COMPUTER SCIENCE AND ENGINEERING
SOFTWARE ENGINEERING II
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RASD

Requirement Analysis and Specification Document

Best Bike Paths

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Contents

1 Introduction

1.1 Purpose

The growing interest in cycling, whether as a recreational activity, a means of transportation, or a sport, brings with it a significant challenge: finding routes that are not only efficient, but also safe and well-maintained. Cyclists often lack reliable and up-to-date information on trail conditions, such as the presence of potholes, obstacles, or roads with little traffic. At the same time, many cyclists meticulously log their trips to monitor their performance, collecting valuable data that, however, remains siloed. This creates a gap where vital community knowledge about trail quality is not easily shared or accessible. "Best Bike Paths" (BBP) aims to provide a solution. Commissioned by a cyclists' association, BBP will be a software system designed to create and manage a community-driven inventory of cycling routes. The platform will help bridge this information gap by allowing registered users to track their trips while simultaneously submitting detailed information on the condition of their routes. Other users, registered or not, will then be able to use this collective data to find and display the best possible cycling routes between two points, ranked by a quality score.

1.1.1 Goals

- **G1:** A registered user wants to track their personal cycling activities and related performance statistics.
- **G2:** A registered user wants to contribute to the community inventory by sharing reliable information on the condition of the trails (e.g. quality, obstacles, potholes).
- **G3:** Any user (registered or not) wants to find and view the best cycling route between an origin and a destination, based on up-to-date and relevant data.
- **G4:** The cycling association aims to provide the community with a tool to create, consult, and maintain a reliable and centralized inventory of cycling routes.

1.2 Scope

The project scope covers users interacting with the system, user-generated actions that influence the system, and system-generated actions that impact the outside world.

For this project, the following users interacting with the system have been identified:

- **Registered User**
- **Any User**

A Registered User will be able to use the application to log and store their trips, tracking their cycling activities and related statistics. When available, this data can be enriched with weather information retrieved from external services. Furthermore, this user is the primary contributor to the inventory. They can enter route information in two ways:

1. In **manual mode**, by actively specifying the route status (e.g., optimal, requires maintenance) and the presence of obstacles (e.g., potholes).
2. In **automatic mode**, by allowing the app to acquire data from GPS and mobile device sensors while cycling, in order to automatically detect potential problems such as potholes.

For automatically collected data, the system will ask the user to confirm or correct the information before making it available to the community. Once confirmed or manually entered, this information becomes publishable.

Any user, whether registered or not, can benefit from the collected information. This user can specify a starting point and a destination and ask the system to display available cycling routes on a map. If multiple routes exist, BBP will present them based on a score, calculated based on the route status derived from the data confirmed by users.

1.2.1 World phenomena

- **WP1:** A registered user starts a cycling activity.
- **WP2:** Any user searches for a cycling route between two places.
- **WP3:** A registered user contributes contribute to the BBP inventory.
- **WP4:** While pedaling a registred user ecounters some kind of problem on the route.

1.2.2 Shared phenomena

World controlled

- **SP_WC1:** The registered user launches starts to register the trip with the application.
- **SP_WC2:** The registered user stops to register the trip with the application.
- **SP_WC3:** The registered user opens the interface for manually entering route information.
- **SP_WC4:** The registered user enters the data (e.g. "optimal" status, "hole" presence) and sends the manual entry form.
- **SP_WC5:** The registered user selects a notification or confirmation request for automatically detected data.

- **SP_WC6:** The registered user confirms to validate automatically the detected data (e.g. a pothole).
- **SP_WC7:** The registered user deletes to invalidate an automatically detected data (false positive).
- **SP_WC8:** The registered user modifies an automatically detected piece of data (e.g. corrects the position of the hole on the map) and saves the change.
- **SP_WC9:** Any user enters a source and destination address.
- **SP_WC10:** Any user starts the route search.

Machine controlled

- **SP_MC1:** The system shows the statistics of the completed trip to the registered user.
- **SP_MC2:** The system shows the weather data associated with the trip to the registered user.
- **SP_MC3:** The system presents the Registered User with a confirmation request for automatically detected data.
- **SP_MC4:** The system shows the user a map with the cycling routes found between the origin and the destination.
- **SP_MC5:** The system displays the details of a route, including its score and confirmed obstacles.
- **SP_MC6:** The system displays an error message (e.g., "Weather service unavailable").

