



A Web-based Multi-criteria Bicycle Route Planning Application

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Declaration

No portion of the work contained in this document has been submitted in support of an application for a degree or qualification of this or any other university or other institution of learning. All verbatim extracts have been distinguished by quotation marks, and all sources of information have been specifically acknowledged.

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Abstract

Cyclists regularly use route planning applications to determine the route they take for their journey, whether to commute, complete a short-circuit ride or a long-distance ride. There is a range of pre-existing applications to allow cyclists to do this; however, most of these have a limited range of customisable criteria considered in the routing algorithm.

This dissertation will investigate how the current solutions consider user-customisable criteria in their routing algorithms and will provide an open-source prototype system. The proposed system will consider pre-existing data, such as weather forecasts and hazard data, whilst catering for custom criteria chosen by the user and location of accommodation for long-distance routes.

Acknowledgements

Much stuff borrowed from elsewhere

Consent to Share

I consent for this project to be archived by the University Library and potentially used as an example project for future students.

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Chapter 1

Introduction

1.1 Overview

Route planning is essential to all cyclists, from casual to professional, as it's important to know where they are going and what to expect on their journey. A casual rider may wish to find the quickest and safest route to their destination. In contrast, a professional rider would want to find the most challenging route, not necessarily the quickest.

Currently, there are multiple route planning applications which range in their flexibility for different types of cyclists and their needs. No one application effectively caters for all cyclists, meaning multiple applications would be required depending on the type of route the user wants to plan.

The proposed solution is a web application enabling cyclists to plan a route ahead of their ride and choose which criteria they want to affect the routing algorithm and, therefore, the final route. Some examples of these criteria are accommodation, road type and elevation. Other criteria will be used in determining the route, such as weather conditions and hazards along the route.

1.2 Aims and Objectives

The overall aim of the project is to develop and build a prototype which can be further developed in the future to plan a range of routes for cyclists with a range of data-driven criteria to cater to the requirements of that specific user. Enabling customisable criteria for each user will allow them to understand the decisions made to plan their route and improve the user's experience when they are cycling, and give more members of the public the incentive to begin cycling.

1.3 Proposed Solution

The solution is a prototype web application designed for cyclists of all levels (casual to professional). It will plan cycling routes based on a range of data-driven, user-customisable and fixed criteria through a user-friendly, modern user interface (UI). Furthermore, the solution will provide key information on the planned route, such as elevation, average speed and time to complete the route.

1.4 Scope

There is a potentially large scope that could be attributed to this project whereby the application could be developed to consider a range of different sports that could benefit from route planning. These sports could be, running, walking and mountain cycling, which would increase the overall scope as there would be many other factors to consider for these sports. This would expand the current scope of the project to a great scale.

To mitigate the risk of the scope becoming unfeasible, it's vital to focus on the key functionality planned for the application. Therefore, the decision has been made to narrow the scope and focus explicitly on catering the application to route-planning Road Cyclists. Focusing on this user-base will ensure focus on the key functionality to provide effective route planning on roads catering to the user's needs.

1.5 Deliverables

This project will consist of two deliverables:

- The project report
- The artefact (web-based bicycle route planner)

1.6 Resources and Facilities used

The section demonstrates all resources and facilities used to complete this project. It includes developing the prototype and writing this document; the list should aid anyone wishing to re-create this project. Some decisions on tools used are personal; for instance, the Integrated Development Environment (IDE), which is predominantly down to preference. On the other hand, the programming languages chosen are specific to the features and performance benefits they provide in developing such applications.

- Applications/websites used to complete research and literature review
 - Google Scholar
 - EBSCO Database
- Programming Languages

- Javascript
- HTML5
- CSS
- Go
- Structured Query Language (SQL)
- Integrated Development Environment/Text Editor
 - Visual Studio Code
- Database Management System (DBMS)
 - PostgreSQL
- Wireframes and Prototyping
 - Figma
- Libraries/Frameworks
 - React.js
 - Vite
 - Bootstrap.js
 - Gin
 - Auth0
 - Open Route Service (ORM)
 - OpenStreetMap (OSM)
 - Leaflet
 - Leaflet Routing Machine
- Testing
 - Jest
 - Go Test Framework
- Browser
 - Google Chromium
- Project Management and Version Control
 - GitHub

- GitHub Interactive Kanban Board
- GitHub Issues
- Git

1.7 Risk Assessment

It is vital to understand the potential risks at the beginning of the project to establish a way to mitigate those risks should they occur. The risks have been identified when considering this project (see Table 1.1, p14).

Table 1.1: Project Risk Assessment

Type	Risk	Likelihood	Severity	Description and Mitigation
Personal	Illness	Low	Medium	There is the chance that I may fall ill unexpectedly during the project. To mitigate the risk of this visit a doctor if unwell and allocate time for rest around university work.
	Supervisor illness	Medium	Medium	The supervisor becoming unwell in any instance could impact the completion of tasks due to the lack of technical guidance and may delay the project's timeline. If this occurs, we will conduct online meetings and plan time in preparation for the potential delay.
Management	Changing requirements	Medium	Medium	During the project, the requirements initially suggested may change. To mitigate this, communicate regularly with the supervisor to discuss the feasibility of the current requirements to prevent any future changes.

	Time availability	Medium	Medium	The time to dedicate to the project may become more limited as I have more work to complete for other modules. To prevent this, plan tasks ahead of time to consider potential future setbacks.
Technical	Data loss/corruption	Low	High	Data loss would mean the prototype must be developed again from scratch. To mitigate this issue, create regular backups on GitHub and locally in case either fails.
	Hardware failure	Low	High	PC/Server/Laptop being used for development/hosting crashes/hardware gets damaged. Ensure multiple devices are being used so development can continue even whilst one device is down.
	Documentation availability	Low	Medium	Documentation for frameworks, languages or libraries is unavailable. There is a range of readily available online for all the required technologies.

