View-Controller (MVC) Pattern. This pattern is ideal for separating the concerns between the data model, user interface, and control logic, ensuring a clear and manageable structure for real-time user interactions and data processing.

The shuttle bus schedule is optimized to minimize waiting time. Using real-time data and historical patterns, the system can generate schedules that reduce idle times and ensure that shuttles are available when needed the most. This optimization process involves continuously updating schedules based on the latest data.

The solution enables live tracking of the shuttle bus location and seat occupancy status. This feature allows users to see the exact location of the shuttles and the availability of seats, improving their planning and reducing uncertainty. The live tracking information is accessible via websites and mobile apps.

DD7.10 Rationale

The Model-View-Controller (MVC) Pattern is beneficial because it allows for a clear separation of concerns, making the system more modular, maintainable, and scalable. This design pattern supports efficient real-time updates and user interactions, which are critical for the ASU Shuttle Dispatcher system.

User feedback is collected and used by the Shuttle Dispatcher Service to optimize future scheduling. This feedback loop ensures that the system continuously evolves based on user experiences and preferences, leading to a more responsive and user-centric shuttle service.

By incorporating user feedback and real-time data, the shuttle dispatcher service can make data-driven decisions that enhance the overall user experience. This iterative process of collecting, analyzing, and acting on feedback helps in continuously refining the shuttle schedules and improving service quality.

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[9] Vidyasagaran, S. R. Devi, A. Varma, A. Rajesh and H. Charan, "A low cost IoT based crowd management system for public transport", 2017 International Conference on Inventive Computing and Informatics (ICICI), pp. 222-225, 2017.

# 8. Traceability

T8.1. Two-Way Traceability from Customer Problem 1 to code: Long Waiting Time
Identifier: CP1-01.

- Description: Long waiting times during peak hours reduce student satisfaction.
- Prose: Long waiting times during peak hours are caused by inadequate scheduling and the absence of dynamic adjustments. The proposed solution incorporates predictive algorithms and real-time updates to streamline shuttle operations, thereby minimizing delays and enhancing student satisfaction.

T8.1.1. Forward (Problem to code)

T8.1.1.1. Concept of Operations (ConOps):

The system optimizes shuttle schedules by analyzing peak-hour crowding and leveraging student usage patterns. Real-time updates inform users of wait times through a mobile app, incorporating shuttle availability data to allocate resources efficiently [17]. Heatmaps visually identify high-demand periods to guide operational adjustments.

T8.1.1.2. Requirements:

The solution implements hourly-adjusting algorithms to meet demand, integrates feedback to improve accuracy, and preempts demand spikes by considering event schedules. Real-time notifications keep users informed of schedule changes [18], while idle times are minimized, and administrative tools are simplified for managing disruptions.

T8.1.1.3. Design:

A modular scheduling platform supports updates without downtime, while AI continuously adapts based on shuttle data [14]. The cloud-based infrastructure manages peak-hour scalability, with fallback mechanisms for manual overrides. Monitoring dashboards track shuttle adherence, and APIs share demand analytics with stakeholders.

T8.1.1.4. Code:

Adaptable algorithms respond to real-time data, simulating scenarios for operational testing.

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[17] Noor, R. M., Rasyidi, N. B. G., & Nandy, T. (2020). "Campus Shuttle Bus Route Optimization Using Machine Learning Predictive Analysis." Sustainability, 13(1), 225. https://doi.org/10.3390/su13010225.

[18] Wang, J., Zhang, Y., Xing, X., Zhan, Y., Chan, W. K., & Tiwari, S. (2022). "A Data-Driven System for Cooperative-Bus Route Planning." Annals of Operations Research. https://doi.org/10.1007/s10479-022-04842-w

[14] Maiti, Richard Rabin, et al. "Using OCR to read handwritten texts in search for NFRs in Agile Software Engineering." Journal of Software Engineering Practice 3.2 (2019).

Backend integration ensures seamless communication with student-facing applications, while automated alerts address resource limits. Predictive error-handling reduces disruptions, and optimized data storage supports fast scheduling.

T8.1.2. Backward (Code to Problem)

T8.1.2.1. Code to Design:

Algorithms improve responsiveness, and monitoring logs validate the effectiveness of schedule changes. Predictive analytics enhance long-term planning, while error handling ensures robust performance during demand spikes. Historical patterns inform updates, and UI testing confirms alignment with user needs.

