B-CALM

Bikeshare Communication, Access, and Logistics Management System

6.1800 Design Project 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 is designed with commuting citizens in mind, 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 evaluate our system and justify design decisions. In Section 6, we discuss implications such as scalability, security considerations, and future expansion plans. In Section 7 and 8, we wrap up with author contributions and acknowledgements.

2. System Overview

B-CALM is separated into modules grouped into three categories: the central communication system, the physical modules, and the virtual modules, as seen in Figure 1. The core of our system is the central communication system (CCS), which contains the following modules:

1. Bike rental system
2. Bike and dock reservation system
3. Angel and Hero system
4. Video storage and access
5. System map and historical data
6. Member and bike databases

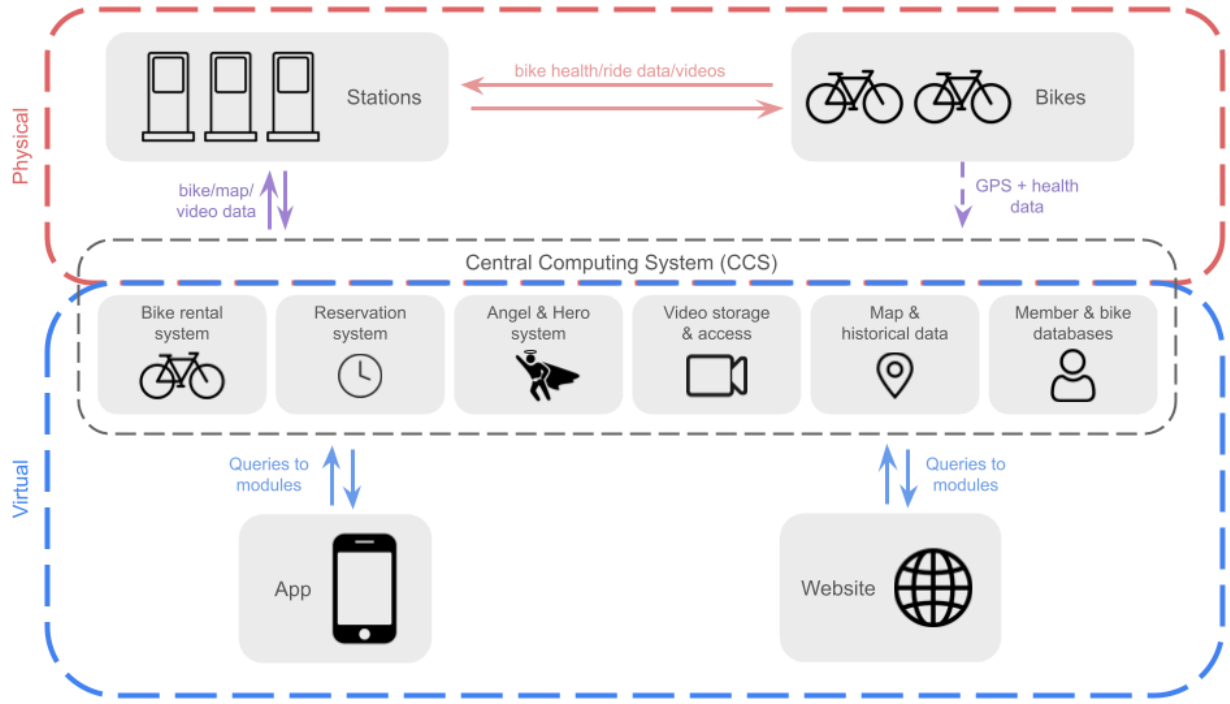
The physical modules are:

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 website, which shares information about the system and allows members to manage their accounts.
2. 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. Users rent a bike from one station and ride it to another station, where the user returns the bike. During a ride, the bike stores the current rider's

ID and the start time of each ride in order to calculate ride duration and cost. 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. We estimate around 200,000 bikes to complete 20 million rides per year, hence the choice of 6 digits. IDs will be reused for broken and replaced bikes.
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 basic bike to the CCS at regular one-hour intervals in the form of small data packets. 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/map information, GPS data, and video data (see section 3.1.3). Our standard bikes will transmit route, map and GPS information to the CCS every minute. Video data will be transferred via USB connection at the end of a ride due to its large file sizes.