1.8 Legal, Ethical, Social and Professional issues

The key legislation to consider for this project is the Data Protection Act 2018 (DPA 2018). The project should not store personal information. However, the user's current location will be requested upon the launch of the application; when the application no longer uses this data, it will be deleted and re-requested when the user enters the application again. Future iterations could implement accounts, storing a small amount of sensitive user information to include more features. However, the submitted artefact shouldn't contain this data; regardless of this fact, it will be ensured the artefact abides by all principles of the DPA 2018 due to it handling the current location data of the user.

One social issue that could arise is that the artefact may entice more public members to start cycling more frequently; whilst this result will be a great incentive for protecting the environment, some road users are cautious, with many cyclists riding unsafely on the roads. The artefact will push users to ride safely and abide by all road safety laws, just as vehicles do; there will also be the option only to use cycle routes/lanes when plotting a route to ensure those cyclists who are less comfortable on roads still feel safe on the routes planned by the artefact.

Chapter 2

Literature Review

This chapter presents the analysis and review of relevant literature conducted throughout this project. The research comprises of literature surrounding different routing algorithms and their current usage within current route planner applications. It also explores other relevant technologies which will be utilised in developing the artefact, such as web frameworks and programming languages.

2.1 Background

This project has a high level of complexity. It utilises custom, user and system inputs into a data-driven route planning algorithm, displaying the output on an OpenStreetMap-based web application.

This review begins with researching literature on different web technologies and programming languages to develop an understanding of what technologies were available to build the proposed system. Once an understanding of the technologies was developed, a review of current competing products was reviewed. This allowed for gaps in the current market to be identified, therefore developing an idea of requirements for the proposed system (see Section 2.3, p17).

Furthermore, research into how cyclists consider different risk factors when planning a ride was key in understanding what routing algorithm was implemented to fit the project's requirements best. An in-depth review of existing literature was conducted to understand two primary risk factors for cyclists: cycling infrastructure (see Section 2.4.1, p18) and weather conditions (see Section 2.4.2, p20).

2.2 Research Methods

An initial exploration of sources and subject areas was conducted using Google Chrome to comprehensively understand the topic at hand. Certain regions of interest were also highlighted through crowd-sourcing ideas from knowledgeable individuals. After these areas were outlined, in-depth research was conducted primarily through Google Scholar

and the University of Portsmouth EBSCO database. The Zotero Chrome plugin and app managed citations and bibliography items (“Zotero | Your personal research assistant”, n.d.). All bibliography items have also been stored in a CSV file, utilising Zotero’s export functionality; doing so ensures that all relevant sources can be re-visited at any time and are not lost after this project has concluded.

2.3 Competing Products

There are many different route planners available with a range of different features, some common between applications and others specific to one. Applications like Plotaroute.com (“Free Route Planner for Outdoor Pursuits - plotaroute.com”, n.d.), Komoot (“Komoot | Find, plan and share your adventures”, n.d.) and Google Maps (“Google Maps”, n.d.) have some commonalities, however serve slightly different purposes (see Figure 2.1, p17).

Desirability (1-5)	Features	Application Name								Number of Applications with Feature	
		Plotaroute.com	Routeyou.com (Paid)	Komoot.com	Cycle travel	Cyclesstreets.net	Maps.google.com	Web.bikemap.net (Paid)	Ridewithgps.com	OSMaps(Paid)	
5	Cycling Infrastructure Issue Waypoints										0
3	Hotels/Campsites on Rt			X							1
3	Measure Section	X									1
2	Annotate	X									1
2	Repeat Route (laps)	X									1
2	Make Route (auto generate)	X									1
1	Repeat Loop (add loops to route)	X									1
1	Plot Radius from Pt	X									1
1	Combine Route	X									1
5	Key Tourist Pts		X	X							2
3	Weather Forecast								X	X	2
3	Shortest Route	X	X								2
2	Replot Section	X									2
2	Split Route	X							X		2
1	Tabletop 3D Augmented Reality (iOS only)									X	X
4	Fitness Level		X	X		X					3
3	Social Sharing	X	X	X			X				4
5	Different Vehicles	X	X	X			X	X			5
4	Import Route	X	X						X	X	5
4	Round Trip	X	X	X					X	X	5
3	Alt Routes	X	X	X		X	X				5
5	Route Terrain Summary		X	X	X				X	X	6
5	Instructions	X	X	X	X	X	X	X			7
4	Reshape Route (Drag Anchor Pts)	X	X	X	X	X	X				7
3	Trace Route	X	X	X	X	X		X	X		7
2	Print		X	X	X		X	X		X	7
5	Export Route GPX/KML/TCS/FIT	X	X	X	X	X					8
5	Snap to Map (fix GPX Errors)	X	X			X	X	X	X	X	8
5	Change Start/End Pt	X	X	X	X	X	X	X			8
4	Export Route (save online)	X	X	X	X	X	X	X			8
4	Reverse Route	X	X	X	X	X	X	X			8
4	Delete Section	X	X	X	X	X	X	X			8
3	Manual Route Planning	X	X	X	X	X		X	X	X	8
5	Elevation Plot	X	X	X	X	X		X	X	X	9
4	Map Layers	X	X	X	X	X	X	X		X	9
Total Number of Features		26	22	19	15	14	13	13	12	11	10

Figure 2.1: Table of current solutions and their included features

2.3.1 Plotaroute.com

Plotaroute.com (“Free Route Planner for Outdoor Pursuits - plotaroute.com”, n.d.), now referred to as Plotaroute, contains a wide range of features, including nearly all features highlighted in Figure 2.1 (see Figure 2.1, p17). The main shortfall of Plotaroute was identified as its UI (User Interface) rather than the features included. The UI of Plotaroute is very cluttered due to the number of features present in the application (see Figure A.1,

p40). Unless the user is an expert and has used the application before, it is initially confusing what each part of the application does. Due to this, at first glace, it's unclear what type of route planner Plotaroute is, which will fundamentally affect a user's initial decision on whether or not to use the application.

