A web-based spatial decision support system for effective monitoring and routing problem

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Abstract—**This paper presents an integrated framework of Geographic Information System (GIS) and a Relational Database Management System (RDBMS) equipped with interactive communication capabilities. The model integrates the design of the database and the management of implementation of the monitoring system which includes the operations of query and analysis using the web and desktop applications. This study aims to apply techniques of analysis of the road network in a GIS to collect geographic data on the monitoring station and the roads. The information on road infrastructure is not only useful for locating monitoring stations, but it is also important to guide a station to follow the shortest path to achieve the objectives of management and routing. Optimal routes based on the minimum cost are identified using Dijkstra's algorithm. The results show that it is possible to use an effective method of GIS to integrate multiple data sets and learn advanced information. The need for such a framework and requirements for the orientation of monitoring stations in the event of a road accident are studied and the architecture of this framework is discussed. The proposed system should be a tool comprehensible, well structured, efficient and scalable which facilitates the location of road accidents and the orientation of the monitoring stations in response to these accidents. Simulated test cases have been carried out for network of Mohammedia City in Morocco.**

Keywords: GIS; Location; Routing; Road network; Monitoring; Dijkstra's algorithm.

I. INTRODUCTION

During the last years, new information technologies have been proposed and proven to be valid and effective to solve real-life problems, such as monitoring of road accidents. Maps are basic tools used to present and analyze information on the spatial distribution of business sectors, resources, and people in need of services; they are also used for location. Woodbury (1996) noted that 85% of all computerized databases in the world have a location component, such as street address, a zip code, a census tract, or a legal description. GIS (Geographic Information System) technology is one of the hottest new research tools in the word today and one of the fastest growing high-tech of monitoring [1]. GIS can bring all that data together quickly and let users analyze and visualize information in an efficient way. GIS in service management: The GIS technology has been implemented in service management for displaying large volumes of diverse data pertinent to various local and regional planning activities [1]. Location and routing are technique commonly used in GIS for decision making. The development of an effective tool to support this kind of decisions take into consideration the presentation of the solution and the exploration of the process in a way easily understandable by the decision-maker, allowing better judgments. Architectures for information browsing, like the World Wide Web (www), are easy and powerful means to deploy databases through the Internet and thus represent obvious options for setting up services such as the one advocated in this work. The www is useful to provide access to central data storage, to collect remote data and to allow GIS and optimization software to interact [2].

Analysis of road networks is important in producing accurate and effective information on the roads, it is considered useful for decision makers to select the optimal routes easily by mathematical calculation of dynamic programming [3, 4]. Determine optimal route is a common research topic in the literature of transport [5]. In order to manage traffic conditions and provide accurate information for monitoring stations, many studies have emphasized the use of travel time and cost to find the shortest distance route. This study aims to implement and evaluate a methodology based on GIS to determine optimal routes of the road network using key information items based on cost of distance. For that reason, an integrated approach to location and routing, and an application that can support the decision, may represent an important competitive advantage. With this paper we will try to help and fill that gap, presenting a decision tool for monitoring stations. This approach saves time by locating the accident site and following the shortest path in real-time. Its rationale is based on the development of a distributed environment for the integration of software applications that share data and operations through a common database repository and which can support the manipulation and retrieval of data. This effort is chiefly based on careful definitions of data type objects and the construction of focused methods to manipulate them. The following paragraphs present data structures, the architecture of the framework followed by implementation, simulated test cases with Dijkstra's algorithm, and conclusion and future work of the framework.

II. ARCHITECTURE

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A. Geographic Information System (GIS)

Geography information systems have been improving since 1970s. GIS is an essential tool for location mapping, dynamic condition visualization, and decision making [6–8]. Geospatial data are useful in monitoring response to accidents. The analysis of real-time data could be achieved through GIS during the response phase to support visualization and automation for efficient decision making. Research has been conducted in GIS that focused on areas such as shortest path analysis [9, 10]. This shows the great potential of GIS applications to facilitate the possibility of having a response time shorter if the geospatial information is implemented in the initial phase of response to accidents.

B. Web service

Web service is a technology based on the Internet that is defined by the W3C as “A software systems designed to support interoperable Machine for Machine interaction over a network” [11].