Each bicycle has cellular data connectivity, which is used to transmit GPS data, map, and route information. Cellular data enables direct communication between the bicycle and the CCS, allowing expeditious updates. The transfer speed of 80 Mbs is more than sufficient for the file

sizes sent and received (GPS and related data should be small data packets). The range covered by cellular towers is also plenty for our purposes. If a bike enters a dead space, its LoRa system takes over, communicating essential information such as bike health, abandonment status and whether an accident has occurred. Map data will be updated once the bike exits the dead space, ensuring uninterrupted reliability.

In contrast, Bluetooth technology has limited speed and range, and only communicates directly with phones, rendering it unsuitable for a transportation system that prioritizes efficiency and reliability. Not only is the transfer process between the phone and bike slow, but communication then has to be established between the CCS and the phone, becoming dependent on a user's cellular service. This lack of efficiency and reliability conflicts with B-CALM's design priorities.

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.

3.1.3 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 station via USB once the bike is docked, during which the bikes will be locked. It will take ~2 minutes to upload a 30 minute video (45MB/s $\times$ 60s/minute $\times$ 30 minutes / 600MB/s = 135 seconds), which is plenty efficient for our system. Each camera has a storage limit of 128GB, so the upload time will never exceed 3 minutes. The station then sends the video to the CCS with a speed of 1Gbps, which takes a couple more minutes. Upon completion of the upload process, the rider has the option to download the video through the app or website.

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

3.1.4 Bike Signaling Lights

The four sets of standard and e-bike lights will be used as the following:

1. Battery life for e-bike: high, low or depleted (green/red/off)
2. Time remaining in ride: > 30 minutes, > 15 minutes, and > 5 minutes (green/yellow/red)
3. Bike health: healthy, damaged (green/red)
4. Abandonment status: red if abandoned

The two sets of basic bike lights will be used as the following:

1. Bike health: on if damaged
2. Abandonment status: on if abandoned

3.2 Stations

Stations communicate with both the CCS and bikes. Each station contains a map of the current system state, refreshed every second, as well as information about upcoming bike reservations (see section 3.3.2).

When a user rents a bike, the ride information (bike ID, starting station, user) is shared between the bike rental system in the CCS and the station the bike is located at. The station sends the ride information to the requested bike via USB before unlocking the dock. When a user returns a bike, the bike transfers its information, including its unique ID, health data, and battery level (for electric bikes), ride information, and any recorded videos to the station, which sends the information to the bike rental system.

3.2.1 Failure Management

B-CALM stations are designed to continue providing biking services despite network or power failures. Stations cache necessary information for basic operation, such as map data and existing reservations. This allows for stations to operate independently for a period of time with little loss to its functionalities.

In the event of a network failure, no new reservations are accepted for that station, but riders with existing reservations can still pick up their bikes, as their reservations are cached in the station. Riders will not be able to communicate with the station through the app or website, and must do so through the kiosk instead. All core services such as renting and docking remain the same. Payment and ride information that needs to be sent to the CCS is temporarily cached in the station, and sent when network connection is restored. Personal video data will not be stored during this period, as we do not want to overload the network with too much data when the network is restored. Accident video data will still be stored and sent.

In the case of a power failure, the station switches to its auxiliary battery and no longer charges E-bikes to save power. All other functionalities are maintained. When the auxiliary battery is low on power, the dock sends all relevant local data to the CCS, ensuring that information is not lost. By maintaining functionality during outside failures, B-CALM achieves system reliability.

3.2.2 Dock Signaling Lights

The four sets of dock lights will be used as the following:

- An empty dock: available, reserved, unavailable (green/red/off)
- Dock with bike: available, reserved, unavailable (green/red/off)

- Battery power for e-bike: high, depleted, none (green/red/off)
- A flashing green light after a bike is rented

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 processes bike rentals, reservations, and Angel and Hero rides. It also contains a real-time map of the current state of the rideshare system, historical data about the rides, and databases holding membership and bike information. We designed our system this way to allow for efficiency and privacy, as described below.

3.3.1 Bike Rental System

The bike rental system interfaces between stations and the system map. When a user rents a bike, the system updates the map as well as the member and bike databases. After a ride is completed, the system once again updates the map, then it calculates the ride cost and bills the user. We designed this system to prioritize efficiency by minimizing the number of requests needed to rent or reserve.