2.3.2 Komoot

Komoot (“Komoot | Find, plan and share your adventures”, n.d.) offers a simpler-looking yet feature-rich application for planning and discovering routes (see Figure A.2, p41). The application has a key focus on community, whereby a user doesn't necessarily need to plan a route, they can simply discover a route or even share a route of their own. This functionality allows the user to require minimal effort when planning location-specific rides, however doesn't offer discovery of longer routes, for example, Land's End to John O'Groats. When compared to Plotaroute, Komoot is clearly more user-friendly without sacrificing the core features needed by users. One primary setback with Komoot, however, is that some functionality for route planning is part of a paid-for service, therefore locking certain user bases out of some key desirable functionality.

2.3.3 Google Maps

Google Maps (“Google Maps”, n.d.) further reduces the specific functionality and offers a very simple, multi-functional route planning and location finding application (see Figure A.3, p41). Google Maps is likely the most user-friendly out of all the applications, simply due to its simplicity and consistency across other Google applications (“Material Design”, n.d.). With this simplicity, however, most cycling-specific functionality is not present; the only option the user has when calculating a route is what the Google routing algorithm calculates with potentially a few alternate routes. Therefore, limiting how much the user can customise their route.

2.4 Risk Factors in Route Planning

Risk-based cycling route planning requires extensive knowledge of the impact of cycling and transportation infrastructure currently in place. It is also critical to understand how other external factors impact the risk of a route on an ever-changing basis. Within this section, a range of risk factors were explored to understand how multiple risk factors can be implemented into route planning algorithms.

2.4.1 Cycling Infrastructure

The cycling infrastructure along a route must be understood because it is common for cyclists to share the same infrastructure as motorised vehicles. However, a cyclist has no physical protection if a crash occurs (Reynolds et al., 2009). There is often purpose-built infrastructure for cyclists, whether bike lanes alongside shared roads or off-road bike paths and this segregated infrastructure can help improve the safety of a route for a cyclist.

Order of Preference	Features	Application Name								National Cycle Network	Number of Applications with Features
		Polarroute.com	Routeyou.com (Paid)	Komoot.com	Cycle.travel	Cyclocrossroads.net	Maps.google.com	Web.bikemap.net (Paid)	Ridewithgps.com		
1	Round Trip	X	X	X				X	X		5
2	Export Route (save online)	X	X	X	X	X	X	X			8
3	Hotels/Campsites on Rt				X						1
4	Different Vehicles	X	X	X							5
5	Manual Route Planning	X	X	X	X	X		X	X	X	8
6	Elevation Plot	X	X	X	X	X	X		X	X	9
7	Cycling Infrastructure Issue Waypoints										0
8	Measure Section	X									1
9	Map Layers	X	X	X	X	X	X	X			9
10	Navigation	X	X	X	X	X	X	X	X		8
11	Annotate	X									1
12	Modify Route (Drag Anchor Pts)	X	X	X	X	X	X	X			7
13	Repeat Loop (add loops to route)	X									1
14	Split Route	X							X		2
15	Replot Section	X									2
16	Alt Routes		X	X	X	X	X				5
17	Export Route (GPX/KML/TCS/FIT)	X	X	X	X	X		X	X	X	8
18	Import Route	X	X						X	X	5
19	Shorten Route	X	X								2
20	Social Sharing	X	X	X			X				4
21	Make Route (auto generate)	X									1
22	Print		X	X	X		X	X	X	X	7
23	Snap to Map (fix GPX Errors)	X	X			X	X	X	X	X	8
24	Repeat Route (laps)	X									1
25	Weather Forecast								X	X	2
26	Delete Section	X	X	X	X	X	X	X	X		8
27	Route Terrain Summary		X	X	X				X	X	6
28	Combine Route	X									1
29	Fitness Level		X	X		X					3
30	Plot Radius from Pt	X									1
31	Reverse Route	X	X	X	X	X	X	X	X		8
32	Key Tourist Pts		X	X							2
33	Trace Route	X	X	X	X	X		X	X		7
34	Instructions	X	X	X	X	X	X	X			7
35	Tabletop 3D Augmented Reality (iOS only)								X	X	2
Total Number of Features		26	22	19	15	14	13	13	12	11	10

Page

Figure 2.2: Features in priority order based on user feedback

Furthermore, Hong states how investing in effective cycling infrastructure "mitigates the negative effects of poor weather conditions" (Hong et al., 2020), which further demonstrates that good, known infrastructure is key to improving the physical and perceived safety of a route in a range of different weather conditions.

Furthermore, crowd-sourced data from route planners, cyclists and fitness applications such as Strava Routes ("Strava | Running, Cycling & Hiking App - Train, Track & Share", n.d.) have been key in developing new infrastructure. Boettge states how the most accurate assessment of a cycle network would come directly from the cyclists who use the network (Boettge et al., 2017). Cyclists who use the network are the most familiar with the quality of each route and how traffic conditions improve the safety of the route. Utilising the GPS information from route planners and fitness tracking applications alongside direct input from cyclists can help build new routes and improve pre-existing routes, therefore preventing injuries and high-risk situations by modifying transportation infrastructure (Reynolds et al., 2009).

Areas with little to no cycling infrastructure, such as busy roads and roundabouts, force cyclists to have a heightened attentiveness that other road users don't have to consider due to not only the physical danger but the cyclists' perceived danger (Doorley et al., 2015). These risks should be considered within route planning to decrease the number of 'risk' areas along a cyclist's route whilst also giving local areas the incentive to make

Measure	Netherlands	Edinburgh	Cambridge
Consistency	4.54	2.17	2.83
Directness	4.29	2.17	3.83
Attractiveness	4.28	2.22	3.56
Road safety	4.41	2.38	3.5
Comfort	4.46	2.33	3.33
Spatial integration	4.43	3.29	3.86
Experience	4.50	2.20	4.40
Socio-economic value	4.67	3.33	3.67
Overall Score	4.45	2.51	3.62

Figure 2.3: Comparison of the bicycle infrastructure scores (Hull and O'Holleran, 2014).