1.3 Definitions, Acronyms, Abbreviations

This section contains the definitions for people that may not know what a specific concept is, acronyms and abbreviations used throughout the document.

1.3.1 Definitions

- **Bike Path:** a route deemed suitable for cycling. This includes paths with a proper bike track or roads where cars are rare and speed limits are compatible with the average speed of a bike.
- **Trip:** a personal record of a user's cycling activity, stored by the system to track performance metrics like distance and speed.
- **Publishable Information:** data about a bike path (e.g., status, obstacles) that a registered user has either entered making it available to the wider community.

- **Path Score:** a metric computed by BBP to rank route options. It is based on the status of the path and its effectiveness in getting the user from their origin to their destination.
- **Obstacle:** any significant element or condition on a cycle path that may represent a danger or hindrance to the cyclist (e.g. pothole).

1.3.2 Acronyms

- **BBP:** Best Bike Paths.
- **GPS:** Global Positioning System.
- **API:** Application Programming Interface.

1.3.3 Abbreviations

- **G*:** Goal.
- **WP*:** World Phenomenon.
- **SP*:** Shared Phenomenon.
- **R*:** Requirement.
- **UC*:** Use Case.
- **D*:** Domain Assumption.

Note: asterisks are intended as a replacement for the number.

1.4 Revision history

- **Version 1.0 (17/11/2025)**

1.5 Reference documents

This document is based on the following materials:

- The specification of the RASD and DD assignment of the Software Engineering II course a.y. 2025/26.
- Course slides shared on WeBeep.
- Past Requirement Analysis and Specification Documents.

1.6 Document structure

1. **Introduction:** a brief description of the project. It contains the main goals and objectives that the final system wants to achieve.
2. **Overall description:** this section is a high-level representation of the system and of the interactions of the system with the other actors.

3. **Specific requirements:** a detailed list of all the requirements needed for the system to achieve the goals. It contains valuable information for developers.
4. **Formal analysis using Alloy:** a formal description of the model of the system with Alloy.
5. **Effort spent:** the time spent on each section of the document, for each member of the group.
6. **References:** reference to documents or tools used for writing this document..

2 Overall description

2.1 Product perspective

2.1.1 Scenarios

Registering a new user

User ”Zoe” has just downloaded the BPP app. She cretaes an account by entering the information and accepting the privacy policy. Once her information were verified she receives a confirmation message, becoming a ”Registred user”.

Activity monitoring and data enrichment

Registered user ”Alessandro” is preparing for his weekly training session. He wants to track his performance, including correlation with the weather. He launches the BBP app, logs in, and from the main screen, presses ”Start Trip”. During the session, Alessandro pedals, focusing solely on the road, while the system silently tracks his GPS route and biometric data (if connected). At the end, Alessandro presses ”End Trip”. The system saves the route and immediately queries the external weather service. A few moments later, Alessandro views the trip summary: he sees his map, the 45 km traveled, his average speed, and, thanks to the weather integration, notes that the strong headwind he detected has negatively impacted his time. Satisfied with the detailed analysis, he closes the app.

Active contribution to the community (manual entry)

Registered user ”Bianca” is riding a popular bike path when she notices that a stretch, previously marked as ”Optimal”, is now blocked by unreported construction. She decides to alert the community. She safely stops and opens BBP. Selects ”Report Problem”, and the system geolocates her location. Bianca selects the ”Obstacle” category and the ”Construction in Progress” subcategory. She adds a text note (”Traffic blocked due to excavation”) and submits the report. The system immediately records the information as ”Publishable”. From that moment, the ”Path Score” for that stretch drops dramatically, and future users planning a route in that area will see a warning and will likely be diverted onto alternative routes.

The Auto-Detection cycle

This scenario describes the complete flow of passive data acquisition, from invisible collection to explicit validation.