3.3.2 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 6 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 6 hours is well outside the standard duration of a ride.

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 through the website from a special access code sent to their email, while members can access their videos through their account, either on the website or in the app. Users then have 4

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. This choice also prevents the CCS from reaching its storage capacity.

Accident videos are sent to their own database and made directly available to the city of Newplace. These videos do not expire, and are only removed when manually labeled resolved. 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 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, storing data such as route, time elapsed, and starting and ending stations. Every second, if there has been a change to the map, it sends an update to all stations.

To store and analyze ride data without overflowing the CCS memory capacity, specific map and ride information is only stored for up to a month. At the end of each month, this data is compressed into a "historical trend," which retains macro data such as total number of rides, reservations, locations that experience frequent accidents, the popularity of different routes, and traffic of each station (bikes rented and docked). Historical trends will be sent to the city to help with road and traffic management.

3.3.5 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. Figure 2 shows the organization of the membership database. It holds account information, whether a member has any videos linked to their account, and the amount of outstanding payment. All personal information is kept encrypted. 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, after which their record is marked for deletion. They will not have IDs or any account associated with them.

Figure 2: Membership Database

Member ID	Personal Information	Payment Information & Outstanding Balance	Video links

Bike information is stored in a separate database, seen in figure 3. 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. To balance the efficiency of our system with our desire for privacy, the CCS receives the GPS location for standard and e-bikes every minute, but only uses it to determine bike routes. The bike database is instead updated every hour with the GPS location of basic, standard, and e-bikes. This allows our system to limit the amount of personal data it stores while still keeping track of bike location.

Figure 3: Bike Database

Bike ID	Bike Health	Bike Status	Location & Timestamp

3.3.5 Data Management

The Central Computing System has a storage capacity of 100TB. The storage will be distributed among the different components as such:

- Video Storage: 50 TB, 5 TB reserved for accident videos.
- Map and Historical Data: 25 TB, estimating 15 TB for recent map and bike information, and 10 TB for historical data trends.
- Members and Bike Database: 20 TB
- Bike Rental, Reservation, and Angel/Hero: 5 TB for all three of these components, as we are requiring near negligible memory usage for these.

With a limited size of 100TB, we will reach our memory capacity quickly. To make sure that this does not happen, we will adopt the following strategies:

In video storage, each video is deleted after 4 hours in the hopes to not reach storage capacity. If the storage capacity of 50 TB is reached, older videos will be deleted. Riders who took these videos will be notified through the app, and will have 10 minutes to download the video before they are removed from the CCS.

Map and historical data also experience storage concerns. To prevent historical trends from piling up over time, at the end of each year, all historical trends are sent to the city and deleted from the CCS. If the module ever reaches its storage capacity, all current map data is compressed into a historical trend, and all trends are sent to the city and deleted.

Member and bike information will expand over time as more and more members are registered into the system. Any information for an account that is inactive for more than 5 years will be deleted from the CCS, and the user will have to create a new account if they wish to use B-CALM again. If still the storage capacity is reached, we will have to expand the hardware memory of the CCS. This will occur very rarely, and can be added to the maintenance and update routine for our system.

3.4 Website and App

The website and the app are housed in the same infrastructure as the CCS. They interface with the CCS modules to allow users to connect with stations. 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 are virtual components housed with the CCS, if the CCS infrastructure is down the website and app will be down as well. However, to ensure some resiliency in our system, if they are not able to access the most recent map update, both the website and the app will display a cached version of the last map update.

3.5 Superstations

Superstations contain largely the same functionalities as regular stations. Both the superstation and geofence will have their location and availability added to the map module, with their GPS data and dock status constantly transmitted. When renting a bike from a superstation kiosk, the kiosk communicates directly to the CCS, which will then decide on a bike and notify the station controller to unlock it.

Superstations will be deployed based upon map data. Deployment will be requested for areas that are out of bikes or missing docks. Specifically, any area with 3 or more empty or 3 or more full stations will invoke a superstation request. Each request will also come with a variable score for how severely the area requires a superstation. This will be a weighted combination of the amount of time the stations have been empty/full and the historical popularity of the stations (rate at which bikes go in and out). Superstations will be mobilized to the area with the highest score.

Each deployment will last a minimum of 2 hours, after which the CCS will relocate it to the current area with the highest score (which could be staying in the same place). Each superstation will be linked to its nearby stations in the CCS map module to specify its coverage, and overlapping coverage will be avoided so that each superstation provides its maximum utility.

