Safe Navigation by Vibrations on a Context-Aware and Location-Based Smartphone and Bracelet Using IoT

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Abstract. How can the use of IoT improve safely navigation for kick scooters? The context-aware and location-based solution combines an embedded smart bracelet and a mobile phone. The integrated platform provides a ubiquitous service, which gives kick scooters the ability to safely navigate by reducing distractions.

A key motivation was to minimize attention to the external disturbances during navigation and maximize attention to the route itself. This was achieved by (1) providing guidance while navigating via synchronized vibro-tactile feedback on a smart bracelet; (2) developing a vibration language on the bracelet; (3) allowing users to produce navigation routes in-advanced on their mobile phone, or consume existing routes in real-time.

The solution was designed for inclusive and tested in real-life situations on busy roads in the city.

Keywords: Ubiquitous and mobile computing · Location based services · Contextual design · Accessibility

1 Introduction

Nowadays, kick scooters have become an integral part of teenagers' daily lives. Research shows that a massive part of road accidents involve two-wheeled vehicle [10]. Kick scooter accidents in school-aged children and adolescents are associated with road accidents [17]. Indeed, the number of patients visiting emergency department due to push scooter accidents increases [9].

Regarding 4-wheels transportation, studies associate mobile phone use to road accidents. Driving while using the mobile phone reduces safety due to cognitive load [6]. Researches proven connection between mobile phone use while driving and traffic safely [8]. On the other hand, drivers who seek for navigation direction need to divide their attention between the road and the mobile device for the purpose of getting directions. Even though distracted drivers are involved in varies levels of self-regulation [11], psychological factors and attitude still determine some mobile phone use while driving [18]. This unsafe behavior is also typical of pedestrians, cyclists and electric or mechanical scooters.

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Therefore, the current study places kick scooter safety at the limelight and explores the effects of Internet of Things (IoT) solutions on safe navigation. First, in order to reduce the use of mobile phone for navigation while riding a kick scooter, a wearable computing will be used. Second, the solution should be designed as a location-based service (LBS) which integrates geographic location (as coordinates) with applications, such as emergency services, car navigation systems or tourism tour planning. These applications run on computers, personal assistants, phones and provide users with added value to mere location information [16]. Third, due to the combination of ubiquitous computing via mobile phone and wearable devices, the use of context is increasingly important where the users' context is changing rapidly [1]. Such changes are relevant in the context of driving and navigating. Fourth, Inclusive Design helps creating products that serve as many people as possible and enables people with diverse characteristics to use a product in a variety of different environments [13].

Therefore, the influence of IoT is examined while implementing four principles: (1) A wearable smart bracelet; (2) A location-based technique, (3) A context-awareness perspective implemented on mobile phone device; (4) Inclusive design approach.

Following the four guidelines, this paper presents the processes of design and implementation of a comprehensive prototype that integrates the four fundamentals: wearable, location-based, context-awareness mobile interface and inclusive design. The solution includes a wearable bracelet for vibrotactile feedback in a guidance systems. Hence, a location-based mobile phone sends GPS data and in-advanced planned route information through the Internet to an embedded smart bracelet. The bracelet transmits the data to navigation guidance and vibrates according to a vibration language, described later. The system allows users to plan the route in-advanced by selecting an existing route or creating a new customized one quickly. All routes are saved in the cloud for future use and customization. Based on saved and analyzed data, the system calculates and offers routes which are optimized to users' preferences

Finally, the system supports inclusive design. People with disabilities can navigate their way from starting point to destination wearing the bracelet and follow vibration guidance while navigating their way.

The next section describes related work.

2 Related Work

Technical solutions for optimized, safe and efficient navigation are evolving. One of the goals of ubiquitous computing, is to make devices 'smart' [2]. One example is a vehicle navigation solution for urban environment using IoT [5]. A second example is XIAOMI BAND, which is a wristband that connects to a mobile device and offers navigation functionality to the user. The XIAOMI is based on cutting-edge technologies and advanced hardware. It can convert vibration alert and digital display. Another example is the SUNU, which is a bracelet that offers a navigation system for the visually impaired or hearing impaired by a combination solution of the bracelet and laminated reality glasses. A recent study explores a vibro-tactile feedback around user's wrist to convey information about a general direction of a target. Instead of defining a route, this study enables free exploration of the surrounding [4]. The current study explicitly highlights safety while navigating to a specific target. Following the above examples of wearable solutions and smart navigation systems, the first two non-functional requirements are:

The Solution Aims to be Designed as a Smart Wearable Product. Meaning, a complementary wearable device, which is activated using a combined application.