- **Detection during the journey**

Registered user ”Carlo” activates ”Automatic Mode” to detect potholes before heading to work. He places his smartphone in the handlebar mount and begins pedaling. As he rides along Via Verdi, the device’s accelerometer registers a strong vertical impact unrelated to braking. The BBP system analyzes the pattern in real time, classifies it as a ”Potential Pothole”, and stores the GPS coordinates and timestamp. All this happens in the background, without sending notifications or sounds so as not to distract Carlo from his riding.

- **Post-trip confirmation**

  Arriving at the office, Carlo finishes his trip. The system displays a notification: ”Two potential problems detected. Would you like to check them?” Carlo opens the review screen. The system displays a map with the two points. Carlo selects the first one, Via Verdi, and clearly remembers the pothole. He presses ”Confirm”. The system promotes that data to ”Publishable Information”.

- **Handling a false positive**

  Carlo examines the second point detected on Corso Italia. He realizes that he deliberately stepped onto a curb to park his bike there. It’s not a traffic hazard. He clicks ”Ignore”. The system discards the raw data and doesn’t create any public alerts, preventing the inventory from being contaminated with incorrect data.

Intelligent route planning (General User)

”Diana”, a tourist, wants to explore the city by bike but is worried about traffic and poor roads. She accesses the BBP website without logging in and enters ”Hotel Plaza” as the origin and ”Museo della Scienza” as the destination. The system calculates three possible routes. Diana notices that the shortest route (3 km) has a low ”Path Score” and is colored orange on the map, with several ”Pothole” icons along the way. An alternative, slightly longer route (3.5 km) has an excellent ”Path Score” and is highlighted in green, indicating a bike path in excellent condition. Diana chooses the green route. While navigating, she avoids stress and dangers thanks to information aggregated by the community.

Data updating and maintenance

Registered user ”Edoardo” is driving along a road where a large pothole had been reported the previous week (which he also confirmed). He is pleased to note that the municipality has resurfaced the section and the pothole is no longer there. To keep the inventory updated, Edoardo selects the pothole marker on the map and presses ”Mark as Resolved”. The system records this new input. If other users confirm the resolution (or if Edoardo has a high confidence level in the system), the obstacle will be removed and the section's "Path Score" will start to increase again.

Historical performance analysis

Registered User "Alessandro", after months of using BBP, wants to analyze his progress. He accesses the "My Trip History" section. The system presents a chronological list of all his saved trips. Alessandro filters by "Last Month" and displays an aggregate graph showing the increase in his average speed and total kilometers traveled. He selects a specific trip from two months ago; the system retrieves all the details from the database, including that day's weather conditions (e.g., "Light rain"), allowing Alessandro to remember why his performance was below average on that date.

