A Mobile-based Navigation Web Application: Finding the Shortest-time Path based on Factor Analysis

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Abstract

With the economic growth, the number of motor vehicles has increased rapidly for the last decades, especially in developing countries like China and India. Availability of more vehicles makes it more convenient for people to travel and merchandise transport. The increase of the number of vehicles also brings stresses to public traffic and pollution to the environment. When the number of vehicles on the road is over the available space, it results in traffic congestion. The problem is being studied and there are several solutions to it, like building more roads, rebuilding the existing streets and enlarging the cities. Based on the traffic reason and the environment reason, the government and the institute of environmental protection appeal to the public to take public transport means instead of private cars. But the measure affects the utilization of motor vehicles.

Global Positioning System (GPS) provides autonomous geo-spatial positioning and navigation service. Once the user enters the destination, the navigation service will show the shortest path from the location of the user to the destination. Following the guide makes the vehicles running purposively, and it is also favorable for traffic control and management.

Theoretically, if the diver keeps the same driving mode, the shortest path will cost the shortest time, but in reality, the traffic environment is complex and the driving speed is variable thus the shortest path is probably not the fastest path. In this study, the hinder factors of the speed and traffic are fixed constructions on the road, like: turnings, hospitals, schools, residential areas, traffic lights and the user-controlled factor (sites of traffic jams, accidents, and temporary construction on the road). We take the hinder factors of traffic and driving speed into consideration while providing the route plan, finding the shortest-time path, and showing the result as an online map via the web Geographic Information System (GIS) application. We show that reducing the travelling time of motor vehicles, makes the traffic flow more rapid and efficient. Also reducing the emission time of motor vehicles, diminishes the greenhouse effect.

Beside these, the achievement of our study also shows that the public can take advantage of open source tools and data to build their GIS application to do spatial and data analysis.

Keywords: Traffic congestion, hinder factors, shortest-time path, web GIS, mobile GPS, navigation, open source GIS, volunteered geographic information
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1 Introduction

Motor vehicles, as a kind of modern transport means, with the advantages of high speed and convenience, are important to people’s daily travel. Activities like going out, travelling to work, shopping, and visiting friends and relatives are often done by using motor vehicles. With the development of economics and technology, the number of motor vehicles has increased rapidly in the past decades. Davis, et al (2011) showed that from 1990 to 2009 in selected countries, the average annual percentage change of the number of cars is 2.3%, for trucks and buses the average annual percentage change is 3.9%, and the growth is still proceeding. Availability of more vehicles makes it more convenient for people to travel and merchandise transport. The increase of the number of vehicles also brings stresses to public traffic and pollution to the environment.

A view from Federal Highway Administration of U.S. (2011) says that “congestion is caused when there are more vehicles than available space on the road”, so more and more motor vehicles running on the roads will be easy to cause traffic problems. The traffic problems can affect the advantages of motor vehicles, increase the time of people’s travel from one place to the destination, delay the route, and increase vehicle emissions and noise pollution.

In reality, road traffic congestion, see Figure 1, is the result of – and in turn affects the - dynamic behavior of and interactions between many road users (Verhoef & Rouwendal, 2004). Taylor (1992) stated that “traffic congestion is the phenomenon of increased disruption of traffic movement on an element of the transport system, observed in terms of delays and queuing, that is generated by the interactions amongst the flow units in a traffic stream or in intersecting traffic streams”.

Traffic congestion almost happens all over the world in every day, especially in big cities. The reasons which cause traffic congestion are various, like traffic accident and atrocious weather (for example, heavy rains and snows). Arnott and Inci (2006) stated that the stock of cars cruising for parking can also increase traffic congestion. The view from Federal Highway Administration of U.S. (2011) that “congestion is caused when there are more vehicles than available space on the road” is widely accepted by the world. In many countries, the government and the institute of environmental protection advocate people to take public transport means, like bus and metro, instead of personal cars to reduce the number of motor vehicles on the road. Besides this, there are other solutions for traffic problems in different countries, like widening the streets, rebuilding the existing roads, building more new roads, and enlarging the area of city. Properly priced on-street parking can greatly reduce traffic congestion (Arnott, et al, 2005).
The researches about how to solve traffic problems can somehow make traffic flow more efficient, but one of the presumable results of following these measures is to affect the utilization of motor vehicles or increase the cost of using motor vehicles. Although traffic congestion brings several problems to people’s daily life and hinders people’s travel, to a lot of people, it is still necessary and important to travel by taking motor vehicles. In this condition, we try to provide other solutions to the traffic problems, by providing a shortest-time route plan to make the traffic flow more time-efficient. By taking the shortest-time path, it will increase traffic control and management, make the motor vehicles running more rapidly and efficiently.