The Solution Aims to be Designed as a Location-Based Mobile Phone.
Meaning, using GPS, the solution integrates geographic location. Information will be shown to the user based on local geographical location on his or her mobile device.

Research shows that vibrotactile wristband delivering messages and information is efficient in order to reduce accidents [3]. In case of warning messages, the vibrations assist in reducing street-crossing risks for all users. Placing user in the center has been shown to be an effective method to ensure that the systems being developed meets users' expectations [12]. Following are the next two non-functional requirements:

The Solution Aims to be Designed as a Context-Awareness Solution. Meaning, the mobile application and bracelet should be aware of the dynamic environment and change accordingly with minimum delays. Notifications, instructions and other information should be displayed or vibrated on-demand.

The Solution Aims to be Designed for Inclusion. Meaning, the product should serve as many people as possible, including teenagers and older, people with hearing disabilities or with cognitive difficulties, etc.

Having explained the non-functional requirements of the solution, the following section elaborates on the content and information being produced and consumed using the product.

2.1 Information Consumption Process

The information being used before and during navigation may range from complex visualization maps on the mobile phone, to simple notification alerts on the bracelet. Information is a peculiar product in that anyone can act as consumer and producer. Each role in the information cycle may lead to differing user-experiences. Therefore, user-experience is treated in this research in two perspectives. The first is the consumer's perspective- consumer's interface design is composed, among others, of content. The content is what the interface presents to users, including text and media [7]. According to this approach, consumers use existing information. In the current research they can search, select and navigate in real-time between existing tracks.

2.2 Information Production Process

The second perspective is from a producer's point of view: the user-experience of producing information via the mobile phone interface. Producers in the current research can create information, such as routes in-advanced, aggregate existing routes or customize tracks. The process of information production is a five-steps process: specification, design, implementation, validation and evolution [14, 15]. The specification step includes determine target audience (impatient youth in grade school, or a hearing impaired person, etc.). In addition, this first step includes understanding the goal and constrains of the produced information. For example, to navigate from home to school safely. The design step includes planning how the consumers will use the produced information. For example, the track should be customized for inclusion. The development step is the actual creation of the information. Meaning, the definition starting point and destination, and choosing the safer path. The validation ensures that produced information fulfills consumers' expectations and needs and that mistakes are minimal. For example, if the goal is to maximize safety for children riding on their kick scooter to school, then through the validation step, the producer should go backwards and verify that the produced track is the safest path for the child, before the child actually uses the track in real-time.

The final step is evaluating the produced information. It can be performed by the producer testing it in real-time on the road in busy streets, to evaluate its safety level.

Having explained the roles of information consumption and production in the context of a location-based, context-awareness solution and design for inclusion, the main functional requirement is as following:

The solution should allow the user to produce information in advanced and consume it in real-time.

The name of the integrated solution is LookUp. The following sections elaborate on its design and implementation.

3 Solution Approach

With the goal to maximize safety on the road, the system approach is to eliminate the need to lower one's eyes out of the way to look at the mobile phone while navigating. LookUp solution embraces IoT methods for communication between smart devices, such as a mobile phone and a smart bracelet. In addition, the system adapts context-awareness definitions, such as automatic interface and offers changes according to both personal user preferences and synchronized notifications based on location and environment.

The solution offers safe navigation for two types of users: track-consumers and track-producers. Track consumer uses the system to orient and navigate using maps displayed with the smart bracelet. These real-time users can wear the bracelet component on the hand and feel the direction indication with real-time vibrations.

Track producers create routes in-advanced on their mobile phone. The application allows customizing an existing route, or alternatively producing a new route from starting point to destination. Producers can search for existing tracks in the repository for aggregation purpose, produce an automatic generator path and control the produced route. Moreover, producers can automatically view the map according to current location and evaluate the produced information.

Following the above, it can be understood that the system is divided to two processes, one for information consumer and the other for information producer. Hence, the system architecture is divided into two phases of the life cycle: predefined activities and real-time activities. Figure 1 displays system overview, focusing on predefined activities. Figure 2 focuses on real-time navigation during activity.