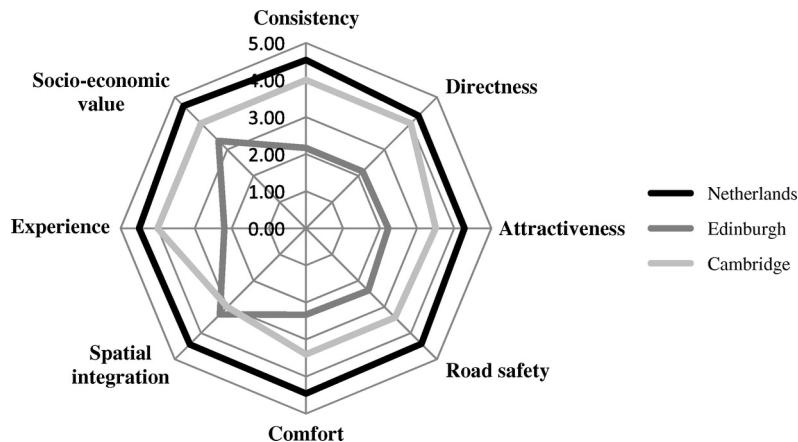


Figure 2.4: Spider web diagram comparing the Bicycle Infrastructure Scores (Hull and O'Holleran, 2014).

infrastructure modifications to decrease the number of 'high-risk' points. Therefore, in the long-term, it will mitigate the need for constant action by cyclists to ensure their safety, which will, in turn, influence individuals' decisions to cycle (Reynolds et al., 2009).

Hull and O'Holleran also demonstrate how cities with a high reputation among cyclists also have safer roads and more attractive infrastructure. The Netherlands scored relatively equally amongst all categories, in comparison to cities with less of a reputation and, therefore, a lower standard of cycling infrastructure (see Figure 2.3, p20) (see Figure 2.4, p20) (Hull and O'Holleran, 2014). This supports how Reynolds et al. further illustrate how investing in cycling infrastructure will greatly incentivise individuals to cycle due to the decreased risk.

2.4.2 Weather Conditions

Weather conditions will also have a pivotal effect on how a route planner will calculate the safest route for a cyclist. Following on from Cycling Infrastructure (see Section 2.4.1, p18), it is demonstrated how a lack of good infrastructure goes hand-in-hand in creating an unsafe route alongside the weather. To ensure the safety of cyclists, all routes and road surfaces must be maintained to withstand different weather conditions (Shoman et al., 2023).

The weather also impacts a cyclist's likelihood to ride; Flynn states that cyclists 'were nearly twice as likely to commute by bicycle when there was no morning precipitation' (Flynn et al., 2012). It is clear that even minor changes in the weather can drastically affect a cyclist's decision to ride, further demonstrating how vital the perceived safety of cycling is in deciding whether to ride.

Contrasting this, Hull and O'Holleran state that the main environmental barriers included too much traffic, too many hills, no bike lanes/trails, no safe place to cycle and badly maintained streets (Hull and O'Holleran, 2014). Therefore suggests that the weather should have a minimal impact on a cyclist's decision to ride if the infrastructure is sufficient. Despite the findings of Hull and O'Holleran, it seems to be a common finding that the perceived safety of cycling, both in regard to the changing weather conditions and cycling infrastructure, is the primary factor in choosing cycling over an alternative method of transport. Miranda-Moreno and Nosal have shown how when infrastructure is implemented, there is generally an increase in total bicycle usage and diversion of cyclist flows away from roads to purpose-built infrastructure even in less ideal weather conditions (Miranda-Moreno and Nosal, 2011).

2.5 Conclusion

To conclude, route planning with different customisable preferences has been implemented by a range of different existing organisations; however, focusing on a risk-based routing approach has not been addressed by these existing solutions. Utilising pre-existing routing algorithms such as Open Route Service ("Openrouteservice", n.d.) or Open Source Routing Machine ("Project OSRM", n.d.) and integrating custom, weather and infrastructure data alongside the usual user-preferences has not been implemented within existing solutions. Therefore, this enables a unique system to be developed whereby crowd-sourced infrastructure data alongside weather data provided by OpenWeatherMap combined form a risk index utilised in a customised routing algorithm.

Furthermore, in order to develop this system, React.js was chosen to develop the front end and Go for the back end. Next.js was initially considered for the front-end. However, it was later found that Next's server-side rendering was not supported by Leaflet; used for Mapping with OpenCycleMap; ("Leaflet — an open-source JavaScript library for interactive maps", n.d.; "OpenCycleMap.org - the OpenStreetMap Cycle Map", n.d.) due to it requiring direct interaction with the DOM. Go with the Gin Web Framework ("Gin Web Framework", n.d.) was chosen to develop the API and back-end due to its increased performance benefits over alternative languages such as Node.js with Express.js.

Chapter 3

Methodology

Choosing which Software Development Life Cycle (SDLC) methodology is a key decision at the beginning of any software development project; the methodology demonstrates the expected route that development will take during the project's lifetime. I have decided to use the Incremental methodology whilst integrating key Project Management methods in other team-focused methodologies, such as Agile, as mentioned in Section 4.

3.1 An Incremental Development Methodology

I have chosen the Incremental Development Model for this project since the Waterfall Model cannot precisely and completely describe the real software development life cycle (Dapeng Liu et al., 2011). Each iteration will represent a full software life cycle vaguely following the waterfall methodology's structure: Requirements analysis, Design, Development, Testing, and Release. Incremental development allows for more flexibility during the software development process. It is feasible for a solo-development project as it does not require collaboration with other team members as the Agile methodology does.