In the case of special events (such as the 4th of July), the superstations also take manual requests. These can be scheduled by either the city of Newplace or Bikes4All.

4. Use Cases

There are several different ways to use our bikeshare system. Here, we detail the most common use cases we anticipate.

4.1 Renting Bikes

This is the main use case and chief purpose of our system. Riders can rent bikes from a station or from the app. When renting a bike, they provide payment information (either directly at a kiosk or through their member account). The station unlocks the requested bike, if it is available, and notifies the user. The user then can ride the bike to any other station in the system. Once the user finishes their ride, they will be billed for the amount of time their ride occurred.

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, the bike reservation system marks that specific bike unavailable both on the system map and in the station the bike is located. Users can only reserve a dock up to an hour in advance and the station will ensure that at least one dock is available during that time period. Reservations are an important part of our system because it makes it significantly easier to use our bike system when commuting, which has the added benefit of reducing car traffic and congestion.

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 anonymized by stripping 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 a rider.

5. Evaluation

We intend to assess our system through three key methods:

1. Analysis of worst-case scenarios
2. Validation through the calculation of relevant metrics of our system
3. Alignment with our design priorities

5.1 Worst Case Scenarios

We predict a few worst-case scenarios that could happen with our system and have designed our system to address them.

5.1.1 Power and Communication Outages

We addressed power and communication outages in section 3.2. B-CALM will be able to continue operating with limited functionality because all necessary information is cached in stations and there is an auxiliary battery.

If there is both a power and communication outage at the same time, then the station switches to its auxiliary battery and only allows riders to rent and dock bikes at stations. All other functionality, besides outstanding reservations, will be down. This includes the Hero and Angel system and any data uploads to the CCS, including video. Once power and communication are regained, uploads will take place and riders will be able to access their videos then.

In the ultimate worst case scenario where there is a power outage and the auxiliary battery does not work, there is unfortunately nothing our system can do to handle this. B-CALM will work quickly to figure out the issue and bring back basic functionality as soon as we can.

5.1.2 Influx of Riders

If there is an influx of riders during a certain time, such as on a holiday or a special event, we do a few things to address this.

For one, we can deploy a superstation as mentioned in section 3.5. However, it is important to note that we are only limited to five superstations, and sometimes, deploying a superstation might not be completely necessary depending on the size of the influx.

Another solution is to use the Angel system to encourage members to help move around bikes. If we find a particular station that has too many or too few bikes, our system will increase the reward to further motivate riders to become an Angel.

Otherwise, if a rider wants to rent or dock a bike but the station is empty or full, riders will have to go to another station nearby. Reservations will take precedence over non-reservations, meaning if there is only one dock or bike left at a station and it is reserved, it will be marked as unavailable and riders will have to find another station.

5.1.3 Storage

There is a chance that our system will run out of storage. Our system works around this by occasionally compressing and deleting data, mentioned throughout Section 3.3. However, in the chance that our system runs out of storage despite these efforts, our system will respond differently depending on which category of storage is out.

If video storage with the CCS is at max capacity, then the kiosk will wait until a video's 4-hours is up in the CCS before uploading the next video. If kiosk storage is out, then storage from other parts of the system will temporarily be allocated to store any data from the kiosk.

If other parts of the CCS are at max capacity, then the map and historical database will aggregate the oldest map and ride data into historical trends, as mentioned in Section 3.3.2, and reallocate storage space to elsewhere if necessary.

In the case that our system scales to a larger user base and the above solutions are still not enough, then the system will notify users that the video download window will go from 4-hours to 3-hours. If needed, we also can upgrade our storage space by investing in more physical storage devices.

5.1.4 Accidents

Riders may get into accidents when using our system. We will notify all riders to wear a helmet and to be cautious when using our system. Cameras will have an accident detection feature, so accident videos will be analyzed to see what can be done to prevent them.

If a bike or dock is destroyed during an accident, they will be promptly replaced. The system will be notified through bike health and station data.

5.2 Calculations of Relevant Metrics

We made a lot of design choices based on the calculations we made from the numbers provided in the design specifications.