2.1.2 Domain Class Diagram

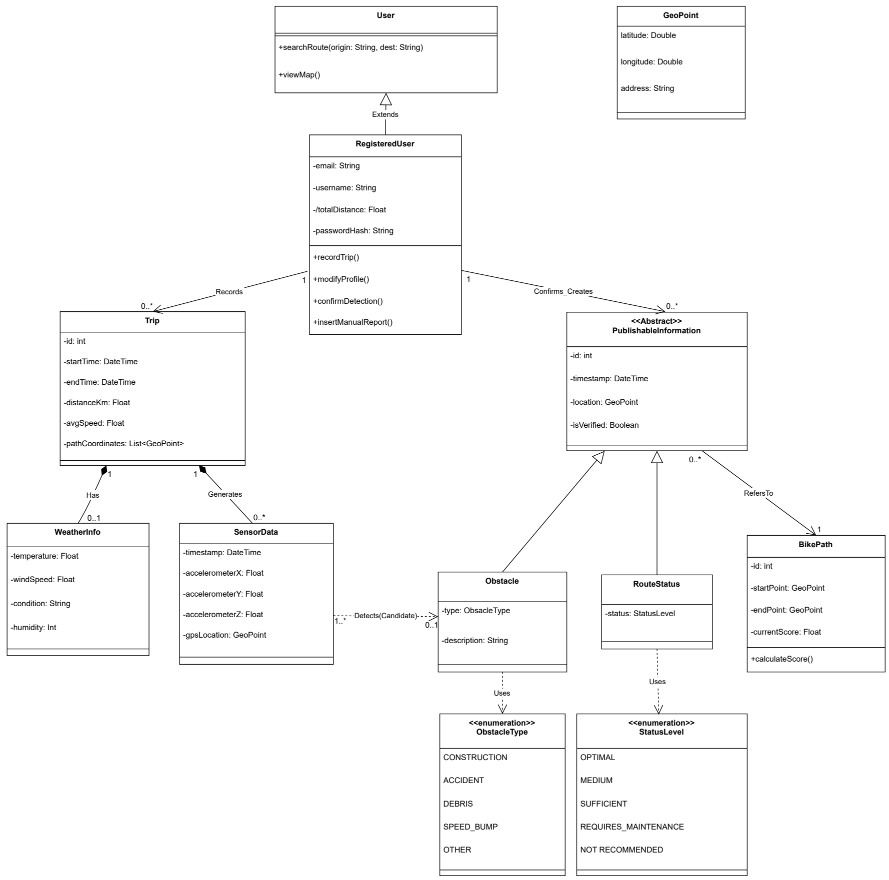

Figure 1: Domain Class Diagram of the BBP system

Figure 1 shows the domain class diagram. The main architectural choices are explained below:

- **User Generalization:** To avoid duplication and facilitate future scalability, the `User` superclass has been introduced. It encapsulates basic functionality accessible to everyone, such as route search and map viewing. The `RegisteredUser` class extends this foundation, adding authentication data and the main writing functionality: `recordTrip()`, `insertManualReport()`, and `confirmDetection()`. This structure allows for easy extension to future roles such as "Administrator" or "Moderator."
- **Information Abstraction and Scoring:** The abstract

PublishableInformation class was created to logically group all alerts (whether RouteStatus or Obstacle). This polymorphic approach greatly simplifies the calculation of the Path Score: the system can iterate over a generic list of confirmed information associated with a trip to calculate its score, without having to use separate logic for each type of alert.

- **Sensor Scalability:** Although the assignment specifically mentions potholes, the model correctly links the raw SensorData data to the generic Obstacle class via the "Detects (Candidate)" dependency. This design ensures that the system can evolve to detect other types of anomalies in the future without changing the core data model.
- **Trip Composition and Data Lifecycle:** There is a composition relationship between Trip and its internal data: WeatherInfo and SensorData. This indicates that this data is closely tied to the trip lifecycle: if a user decides to delete a trip from their history, the associated weather data and raw sensor data will also be automatically removed, preventing data fragmentation and ensuring database cleanliness.