C. Web GIS

Web GIS provided only the Client port used Browser and then the basic function of GIS, in such a way to reduce the cost of system. Browser is the best option because that can extensively use GIS, reduce the software cost, decrease the complicated operation and provide the simple and easy interface [12, 13].

D. System components

The web framework based on a three-tier architecture consisting of the client layer, middleware layer and the layer of the database (Figure 1). These components together provide a unified interface for consultation data, request and decision making for users, the database is accessed through the Internet, in such a way that the user does not need to be aware of the location of the database, it is sufficient that the user is able to consult, add modify the data as needed. The following sections discuss these components in more detail.

Application uses PostgreSQL as the database management system with the geospatial extension PostGIS. Additional to relational queries, PostGIS provides spatial queries to the users.

As the Internet has become an important resource for acquiring and disseminating information, a number of Internet GIS products have been brought to market, we used Mapserver and Cartoweb, Mapserver is used here just as library PhpMapScript, Cartoweb is a solution designed for the web, it allows its architecture CartoClient / CartoServer to answer several web service in the world of free Web Mapping. This solution thus far is the closest features of a traditional GIS while being adapted to the characteristics of the Internet. It fits easily with Apache and php5. Typically, there are two basic approaches to deploying this GIS application on the Internet: server-side and client-side [14]. Web-based GIS users can use a Web browser to navigate maps and to complete basic spatial analysis. In other words, for our Web-based GIS application, users enter specifications such as location or search requests on the Web page to set up their environment for mapping or searching. The requests from the user are sent to clients by way of HTML forms. The form is passed to the Web Server Apache and a gateway at the Web server passes the request to GIS server Cartoweb, then Cartoweb queries the database.

The described system is designed to support two types of users: the system administrator and the teleoperators. The system administrator must update the databases (user accounts and layers) and guarantee all the functionalities. All other data are entered, edited and deleted by the teleoperators through a distributed Graphical User Interface (GUI). Data collected and used by the system are of two different types: geographic and semantic. The geographic database contains the geographic map of the road network in the region of interest, monitoring stations and all the geographic information needed to generate an output GIS on the Web. The semantic data, maintained by a relational database, contains information about the accidents, breakdowns, the monitoring station and vehicles.

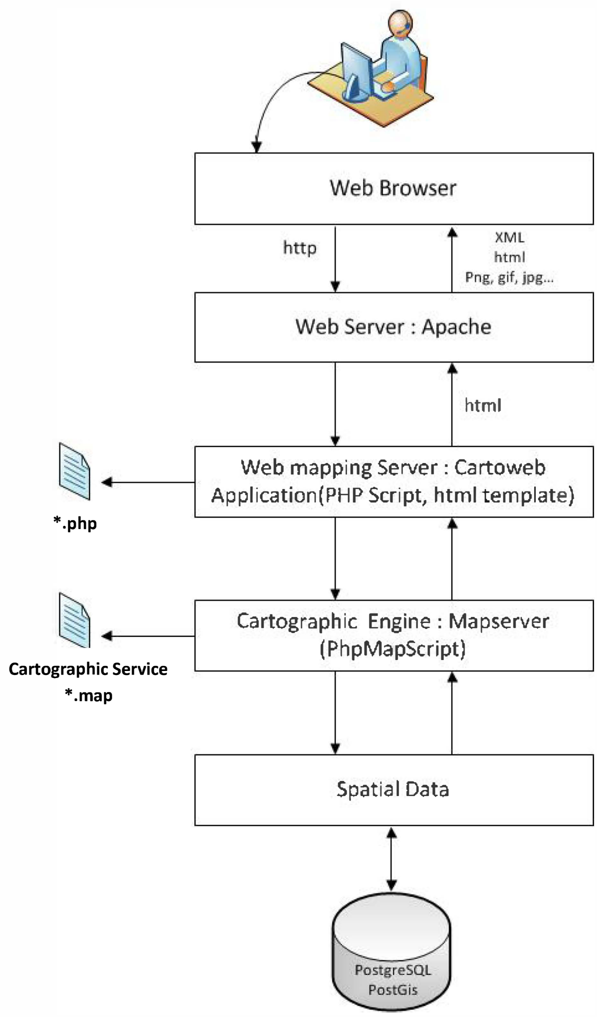

Figure 1. System architecture.