5.2.1 Communication Network

As mentioned in 3.1.3, we decided to use cellular data to send and receive GPS, map and route information. Video data is transferred through USB from bike to dock. The following calculations are to justify these choices:

For GPS, map and route information, which are transmitted at each minute, we expect file sizes of less than 5 MB. With a cellular data speed of 80 Mbps, this will take
5 MB * 8 Mb/1 MB / 80 Mb/s = 0.5 seconds to complete (more than fast enough).
From section 3.1.3, upload times will never exceed 3 minutes for videos from bike to dock. Docks have a network capacity of 1 Gbps, so with a maximum video of 128 GB, it will take max 128 GB * 8 Gb/1 GB / (1 Gb / 1 s) * 1 min / 60 s = 17 minutes. Since this delay does not affect any other components, and it is short enough that riders will be able to find their videos fairly quickly, it is more than reasonable.

5.2.2 Request Latency

Each time a request is made to our system, whether through app, kiosk or website, it must travel to the CCS which must also send a response back. Requests such as reservations, renting, docking, and all related data should be small in size, presumably less than 5 MB. At this size, traveling to the stations and CCS which have 1 Gbps and 1 Tbps network interfaces respectively should take milliseconds, plenty efficient for our system.

5.2.3 Scale Limitations

Our system's main scaling limitation is the 100TB storage capacity we have in the CCS. Since videos will consist of the largest data files, we allocated the most to it with 50TB. We also estimate that maps and historical data will take a decent amount of data as we expect thousands of rides to happen daily. Thus, we allocate it with the second most storage capacity at 25TB. We plan to compress data monthly into historical trends to save our storage. We allocated 20TB for the members and bike database because we want our system to be able to handle a lot of users, but we made capacity slightly less than map and historical data because we expect the number of users to grow at a slower rate than the amount of data being gained from the rides themselves. However, in the chance that our members and bike database is full and unable to handle more users, we will allocate more capacity to this database and take from the map and historical database. Lastly, we made the bike rental, reservation, and Angel/Hero the smallest because any data that is stored is temporary data and won't require a lot of capacity.

5.3 Design Priorities

5.3.1 Efficiency

B-CALM is designed primarily with efficiency in mind. Because we hope to integrate our bikeshare system into everyday commutes, we designed a quick and responsive system. To accomplish this, we designed our modules to limit the time it takes to accomplish important use cases (see section 5.2.2). In doing so, we made important tradeoffs. The first is storing most of our information in a central location. While it makes it much simpler to access and manipulate our information, it comes at a cost of very limited functionality in case of an outage. Another tradeoff is the short (four hour) availability of a video after a ride completes. We made the choice to do so because it avoids complicated video storage. We also prioritize efficiency over privacy in the storage of accident videos (see section 3.3.3). However, we sacrifice efficiency in two important cases: reliability in case of outage (section 5.3.2) and user privacy (section 5.3.3).

5.3.2 Reliability

In the case of a system outage, our system is designed to maintain a limited functionality (for details, see sections 3.2.1 and 5.1.1). We decided to cache data in the stations to prioritize

reliability over efficiency. While centralization makes our system simpler, having a single point of failure harms its ability to provide consistency to users relying on our system for their commute. However, as seen in section 5.2.1, we ensure that the extra transmissions of data does not flood our communication networks.

5.3.3 Privacy

Beyond efficiency and reliability, our system ensures privacy through our data management system. Information on personal information, payments, and videos is encrypted when sent to and from the CCS and is only stored in one location. We chose to store sensitive data securely in order to maintain trust in our system, and limited the amount of sensitive data to ensure that the encryption does not severely harm our efficiency.

6. 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.

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.

We believe that the main limitation of our system is in the form of scalability. Video storage makes up the bulk of our system, but to preserve our main functionalities the system cannot store a lot of videos, even with the short storage time. Another limitation is network traffic. If many bikes are being used at once, our system may encounter latency issues, leading to potential slowdowns. Future iterations of our design should also consider how to further protect users' privacy in our system. While we protect sensitive data, there are many areas where we fall short, such as storing identifying information about bystanders in personal and accident videos.

7. Author Contributions

The authors of this report collaborated closely with each other when designing the system and writing the report. The drafts of different subsections of the report were divided between us and we all worked together to edit the final report. As for specific contributions, Rhea worked on the diagrams and figures, Timmy worked on the worst case scenarios, and Tony worked on the data management and calculations.

8. Acknowledgements and References

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