B-CALM: Bikeshare Communication, Access, and Logistics Management System

6.1800 Design Project Preliminary Report

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1. Introduction

Hoping to make transportation affordable and enjoyable for citizens, Newplace is building an enhanced bike-share system that adds improved software and hardware capabilities to existing systems. We propose B-CALM (Bikeshare Communication, Access, and Logistics Management), which allows easy access to bikes and stations, fast and secure data collection, and reliable and efficient communication across system modules.

B-CALM impacts commuting citizens, so its focus is on efficiency and reliability. Our primary objective is efficiency, defined as the speed and simplicity at which bike requests and functionalities are processed. Efficiency is crucial because, as a transportation system, users have concerns over punctuality in commutes such as to work or meetings. A slow and inefficient system fails at the basic requirements of a transportation system and speeds up travel times. We prioritize efficiency to ensure that users can quickly access bikes, dock them at their destinations, and plan their journeys.

A secondary priority is reliability, or the ability of the system to retain its core functionalities even in the face of power or communication outages. Loss of essential functionalities (such as renting and docking) could result in dissatisfaction and may turn users away from the rideshare services. Also, a reliable system ensures that data is not lost and that the system can recover quickly from any disruptions, maintaining trust and confidence in the service.

B-CALM improves efficiency by supporting high-speed data transfer from each separate physical and virtual module to a centralized computing system, which allows for low-latency communication when processing user requests. B-CALM achieves reliability by caching information in stations so that each station can run independently with all core bike share functionalities.

In Section 2, we cover the system overview of B-CALM. In Section 3, we highlight important design components involved in the system. In Section 4, we detail use cases and potential impacts of the system. In Section 5, we discuss implications such as scalability, security considerations, and future expansion plans.

2. System Overview

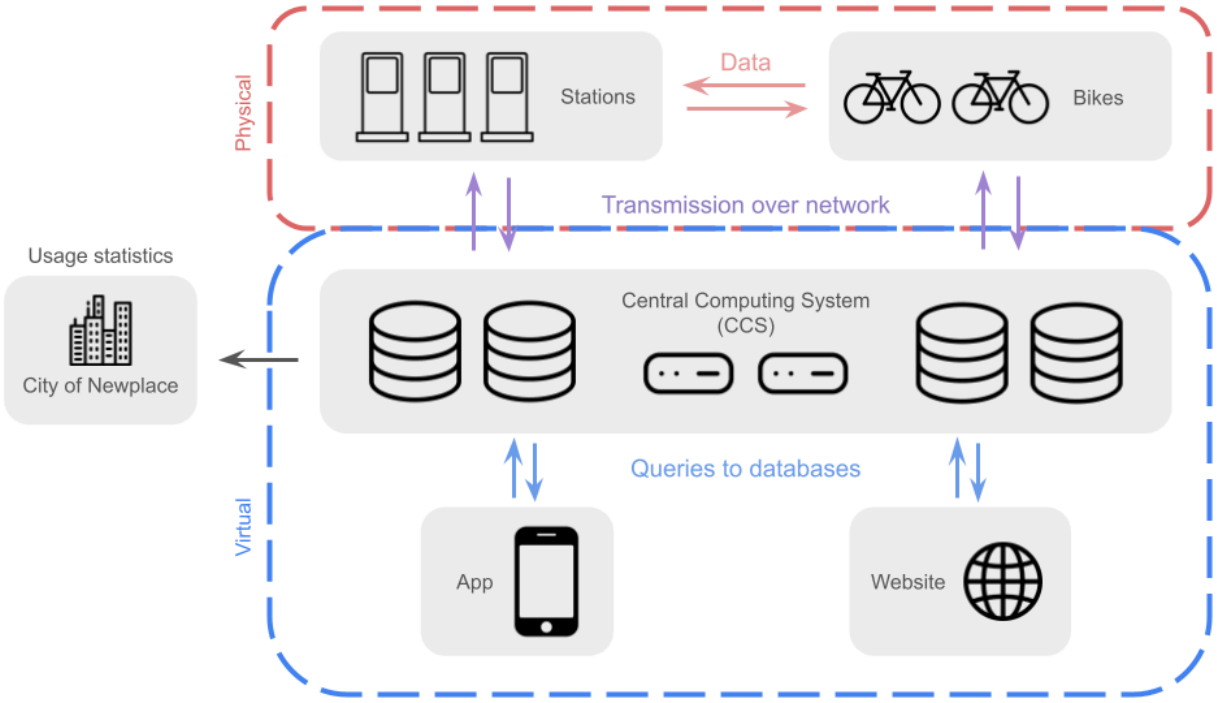
B-CALM is separated into five modules grouped in two categories: physical and virtual, as seen in Figure 1. The physical modules are:

1. Stations, which include the rideshare kiosks and bike docks, and determine ride information
2. Bikes, which include basic, standard, and e-bikes.

The virtual modules are:

1. The Central Computing System (CCS), which coordinates the bike-share system, communicates between the physical and virtual parts of the system and stores all the data.
2. The website, which shares information about the system and allows members to manage their accounts.
3. The phone app, which helps members manage their rides.

Figure 1: B-CALM System Diagram



3. System Description

3.1 Bikes

Bikes are the core component of our system. To provide the best user experience, B-CALM supports basic, standard, and electric (e-bikes).

Each bike has the following key functionalities:

1. **Unique Identification**: A 7-character identifier. The first character is "B", "S", or "E" to indicate the bike type (basic, standard, or e-bike, respectively), followed by a 6-digit

number that is unique within its type. This design choice allows for efficient and straightforward identification of the bike.

2. **Communication Capability:** Each bike can transmit its unique ID and GPS location to the CCS.
3. **Receiving Instructions:** Each bike can receive information from the CCS, such as whether the bike is reported as lost or stolen.
4. **Remote Lock:** Depending on its status, each bike must have a remote-controlled lock that allows the CCS to lock and unlock the bike when necessary.

3.1.1 Basic Bike Communication

Basic bicycles employ a LoRa radio system for communication purposes when they are away from a station. Due to the inherent limitations of LoRa technology, such as restricted bandwidth and power constraints, data transmission to and from basic bicycles during rides is slow and limited. To optimize efficiency, the information exchanged between basic bicycles and the system is restricted to GPS location and lost/stolen status reports.

To maintain reliability, health and GPS information is transmitted from the bike to the CCS at regular one-hour intervals. This strategy preserves battery life while keeping track of the bike's location in case it encounters unexpected situations. If a bike is marked as lost or damaged, the CCS remotely locks the bike, and it will be unlocked only when a signal is sent from the CCS.

3.1.2 Standard and Electric Bike Communication

Standard and electric bicycles are equipped with more sophisticated electronic systems. Communication to and from these bicycles includes route information, GPS data, and video data (see section 3.1.4). The expected data transfer is relatively large and requires real-time updates.

Each bicycle has cellular data connectivity, ensuring the necessary transfer speed to meet our requirements. Cellular data enables direct communication between the bicycle and the CCS, allowing expeditious updates. Its transfer speed of up to 80 Mbs means bicycles will be quickly available after video footage is successfully uploaded and subsequently removed from local storage. The range covered by cellular towers is sufficient for our purposes. If a bike enters a dead space, its LoRa system takes over, communicating status and ensuring uninterrupted reliability.

In contrast, Bluetooth technology has limited speed and range, rendering it unsuitable for a transportation system that prioritizes efficiency. Bicycles would be locked while waiting to transfer large amounts of data, such as accident videos. The core motivation behind B-CALM is to make the rider experience enjoyable and affordable; therefore, we do not want to require users

to utilize their personal phone data when transferring information to and from the system or the app.

While Wi-Fi modules could potentially provide additional speed and coverage, they offer little added value for our purposes, as cellular data can adequately handle all of our needs in data transfer. The extra accumulated spending may increase the cost of renting, which is undesirable for keeping our system affordable to all citizens.

3.1.4 Camera Modules

Both standard and electric bikes are equipped with camera modules that enable riders to record personal videos during their rides. The video is sent to the CCS after the ride via the encrypted cellular data network. Upon completing a ride, the rider has the option to download the video.