III. DATA STRUCTURES

A. Study Area

The city of Mohammedia is located at 24 km northeast of Casablanca which is the economic capital of the Kingdom of Morocco. It was chosen, as the study area, for the design and implementation of a monitoring system of road safety based on GIS.

B. GIS Layers

The Global Positioning System (GPS) is used to collect the values of longitude (X) and latitude (Y) identifying the geographic location of monitoring sites. The values of the GPS coordinates, expressed in meters, are conversed into Lambert coordinates. The projection system used is Lambert Morocco (Business Expansion, IAV Hassan II), Zone I (Northern Morocco). The application is based on real data embedded in maps as layers. The spatial data cover the roads, street names and locations of monitoring stations. There are three distinct layers, which are: the road layer, the layers of street names, the layer of monitoring stations (civil protection and police).

The roads are represented by polylignes, while the names of streets and the monitoring stations are represented by points. The name of the street, represented by a point, is located on the line of the road in order to make the plugin routing operations operational. The table "name_street" contains only a few names for the test, other names will be scanned and entered into the database in the next version of the application.

C. Modeling

The database was built on a relational structure. The schema of the database developed, consisting of entities and attributes, has been developed using the diagram of the Unified Modeling Language (UML). This is a general form of data modeling that can be applied to all roads networks. The important entities in the database are: "accident", "breakdown", "vehicle", "vehicle_category", "monitoring_station", "nature_ monitoring_station", "route" and "name_street", other tables will be created to manage the plugin routing; these include "route_edges", "route_vertices" and "routing_results." The relational model of database is shown in the entity-relationship diagram (ERD) in UML (Figure 2).