The Incremental model breaks larger tasks into smaller, more achievable sub-tasks/increments. Each task can be broken down into all or some of the stages mentioned earlier. Therefore, if some stages are unnecessary for an increment, they don't need to be followed. Development of the increments can be managed using a Kanban board. It can also manage progress in completing this document. To see the added benefits of using Kanban, see Section 4.2.

There are some downsides to using the Incremental model, with one key failure of the model being merging changes between increments. This downfall of the model introduces a discontinuity of design purpose where the user interface and programming interfaces become discontinuous between increments (Dapeng Liu et al., 2011). To mitigate this issue, a consistent programming interface be implemented to aid in developing easy-to-read source code throughout the development of increments.

Chapter 4

Project Management

4.1 Methodology

As stated throughout (see Chapter 3, p22), the chosen methodology for this project is the Incremental SDLC Model. The project will be split into increments to break down larger tasks into smaller, more manageable subtasks. Each subtask will have its deadline to contribute to the changes within that increment. There will be regular incremental changes during the development and implementation of the artefact. All tasks to be completed will be managed with GitHub projects utilising its Kanban, Table and Milestones functionality, mentioned in Section 4.2.

4.2 GitHub

4.2.1 Kanban Board and Projects

From the beginning of the project, a GitHub project was created alongside the GitHub Repository to manage all tasks to be completed for this document and the development of the artefact. All tasks to be completed were added to the backlog at the beginning of development and allocated a milestone and label to categorise each task.

Milestones were created for each Increment of the prototype and for each section of this document to be completed. This would allow tasks to be assigned to each milestone to better manage which task belongs to which overall objective. Each task would then be assigned a 'To Do' status when selected for development/writing and would progress throughout the other Kanban Board stages until it is marked as 'Done' and closed.

An extra status has been added to the Kanban board with the name 'In Review'; tasks placed in this status were awaiting guidance from the project supervisor (see Section 4.3, p24).

4.2.2 Version Control

GitHub will host the project source code with Git Software Version Management (SVM). Using GitHub and Git enables branches to be created in the repository to manage code changes and link each change to a pull request which enables incremental development. Branches will allow for branch-level testing and pull requests for automated merges once the increment has been completed. These merges will also throw merge conflicts if issues in the code arise between increments, ensuring the code base remains accurate and forcing the conflict to be resolved before changes are made. Commits are also highly-valuable during development as they allow code changes to be managed and reversed if needed.

4.3 Supervisor Meetings

Meetings will be scheduled on a weekly or fortnightly basis; my supervisor allocates a range of slots each week where I can book a time which works for me. The aim is to have all meetings face-to-face where possible. However, if the supervisor or I become unwell, we will conduct a video conference where possible. If the supervisor has planned leave, or I will be away for some time, we will communicate ahead of time to devise a plan for the project while one or the other is away and unable to meet regularly. Doing so will further allow me to plan my workload ahead of time and effectively keep track of the progress throughout the project.

Chapter 5

Requirements

The identification of requirements was critical to the success of the project. Primary research was undertaken to gather an understanding of real user preferences from a list of proposed functionalities as to understand their wants and needs of the application. It was critical to declare clear and concise requirements to ensure absolute clarity throughout the project. This chapter discusses all methods undertaken to gather requirements, including the final requirements found as a result of this process.

5.1 Requirements Gathering

Requirements were gathered via multiple channels, initially research was undertaken to understand the offerings of current solutions to gather a list of potential functionalities. These were then taken to the client to set out a base set of user requirements to be used in primary research. A simple research application was developed to collect the opinions of cyclists in the general public, enabling participants to order a subset of a wider list in order of preference (see Figure 5.2, p27).

5.2 Identifying Users

The aims highlighted the need to expand the route planning functionalities available to cyclists (see Section 1.2, p10). Multiple user groups were identified from this:

- Commuter - A commuter would require a simple round trip route, likely focused on ease of ride and speed taken to commute.
- Regular Cyclists - A cyclist who focuses on planning a ride tailored for their skill level. Wants multiple route options with varying levels of intensity.
- Pro Cyclists - A pro cyclist would require a deeper level insight into each planned route, including a range of customisability and integration with fitness applications.

5.3 Requirements Specification

User stories were established through various methods: regular face-to-face meetings were conducted with the client and research was conducted through a web application built to understand the users' preferred functionality (see Figure 5.2, p27). Each user story was broken down into specific system requirements. The requirements have been ranked using the MoSCoW model; this demonstrated each requirements' level of importance aiming to prioritise the necessary requirements, limiting the time spent on the less-necessary requirements. The MoSCoW model seemed the most appropriate choice in prioritising requirements because of the research undertaken with real-world users, utilising the data collected on user preferences (see Figure 5.1, p26)(see Figure 2.2, p19).

