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Enhancing routes selection with real-time weather data integration in spatial decision support systems

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Abstract
A notable shortcoming in contemporary digital navigation systems is their failure to incorporate live weather data. This study investigates the possibility of improving urban navigation experiences by integrating real-time weather data. We developed a navigation tool that utilizes weather data from the OpenWeather API, providing users with real-time insights into weather conditions such as temperature, wind speed and direction, precipitation, and atmospheric pressure. This tool enables users to make informed decisions about their routes and travel plans by providing updated temperature information for selected routes and assessing the risk of road sections based on weather conditions. Incorporating weather data into navigation systems has the potential to enhance driving safety, minimize travel durations, and alleviate weather-related disturbances in urban settings.

Keywords Weather integration · Real-time weather data · Navigation tool · Decision support systems

1 Introduction

Weather conditions significantly impact various modes of transportation, including air, sea, and land [1]. Adverse weather conditions might lead to cautious driving speeds, extended travel times, and unexpected delays [2]. Inclement weather such as strong winds, heavy rain, and dense fog often disrupt aviation schedules, necessitating changes in flight paths and causing delays in travel plans. Such perturbations not only disrupt personal schedules but also saddle both commuters and transportation enterprises with logistical challenges and financial implications [3]. Contrary to the prevailing perception that aligns meteorological challenges primarily with icy terrains and snow-laden pathways, torrid heatwaves and blistering temperatures pose equally daunting, albeit contrasting, hurdles. Specifically for those reliant on non-mechanized mobility, like cycling or walking, sweltering conditions can prove especially taxing [4]. Prolonged exposure to such oppressive climates can accentuate discomfort for wayfarers, whether they tread on foot or journey within transit vehicles, invariably leading to diminished gratification with the provided transport services [5].

A significant oversight in today's leading digital navigation platforms is their lack of integration with live meteorological data. These technologically advanced tools, despite their vast potential, predominantly anchor their navigational advice on metrics such as journey distance or estimated transit timeframes [6]. Such an omission, glaringly evident in the face of the pivotal role weather plays in mobility, marks a chink in their otherwise sophisticated armor. Indeed, while quantifiable metrics like distance and projected timeframes serve as essential benchmarks, they remain somewhat myopic, failing to encapsulate the intricate tapestry of constantly shifting meteorological patterns. These dynamic weather shifts, with their cascading ripple effects, can drastically alter the viability and safety quotient of recommended travel pathways [7]. The repercussions

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of such an oversight can be manifold, ranging from minor inconveniences to significant, even life-threatening ramifications. When navigation utilities, especially those with widespread global usage, sidestep the integration of real-time atmospheric indicators, they inadvertently risk guiding users into potentially treacherous terrains or unforeseen logjams. Such scenarios not only compromise safety but also prolong travel times, fueling frustration and, at times, leading to economic repercussions [8]. Given the indispensability of weather considerations in the larger mobility landscape, this deficit in contemporary navigation systems becomes more conspicuous.

Addressing this glaring gap necessitates the development of an all-encompassing navigation solution that deftly fuses meteorological insights, ensuring that climatic considerations are inherently embedded within routing and decision-making frameworks. With the assimilation of real-time weather intel into the navigational matrix, voyagers are better equipped to calibrate their itineraries and course determinations. Immediate and precise meteorological pointers empower journeyers to gauge prospective hazards tied to unfavorable climatic episodes, thus paving the way for the adoption of routes that are not only swifter but also inherently safer. By inherently accounting for the whims of the weather, navigation platforms can intuitively steer users clear of locales besieged by torrential downpours, formidable gusts, or dense mists, drastically curtailing the chances of stumbling upon holdups, mishaps, or other meteorological adversities. The navigation tool under discussion has strategically chosen to leverage the capabilities of the OpenWeather API for its meteorological data acquisition needs. This decision is rooted in OpenWeather API's reputable standing in the domain, being widely recognized for its accuracy and comprehensive data sets. This digital interface not only furnishes key metrics such as ambient temperature, the velocity and cardinal direction of winds, precipitation levels, and barometric pressure, as cited by [9], but also offers a myriad of other invaluable meteorological insights. These encompass humidity levels, cloud cover percentages, and even predictive forecasts which give users a glimpse of forthcoming weather scenarios.