2.1.3 State Diagrams

User Session Lifecycle

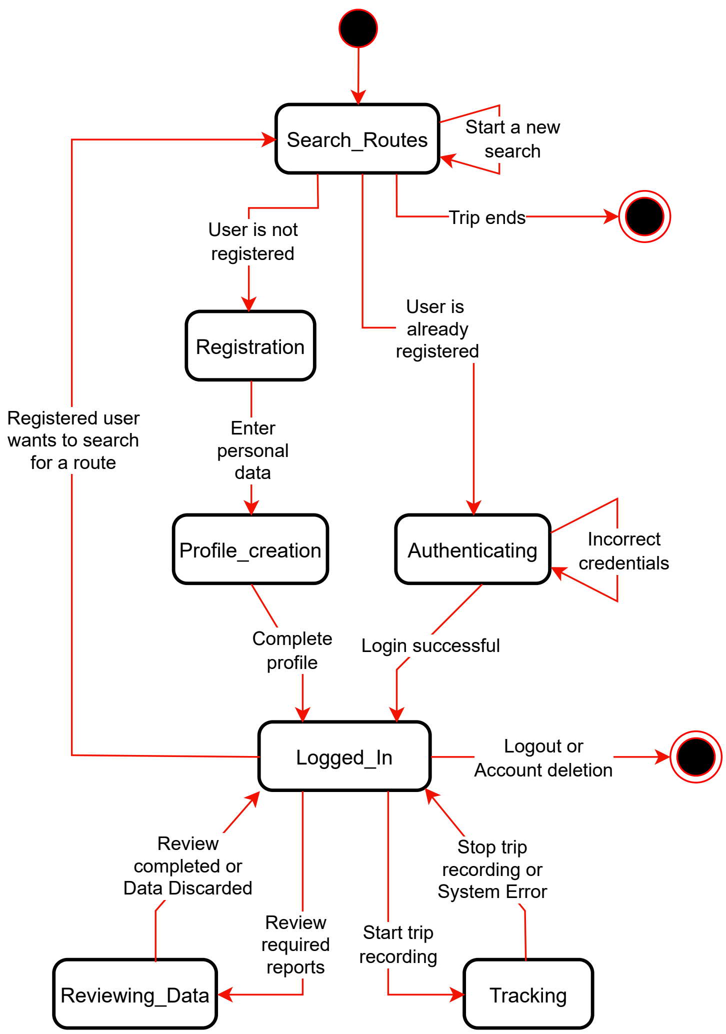

Figure 2: State diagram of a BBP system user's lifecycle

The finite state diagram in Figure 2 models the **user session lifecycle** within the BBP system, defining how the user transitions from the anonymous browsing state to the fully operational one. The system is designed to ensure that all basic functionality, such as route search and map viewing, is immediately accessible, with a single initial state that converges on `Search_Routes`, the universal entry point. From this anonymous browsing state, the user can choose to authenticate whether they are already logged in or not. Once the `Logged_In` state is reached, the user unlocks the contribution capabilities, which are critical to the system's value. This state serves as a hub, allowing the user to initiate trip tracking by moving to the `Tracking` state (when sensors are active) or to proceed to `Reviewing_Data`. Both contribution states are separated to reflect their high impact on resources (tracking) or data consistency (auditing). The session can end by exiting `Search_Routes` (for both anonymous and registered users) or by `Logout` from the operational state for the registered user.

Trip Lifecycle

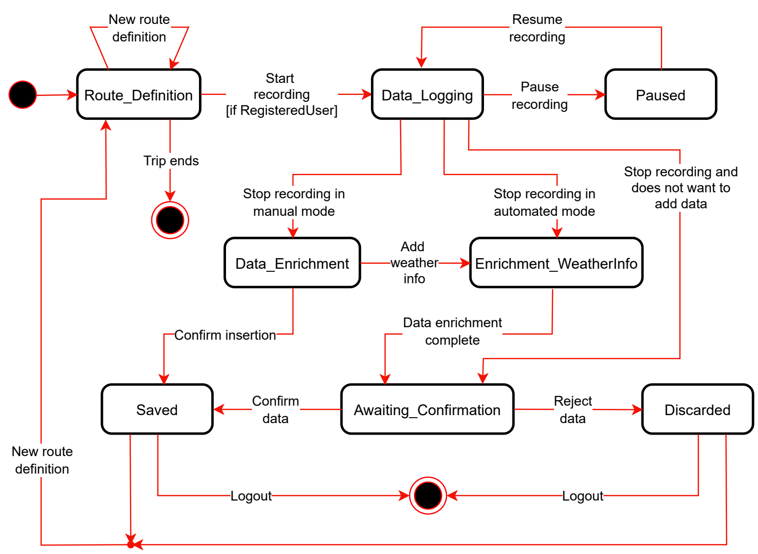

Figure 3: State Diagram of the Lifecycle of a Trip in the BBP System

The diagram in Figure 3 models the complete lifecycle of a `Trip`, from its inception to its final storage or discard. The process begins in the initial `Route_Definition` state, which represents the hub where a new route can be defined or an existing one can be used. The fundamental transition to data acquisition occurs only if the `[if RegisteredUser]` guard condition is satisfied, ensuring that only authenticated users can initiate tracking, based on the system's contribution requirements. Once in the `Data_Logging` state, the system actively logs raw sensor data (GPS, accelerometer) if in automatic mode. This state offers flexibility, allowing data acquisition to be paused and resumed via transitions. The system manages three distinct transitions when recording is stopped, resulting in separate processing paths:

- **Stop in manual mode**: This transition allows the user to actively add non-sensor data to the route.
- **Stop in automated mode**: Indicates that the route has ended, starting the automatic processing cycle.
- **Stop without data**: If the user does not wish to add any data, they go directly to the confirmation to save or delete the collected data (if collected).