T8.1.2.2. Design to Requirements:

Heatmaps validate alignment with peak-hour projections, while real-time tracking confirms reliable notifications. Modular design supports quick updates, and analytics verify reductions in wait times. Feedback ensures that operational goals are consistently met.

T8.1.2.3. Requirements to ConOps:

Reduced wait times confirm system efficiency, while enhanced communication channels foster user trust. Dynamic responses handle fluctuations, equitable service ensures inclusivity, and sustainability goals are supported through efficient operations.

**Table for Customer Problem 1:**

| **Traceability** | **Details** |
|---|---|
| **Problem to ConOps** | Reduce wait times by using demand analysis and real-time tracking. |
| **ConOps to Requirements** | Integrate predictive scheduling, provide real-time updates, ensure user-friendly interfaces. |
| **Requirements to Design** | Build algorithms for predictive analysis, real-time adjustments, and app-based notifications. |
| **Code to Design** | Dynamic updates ensure alignment with design goals. |
| **Design to Requirements** | Validated through reduced wait times and feedback. |

T8.2. Two-Way Traceability from Customer Problem 2 to Code : Crowded Shuttles
Identifier: CP2-01.

- Description: Overcrowded shuttles during peak hours decrease comfort and usability.
- Prose: Overcrowding significantly impacts student comfort. The solution redistributes shuttle resources dynamically, using occupancy sensors to monitor capacity. Route assignments are optimized, and user feedback aids in addressing crowding issues

proactively. This builds upon research by Schuß (2022), which explores operator influence in automated urban shuttles.

T8.2.1. Forward (Problem to Code)

T8.2.1.1. Concept of Operations (ConOps):

The system introduces a seat-reservation option and prioritizes capacity adjustments based on surveys. Occupancy metrics inform frequency redistribution [19], and advance updates on busy routes enable better planning. Feedback from users ensures ongoing improvement.

T8.2.1.2. Requirements:

Shuttles are equipped with smart occupancy sensors, and seat availability is displayed via mobile apps [9]. Dispatch teams receive alerts for capacity breaches, while policies limit shuttle riders per trip. Incident logs identify crowding patterns to refine future scheduling.

T8.2.1.3. Design:

The system supports high sensor data loads and includes dynamic occupancy indicators in apps. Synchronization with local transit ensures smooth operations, and visual tools aid dispatchers in decision-making. Usage history anticipates high-demand periods.

T8.2.1.4. Code:

Data pipelines process sensor feedback, triggering real-time notifications for seat availability. Seamless syncing between app updates and dispatch alerts ensures rapid responses. Fallback mechanisms handle sensor failures, and app prompts facilitate seat pre-booking.

T8.2.2. Backward (Code to Problem)

T8.2.2.1. Code to Design:

IoT sensors validate real-time occupancy tracking, and automation reduces manual intervention. Notification logic ensures timely capacity alerts, while error logs resolve discrepancies. Continuous monitoring informs interface updates, and occupancy statistics refine scheduling.

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[19] Schuß, M., Rollwagen, A., & Riener, A. (2022). "Understanding Operator Influence in Automated Urban Shuttle Buses." Multimodal Technologies and Interaction. https://doi.org/10.3390/mti6120109

[9] Vidyasagaran, S. R. Devi, A. Varma, A. Rajesh and H. Charan, "A low cost IoT based crowd management system for public transport", 2017 International Conference on Inventive Computing and Informatics (ICICI), pp. 222-225, 2017.

T8.2.2.2. Design to Requirements:

Real-time seat availability aligns with app requirements, and heatmaps mitigate crowding patterns. Notifications meet user needs, while modular designs scale for high demand.

Integration tests verify seamless data flow, and operator feedback confirms design assumptions.

T8.2.2.3. Requirements to ConOps:

Resource allocation minimizes crowded conditions, improving student satisfaction. Capacity adjustments and route re-optimization ensure balanced shuttle loads, while data initiatives enhance planning.

**Table for Customer Problem 2:**

| Traceability | Details |
|---|---|
| **Problem to ConOps** | Address crowding by dynamically redistributing shuttle resources. |
| **ConOps to Requirements** | Integrate occupancy sensors and notify users of shuttle capacity in real-time. |
| **Requirements to Design** | Build a modular system for real-time occupancy monitoring and app notifications. |
| **Code to Design** | Sensor feedback loops provide occupancy data to apps and dashboards. |
| **Design to Requirements** | Validated by consistent user feedback and improved resource allocation. |

8.3. Two-Way Traceability from Customer Problem 3 to Code: Lack of Real-Time Information
Identifier: CP3-01

- Description: Students cannot predict shuttle timings or availability.
- Prose: Students often lack real-time updates on shuttle locations, causing uncertainty. This issue is mitigated by integrating GPS tracking and a notification system.