B-CALM imposes strict privacy measures. Videos will remain accessible on the camera for a maximum of ten minutes after the ride has concluded. After this window, the videos are deleted from storage, either upon successful upload to the CCS or upon expiration of the timer. Further discussion on the security measures for these videos is covered in section 3.3.3.

3.2 Stations

Stations communicate with both the CCS and bikes. Each station receives map and reservation information from the CCS (see section 3.3.2). B-CALM stations are designed to continue providing biking services despite network or power failures. Stations cache necessary information, such as map data and existing reservations. In the event of a power or network failure, no new reservations are accepted for that station, but riders with existing reservations can still pick up their bikes. When a bike is docked at a station, it connects to the station and transfers its information, including its unique ID, bike health data, and battery level (for electric bikes). This information is then sent to the CCS to update the map and identify bikes that need to be locked. By maintaining functionality during outside failures, B-CALM achieves system reliability.

3.3 Central Computing System (CCS)

The CCS, hosted in a single computing facility, is responsible for storing the data of the system and coordinating the flow of information between different modules. The CCS contains databases holding membership information, bike information, and videos recorded by the optional camera module, as well as a real-time map of the current state of the rideshare system, historical data about the rides, and processes to manage the Angel, Hero, and reservation systems. We designed our system this way to allow for efficiency and privacy.

3.3.1 Member and Bike Databases

The CCS stores membership information in its database. This allows us to maintain privacy: the membership database can be specifically encrypted to ensure that all personal information is kept secure. The membership database holds account information, whether a member has any videos linked to their account, and the amount of outstanding payment. To keep the system efficient, when a non-member rents a bike, their information is added to the membership database until they have no outstanding payment or videos (see section 3.3.3), after which their record is marked for deletion.

Bike information is stored in a separate database. This database is organized by bike ID, and stores the bike's health, status, and GPS data. The bike status determines if the bike can be rented, if it is reserved, if it is lost, or if it is a candidate for the Angel system (see section 3.3.4). To balance the efficiency of our system with our desire for privacy, the central server stores the GPS location at 1-hour intervals, which would hide a single user's ride while still giving a large picture of the bike's movements.

3.3.2 Map and Ride Information

B-CALM's central computing system stores an up-to-date map of the current state of the rideshare system, which includes the status of each station (its health, the number of available docks, the bikes currently at that station). This map is updated whenever a station, the website, or the app sends new information. In addition to the map, the system logs all rides which occurred in the last 24-hour period. For privacy, this information is anonymized and aggregated before being sent to a database that stores historical ride data.

3.3.3 Video Storage

B-CALM stores personal videos and accident videos in two different locations. Personal videos are temporarily securely stored until they are sent to their owner. Non-members get personal videos sent to their email, while members can access their videos in the app. Members then have 24 hours to decide whether to download the video to their phone or to delete it. After this, the videos are deleted from the system. We made this decision to prioritize user's privacy, minimizing the amount of time users are not in control of their personal videos.

Accident videos are sent to their own database and made directly available to the city of Newplace. We decided to prioritize efficiency over privacy in this case, as we determined that the proper storage of accident videos is more important than anonymizing them.

3.3.4 Reservation, Angel, and Hero Systems

When a reservation is made on a station, the app, or the website, the central system will update the map, bike database, and member database to make note of this. It will then send the reservation information to the necessary stations as well as a general map update to all stations.

B-CALM's central system feeds current map data and historical ridership data to the angel tool to determine which bikes can be moved as part of the Angel system. These bikes are marked as such in the bike database. A request for an angel ride will return an appropriate bike and its destination, and reserving that ride will update the map as described above.

When a bike remains undocked for 24 hours, it is marked as lost. The central system runs checks on the bike database every few hours to determine this. A request for a hero ride then returns a lost bike and its last known GPS location. This is another point where we prioritize efficiency over privacy, as we determine that 24 hours is well outside the standard duration of a ride.

3.4 Website and App

The website and the app allow users to connect with stations through the CCS. On the website, all users can view a map and see information on the availability of bikes and docks at each station. Members can also manage their accounts or make a reservation once they log in.