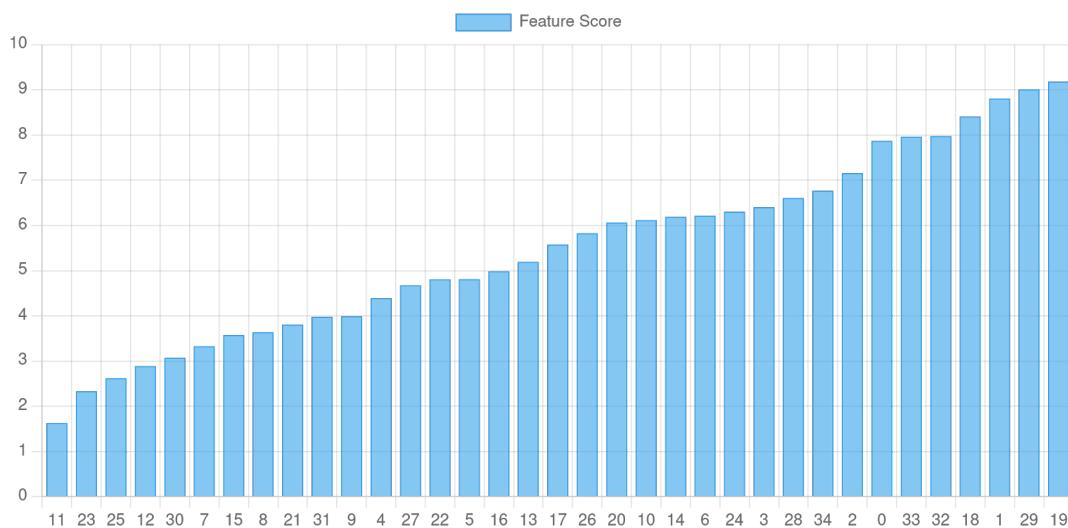


Figure 5.1: User Feedback

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- Imagine you are going to plan a bike ride. This ride could be short or long, perhaps for a commute, a workout or even a longer cross-country journey. I'm looking to understand what functionality you would prefer to see in a route planner.
- Drag the features (below) into your preferred order from top-to-bottom (top being the most important and bottom being the least).
- Items in the list are a subset of a much larger list, so you may not see all the features you expect or think are required, it's the ranking of this subset that is important.
- Click 'Submit' when you're done.
- You can participate multiple times and will get different items each time.

[Submit](#)

Toggle different map layers to customize the map view during route planning.

Locate hotels and campsites along the planned route for traveler convenience.

Add personal annotations or notes to the route, providing additional information or reminders for yourself.

Waypoints which highlight key infrastructure issues along the route, these will be input into the application through local experts.

View an elevation plot of the route, providing insights into its elevations changes.

Manually plan and customize the route based on user preferences and requirements.

Measure specific sections of the route for distance, elevation, or other metrics.

Add loops to the route to increase distance or vary the path. (loops being repeating the sections of a route along the route).

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Figure 5.2: Firebase Research Application

5.4 Elicited Requirements

The elicited requirements were a direct result of discussions with the client and the primary research undertaken (see Section 5.3, p26). Each user story was divided into multiple acceptance criteria/system requirements and were segregated into a table per user story.

Table 5.1: User Story 01

As a user, I want a page that allows me to configure my starting and destination location to plan a route.

Acceptance Criteria / System Requirements	Priority	ID
The system must provide a route configuration panel.	Must	SR1
The route configuration page must provide a starting and destination location input field.	Must	SR2
The route configuration page should suggest accurate geolocations based on the location inputs.	Must	SR3
The route configuration page must determine the geolocation based on the user input.	Must	SR4
The route configuration page must plan the route once two or more locations are input.	Must	SR5

Table 5.2: User Story 02

As a user, I want to change preferences to allow me to customise the route, including avoiding certain road types and road altitudes.

Acceptance Criteria / System Requirements	Priority	ID
The system must provide an overlay window to allow the user to update routing preferences.	Must	SR6
The update preferences overlay must provide options to 'avoid' along the route.	Must	SR7
The update preferences overlay must provide a 'via' user input field.	Should	SR8
The update preferences overlay must provide a 'leave time' user input field.	Should	SR9
The update preferences overlay must provide a 'arrive time' user input field.	Should	SR10
The update preferences overlay must provide a 'round trip' user input field.	Could	SR11

Table 5.3: User Story 03

Acceptance Criteria / System Requirements		Priority	ID
The system must provide an option to export the planned route.	Must	SR12	
The system must provide an export feature to export the route to the 'GPX' file format.	Must	SR13	
The system must provide an export feature to export the route to the 'GeoJSON' file format.	Should	SR14	
The system must provide an export online (to Google Drive, OneDrive and/or other cloud services)	Must	SR15	

Table 5.4: User Story 04

Acceptance Criteria / System Requirements		Priority	ID
As a user, I want to share my route with other people.			
The system must provide a share functionality overlay.	Should	SR16	
The share overlay must provide an option to share direct over email.	Should	SR17	
The system must provide an option to share the route direct to Strava.	Could	SR18	

Table 5.5: User Story 05

Acceptance Criteria / System Requirements		Priority	ID
As a user, I want to be provided with route suggestions based on predicted weather conditions over the week.			
The system must provide the user with a weather condition overlay.	Must	SR19	
The weather condition overlay must provide the user with the weather for the current day.	Must	SR20	
The weather condition overlay must provide the user with the weather for the next week.	Should	SR21	
The weather condition overlay must provide the user with the option to enable weather conditions in the route planning algorithm.	Could	SR22	
The weather condition overlay must provide the user with suggestions on the best days to cycle.	Could	SR23	
An option to include weather in route planning should be provided, ensuring the user enters the planned day to ride	Could	SR24	

Table 5.6: User Story 06

As a user, I want to view the route in detail and get information about parts of the route.

Acceptance Criteria / System Requirements	Priority	ID
The system must provide the user with an interactive map to display the planned route.	Must	SR25
The interactive map must allow the user to zoom into parts of the planned route.	Must	SR26
The interactive map must allow the user to select parts of the route and receive detailed information about that subsection of the route.	Should	SR27
The interactive map must allow the user to select and drag the planned route to modify its path.	Should	SR28
The system must display an elevation graph for the planned route beneath the interactive map.	Should	SR28
The system must allow the user to measure chosen sections of the route	Must	SR29
The system must provide multiple map layers to give users the greater options when viewing the route	Must	SR30

Table 5.7: User Story 07

Acceptance Criteria / System Requirements	Priority	ID
The system must provide a user input modal to input Hazard and Infrastructure Data.	Must	SR31
The hazard input modal must provide a Type drop-down menu based on the OSM Hazard Types.	Must	SR32
The hazard input modal must provide a date entry point to specify the date the hazard was seen.	Should	SR33
The hazard input modal must provide a submit button to add the hazard to the hazard index.	Must	SR34
The infrastructure input modal must provide a Type drop-down menu with different types of cycling/road infrastructure	Must	SR35
The infrastructure input modal must provide a date entry point to specify when the bad infrastructure was found	Must	SR36
The infrastructure input modal must provide an input box providing the user with the option to supply more detail	Should	SR37
Both Hazard and Infrastructure data should be displayed on the map, with an option to toggle on/off, and report errors	Should	SR38