T8.3.1. Forward (Problem to code)

T8.3.1.1. Concept of Operations (ConOps):

Real-time tracking provides visibility, while accurate timings reduce uncertainty. Notifications and improved communication enhance student confidence, and operational efficiency ensures smooth transitions with local transit.

T8.3.1.2. Requirements:

GPS tracking, user notifications, and mobile integration deliver real-time data. The app offers a simple interface for tracking shuttles and estimated arrivals, reducing stress and uncertainty.

T8.3.1.3. Design:

Interactive maps display shuttle locations, while notifications alert students about changes. Event integration adapts to campus needs, and user feedback informs improvements to notifications and maps.

T8.3.1.4. Code:

GPS integration feeds real-time data into the app, while notification systems synchronize with tracking updates. Data logging captures user interactions, improving functionality, and ensuring reliability.

T8.3.2. Backward (Code to Problem)

T8.3.2.1. Code to Design:

GPS ensures accuracy, while notifications align with interface elements. Interaction logs refine designs, and delay alerts ensure reliability. Real-time tracking enhances visual updates, verified by low latency during testing.

T8.3.2.2. Design to Requirements:

Maps and notifications meet real-time tracking needs, while responsiveness supports instant updates. Analytics confirm user engagement improvements, and feedback ensures design flexibility.

T8.3.2.3. Requirements to ConOps:

Accurate updates improve planning, reducing stress. Operational goals of predictability and transparency are achieved, fostering trust.

**Table for Customer Problem 3:**

| **Traceability** | **Details** |
|---|---|
| **Problem to ConOps** | Provide real-time shuttle tracking for reduced uncertainty. |
| **ConOps to Requirements** | Build GPS-enabled tracking, user notifications, and mobile apps. |
| **Requirements to Design** | Implement GPS tracking systems integrated with mobile interfaces. |
| **Code to Design** | Real-time data synchronization ensures consistent tracking. |

T8.4. Two-Way Traceability from Customer Problem 4 to Code : Inefficient Scheduling
Identifier: CP4-01

Description: Poor shuttle dispatching leads to underutilized capacity and delays.

Prose: The inefficiency in shuttle scheduling, causing underutilized capacity and delays, is addressed through predictive algorithms and real-time data integration. This ensures dynamic schedule adjustments, better resource allocation, and improved operational efficiency.

T8.4.1. Forward (Problem to Code)

T8.4.1.1. Concept of Operations (ConOps):

Predictive algorithms analyze past data and forecast demand. Real-time schedule adjustments respond to disruptions, and coordination with event planners ensures readiness for large events.

T8.4.1.2. Requirements:

Machine learning predicts demand, while syncing with local transport creates dynamic routes. Real-time updates notify users, and administrative tools facilitate manual overrides when necessary.

T8.4.1.3. Design:

A data analytics engine visualizes shuttle usage, while real-time dashboards allow adjustments. External APIs provide transport data, supporting instant schedule changes and scalability.

T8.4.1.4. Code:

Adaptive algorithms adjust schedules based on real-time inputs. Cloud technology handles high data volumes, and fallback options address failures. Traffic-aware routing ensures reliability during disruptions.

T8.4.2. Backward (Code to Problem)

T8.4.2.1. Code to Design:

Algorithms simulate scenarios for optimal outcomes, while adaptive features manage unanticipated events. Metrics validate design assumptions, and APIs ensure communication between systems.

T8.4.2.2. Design to Requirements:

Real-time dashboards improve monitoring, while analytics verify adherence rates. Testing ensures scalability, and user feedback confirms usability aligns with design goals.

T8.4.2.3. Requirements to ConOps:

Dynamic scheduling optimizes shuttle utilization, aligning with sustainability and operational goals.

**Table for Customer Problem 4:**

| **Traceability** | **Details** |
|---|---|

| | |
|---|---|
| **Problem to ConOps** | Predict shuttle needs and adjust for traffic/events in real-time. |
| **ConOps to Requirements** | Use machine learning to forecast demand and sync with local transport. |
| **Requirements to Design** | Create a flexible system that integrates real-time data and external transport info. |
| **Code to Design** | Build adaptive algorithms for real-time schedule adjustments. |
| **Design to Requirements** | Ensure accuracy through real-time data and visualizations. |
| **Requirements to ConOps** | Better scheduling efficiency and less underutilized capacity. |

# 9. Implementability

## I9.1 Highest Priority Received Requirements

The highest priority received requirements focus on automating schedule creation, enabling manual admin approval, and collecting student usage data. These are all feasible for typical designers and programmers to implement using existing technologies and standard practices.