Upon retrieving this trove of weather data, the navigation system engages in meticulous data processing, sifting through the vast influx of information to distill the most pertinent and actionable insights. Advanced algorithms and analytical methods are employed to correlate this weather data with navigational information. This integrated analysis is the foundation on which the tool's dynamic routing capabilities are built. Users are thus presented with not only real-time weather snapshots but also with predictive forecasts that offer insights into expected conditions over their journey's duration. Empowered with this multifaceted weather-aware navigational framework, travelers can chart their paths with enhanced confidence and foresight. The system actively suggests alternative pathways, and by using strategic algorithms, it proffers intelligent detours and strategies tailored to sidestep potential weather snags. This proactive approach significantly amplifies the navigation tool's value proposition by assuring travelers of shortened travel durations and diminished risks of weather-triggered inconveniences. In the broader landscape of contemporary navigation solutions, this tool, with its weather-centric orientation, can predict, interpret, and provide actionable navigational insights based on evolving weather patterns underscores its transformative potential. By seamlessly bridging the meteorological and navigational spheres, this tool could facilitate a safe, informed, and efficient travel, effectively shielding voyagers from the unpredictable whims of nature and ensuring journeys remain as seamless as possible.

2 Data and methodology

In our study, we utilized the capabilities of two crucial Application Programming Interfaces (APIs) to create an advanced real-time navigation tool: the Google Maps API, specifically the Google Directions API, and the OpenWeather API. Our main goal in developing this tool was to provide users with not just navigation but also informative guidance. By integrating route details with live weather data, users gain valuable insights that enable them to choose the most suitable route while avoiding unfavorable weather conditions that might disrupt their journey.

The Google Directions API offers robust features for computing directions between different locations[10]. Going beyond basic direction-finding, it utilizes advanced algorithms to determine the most efficient routes, considering factors like traffic conditions and road closures. On the other hand, the OpenWeather API serves as a repository for real-time and predictive meteorological data, which is crucial in today's world where unexpected weather changes can significantly impact travel plans. By combining this weather information with the route insights obtained from the Google Directions API, we created a navigation system that is both dynamic and adaptive.

To illustrate the intricate yet seamless interaction between these two APIs, Fig. 1 demonstrates the relationship between the API keys and the overall architecture of our navigation tool. This workflow delineates the steps taken by the APIs to obtain specific data and the results generated as a result of this process.

2.1 Algorithms in Google Directions API

Dijkstra's algorithm holds a fundamental place in computational theory, specifically crafted to address the