1.1 The shortest-time path

In general, the shortest-time path, as the name implies, is the path which costs the shortest time of all possible paths from one place to another. In order to figure out such path, the time cost of each path should be able to be measured or calculated. However, in reality, the time cost of a journey not only depends on the fixed length of the roads which the driver chooses, but also depends on the complex traffic condition and the variable driving speed, so in reality, the shortest path is probably not the shortest-time path.

The hinder factors of traffic are various, like the amount of vehicles, the number of pedestrians, weather condition and the road condition (width, pavement condition, gradient and visibility). The driving speed is also impacted by many factors, such as vehicle type, driver’s choice, traffic condition, weather and so on. Although there are methods to calculate the driving speed, like it is studied by Zhao (2010), but in reality, it is impossible to measure the speed of all vehicles on the roads, therefore, the time cost
of motor vehicles’ travel is impossible to estimate without measuring it individually.

According to law, while drivers are driving on the road, it should be speeding down when they drive across hospitals, schools and the pedestrian crossings, and motor vehicles must stop if the traffic lights turn to red. Based on this, the authors take fixed constructions, which are close to the roadside and where the divers must speed down (like hospitals, schools, residential areas and traffic lights) as the hinder factors of driving speed. The combination of those factors with the distance of each path will normalize the time cost of each route plan and thus present the most time efficient choice.

Providing the shortest-time route plan to the drivers, to make sure the motor vehicles running highly efficient is also our solution to traffic congestion. Taking the shortest-time route plan will also reduce the emission time of motor vehicles to diminish the greenhouse effect.

Our study provides a new method to this field. There is no similar work, nor the method to calculate the time cost with given factors as mentioned above. What is more, according to the process of our study, it also shows how the public take advantage of open source tools and data to build their Geographic Information System (GIS) application.

1.2 Web GIS and VGI

GIS as in Figure 2 is an efficient tool to do spatial analysis and data analysis. It has been extensively applied to traffic control and management. There are several kinds of GIS software that can deal with traffic analysis, such as ArcGIS, but the software is not easy to use by the public, part of reasons are that the users must have GIS background knowledge and skills to take advantage of the software, what is more, the users must pay for getting access to the software. So it is difficult for general public to achieve their personal traffic analyses scientifically.

![Figure 2: Components of GIS](image)
With the development of Internet technology, the web is easy to get access and be widely used all over the world. Web GIS, as the combination of Web and GIS, has grown into a rapidly developing discipline since its inception in 1993 (Fu & Sun, 2010). More and more GIS applications are achieved based on web, and some of them are utilized almost every day, such as Google Maps and Bing Maps. Unlike professional software, these Internet sites are easily accessible by the public. These web-based services provide a large amount of online map information and simple query interface to the public. Another advantage is that these internet sites are free of charge. Web GIS has considerably changed the way geospatial information is acquired, transmitted, published, shared, and visualized (Fu & Sun, 2010).

Volunteered Geographic Information (VGI) (Goodchild, 2007), is another very important form of web GIS these days. VGI is contributed by numerous volunteers by web 2.0 technologies. The characteristics of VGI can be described as follows:

1. Everyone can contribute geographic data to OSM.
2. Everyone can edit (fix) the geographic data errors of anyone.
3. The geographic data must be machine-readable, and it would better to be human-readable, but not required.
4. The most important, everyone can get access to these geographic data freely.

Therefore, the quality of VGI totally depends on the volunteers. More the volunteers get involved, better the quality of the data will get. With these geographic data, some geographic-related studies or applications become possible. For example, emergency route service for Haiti (Neis, et al. 2001), scaling of geographic space analysis (Jiang & Liu, 2012), or just an application like MapBox (2012), a commercial web application that helps you build your own map with user-defined style. All of them are based on OpenStreetMap (OSM), a representative of VGI. Later in the paper, we will give it more detailed introduction.