I9.1.1 As an admin I want schedules to be created automatically to optimally fit the data. This can be readily implemented by training a machine learning model (e.g., Support Vector Machine) on historical shuttle usage data, factoring in variables like time of day, day of the week, and special events. The model would then predict shuttle demand for different time slots and generate an optimized schedule. Many scheduling systems already utilize machine learning for optimization, with constraint satisfaction algorithms being a common approach.

I9.1.2 As an admin I want to approve schedules manually to avoid potential issues. This is easily implemented using standard authorization and workflow patterns found in most enterprise resource planning (ERP) and workflow management systems. The system can notify the admin when a new schedule is generated, and the admin interface would allow viewing, approving, or rejecting it with feedback options.

I9.1.3 As an admin I want student usage data to be collected from sensors. This is standard practice in IoT and data analytics, as evidenced by many transportation systems using sensors for data collection (e.g., traffic monitoring, passenger counting). Deploying sensors (e.g., infrared counters) on shuttles to collect real-time usage data and transmit it wirelessly to a central server is a feasible implementation.

## I9.2 Derived Functional Requirements

I9.2.1 Automated Schedule Creation: This builds upon I9.1.1 and is feasible due to the availability of many libraries and frameworks for machine learning and schedule optimization. Constraint satisfaction algorithms (e.g., Google OR-Tools) can be used to generate schedules that meet various constraints (e.g., driver availability, shuttle capacity) [20].

I9.2.2 Comprehensive Testing and Validation: The system will undergo rigorous testing and validation procedures to identify and address potential biases in the data or algorithms. This includes using diverse datasets, simulating various scenarios, and employing fairness-aware machine learning techniques. The goal is to ensure that the system does not disproportionately benefit or disadvantage any particular group of students or staff.

I9.2.3 Regular Audits: Periodic audits will be conducted to assess the system's performance across different demographics. This will involve analyzing ridership data, wait times, and other relevant metrics to identify any disparities in service provision. The audit results will be used to make necessary adjustments to the system and ensure equitable access to transportation for all members of the university community.

I9.2.4 The system will incorporate feedback mechanisms to gather input from students, staff, and other stakeholders. This will help to identify any concerns regarding fairness and inclusivity and ensure that the system is responsive to the needs of the community. The feedback gathered will be used to improve the system and promote transparency and accountability in its operation.

I9.3 Non-Functional Requirements

I9.3.1 Security - Data Security and Privacy Standard security practices and technologies can be applied to ensure data security and privacy, guided by industry standards like OWASP Top 10 and CWE Top 25. This includes encrypting sensitive data (e.g., student schedules) in transit and at rest, implementing access controls, and regularly auditing the system for vulnerabilities.

19.3.2 Performance - Real-time Schedule Updates Real-time updates are achievable with modern web technologies, as seen in many apps like ride-hailing apps and GPS navigation. Using WebSockets or Server-Sent Events for efficient server-to-client communication and optimizing database queries and application logic can ensure real-time performance.

I9.3.3 Data Minimization: The system should only collect and store the data that is absolutely necessary for its operation. This helps to reduce the risk of data breaches and ensures that sensitive information is not unnecessarily exposed.

I9.3.4 Regular Security Assessments: Periodic security assessments (e.g., penetration testing, vulnerability scanning) should be conducted to identify and address potential vulnerabilities in the system. This helps to ensure that the system remains secure over time and that any emerging threats are mitigated.

I9.5 Client's Highest Priority Goal

19.5.1 Automated Schedule Creation

Shuttle Scheduling: This is the foundation of achieving accurate and efficient scheduling. By automating the schedule creation process, the system can leverage data analysis and optimization algorithms to create schedules that best meet the needs of students and staff. This eliminates the inefficiencies and potential inaccuracies of manual scheduling.

Automated Schedule Creation: This builds upon the previous requirement by specifying the use of machine learning for schedule optimization. Machine learning algorithms can analyze historical data, identify patterns, and predict future demand, allowing the system to dynamically adjust schedules and optimize shuttle utilization.