The app provides access to all rider functionalities of this system for members only. Members can carry out all tasks available on the website and the kiosk using the app. Utilizing phone GPS data, members also can view route maps before and during their ride, and can change their route mid-ride. For bike rides with cameras, members can access the recorded videos via the app. Members have the opportunity to become an Angel or Hero through the app, which will communicate with the CCS to gather all required information.

Because the website and the app have functionalities exclusive to members, if the CCS is down, members cannot access them. However, users can still access the map on the website, which will display the most recent map before the outage with its associated timestamp.

4. Use Cases

4.1 Renting Bikes

Riders can rent bikes from a station or from the app. When a member rents a bike from the app, the app sends the information through the CCS to the necessary station. The station unlocks the requested bike if it is available and sends the ride information to the CCS. When a ride is finished, the bike sends ride information to the station, which is then sent to the CCS. The CCS

logs information and computes any outstanding payments. In the case of an outage, each station caches its own information and sends it to the central server once the outage is resolved, permitting rentals to continue during the outage.

4.2 Reservations

B-CALM allows members to reserve a bike for pick-up at the start of their ride or a dock for drop-off. When a bike is reserved, it is marked unavailable. During a 30-minute period surrounding a drop-off time, the reserved dock is locked and unable to take any other bike. Requests are sent either from the website, app, or kiosks, which it is then processed through the CCS, and then sent to the respective stations. In the case of an outage, members are not able to make any new reservations, but any existing reservations are still valid as the information is stored locally at each station.

4.3 Videos

Riders may choose to record videos during their rides for a variety of reasons. Firstly, having video footage can serve as valuable evidence in the event of an incident or accident. Such recordings can help establish liability and support the rider's account of what occurred, ensuring their side of the story is accurately represented. Riders may also wish to capture scenic routes, landscapes, or noteworthy experiences along their journey. These videos can then be shared with family and friends or used to create engaging content for social media platforms. Implementing camera features allows for a more enjoyable experience using B-CALM, while providing an added sense of security to riders who have safety or traffic-related concerns. B-CALM sends video data directly from the bike to the CCS where it is stored and processed.

4.4 Angels and Heroes

To help with bike availability, B-CALM provides additional features where members can help move bikes to high-demand areas as an Angel or rescue abandoned bikes as a Hero. Interested members can easily become an Angel or Hero through the app. Requests are processed by the CCS which will then match Angels with specific bikes and docking stations and match Heros with abandoned bikes. Upon successful completion of an Angel ride or Hero rescue, members receive credits associated with their account that can be redeemed for future rides which will be logged in the CCS. In the case of an outage, members will not be able to sign up to become an Angel or Hero. However, if an outage happens during a ride, stations will cache information on the rider and the bike and send the information to the central server once the outage is resolved.

4.5 Data Collection

B-CALM collects data to provide information to the city of Newplace to improve safety and traffic management as well as Bikes4All to improve the system and understand the customer base for future growth. The information that is collected derives from various sources, from user surveys to GPS trackers on bikes to analytics of different functionalities, such as how often and where reservations are being made. All information that is collected for this purpose is stripped from any personal data to ensure privacy, so even if some of the data collected may include the start and end destinations of a ride, it cannot be linked to the rider.

5. Conclusion

B-CALM is a bike-share system designed around efficiency and reliability, allowing for robust communication capabilities and rapid, yet secure, data processing. Through this system, anyone can easily borrow and return bikes, whether they want to explore the city or need a fast way to get to work. Even through an outage, B-CALM provides the basic functionality of bike sharing.

Beyond efficiency and reliability, our system ensures privacy through our data management system. Information is encrypted when sent to and from the CCS and is only stored in one location. While it limits functionality during an outage, it is crucial for the privacy of our users.

B-CALM holds promising implications for scalability, security, and future expansion. By designing a system with efficient and secure data management and seamless communication between physical and virtual components, B-CALM can adapt to growing user demands and technological advancements while upholding privacy and user control.

There are still a few problems that remain for future iterations. For one, if the CCS is down, a lot of B-CALM's functionalities go down. We want to look into alternative communication channels during outages or different ways for the virtual components to still be functional. We also want to look into safety and privacy for non-riders, as this system allows anyone to rent a bike even if they don't know how to ride it and bike cameras may pick up the faces of bystanders during the ride.