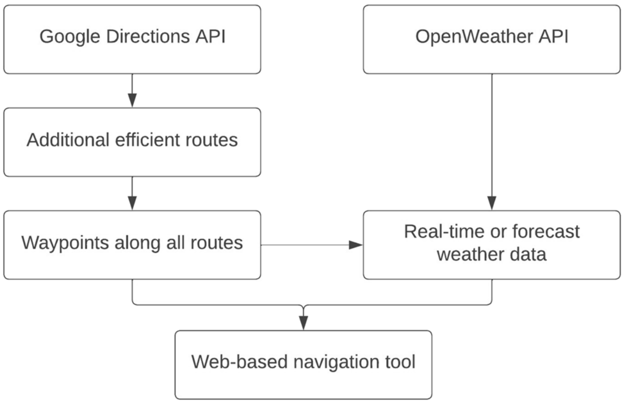


Fig. 1 The association between Google Directions API and OpenWeather API

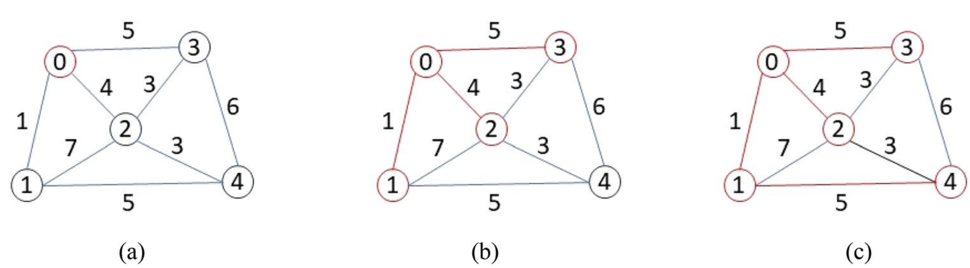
challenge of finding the shortest path from a single source in assignment graphs. As highlighted by[11], this algorithm plays a vital role in graph theory and its practical applications. Over time, numerous variations of the classic Dijkstra algorithm have emerged, all centered around the common goal of identifying optimal routes. This wide range of applications is demonstrated by works such as [12–14]. Essentially, Dijkstra's algorithm was designed with a clear objective: to systematically reveal the shortest route. It meticulously identifies the nearest unexplored node, recalibrating distances of adjacent nodes in the process. Deng et al. [15] elucidated this process, shedding light on its iterative nature and precise approach. However, as the modern world advances, there is a growing interest in incorporating safety metrics into the foundational structure of Dijkstra's algorithm. By redefining the cost function, the algorithm expands its original purpose from simply finding the shortest route to determining the safest one. This nuanced approach requires the integration of parameters encompassing safety considerations, geographical intricacies, and infrastructural attributes. The resulting algorithm, often termed the 'modified Dijkstra algorithm,' aims to minimize this redefined cost function. Its outputs are not just the shortest paths, but rather routes that strike a balance between brevity and safety. Byon et al. [16] exemplify this evolution. Their research introduced an innovative twist on the classic Dijkstra algorithm, incorporating parameters such as crime rates, road inclines, the aesthetic value of surroundings, and topographical elevations into its cost functions. This algorithm not only suggests the shortest route but also one where users can find security and appreciate scenic views. In a world where safety and experience are paramount, these modifications signify a shift towards comprehensive route optimization.

To demystify this intricate yet intuitive algorithmic process, Fig. 2 visually illustrates the inner workings and step-by-step progression of the Dijkstra algorithm. In this representation, circles represent nodes, and the edges are weighted by numbers. First, the process begins by selecting Node 0 as the initial point to find the shortest path connecting all nodes. As depicted in Fig. 2a, Node 0 is highlighted in red, and all edge weights are indicated. Moving on to Fig. 2b, Node 1, Node 2, and Node 3 are directly linked with Node 0, and these connections are shown in red. Determining the best way to add the final node, Node 4, involves exploring various possibilities. The most efficient route, passing through Node 1, is selected. In Fig. 2c, both Node 4 and the edge connecting Node 1 to Node 4 are highlighted in red. Ultimately, the algorithm's optimized pathways ensure all nodes are interconnected.

Additionally, route planning has utilized the A* algorithm, often coupled with a modified heuristic function [17, 18]. A* is a widely recognized path-planning algorithm applicable to metric or topological configuration spaces. Similar to the Dijkstra algorithm, the A* algorithm takes input parameters that include geographic information for the origin and destination points, along with safety-related factors. It is considered a best-first algorithm because it evaluates each cell in the configuration space based on the heuristic distance (typically Manhattan distance) from the cell to the goal node, as well as the length of the path from the initial node to the goal node through the selected sequence of cells [19]. The Manhattan distance represents the number of steps from the current node to the goal node, excluding diagonal nodes.

Figure 3 illustrates the process of the A* algorithm. In the diagram, the red node signifies the starting point, while the yellow node represents the endpoint. The numbers within the squares denote the distances from each square to the starting point. After calculating all the distances, the algorithm selects the shortest path from the endpoint to the

Fig. 2 Process of Dijkstra algorithm



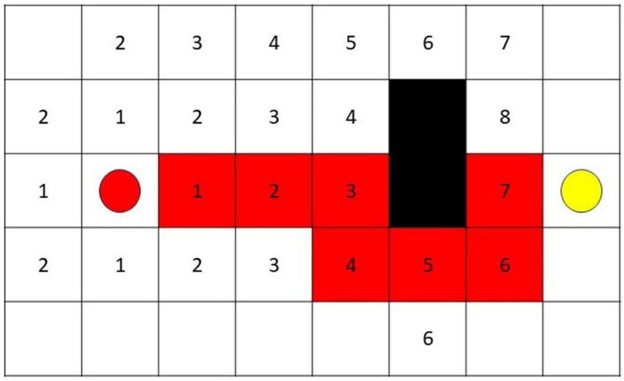


Fig. 3 Process of A* algorithm

starting point in reverse. The resulting red line represents the final path determined by the A* algorithm.