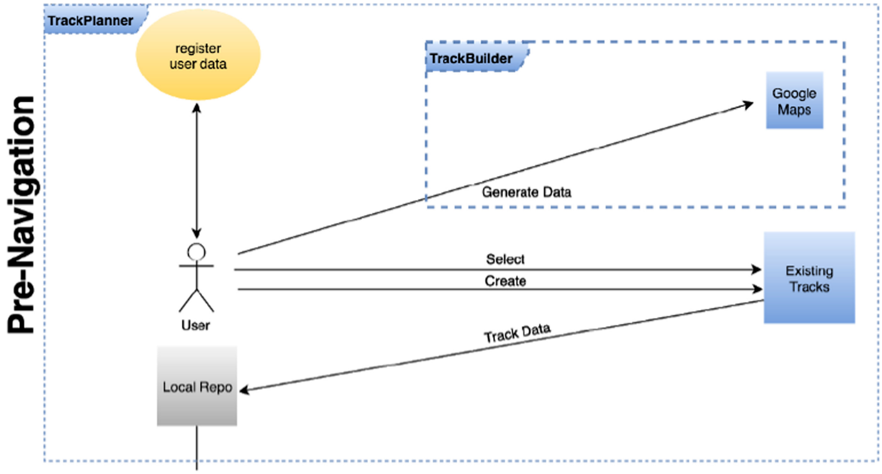

Fig. 1. System overview: predefined activities

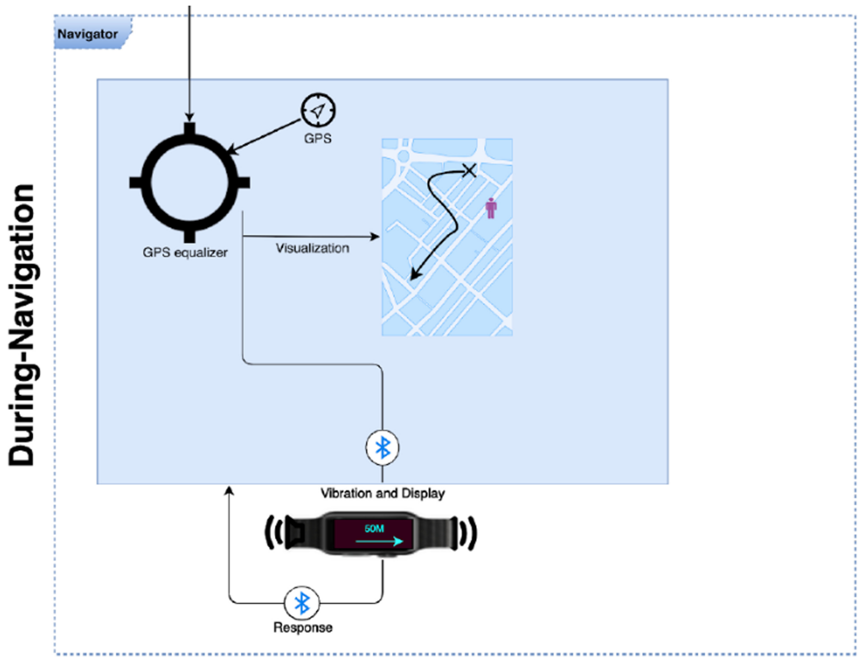

Fig. 2. System overview: real-time navigation

Figure 3 describes roles, data and activities in the integrated solution, separated to pre navigation and during navigation processes. In addition, Fig. 3 displays the various activities for the main roles: track producer and track consumer. The platform uses Maps

API'S combined with Bluetooth technology, GPS location, and the available activities for users when in-advanced planning and during navigating a route.

Fig. 3. Roles, data and activities

4 The Vibration Language

The study involved two steps before developing the vibrational language. The first phase included a preliminary pilot to assess the feasibility and efficiency of the language. We conducted the second phase after the development of a prototype. The purpose of the second experiment was to examine the solution before full development.

4.1 Participants and Experiments

The first pilot involved 25 participants, randomly selected on the street. We chose a partially crowded street in a central city in the country. Participants were of ages 20 to 40 and were informed in-advanced about the purpose of the study. Following the preliminary pilot, we came to the realization that a vibration language using signals on one side of the bracelet is not attractive nor effective.