1.3 Mobile GPS

With the development of Global Navigation Satellite System (GNSS) as in Figure 3, there are several kinds of on-vehicle mobile Global Positioning System (GPS) equipments as which can provide autonomous geo-spatial positioning and navigation service. With the help of navigation service of on-vehicle GNSS, once the users enter the destination of their travel, the system will provide the shortest paths from the users’ current location to their destination. This makes the flow of vehicles more rapid and efficient.
Because of the advantages of mobile GPS and web GIS, both of them are useful tools for people’s daily life, and there already exists research about how to integrate GPS and GIS for traffic congestion studies (Taylor, et al, 2000). In our future web application, we will utilize GPS as technical support of Location Based Service, which is also one of main functions and advantages of our application.

1.4 The aim of our study

To people who are not familiar to the driving environment, and want to reach their destinations in the shortest time without special habits, it is necessary to provide a route plan which will cost the fewest time. Theoretically, if the diver keeps the same driving mode, the shortest path will cost the shortest time. In practice, regarding to the traffic environment, it is hard to keep the vehicles running at constant speed, the speed will be impacted by a lot of traffic factors and anthropogenic factors like the numbers of pedestrians and motor vehicles on the roads, speed limits, traffic lights, turnings and so on. The route plan provided by the on-vehicle GPS sometimes is not the most time efficient plan.

By taking advantages of mobile GNSS and web GIS as background knowledge and technology, and using open source data and tools, the purpose of our study is to combine web GIS and mobile phone with GPS module (which also must be able to connect to internet), to design and develop a web-based application which can provide
intelligent vehicle navigation service as in Figure 4.

Figure 4: Mobile-based navigation web application

Via the web application, the users should be able to upload the data of their location to the relative database, and based on the data, after the steps of processing, make a traffic analysis. Then combining the length of the path and the traffic condition, by avoiding the factors which will affect the driving speed, provide route planning which will cost fewest time.

In our study, the fixed factors which will impact the speed of motor vehicles are: turnings, schools, hospitals, traffic lights, and residential area. We set different weights to different factors. Besides factors mentioned above, we also set a user-controlled factor, which stands by the sites of traffic jams, accidents, and temporary construction on the road. This factor is controlled by the users. Users can upload the position of such site, so the road close to the site will not be taken into consideration while providing the optimal route plan to other users.

By the achievement of our study, it also shows that people can use open source to do their GIS analysis.
1.5 Delimitation of this work

Our application will be suited for the traffic condition in big cities for whole day of the year except holidays. The reasons are shown as below:

- The traffic environmental reason: in the application, the factors which hinder the traffic are: schools, hospitals, turnings, traffic lights, residential areas and user-controlled factor (sites of traffic jams, accidents, and temporary construction on the road). Compared with small city, there are more schools, hospitals, streets and pedestrian in big city, and the traffic environment in big city is more complex than small city.

- the time reason: regardless of the time difference of a day (work time or non-work time, rush hour or non-rush hour, and day time or night time), this application works for whole day. But there are a lot of festivals or special days in a year, like New Year’s Day and National Day, in such days, the streets are overcrowded and the flow of traffic is affected by excessive pedestrian. In such special conditions, our application is unable to work correctly or efficiently.

So, only in non-festival days in big cities, the impact of the factors in our application will be more obvious.

The audiences of our application are persons that are not familiar to the traffic environment, have no special driving habit, and want to reach their destination in the shortest time.

1.6 Research Questions

By doing the study, we try to find the answers to these questions:

1. Is it possible to use open source to build a web application to do GIS analysis?
2. Is it possible to provide a more time efficient route plan by using the web application?
3. Can the application be used for other researches or analyses?
2 Current Trends in Shortest-path Calculation and Application

In this part, there is an introduction to the background knowledge presented. Techniques, tools and relative research, which are also useful and helpful to our study, will be discussed.

2.1 Smart mobile equipment

Since the invention of the Internet, many information tools and systems have been changed dramatically. More and more people are not restricted in front of personal computers. With the development of mobile technology, smart mobile equipment (like smart phones) becomes not only people’s daily used tools, but also the lifestyle. A smart mobile equipment is possible be able to do almost everything that a personal computer can do from a common user perspective. In addition, mobile phones are provided with flexibility, portability and instantaneity.