2.2 Dynamic algorithms

Route-finding algorithms, crucial components of modern navigation systems, can be broadly classified into two categories based on their response to real-time information: static and dynamic. This distinction has been emphasized in several studies [20–23] and serves as the foundation for navigational strategies. The fundamental difference between these two classes lies in their approach to real-time data integration. Static algorithms, as the name implies, operate with a degree of constancy. They heavily rely on historical datasets and predefined criteria to chart routes. Essentially, they generate paths based on past patterns, ignoring the fluctuations in current traffic conditions. While they excel in computational speed and resource conservation, they may struggle when faced with unexpected roadblocks or sudden surges in traffic. In contrast, dynamic algorithms epitomize adaptability. They continuously adjust routes based on real-time data, including current traffic dynamics, roadwork updates, and accident alerts. The strength of dynamic algorithms lies in their agility; they can swiftly modify routes, potentially reducing travel times and avoiding high-traffic areas.

However, this distinction holds significant implications for professionals in the transportation industry and researchers. Understanding the differences between static and dynamic algorithms enables them to choose the most suitable approach for their specific navigational needs. This ensures the development of navigation systems that are not only efficient but also tailored to diverse scenarios. Both types of algorithms rely on geographical datasets, which meticulously document spatial information, detailing the intricacies of road networks and the coordinates of the starting and ending points of a journey. Platforms such as OpenStreetMap, Bing Maps, and Google Maps, as highlighted in studies [24–26], serve as goldmines for this geographical information. Delving deeper into the realm of static algorithms, there's an added layer of intricacy. These algorithms, apart from geographic data, also harness historical data as a barometer for safety, knitting past patterns into the fabric of their route suggestions.

The OpenWeather API stands out as a prominent player in the digital meteorological landscape, renowned for providing both real-time and historical weather data. Designed to cater to a wide array of sectors, it finds utility not only in navigation and transportation but also in diverse fields such as agriculture and energy. What sets this API apart is its extensive data coverage—it goes beyond just temperatures and rainfall. Users can access a wide range of weather metrics, including humidity levels, atmospheric pressure, wind patterns, cloud formations, and more. The versatility of the OpenWeather API mirrors its ability to offer comprehensive insights.

One key to its robustness is the diverse sources of data it utilizes. The API doesn't rely solely on one data source; instead, it aggregates information from various channels, including ground-based weather observatories, advanced satellites, and sophisticated weather simulation models. However, raw data, no matter how vast, requires careful processing and refinement. This is where the OpenWeather API's proprietary algorithms come into play. By meticulously analyzing this wealth of data, these algorithms ensure that the information provided to end-users is not only extensive but also accurate and up-to-date. In essence, the OpenWeather API is more than just a static data repository; it functions as a dynamic meteorological engine, constantly evolving in real-time.

3 Results

3.1 Data collection

In our endeavor to develop an advanced web-based navigation tool, we strategically integrated two distinct APIs with the primary goal of seamlessly incorporating real-time temperature data directly into the user interface. This fusion not only enhances the tool's functionality but also elevates the user experience by providing relevant temperature insights during navigation. To fully leverage the potential of this tool and ensure its smooth operation, specific input parameters are required. These parameters are outlined in Table 1, which serves as a structured and comprehensive guide.