Thus, in the second stage, we enlarged routes indications by signaling on two sides of the bracelets and by adding a small screen with additional information. We developed a friendly and easy to remember language for the navigation signals.

After an initial development and with the first prototype of the product, we approached 15 random people on the street. We invited them to use the product and experience the live navigation. Following their responses, we concluded results: 12 people out of 15 expressed interest in using the bracelet for safe navigation (three people expressed no interest).

4.2 The Language

Table 1 describes the vibration language. The number of vibrations reflects the distance-as closer the rider gets to the turn, the more vibrations accrue. For example, twenty meters before a turn, the bracelet vibrates once. Five meters before the turn, the bracelet vibrates twice. When the rider reaches the turn, the bracelet vibrate three times. This behavior is similar to the phone ringing behavior. At first it is weak and over time the sound becomes stronger. Alarm clock also starts with a weak sound and over time increases. When driving back in the car, the beep sound of the alarm device increases as the car approaches the object behind the vehicle. In translation to the vibrations language, as the turn approaches, the vibrations increase.

Table 1. Vibration language.

Trigger	Vibration on the left	Vibration on the right
0 meters before turn (left / right)	3 vibrations	3 vibrations
5 meters before turn (left / right)	2 vibrations	2 vibrations
20 meters before turn	1 vibration	1 vibration
Continue straight	3 short left and right vibes	
Beginning / End Navigation	One long left and right vibration	

5 System Overview

This section details the development environment and programming languages. On the client side, the system is developed using JavaScript (JS) React library, which uses Virtual DOM for faster updates. Moreover, React supports data binding technique that enables synchronization between the properties of two separated objects and thus facilitates the transfer of information to the bracelet in real time. In addition, LookUp uses external APIs such as Google Maps API and Google Directions API.

On the server side, the system is developed using Node.js, which interprets JS written in C++ and based on a V8 engine, runs on a Chrome browser. LookUp implements modern RESTful architecture on the server side, which is suited to the needs of the system and server side technology.

The bracelet is based on Arduino C using built-in i2c display libraries. The Bluetooth component through which the communication is made is HC-08, which supports version 4.0 to match the support with an Internet browser. The interface is performed by setting up a serial port to connect, receive and process data received therein.

5.1 In-Advanced Planning Routes on Mobile Phones

Figure 4 displays planning in advanced route in a mobile phone device. In specific, it displays Custom generate track page in the planning process. The interface is responsive for tables and desktop devices.

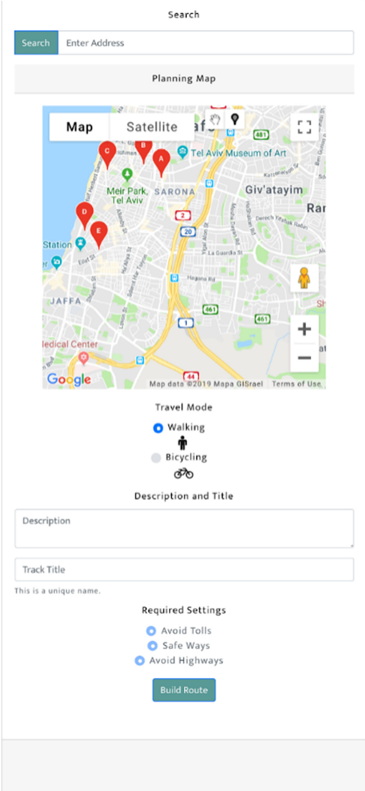

Fig. 4. Planning route in-advanced

Once the track producer generates a route, the system is ready for the track consumer for real-time navigation.

The next section details activities available during navigation.

5.2 The Bracelet for Real-Time Navigation

This section describes the embedded part of the integrated solution. The bracelet is aware of user location and context, therefore it vibrates based on route and dynamic environment.

LookUP was first developed on an Arduino UNO. After fully developing its software and prototype hardware, the goal was to minimize the solution. Figure 5 displays the initial prototype, which was not suitable to be a wearable device due to its large size. The second phase included adjustments and performance evaluations in order to create a wearable fully working component. Eventually, the final product's minimized and optimized schema is presented in Fig. 6. It is based on an Arduino pro mini microprocessor, Bluetooth component HC-08 in order to support BLE v4.0 (which is necessary for Web BLE support). Equipped with an OLED 0.96 Inch screen for visual indications, two vibration motors and a 3.7 V lithium battery which provides eight hours of continuous work.