2.2 Location Based Services (LBSs)

“Location Based Services are information services accessible with mobile devices through the mobile network and utilizing the ability to make use of the location of the mobile device” (Virrantaus, et al. 2001). The idea of LBSs in our application is by using mobile GPS to upload the location of the motor vehicle, and then the application is able to take this location as the position of start point of the travel, base on the location of start point to provide the route plan to the destination, where should be possible to be clicked on the online map or searched via the application.

2.3 Shortest path problem

The shortest path is the path with the minimized weight between a pair of nodes in a graph. As shown in Figure 5, each letter represents a node, and each line represents an edge, the number on each edge is the length of that edge. Comparing the length of each route, in this model, the shortest path from node $A$ to node $B$ is $A-d-e-B$ (as it is marked by the red dotted line).
As the result of years’ of studies, there are many solutions developed for such kind of problems. One of the most notable solutions is the classic Dijkstra algorithm introduced by Dijkstra (1959). Based on the native Dijkstra algorithm, there have been many studies developed that make it faster or meet some specified requirements. As a result of the study, an improved Dijkstra algorithm, the Dijkstra algorithm with double buckets, has been regarded as the best algorithm in natural road networks (Zhan & Noon, 1998).

Besides the shortest path problem, many research efforts have resulted in a number of algorithms in a specified way. For example, Duckham and Kulik (2003) based on the solutions to the shortest path problems, provided the algorithm to find a “simplest” path through a network for automated navigation systems; Wu, et al(2011) introduced the algorithm for computing the shortest safe path between two nodes over a large time-dependent transportation networks in special applications; Jiang and Liu(2011) developed an algorithm about computing the fewest-turn map directions or routes based on the connectivity of natural roads. In our study, we solve another shortest path problem - the shortest time path problem- instead of the shortest distance path.
2.4 Web application

Internet is a changing society. With the rapid growth of the number of Internet users all over the world, World Wide Web (WWW), as the major carrier of information on the Internet. It is becoming a part of people’s daily life. The web technology keeps changing day and night.

Over recent years, there has been an explosion of web mapping applications as well, and typical ones are ESRI (which provides a full web GIS platform), Bing maps, and Google Earth (which seems to be more known to the public). Through web browsers, all users can implement most operations of a normal GIS, such as capturing, presenting, managing or even analyzing geographical information data. However, the disadvantages of those commercial GIS solutions are obvious: they are neither free nor open-source. For some small business companies or the GIS students who devote themselves to open source, OpenGIS is probably a better solution. OpenGIS is an open platform based on a series of open standards in terms of GIS, which are developed and maintained by the Open Geospatial Consortium, Inc. (OGC). In truth, according to registered products list, there have been a number of OpenGIS solutions that have been serving for years. A typical traditional OpenGIS architecture is composed of PostgreSQL (2011) as database back-end, MapServer (2011) or GeoServer (2011) as web server, WFS/WMS as communication data specifications. As an example, Finnish Geodetic Institute uses this classic combination to create a regional distributed GIS network.

In our application, we also use PostgreSQL as database back-end, because it is open source and free for using. With the PostGIS extension, PostgreSQL is able to deal with spatial analysis. OpenLayers is adopted as a browser side map client. OpenLayers is a popular open source map client that is written in JavaScript language. It is easy to use: the users can get started only from a few configurations which are written in the Hypertext Markup Language (HTML) of the display page, or extend more features by using its Application Interface (API). It supports a number of geographical data formats such as Geography Makeup Language (GML), GeoJSON (2011), Scalable Vector Graphics (SVG) and so on. What is more, it has a native support for the OpenStreetMap (2011) service, for example, directly displaying map from OpenStreetMap without writing any new code.

GeoJSON is a data format that is able to encode a variety of geographic data structures. It is based on JSON (JavaScript Object Notation), which is very popular lightweight data-interchange format. Since both PostGIS and OpenLayers provide the support for GeoJSON, so our application uses it to store geographical data and communicate information between the server and the client.
3 Materials and Methods

In this part, the authors show how the data was collected and processed. The algorithm, the structure of the application, and how we designed and developed the application is explained in this section.