Within this table, we have organized the input parameters into two clear categories for clarity: 'Essential' and 'Optional'. The 'Essential' parameters are vital for the basic operation of the tool, ensuring users receive fundamental navigational and temperature data. On the other hand, the 'Optional' parameters, while enhancing the user experience with additional layers of information or customization, are

Table 1 Required and optional information for Google Directions API and OpenWeather API

API	Google Directions API		OpenWeather API	
	Required	Optional	Required	Optional
Parameters	Destination Origin	Alternatives Mode Waypoints	Latitude longitude	Units Mode

not mandatory for the tool's primary functionality. By adhering to the guidelines provided in Table 1, users can effectively navigate the tool, maximizing its utility and ensuring a streamlined and informative user journey.

Following the initial setup, our tool seamlessly interfaces with the Google Directions API, leveraging its capabilities to retrieve detailed route information. This API serves as the core component, providing intricate navigation guidance to lead users from one point to another. Concurrently, in order to complement the route data with real-time weather insights, the tool integrates with the OpenWeather API. This integration ensures that users receive not only information about their route but also updates on the weather conditions they may encounter during their journey. The interaction between these two APIs is illustrated in Table 2, showcasing how route information from the Google Directions API is harmoniously combined with meteorological data obtained from the OpenWeather API. This synergy provides users with a comprehensive and contextually accurate navigation experience.

3.2 Framework of Web-based navigation tool

In Fig. 4a, viewers can observe a conceptual mockup of our customized Navigation Tool—an innovative creation that combines the capabilities of the Google Directions API with the meteorological expertise of the OpenWeather API. This visualization provides a glimpse into the tool's user interface, characterized by its user-friendly design and seamless integration of six distinct components. Each component has been meticulously designed, ensuring users encounter an interface that is not only visually appealing but also functionally robust.

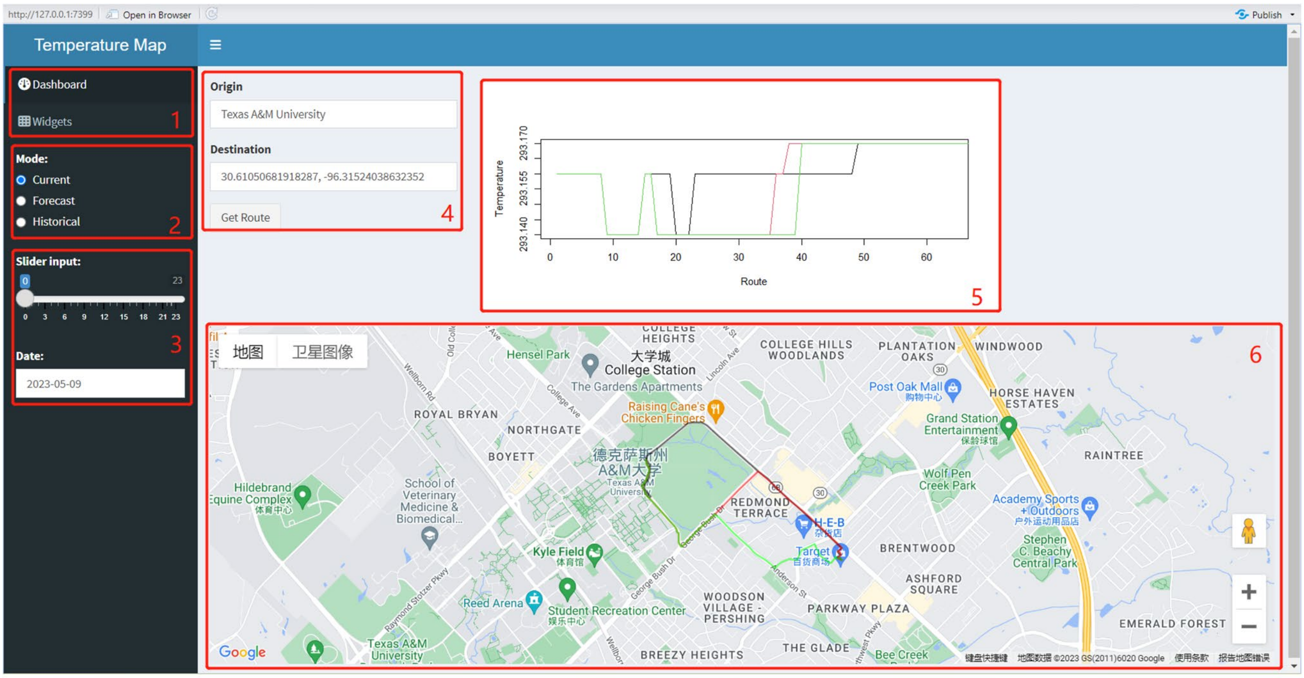
Additionally, Fig. 4b delves deeper into the navigational aspect by showcasing the routes directly sourced from Google Maps. This visualization offers users a clear perspective on the dynamics of the route, displaying pathways, potential turns, and landmarks. It emphasizes the tool's ability to provide precise and actionable route information, facilitating a hassle-free journey.