Chapter 6

Design

6.1 Architecture Design

6.1.1 Client-Server Architecture?

6.1.2 Alternative Architecture Patterns

6.1.3 Architecture Diagram

6.2 System Design

6.2.1 REST API

6.2.2 Open Weather Map API

6.2.3 OSRM (Open Source Routing Machine)

6.2.4 Google Distance Matrix API

6.2.5 Use Case Diagrams

6.2.6 Hierarchical Task Analysis (HTA)

6.3 User Interface Design

6.3.1 Low Fidelity Prototype

6.3.2 High Fidelity Prototype

6.4 Database Design

6.4.1 Users

Chapter 7

Implementation

7.1 Development Environment

7.2 Programming Languages

7.3 Database

7.4 Increments

7.4.1 Increment 1

7.4.2 Increment 2

7.4.3 Increment 3

7.5 Documentation and Linting

7.6 Challenges and limitations

Chapter 8

Testing

8.1 Unit Testing

8.1.1 Testing here

8.2 Postman

8.3 Chrome Developer Tools

Chapter 9

Evaluation

9.1 Evaluation Methods and Techniques

9.2 Evaluation Process

9.3 Evaluating Requirements

9.4 Future Work

Chapter 10

Reflection and Conclusion

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Appendix A

Appendix

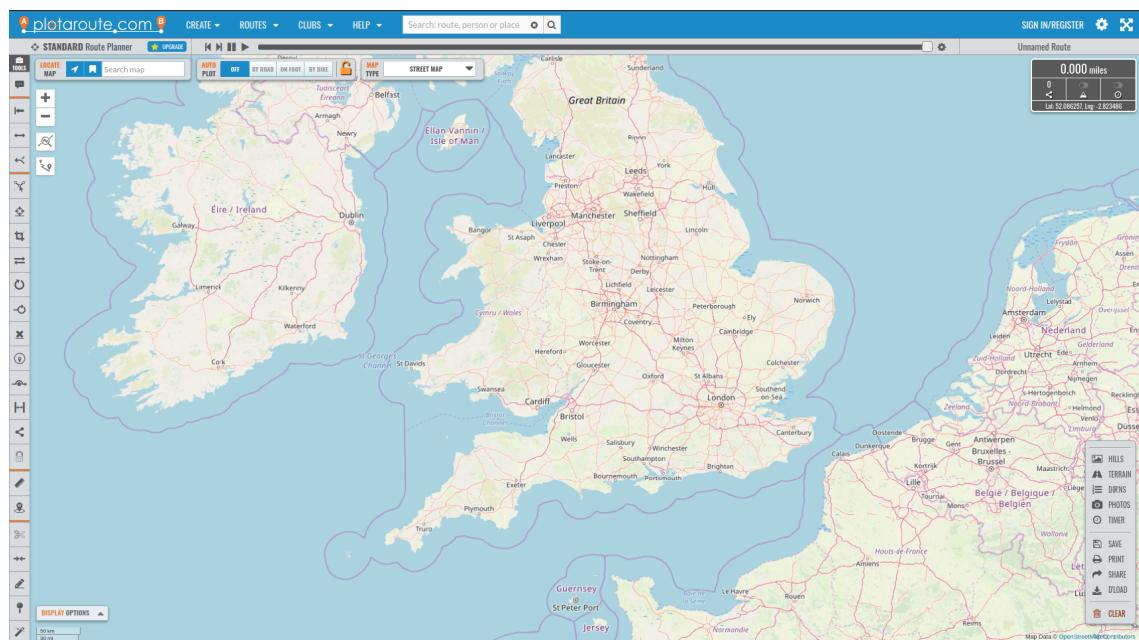


Figure A.1: Plotaroute.com UI

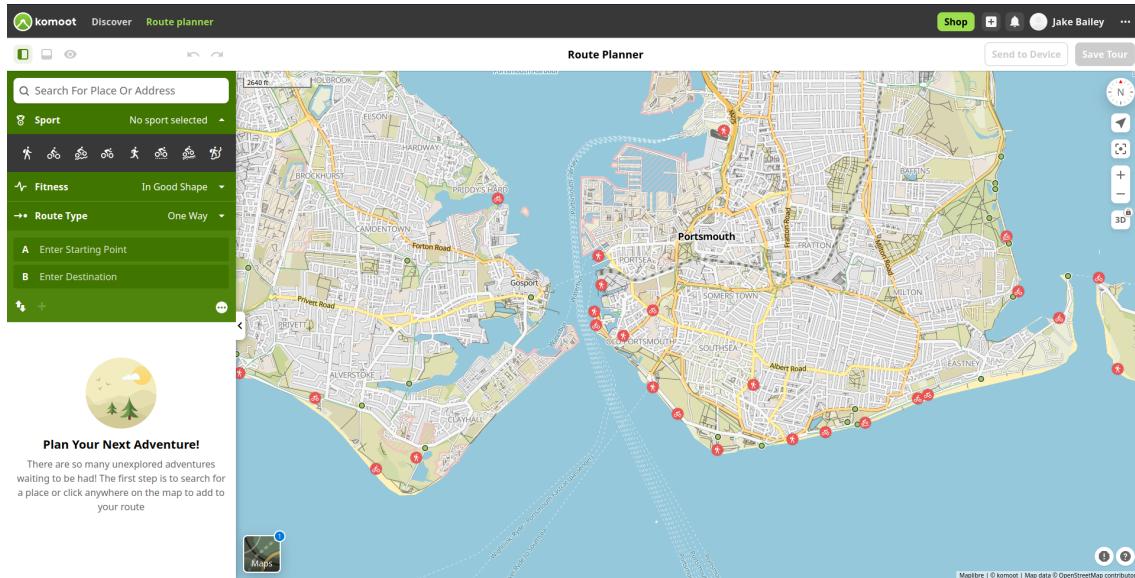


Figure A.2: Komoot UI

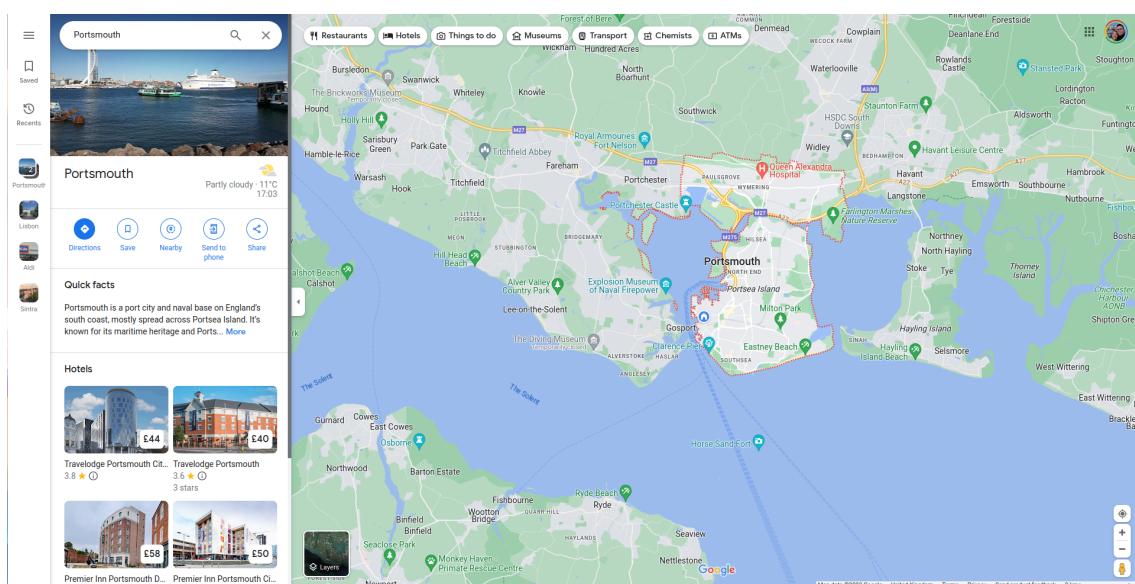


Figure A.3: Google Maps UI

Initial User Requirements

Table A.1: User Story 01

Acceptance Criteria / System Requirements	Priority	ID
The system must provide a route configuration page.	Must	SR1
The route configuration page must provide a starting location input field.	Must	SR2
The route configuration page must provide a destination location input field.	Must	SR3
The route configuration page should suggest locations based on the user input fields.	Should	SR4
The route configuration page must find the location position based on the user input.	Must	SR5
The route configuration page must verify both locations are correct before the user can continue.	Must	SR6
The route configuration page must provide a 'Plan' button to initiate the route planning algorithm.	Must	SR7

Table A.2: User Story 02

Acceptance Criteria / System Requirements	Priority	ID
As a user, I want to change preferences to allow me to customise the route further, including avoiding certain road types and road altitudes.		
The system must provide an overlay window to allow the user to update routing preferences.	Must	SR8
The update preferences overlay must provide an 'avoid' user input field.	Must	SR9
The update preferences overlay must provide a 'via' user input field.	Should	SR10
The update preferences overlay must provide a 'leave time' user input field.	Should	SR11
The update preferences overlay must provide a 'arrive time' user input field.	Should	SR12
The update preferences overlay must provide a 'round trip' user input field.	Could	SR13

Table A.3: User Story 03

Acceptance Criteria / System Requirements		Priority ID