For the purpose of inclusive design support, the bracelet fits a variety of users with different body figures. Its tough plastic casing emphasis the vibrations in order for the user to identify the vibrations language. The bracelet's rubber customizable bands are adjustable and exchangeable in order to provide the user with the comfort needed while navigating. Figure 7 displays the smart bracelet, in its final look. Figure 8 is a live camera frame, taken when tested the final version of the system. A teenager is riding the kick scooter wearing the smart bracelet and navigating in real time on the road.

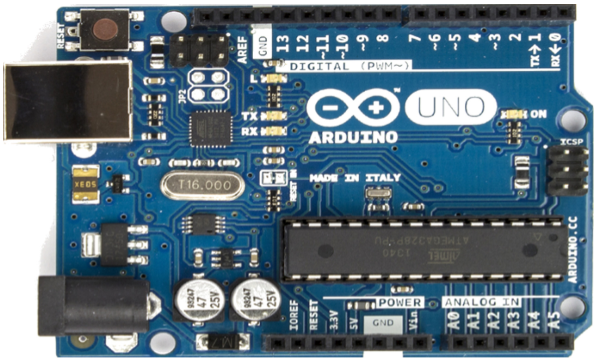

Fig. 5. The initial prototype

The next section elaborates on the synchronization between the mobile and bracelet, and their connectivity to the cloud.

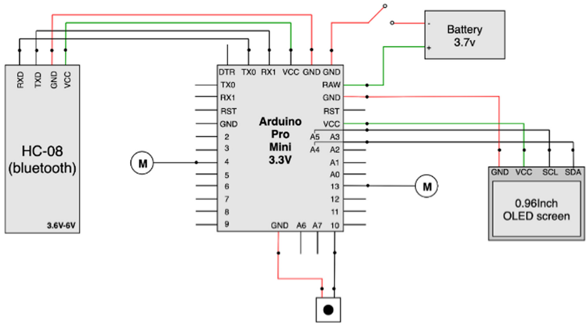

Fig. 6. Smart bracelet - electrical scheme

Fig. 7. The final smart bracelet

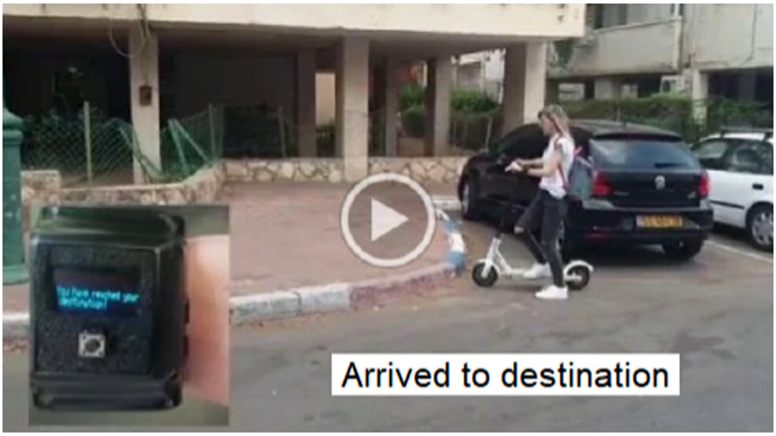

Fig. 8. Real time alerts

5.3 Synchronization Between Mobile, Cloud and Bracelet

Synchronization between the mobile phone, the cloud for saving and analyzing data; and the smart bracelet is critical for real-time data and navigation decision making.

The interactions between core modules and components includes: Track Planner module, Track Builder module and Navigation controller. Track Planner handles interaction with the user, synchronizes user preferences with Google Maps API and handles data retrieval from the database. The Navigation controller manages the navigation process. It communicates requests from Track Planner and forwards requests to Track Builder. In addition, the Navigation controller sends route details and directions to the embedded bracelet. The Track Builder interacts with Google Directions API and creates new tracks requested by Track Planner (Fig. 9).