The automated processing cycle begins with `Enrichment_WeatherInfo`, where the system enriches the trip with weather data retrieved from external services. Once enrichment is complete, the flow moves to `Awaiting_Confirmation`. This state is crucial for data quality: here, the user must decide whether to validate the anomalies detected by the sensors (e.g., potholes) or discard them. The cycle closes by returning to the `Route_Definition` state or definitively exiting the system, demonstrating how data only goes from ephemeral to persistent information through a rigorous validation process.

Data Lifecycle

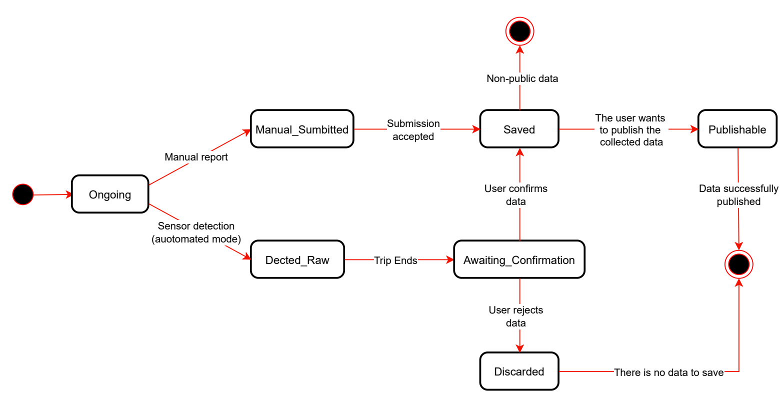

Figure 4: Data lifecycle state diagram in BBP system

The diagram in Figure 4 models the complete data lifecycle, from its origin to its final state. The process rigorously distinguishes data based on its source to direct it to the correct validation path. The flow forks immediately from the initial state:

- **Manual Path:** The user generates a `Manual report` that transitions to the `Manual_Submission` state. The data, being the result of an explicit action, is initially saved and can be published if the user wishes.

- **Automatic Path:** The data passively detected by the sensors transitions to the `Dected_Raw` state. This raw data must pass through the `Awaiting_Confirmation` state at the end of its journey.

The pending confirmation state is the critical checkpoint: the user is responsible for validating the discovery to allow it to move to `Publishable`, or discarding it, moving it to `Discarded`. Only data in the `Publishable` state is integrated and can influence the `Path Score`. The cycle ends with final publication or discard.

Bike Path Status Lifecycle

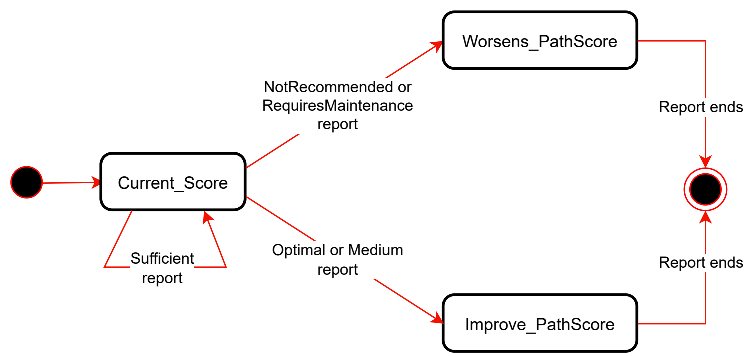

Figure 5: BBP Path State Lifecycle State Diagram

The diagram in Figure 5 models the evolution of a Bike Path's Quality Score in response to user contributions. The entry point is the `Current_Score` state, which represents the value of the path at the time of consultation. This value is dynamic and subject to change based on active reports:

- A hazard or maintenance report (`NotRecommended or Requires Maintenance report`) triggers the `Worsens_PathScore` state. This indicates an immediate degradation in quality.
- Conversely, an `Optimal or Medium report` triggers the `Improve_PathScore` state, indicating an improvement in the path's quality.
- A `Sufficient report` acts as a validation of the current score, maintaining its status and contributing to the data's freshness without drastically altering its perceived quality.