3.1 Data and data processing

In this application, all data was downloaded from OpenStreetMap (OSM). We used OSM as our study data source and presentation layer. As an open web mapping service, OSM provides its data in the form of “osm” file. An “osm” is an Extensible Markup Language (XML) variant document, which contains all spatial data and attributes data. However, since the XML only rules these data and it doesn’t provide any operations on these data itself, we need to convert these XML data into the spatial database, which provides some spatial operations such as distance calculation, spatial relation determination and so on. These operations are significant to the algorithm of finding the shortest time path.

The data preparation can be described in the following steps:

1. Import “osm” file into the database.
2. Find all highways and store them into the table “highways”.
3. Determine the highway intersections (i.e. crossroads) and store them into the table “vertexes”.
4. Determine the highway edges and store them into the table “edges” based on vertexes.
5. Calculate the total weights of each edge and store them into the weight column of the edge table.

After the data is pre-processed, the vertexes and the edges should have the relation as shown in Figure 6. In order to view the relation in clearer version, we take a portion of the OSM map as an example as in Figure 7. Crossroads are stored as nodes (white circles) and roads are stored as edges (black lines) in the database. This data model is important because it will be used as the basic data structure in the shortest path algorithm.
Figure 6: Relations of the data

Figure 7: Data relations on the OSM map
3.2 Algorithm for computing the time costs

In our study, we adopted Dijkstra as our shortest path algorithm. This algorithm starts from source node and search the road network until the destination node is found. In the algorithm procedure the weight of each edge (usually a nonnegative value) will be taken into consideration to compare which route to current node is the shortest. If the destination node is found, the searched path will be considered as the shortest weight time path.

3.2.1 The weight of fixed hinder factors

In our study, the fixed hinder factors of the speed are: turnings, hospitals, schools, residential areas and traffic lights. As mentioned in the introduction part, according to the law, the drivers should speed down when they drive across turnings, hospitals, schools and residential areas, and the motor vehicles must be stopped if the traffic lights turn to red. The reason is there are more pedestrians in such places, so the traffic in such places heavier. Based on the influence relations of each criterion on each factor, see Table 1, we set the weight of each hinder factor as shown in Table 2.

Table 1: Impact relations between criteria and hinder factors

<table>
<thead>
<tr>
<th>Factor Criteria</th>
<th>Turning</th>
<th>Hospital</th>
<th>School</th>
<th>Resident Area</th>
<th>Traffic light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Law</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Non-rush hours</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Driver choice</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Holiday</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Season</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Weather</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
</tbody>
</table>

We explain the choice of weights from Table 1 as follows: if the criteria (law, non-rush hours, driver choice and holiday) or the difference of the criteria (season and weather) impact the effect of each factor to traffic and driving speed, it is marked with cross symbol in the table.

- Law: the drivers should speed down when they drive across turnings, hospitals, schools and residential areas, and the motor vehicles must stop if the traffic lights turn to red.
- Non-rush hours: the pedestrians near schools are less than that in rush hours.
- Driver choice: the drivers trend to drive faster if there is neither traffic stress nor psychological effect (Quimby, et al, 1999).
- Holiday: the schools are closed during holidays, so the pedestrians are less.
- Season: there are different seasons, in falling-leaves season, the leaves cover the ground and the government priors to clean the fallen leaves on main roads.
However, in residential areas, the pavement condition is worse, and the driving speed is affected by the road condition.

- Weather: the driving speed in bad weather condition (like snow, rain and fog) is lower than in good weather condition.

Based on the impact relations table and the description above, for the fixed hinder factors, we assumed that if a hinder factor is easier to be impacted by the criteria, the weight of the factor is less. The weight of each hinder factor was shown in Table 2.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Turning</th>
<th>Hospital</th>
<th>School</th>
<th>Residential area</th>
<th>Traffic light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.15</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### 3.2.2 Calculation of the shortest-time path

As mentioned in the introduction part, because of the complex traffic environment and the varying driving speed, the shortest path is probably not the shortest-time path. In our study, we introduced a new method to evaluate the time cost of a route plan. By combining the distance of the path between two places and the hinder factors to the traffic on that path, to normalize the time cost into a time coefficient. The route with the smallest time coefficient is the shortest time path.