I9.5.2 Data Collection

Sensor Data: Accurate scheduling relies on having good data. This requirement ensures that the system collects the necessary data on student usage patterns, which can then be used to inform the scheduling process and make adjustments based on actual demand [21].

I9.6 Environmental Optimization

Environmental Advocate: This requirement contributes to efficiency by maximizing shuttle utility and minimizing waste. By ensuring that shuttles are used to their full potential, the system can reduce the number of unnecessary trips, which in turn saves fuel and reduces environmental impact [22].

Reduced Environment Impact: These further details how the system optimizes for reduced environmental impact through efficient routing and resource allocation. By considering factors such as distance, traffic, and passenger demand, the system can create routes and schedules that minimize fuel consumption and emissions.

I9.7 Driver Scheduling

Drivers Schedule: Allowing drivers to select their preferred work days and hours can improve efficiency by ensuring driver availability during peak times. This helps to prevent staffing shortages and ensures that there are enough drivers to meet demand.

Driver Preferences and Availability: This expands on driver scheduling by detailing how the system incorporates driver preferences and availability into the scheduling process. By taking driver preferences into account, the system can create schedules that are more likely to be followed, leading to improved efficiency and driver satisfaction.

In summary, these requirements work together to ensure that the shuttle scheduling system is accurate, efficient, and responsive to the needs of students, staff, and drivers. By automating schedule creation, collecting relevant data, optimizing for environmental impact, and incorporating driver preferences, the system can achieve the client's goal of having a reliable and sustainable transportation service.

[20] Elhalid, Osama Burak, and Ali Hakan Isık. "ENHANCING MEDICAL OFFICER SCHEDULING IN HEALTHCARE ORGANIZATIONS: A COMPREHENSIVE INVESTIGATION OF GENETIC AND GOOGLE OR TOOLS ALGORITHMS FOR MULTI-PROJECT RESOURCE-CONSTRAINED OPTIMIZATION." *International Journal of 3D Printing Technologies and Digital Industry* 8.1: 92-103.

[21] Kayastha, Nipendra, et al. "Smart grid sensor data collection, communication, and networking: a tutorial." *Wireless communications and mobile computing* 14.11 (2014): 1055-1087.

[22]Oikonomou, Maria G., et al. "Impacts of autonomous shuttle services on traffic, safety and environment for future mobility scenarios." *2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2020.

# 10. Screencast

Link for the Screencast video: https://youtu.be/pXnj3UnP6YI


| | |
|---|---|
| Introduction<br><br>Current Problem | Chi Ao, Chen |
| Solution Overview | Jean Johnson |
| Feature: Smart Scheduling<br><br>Feature: Enhanced User Communication | Dominic Baker |
| Features: Co-ordination of ASU events<br>Feature: Social & Environment Impact | Hana Almuallem |
| Conclusion | Aryan R. Suthar |

# 11. Conclusion

## 11.1. Overview
This project has provided valuable insights into shuttle system optimization through real-time data integration, dynamic scheduling, and IoT advancements. Beyond addressing the core problems, it uncovered key lessons and recommendations to guide future work.

## 11.2. Key Lessons Learned

### 11.2.1. Conclusion 1: User-Centric Design is Essential

The mobile app enhances navigation through clear visual cues, making it easier for students to find their way. Notifications foster a sense of reliability and trust by keeping users informed. Transparent feedback loops promote active user engagement, while smoother cross-modal connections elevate the overall travel experience. Additionally, real-time occupancy data empowers students to plan their journeys more effectively, and customizable features ensure the app meets individual preferences, offering a personalized experience.

### 11.2.2. Conclusion 2: Data-Driven Decisions Drive Efficiency

Our system ensures minimal waiting times for users through real-time updates and optimizes shuttle usage with demand-based scheduling, reducing idle fleet hours. By incorporating user feedback, the scheduling process is continually refined to better meet student needs. Event synchronization helps the system anticipate and manage peak load challenges effectively. With multi-source data integration, the platform becomes more adaptable, while automated decision-making accelerates response times, ensuring a seamless and efficient transportation experience.

### 11.2.3. Conclusion 3: Scalability Requires Planning
Our approach emphasizes eco-friendly practices through emissions tracking, ensuring the shuttle system aligns with sustainability goals. Optimized schedules minimize unnecessary fuel consumption, promoting efficiency and reducing environmental impact. The system is designed for sustainable scalability, ensuring its long-term viability as the campus grows. By coordinating with local initiatives, we support shared environmental objectives while fostering community collaboration. Detailed metrics provide the foundation for evidence-based environmental reporting, helping ASU demonstrate its commitment to sustainability. Additionally, the reduction in resource wastage aligns seamlessly with the university's institutional goals for a greener future.