The diagram emphasizes that the score is a dynamic value, constantly recalculated based on the validity and freshness of the active reports in the BBP inventory.

2.2 Product functions

Sign up & Login

This feature is the entry point for any user wishing to actively contribute to the inventory. A visitor can register by providing their information and credentials, and the system creates a `RegisteredUser` profile, enabling write permissions. Once the account is created the user can log in to access their reserved area, view their travel history, and use the tracking features. Without authentication, the user remains in "read-only" mode, without access or all the features expected of a registered user.

User Profile Management

Registered users have access to a dedicated section for managing their personal data. Here they can update their contact information and personal details, change their password, or delete their account. These actions ensure that the user maintains full control over their digital identity within the system.

Trip Recording

This is a core feature available exclusively to authenticated users. Users can start a recording session at the beginning of their activity. During the trip, the system tracks their geographic location via GPS in real time. Users have the flexibility to pause and resume recording (for example, during a rest stop). Upon completion, the trip is stored in the user's personal database.

Statistics Calculation and Data Enrichment

Upon completion of a trip, the system processes the raw data to provide detailed statistics, such as total distance traveled and average speed. Additionally, BBP automatically queries external services, if available, to retrieve weather information (temperature, wind, and weather conditions) for the area and time of the trip. This data is integrated into the trip record, providing the user with richer context for analyzing their performance.

Manual Data Entry

Registered users can actively contribute to the quality of the inventory by entering manual reports. Through a dedicated interface, users can specify the status of a road segment (e.g., "Optimal," "Requires Maintenance") or report the presence of specific obstacles. The system associates this information with the current GPS coordinates (or those selected on the map) and makes it immediately available to the community.

Automatic Detection via Sensors

If the registered user enables "Automatic Mode" while driving, the system uses the mobile device's accelerometer and gyroscope to monitor vibrations and sudden movements. Internal algorithms analyze this data to identify potential road surface anomalies, such as potholes. This process occurs in the background so as not to distract the user while driving.

Review and Confirmation of Detections

To ensure data reliability and filter out false positives, automatic detections are not published immediately. At the end of the journey, the system presents the user with a list of detected anomalies. The registered user must explicitly confirm the presence of the obstacle (validation) or discard the detection (if incorrect). Only confirmed data is promoted to publishable information. The published route data is then used to calculate the Path Score.

Route Search

This function is accessible to all users, regardless of registration. The user enters a point of origin and a destination in the search interface. The system processes the request and calculates one or more possible cycling routes connecting the two points.

Display and Path Score

The routes found are displayed on an interactive map. For each route, the system calculates and displays a `Path Score`. This summary score aggregates information about the route's status and the presence of confirmed obstacles, allowing the user to quickly assess not only the distance, but also the safety and quality of the proposed route.

2.3 User Characteristics

This section describes the general characteristics of users who interact with the BBP system. There are two main categories of users: Registered Users (the active contributors) and General Users (the passive users).

2.3.1 Registered Users

The Registered User represents the core of the BBP ecosystem. This profile typically corresponds to a regular cyclist (commuter or recreational) who wishes to monitor their performance and actively contribute to community safety.

Profile and Skills

The user must have a personal account with login credentials. It is assumed that they have moderate familiarity with the use of smartphones and GPS technology. Since the app is used in mobile contexts, the user requires a clear interface that minimizes distractions.

Needs and Interactions:

- **Tracking:** The user wants to track their trips to analyze statistics such as speed and distance, contextualized with weather data if available.
- **Active Contribution:** The user wants to report obstacles or assess road conditions to help other cyclists. They can do this manually or by activating automatic mode.
- **Validation:** The user is responsible for data quality. The system relies on them to confirm or discard automatic sensor detections (e.g., potholes) at the end of the trip, ensuring that only truthful information influences the Path Score.
- **Privacy:** The user wants sensitive data (such as personal travel history) to remain private, while agreeing to share anonymized road condition data publicly.

2.3.2 Generic User

The Generic User includes anyone who accesses the platform without authenticating. This profile includes tourists, occasional cyclists, or route planners who need quick and reliable information without the commitment of registration.