At the top of the interface, there are clearly defined tab items that facilitate easy navigation for users. These tabs allow seamless switching between multiple pages within the application, as indicated in Fig. 4a. The highlighted tab indicates the user's current location within the software, currently showing the Dashboard page. Below the tabs, the second component presents an intuitive set of radio buttons. These buttons allow users to quickly toggle and select from various modes, determining the specific type of temperature data to be displayed. For example, users can choose between current temperature trends and historical patterns based on their preferences. The third component introduces a user-friendly date selector, particularly useful in historical mode. Users can select a specific historical date of interest, enabling analysis of past temperature variations on that day.

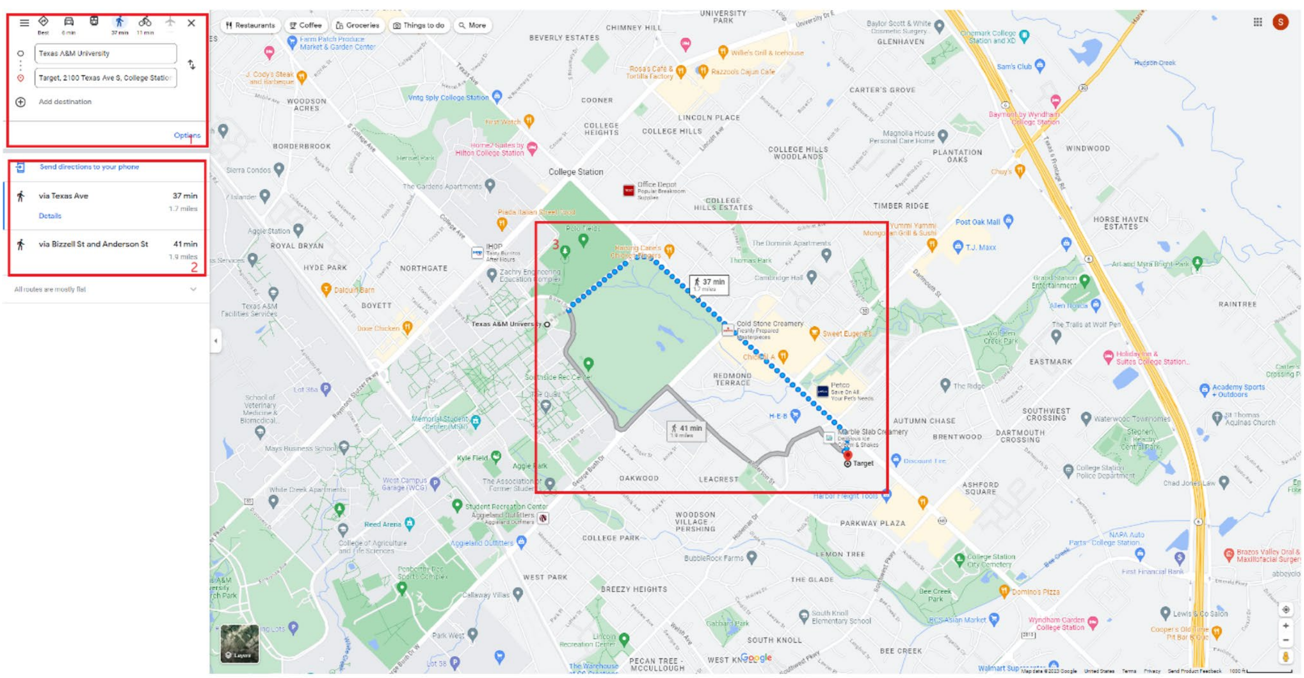
Moving on, the fourth component, placed centrally, is an interactive input area. Here, users can specify their journey's starting point and endpoint by entering location names (e.g., "New York City") or precise coordinates. Once the journey details are populated, a prominently placed "Get Route" button initiates a search for the most efficient travel routes. Accompanying this, users are presented with a visually appealing line graph in the fifth component, dynamically displaying temperature fluctuations along the chosen route.