## 11.3. Open Issue 1: Data Security & Privacy

### 11.3.1. Data Protection Measures
To protect student privacy, it is essential to encrypt sensitive information both at rest and during transmission. Multi-factor authentication should be implemented for all user accounts to prevent unauthorized access. Regular audits must be conducted to ensure compliance with legal regulations such as GDPR and FERPA, safeguarding the system’s data security.

Additionally, anonymization techniques should be employed during data analysis to protect personal identities while enabling the optimization of services.

11.3.2. Commitment to Transparency and Growth
To ensure transparency and build trust, we will develop clear and comprehensive privacy policies and terms of service to inform users about how their data is collected, used, and stored. Users will have the option to opt out of non-essential data collection, giving them greater control over their personal information. Additionally, we will establish a user trust management system to provide regular updates on how collected data contributes to system improvements. To further reinforce our commitment to privacy, we will create a public dashboard that highlights ongoing data security measures and any updates to our privacy policies.

11.4. Open Issue 2: Scalability and Peak Performance

11.4.1. Performance During Peak Times
To effectively handle sudden spikes in demand, particularly during events or peak hours, a comprehensive scaling strategy is essential. This includes leveraging cloud-based infrastructure to dynamically allocate shuttle resources based on real-time traffic and crowd data. To ensure the system performs seamlessly under varying levels of stress, simulations should be conducted to test its responsiveness and reliability. Additionally, incorporating edge computing solutions can help reduce latency and improve performance during periods of peak demand.

11.4.2. Proactive and User-Focused Development
To ensure the ASU Shuttle Dispatcher system operates efficiently, user feedback should be collected regularly to anticipate changes in demand and proactively adjust schedules or resources. Leveraging machine learning, the system can forecast future capacity needs and modify shuttle frequency in advance, helping to reduce congestion during peak times. Continuous performance monitoring will track resource utilization and promptly alert teams to potential bottlenecks, enabling swift action. Additionally, robust contingency plans should be developed to maintain service continuity in the face of unexpected demand surges or infrastructure challenges.

11.5. Parking Lot

11.5.1. Parking Lot Item 1: Enhanced AI Models
To enhance the capabilities of our system, we plan to explore hybrid AI frameworks that improve predictive accuracy by combining multiple machine learning approaches. Integrating real-time weather data will further refine scheduling and dispatch decisions, ensuring more adaptive responses to changing conditions. Additionally, we aim to enable scenario-based forecasting, particularly for large-scale events, to better accommodate fluctuating demands. User feedback will play a critical role as we incorporate it into our machine learning models, ensuring continuous improvement and alignment with user needs. To validate the efficacy of our AI solutions, we will conduct pilot studies, gathering data to refine our approach. Finally, we

intend to publish our findings to encourage collaboration and knowledge sharing with other campuses, fostering innovation in sustainable transportation systems.

### 11.5.2. Parking Lot Item 2: Multi-Modal Integration

Deploying autonomous systems requires addressing ethical concerns and ensuring regulatory compliance for safe operation. Testing features like route adaptability is critical, alongside awareness campaigns to build public trust. Gradual transition on select routes allows for controlled integration, with rigorous evaluation of safety metrics to ensure reliability.

### 11.5.3. Parking Lot Item 3: Focus on Sustainability

To enhance public transit, we should work with operators to align schedules and offer incentives for students using connected transport. Improving our app for real-time tracking of connections will help students plan their journeys better. We can also simplify payments with joint ticketing options. Lastly, investing in infrastructure for smooth transfers and using analytics dashboards will optimize the overall experience for everyone.

# 12. Appendix A: Credit Sheet

| Team Member Name | Contributions |
| --- | --- |
| Chi Ao, Chen | Executive Summary<br>Architectural Design<br>Detailed Design |
| Aryan R. Suthar | • Responsible for Traceability Section.<br>• Updated Conclusion Section.<br>• Participated in Screencast presentation.<br>• Attended team discussions for Phase Development. |
| Dominic Baker | Received Requirements<br>Derived Requirements<br>Implementation |
| Hana Almuallem | Helped create the presentation<br>Wrote initial script for the presentation<br>Helped format the deliverable |
| Jean Anna Johnson | Worked on the Presentation for the Screencast<br>Added the Customer Problem in prose<br>Added the Concept of Operations in prose |