In the application, we set the start point of the route plan as point $A$, the end point as point $B$, and the arc length of each edge of the route plan is $d$. The fixed hinder factors are: turnings, hospitals, schools, traffic lights and residential areas. The formula of calculating the coefficient is shown as following.

In our case, the coefficient of the time cost is assigned according to the Equation (1) to (3) shown as below:

$$ T = \sum c \hspace{1cm} (1) $$

$$ c = d + d \cdot w \hspace{1cm} (2) $$

$$ w = \sum w_i \hspace{1cm} (3) $$

Where,

- $T$ is the time coefficient of the time cost of the route.
- $c$ is the time coefficient of each edge of the route.
- $d$ is the arc length of each edge between $A$ and $B$.
- $w_i$ is the weight of each hinder factor that we discussed in our study.
- $w$ is the total weight of each edge of the route plan.

Based on the equations, here is a simple model to explain how to compute the shortest time path. Assuming a motor vehicle will start from source node $A$ to the destination node $B$, and the driving speed will keep fixed. We figured out that there are
two driving routes from A to B, denoted as route 1 and route2 respectively. In this simple case, there are only two hinder factors, traffic light and hospital, and the weight of traffic light is greater than the weight of hospitals ($w_{tl} > w_{h}$). There are 4 situations, which are illustrated with examples as in Figure 8 as follows:

Figure 8: Example cases for the equation

(1) If the lengths of both routes are equal ($d_{route1} = d_{route2}$), and their factor weights are equal ($w_{route1} = w_{route2}$), according to the calculation, $T_{route1} = T_{route2}$, then both routes are the shortest-time path.

(2) If $d_{route1} = d_{route2}$, $w_{route1} ≠ w_{route2}$, because $w_{tl} > w_{h}$, so $T_{route1} > T_{route2}$, then route 2 is the shortest-time path.

(3) If $d_{route1} < d_{route2}$, $w_{route1} = w_{route2}$, according to calculation $T_{route1} < T_{route2}$.

Then route 1 is the shortest-time path.

(4) If $d_{route1} < d_{route2}$, $w_{route1} ≠ w_{route2}$, then the route with the less time weight (i.e. $T$), calculated by the general formula (1), (2) and (3), is the shortest-time path.
3.2.3 User-controlled factor

In our study, besides the fixed hider factors mentioned above, we introduced a user-controlled factor, which stood for the sites of traffic jams, accidents, and temporary construction on the road. This factor is controlled by the users. Users can upload the position of such site, and mark it on the layer map, so the road close to such site will not be taken into consideration.

To ensure the reliability of the data uploaded by the users, we designed a vote system. Once a user uploads such data, the application will pop up a vote dialog (as in Figure 9) to other users who upload their location nearby. The vote dialog will ask whether the traffic jam, accident or temporary construction exist or not. The users can choose “YES” (exist), “NO” (non-exist) or “CANCLE” (giving up voting).

![Vote dialog for traffic jam](image)

*Figure 9: Vote dialog for traffic jam*

Only if there are more than 5 votes and the percentage of “YES” is over 50%, the application will not suggest the road with such user-controlled factor in the route plan to other users.

The factor is valid for 30 minutes, that means if there is no vote for “YES” within 30 minutes, or the percentage of votes for “NO” is over 50%, then the mark of the factor will be canceled from the map, and the roads will be suggested to other route plan again.
3.3 Application development

In order to implement the idea we discussed above, we chose a number of open source software and technologies to construct the application. The application consists of 3 components: the database, the web server and the client. In Figure 10, we show how these components cooperate.

![Diagram showing components cooperation](image)

**Figure 10: How the components cooperate**

The software or technology we used for each component is described as follows:

- Database: PostgreSQL and PostGIS, as well as OSM data source.
- Web server: a simple Common Gateway Interface (CGI) script was written as our server application to process the request from the client side and return calculated route data back.
- Client: we utilized OpenLayers to display the map and interact with users in front of web browsers.

In addition, we used GeoJSON as the communication data format, which is supported by the server, the client and the database system.

Here we will illustrate what is happening in the background when users click or tap on the mobile phone screen:

1. The client side will send your current location (source point) and the clicked location (destination point) to the web server.
2. Once the web server receives such request, it finds the nearest roads of both points and inserts two pseudo-crossroads as in Figure 11, and marks them as the start node and end node respectively.
3. The algorithm described calculates the shortest time path between start node
and end node. This procedure will continuously ask the database to find the neighbors of each searched node.