Table 2 Information returned by OpenWeather API

Attribute	Unit	Attribute	Unit
sunrise	Unix, UTC	dew_point	default: kelvin, metric: Celsius, imperial: Fahrenheit
sunset	Unix, UTC	uvi	UV index
temperature	default: kelvin, metric: Celsius, imperial:Fahrenheit	clouds	%
feels_like	default: kelvin, metric: Celsius, imperial:Fahrenheit	visibility	metres
pressure	hPa	wind_speed	default: metre/sec, metric: metre/sec, imperial: miles/hour
humidity	%	weather	description



(a) Proposed navigation tool



(b) Google Maps

Fig. 4 User interface of navigation tool based on weather data

This graph provides a comprehensive understanding of the temperatures users might experience during their journey.

A standout feature of the tool is its sixth component: the main map panel. This visual space prominently showcases the shortest travel time route, highlighted in vibrant green. Users can zoom in and out, allowing detailed examination of each segment of their chosen route. Adjacent to this, the fifth component features a meticulously designed line graph that offers insights into temperature fluctuations along potential routes. By interpreting this data, users can identify routes with comfortable temperature ranges, enhancing their journey's comfort.

Drawing a parallel with Google Maps, our tool utilizes the Google Maps API for directions. However, our tool goes beyond simple navigation by offering additional layers of information. Unique features, such as temperature insights, transform our tool into a comprehensive travel planner. Users, whether pedestrians seeking shaded walks in the summer or drivers aiming for cooler routes, can base their decisions on temperature data. This means choosing routes with lower temperatures in hot seasons, indicating more shade or less direct sunlight exposure, thereby enhancing overall travel comfort.

4 Discussion

In our effort to assess the effectiveness of the web-based navigation tool, we conducted a thorough evaluation, focusing on its ability to assist users in selecting fast and efficient routes while also highlighting temperature differences. Our comprehensive assessment yielded positive results, confirming that the tool successfully achieves its intended objectives. As part of this evaluation, we employed a line graph analysis, which revealed interesting temperature patterns across various routes. Specifically, it identified segments of different routes that share similar temperature profiles. These insights are invaluable for users who prioritize specific temperature conditions when choosing their route. Figure 5 delves deeper into these findings, displaying the complete line graph. This visualization allows viewers to discern the temperature intricacies associated with different segments of the routes, emphasizing the tool's commitment to providing a comprehensive navigation experience.

While the web-based navigation tool effectively incorporates route optimization with temperature variations, it faces certain limitations. One significant drawback revolves around its method of representing temperature data across different routes within a static time frame. This approach can be misleading, as displaying uniform temperature readings across all paths might not accurately capture the real-time temperature changes experienced during a journey. It's essential to recognize that temperature dynamics are not only location-specific but are also influenced by the time of day. Therefore, this static representation may lead to potential discrepancies in the information provided to users.

To enhance the tool's functionality, there is a critical need to implement a mechanism for real-time temperature updates. Integrating such a feature would ensure that users, as they navigate their chosen path, receive the most recent and accurate temperature data for every segment of their journey. This continuous update of data would enable users to make decisions based on dynamic, real-time temperature information, leading to a safer and more informed travel experience.

In summary, the web-based navigation tool grapples with the challenge of displaying fixed-time temperature data. To truly elevate its effectiveness and maintain its status as a reliable navigation companion, integrating real-time temperature data updates is essential. This enhancement would not only enhance the tool's credibility but also increase user confidence by providing them with the most current temperature readings, thereby ensuring their journeys are both safer and more efficient.