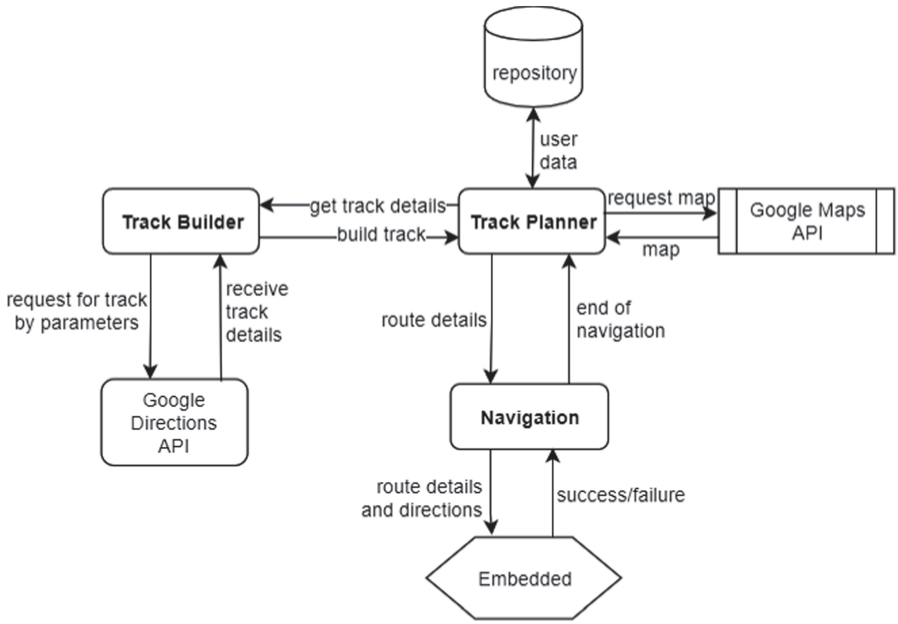

Fig. 9. Interaction between core modules

In summary, the system is divided into several key parts, each of which plays a significance role in the LookUp system, enabling reducing network traffic loads to maintain real-time information transfer.

6 Limitations

In order to create a custom itinerary, it is necessary to design a route as a separated layer on the map. In addition, access to the Internet is required in order to send requests and receive responses from the cloud and the mobile phone. In addition, it is required to keep continuous Bluetooth connectivity from the mobile device to a component throughout the navigation path. A non-functional requirement is the need to immediately generate vibrations and keep synchronization with the navigation path. Therefore, minimum latency as possible is required. In order to activate the system, the user must have a mobile device that allows the use of location data using a built-in GPS antenna. Moreover, the user must have a mobile device that supports Bluetooth version 4.2 or higher.

7 Discussion and Conclusion

With the aim of finding if the use of IoT improves safely navigation for kick scooters, this study defined major nonfunctional and functional requirements, validated the process of design and implementation and eventually presents a context-aware and location-based solution combines an embedded smart bracelet and a mobile phone. Moreover, the comprehensive product provides a ubiquitous application, which gives kick scooters the ability to safely navigate by reducing distractions.

The main nonfunctional requirements were fully implemented and evaluated: (1) the solution was designed as a smart wearable product; (2) it was designed as a smart wearable product; (3) the solution was designed as a context-awareness application; (4) The solution was designed for inclusion. In addition, the core functional requirement was to allow the user to produce information in advanced and consume it in real-time.

Attention to external disturbances was minimized during navigation. In addition, attention was maximized to the consumed route. This was achieved by (1) providing guidance while navigating by vibration feedback on a smart bracelet; (2) creating a vibration language and evaluated it in real-time; (3) allowing users to produce and share navigation routes in advanced on their mobile phone, or consume existing routes in real time.

Aiming to offer a safe navigation alternative, while keeping inclusive design rules, required examination of two key issues during the process. The first issue is the vibration language. For this purpose, we conducted two experiments. The conclusion from the analysis of the results is that signaling only on one side does not allow defining a rich language for real-time navigation. The second issue refers to the technical alternatives. After examining related location-based solutions, and examining context-awareness applications, the conclusion was to combine the two methods: location-based and context-awareness, into an integrative solution using a smart bracelet with a smartphone. Data transfers between the two devices, stored in the cloud, and analyzes for learning and improvement. In addition, enhancing the application with options to pre produce routes, save favorites routes, enable both automatic and custom creation of routes, enriches the solution for the consumers in real-time situation.

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