4. If a shortest time path is found, the server will return the result, the path data in form of GeoJSON, back to the client, otherwise, return a readable error message.

5. The client renders the path data or alerts the error message in the response.

![Figure 11: Pseudo-vertexes (node A and node B)](image)

### 3.4 Interface design

Designing web application is different for mobile phones than for desktop computers. Although mobile phones have been developed rapidly in recent years, it is still hard to catch up the rapid development of web technology and desktop computers. Mobile phones are limited in the screen size and the system resources. In order to avoid these limitations, the interface design aims to be simple to view and easy to use, especially be friendly and convenient to mobile users as well as the drivers.

The functions of our application are as follows:

1. Get the current location.
2. Once setting the destination, both the shortest-time path and the shortest distance path between the current location and the destination are shown on the map.
3. Show the path and zoom to the current position.

In addition, other common browsing operations are supported as well. For the touch-screen input mobile equipment, the users can multi-touch the screen to zoom in
or zoom out, shake the equipment to update the current location and so on.

Due to the limits of the mobile screen size, the view of our web application must be simple to save space. There were only a few small buttons on the screen, like zoom in/zoom out, Search, Locate and Layers. Besides these, all the other space was left for the map, so that it enables to show as much map information as possible, see as Figure 12.

![Figure 12: Interface of the web application, based on OSM (2012)](image)

The operation of our application must be easy. Since people do not pay much attention on the screen of smart mobile equipment while they are driving, the application only needs the driver to input one parameter: the destination. Inputting the destination does not mean the user needs to remember the coordinates of the place. If the user knows where it is on the map, it is possible to just click or tap on that place; otherwise, the user can utilize the “search” function. By clicking the Search button, and entering the right address in the text area as in Figure 13, the destination is shown on the layer map.
The Location buttons used for get the current location, and once clicking on the Layer button, all feature layers contained in the application are shown in a list as in Figure 14. If the users do not want to show a layer on the map, or calculate the time coefficient without a given hinder, it can be unmarked on the layer list to achieve this.

Designing the interface in such way aims at meeting the requirement and implementing the function of our web application. Compared the interface of our application with other similar online maps, like Google map as in Figure 15, which is popular and widely used by the public, Google map provides more functionality and with more information on the map.
Figure 15: Main interface of Google maps (2012)
4 Results and Discussions

In this part, there are print-screens which show how the web application works as well as explanations to it.

4.1 Get the current location

Clicking on the button Locate, the current location was marked as a green "A" on the layer maps in Figure 16, and it was also the start point of the route plan.

![Figure 16: Current location, marked as a green "A", based on OSM (2012)](image)

4.2 Find the shortest path and shortest time path

With the help of search function, the destination as what the user entered in the text area (mentioned above in the interface design part). Both the shortest path (marked by red line) and the shortest-time path (marked by blue line) are shown on the map, as you may see in Figure 17. From the calculation results for both paths, the relative weights of the two route plans were shown in Table 3.
Figure 17: Route plans: shortest path (red) and shortest-time path (blue). Based on OSM (2012)

Table 3: Relative weights of the routes with all hinders

<table>
<thead>
<tr>
<th>Path</th>
<th>Total time coefficient</th>
<th>Total length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortest path</td>
<td>0.05295</td>
<td>0.04207</td>
</tr>
<tr>
<td>Shortest-time path</td>
<td>0.05098</td>
<td>0.04273</td>
</tr>
</tbody>
</table>

Compared the total length of the two routes, it is obvious that the length of the shortest path is less than the length of the shortest-time path, but after combining the weights of the hinder factors with the distance, the time coefficient of shortest-time path is smaller. In our study, we suggested the users took the shortest time path as the route plan.