5 Conclusion

The innovative tool we propose has the potential to revolutionize navigation experiences, ushering in heightened safety, efficiency, and economic viability. Picture a world where adverse weather conditions, a major cause of transportation disruptions, no longer pose significant obstacles. Instead, travelers can confidently navigate their routes armed with real-time weather insights, ensuring they reach their destinations safely and punctually. This vision is no longer a distant dream but an imminent reality with our tool in hand. This navigation tool is more than just directions; it's about empowering its users. By seamlessly integrating real-time temperature data with superior navigational capabilities, it shifts the paradigm from reactive decision-making to proactive planning. Travelers can

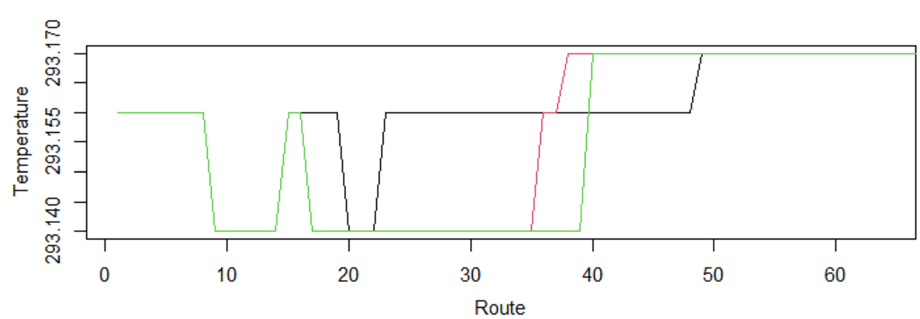


Fig. 5 Line graph in our navigation tool

now make informed decisions about their routes, taking into account temperature variations and potential hazards that might traditionally have been overlooked. In essence, this tool is not merely a navigation aid—it's a co-pilot, a weather advisor, and a safety advocate rolled into one. By enabling travelers to avoid potential risks and select the most favorable routes, it promises a future of transportation that prioritizes safety, punctuality, and efficiency above all else.

Moreover, the tool's ability to address transportation challenges arising from inclement weather represents a transformative stride in navigation solutions. Each year, countless delays, accidents, and missed engagements occur due to adverse meteorological conditions. These disruptions are not only a logistical nightmare but also pose significant safety and financial challenges. By seamlessly integrating reliable weather data into the navigation process, this tool actively confronts these challenges. It serves as a sentinel, forewarning travelers of potential weather threats and suggesting optimal routes that bypass such obstacles. The impact of this is profound—not just in terms of logistical benefits like reduced delays and more predictable travel times, but also in the broader context of public safety and well-being. In essence, with this tool in their arsenal, travelers aren't just navigating; they're proactively planning and preempting. The result is a journey that is not only more efficient and timely but also markedly safer, marking a significant leap forward in the realm of intelligent transportation.

While the tool represents an exciting frontier in navigation technology, it's crucial to temper our enthusiasm with an acknowledgment of its current constraints. At its current stage, the tool primarily focuses on providing temperature data alongside fundamental navigation capabilities. It falls short of offering a comprehensive risk map or the ability to suggest optimal paths based on real-time weather insights. Essentially, the current version of the tool serves as a foundational step toward a comprehensive navigation solution rather than a fully realized product. Although it may not yet rival the depth and breadth of features found in leading navigation platforms, it's vital to recognize the significance of this pioneering phase. The architecture and methodology employed in this tool establish the groundwork for an expandable framework. The same foundational principles can be applied and extended to encompass other critical real-time weather metrics, such as visibility, precipitation, or wind patterns. Furthermore, the tool can evolve to offer advanced route optimization based on an array of weather variables. In conclusion, while the current iteration of the tool may have certain limitations, its foundational approach is both commendable and promising. It acts as a springboard, setting the stage for a more comprehensive, sophisticated navigation system that seamlessly integrates diverse weather metrics. The future looks promising, with the tool's potential evolution poised to usher in a new era in intelligent, weather-aware transportation solutions.

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Declarations

Conflict of interest The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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