The system must provide an option to export the planned route.	Must	SR14
The system must provide an export feature to export the route to the 'GPX' file format.	Must	SR15
The system must provide an export feature to export the route to the 'GeoJSON' file format.	Should	SR16
The system must provide an export feature to export the route direct to Strava.	Could	SR17

Table A.4: User Story 04

Acceptance Criteria / System Requirements		Priority ID
The system must provide a share functionality overlay.	Should	SR18
The share overlay must provide the user with the option to share direct over email.	Should	SR19
The share overlay must provide the user with the option to share direct over Google Drive.	Could	SR20
The share overlay must provide the user with the option to share direct over OneDrive.	Could	SR21
The share overlay must provide the user with the option to share direct over Dropbox.	Could	SR22

Table A.5: User Story 05

Acceptance Criteria / System Requirements		Priority ID
The system must provide the user with a weather condition overlay.	Must	SR23
The weather condition overlay must provide the user with the weather for the current day.	Must	SR24
The weather condition overlay must provide the user with the weather for the next week.	Should	SR25
The weather condition overlay must provide the user with the option to enable weather conditions in the route planning algorithm.	Could	SR26
The weather condition overlay must provide the user with suggestions on the best days to cycle.	Could	SR27

Table A.6: User Story 06

As a user, I want to view the route in detail and get information about parts of the route.

Acceptance Criteria / System Requirements	Priority	ID
The system must provide the user with an interactive map to display the planned route.	Must	SR28
The interactive map must allow the user to zoom into parts of the planned route.	Must	SR29
The interactive map must allow the user to select parts of the route and receive detailed information about that subsection of the route.	Should	SR30
The interactive map must allow the user to select and drag the planned route to modify its path.	Should	SR31
The system must display an altitude graph for the planned route beneath the interactive map.	Should	SR32

Table A.7: User Story 07

As a user, I want to input hazards from routes I have cycled so the next route planned would attempt to avoid that area.

Acceptance Criteria / System Requirements	Priority	ID
The system must provide a user input modal to input Hazard Data.	Must	SR33
The user input modal must provide a Type dropdown menu based on the OSM Hazard Types.	Must	SR34
The user input modal must provide a date entry point to specify the date the hazard was seen.	Should	SR35
The user input modal must provide a submit button to add the hazard to the hazard index.	Must	SR35