The shortest-time path was the result of the combination of distance and hinders. If the hinders were changed, for example, we only take turnings, hospitals and traffic lights as hinder factors, the result of shortest time path was changed as in Figure 18, and the relative weights was shown in Table 4.
Table 4: Relative weights of the routes with hinders: turning, hospital and traffic lights

<table>
<thead>
<tr>
<th>Path</th>
<th>Total time coefficient</th>
<th>Total length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortest path</td>
<td>0.05179</td>
<td>0.04207</td>
</tr>
<tr>
<td>Shortest time path</td>
<td>0.05105</td>
<td>0.04273</td>
</tr>
</tbody>
</table>

As mentioned early in the algorithms part, $T$ is impacted by $d$ and $w$, regardless of $d$, $T$ grows as the increase of $w$. $d$ is the arc length of each edge between $A$ and $B$, actually, it is fixed, so the result of the shortest time plan is more affected by the weights of the fixed hinder factors. Because the weights is decided by the impact relations between the criteria and the hinder factors, if there are more or different criteria, the weights of each hinder factor are probably changed. For example, if we still take all the hinder factors in the study into calculation, but change the weights of the hinder factors to that were shown in table 5, the results of route plans was shown in Figure 19.

Table 5: Weights table for testing

<table>
<thead>
<tr>
<th>Factors</th>
<th>Turning</th>
<th>Hospital</th>
<th>School</th>
<th>Residential area</th>
<th>Traffic light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>
It is obvious that, once the weights of the hinder factors are changed, the result of shortest time path is also changed.

After we have done the development and the tests of our application, about the method, there are other approaches should be considered. As the number of hinder factors and the weight of each factor will affect the result, the way to decide the hinder factor and the weight of each factor should be more precise. In addition, because the tests were made in simulated environment, to test the application in reality by more users will help us to check the reliability of our results.
5 Conclusions and future perspectives

In this section, the three questions mentioned in the Introduction section will be answered. According to the process of building the application, we show that it is possible to use open source to build a web-based GIS application, which provides a more time efficient route plan, and the application can be also used by other researches and analyses. We present the reasons as follows.

1) Is it possible to use open source to build a web application to do GIS analysis?
   In our study, in order to achieve the goals, such as to make the traffic flow more time efficient, based on the techniques of web GIS and mobile GPS, we take the hinder factors of traffic flow and driving speed into consideration while providing the route plan, finding the shortest-time path, and showing the result as an online map. We implemented the studied ideas, and a mobile web application for the shortest-time path navigation was developed. The development of the application shows the way to use combinations of various open source GIS software to build a modern mobile GIS application.

2) Is it possible to provide a more time efficient route plan by using the web application?
   All the tests were made in the simulated environment. The interface was only tested under laptops, iPhone and iPad, and the compatibility with other mobile systems was not tested. We get the following conclusion from the tests shown in the result part: both the number of hinder factors and the weight of each hinder will affect the result of the shortest-time path.
   Although the hinder factors in our study show how they impact the travel of motor vehicles, and we provide a shortest-time path from one place to another, the real traffic is more complex than what we analyzed in our research. Besides the factors we discussed in our study, some other factors are also significant to the traffic and driving speed, but difficult to be implemented in the application. For example, the numbers of vehicles and pedestrians. Road traffic congestion in reality is the result of dynamic behavior of and interactions between many road users (Verhoef & Rouwendal, 2004). Actually, it is impossible to count exactly how many people and vehicles are on the roads, it is hard to collect the dynamic data, and it is difficult to put it as a factor into calculation, because the value is changing as time goes by. Weather condition is another important hinder factor to traffic, but the impact is hard to estimate before it happens. In reality, it is impossible to find out the real shortest-time path, we just introducing a new method to find the possible time efficient path according to factor considerations. If there are sufficient spatial data and statistics data, the researchers can choose more proper hinder factors and weight the factor in a more precise way, to make the result more reasonable.

3) Can the application be used for other researches or analyses?
In our study, all the hinder factors are fixed constructions, we provide the path with less hinders to the traffic and driving speed. The method may serve as a reference while doing urban planning. Careful planning of building roads close to those constructions (schools, hospitals, traffic lights and residential areas) will diminish the risk of traffic congestion. To the researchers and students of Geo-science and computer science, the method to implement the function of our application can be a reference when they do similar work and study. Besides this, as utilizing various techniques and tools in the application, like GIS, traffic analysis, web development and so on, our application will be useful to people who are interested in these techniques or tools.

The application works according to the description, but there are problems that should be solved in the further study. The algorithm needs to be improved in order to speed up the long response time. In the future, we hope we can maintain the application project regularly and improve the method, to make our study be usable to the public.
References