Profile and Skills

They do not have a persistent profile in the system. Minimum proficiency in using digital maps and web/mobile interfaces is required. Interaction is sporadic and aimed at an immediate goal: reaching a destination.

Needs and Interactions:

- **Safety and Planning:** The primary need is to find the safest or most efficient route between two points. The user relies on the system to avoid poor or dangerous roads.
- **Immediacy:** They want to view routes and their Path Score immediately. It's not interested in contributing data or saving history, but only in consuming aggregated information generated by the community.
- **Reliability:** It expects the obstacle reports (e.g., potholes) displayed on the map to be up-to-date and verified, so it can plan its trip with confidence.

2.4 Assumptions, dependecies and constraints

2.4.1 Domain Assumptions

The following assumptions describe real-world conditions that the system considers true and necessary for the correct functioning of the intended features:

- **D1 - Hardware Equipment:** It is assumed that the user's mobile device is equipped with functioning and calibrated hardware, specifically: GPS receiver, accelerometer, and gyroscope. The system cannot compensate for physical hardware failures of the device.
- **D2 - Accuracy of User Data:** It is assumed that the information entered by users is correct and truthful. This includes:
  - Registration data.
  - Manual reports.
  - Confirmation of automatic detections (the user does not intentionally confirm false positives).
- **D3 - Accuracy of Basemaps:** It is assumed that third-party mapping services provide a correct topological representation of reality. If a road exists on the map, it is assumed that it physically exists and is drivable (unless otherwise reported on BBP).
- **D4 - GPS Signal Availability:** It is assumed that, for most of the duration of an outdoor trip, satellite coverage is sufficient to ensure useful location accuracy.
- **D5 - Distinguishable Movement Patterns:** It is assumed that the physical characteristics of cycling are sufficiently distinct from those of other modes of transport or walking, allowing classification algorithms to operate with an acceptable level of accuracy.
- **D6 - Compliance with Highway Codes:** It is assumed that users use the application in compliance with applicable laws (e.g., not looking at the screen in dangerous situations), absolving the system from liability for accidents caused by distraction.

2.4.2 System Dependencies

The BBP system is not an island; it relies on external services to provide added value. Failure of these services degrades the system's functionality as follows:

- **External Weather Service:** BBP depends on third-party APIs to retrieve weather data (temperature, wind). If this service is unavailable, the system will continue to record trips, but the "Weather Enrichment" feature will not be performed, and the trips will be saved without this metadata.

- **Mapping Services:** Route visualization and address geocoding depend on external map providers. If these are unavailable, the "Route Search" and "Map View" features will be compromised.

2.4.3 System Constraints

- **GDPR and Privacy:** Since the system tracks users' physical movements (sensitive data), the management, storage, and sharing of GPS data must strictly comply with the GDPR regulation. Personal travel data must not be accessible to other users without explicit consent.
- **Energy Consumption:** The automatic detection algorithm must be optimized to avoid draining the mobile device's battery quickly, ensuring coverage of medium-duration trips (e.g., 2-3 hours).
- **Intermittent Connectivity:** Since cycling routes can pass through areas with poor network coverage, the mobile application must be able to store sensor data locally and synchronize it with the server as soon as the connection is re-established.

3 Specific requirements

3.1 External interface requirements

3.1.1 User interfaces

3.1.2 Hardware interfaces

3.1.3 Software interfaces

3.1.4 Communication interfaces

3.2 Functional requirements

3.3 Performance requirements

3.4 Design constraints

3.4.1 Standard compliance

3.4.2 Hardware limitations

3.4.3 Any other constraint

3.5 Software system attributes

3.5.1 Reliability

3.5.2 Availability

3.5.3 Security

3.5.4 Maintainability

3.5.5 Portability

4 Formal anlaysis using Alloy

5 Effort spent

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- 11/11/2025 1h (RASD document structure)

Lo Conte Francesco

- 17/11/2025 4h (Completing Section 1 (Introduction))
- 18/11/2025 7h (Section 2 - StateDiagrams, DomainClassDiagram, Scenarios)
- 19/11/2025 1h (Completing Section 2)

6 References