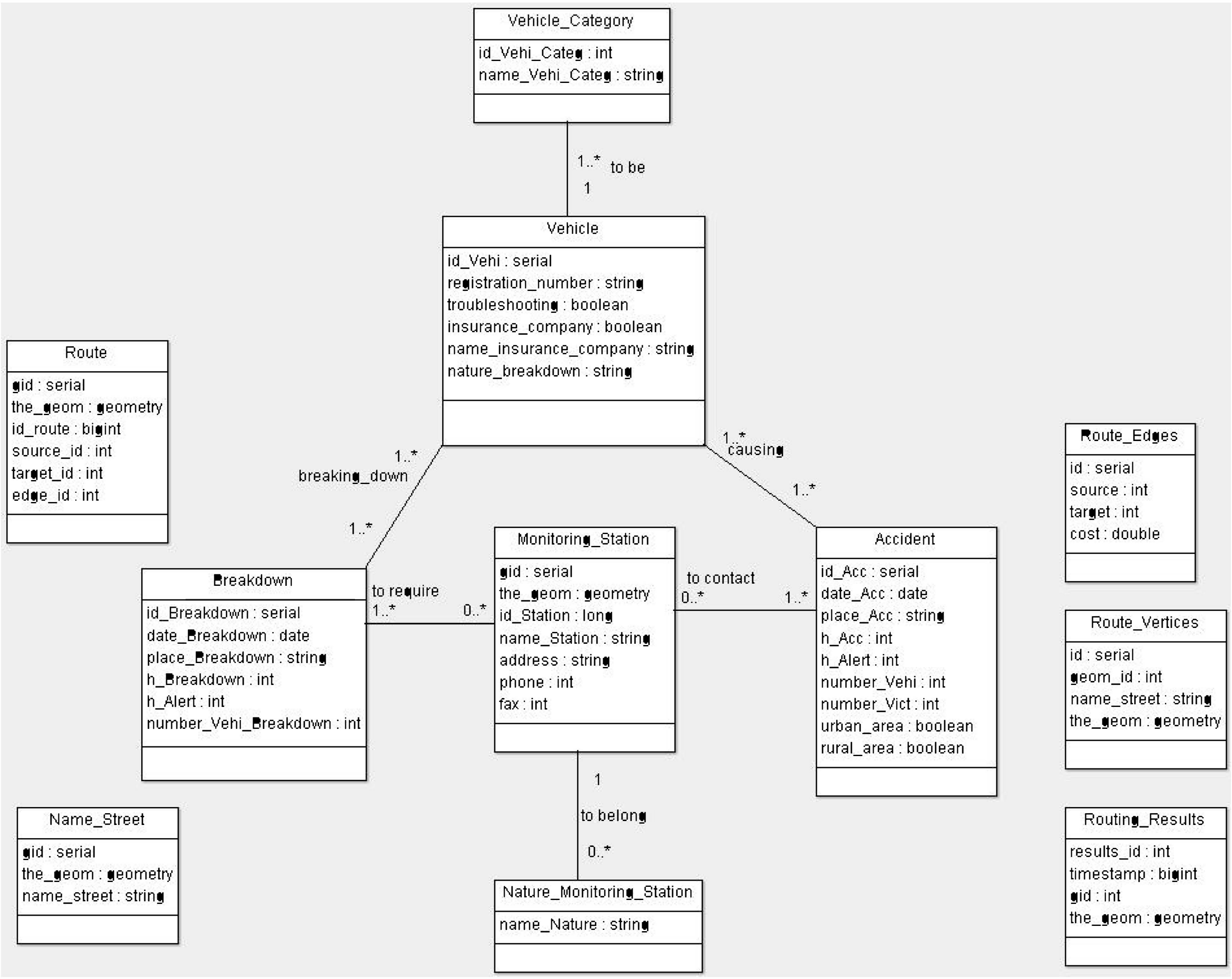

Figure 2. The entity relationship diagram.

IV. IMPLEMENTATION

The choice was preferentially oriented means "Open-source" such as Mapserver, Cartoweb and PostgreSQL, which appear to have identical capabilities to commercial solutions at a cost of setting up small. In this application, we do not expect users (decision-makers) to have any background on modeling and implementation aspects. Thus, the information provided to users is neither technical data nor conceptual data; we focused instead on providing a usable interface. To implement the application, we used an Object-Oriented (OO) methodology (Unified Modeling Language—UML) and PHP, version 5. The developed application is organized around a main window, with all the functionalities accessible in this window, through the toolbar, or the menu (in a way easily understandable by users). In this context, the target user of this application is typically a decisionmaker with moderate computer literacy. This user profile suggests that the main usability goal should be ease of learning; therefore, the user interface should be extremely intuitive. The tool consists of two sub-systems:
• a system to enter, edit or delete data from a road accident or breakdowns of a vehicle;
• a system for manipulating geographic data;
The tool developed is composed of a set of graphical user interfaces. It was implemented for Windows platforms and has an open architecture which allows an easy integration of new functionality.

A. *Graphical User Interface (GUI)*

The main purpose of the GUI was to allow an easy and efficient access. Thus, according to [15], the following characteristics are fundamental:
• Easy to learn: allowing the intuitive use of the tool by any user;
• Robustness: allowing the user to recover from unintended situations;
• Interactivity: allowing the information to effectively flow between the user and the system;
• Based on events: allowing the user to always be aware of the tasks he is performing.

B. *Tools*

Semantic database is managed by the management system of the database PostgreSQL. Graphic layers obtained with GIS from the digitization of monitoring stations (police and civil protection) , street names and the road network of the Mohammedia city are imported into the cartridge spatial DBMS: PostGIS. The use of this cartridge spatial allows interaction with the mapping module of the Web server: Cartoweb.

C. *Decision model*

The web is the main interface to connect a user to the system. The teleoperator uses GUI to make the interpretation of information easier, he will be able to (Figure 3):
• see or not some layers;
• perform operations such as, zoom in, zoom out, expansion, planning and query capabilities on a specific area of the map to get a better view of the data in this area;
• focus directly on a monitoring station (police, civil protection);
•visualize the scale of the map in different ways (changing the scale of representation);
• visualize a map reference to be located more easily;
• show full caption layers;
• use drop-down lists and checkboxes to query the database, users can query the database directly with SQL (Structured Query Language) statements with a mixture of relational and spatial query;
• perform spatial queries in different ways: either by clicking the monitoring stations to query the map objects, the results are displayed in a table, or by entering the identifier or the designation or the X and Y coordinates of the post, in this case the results are transmitted to the customer as an XML document on the web;
• edit, modify or delete the geographic features online and directly on the map knowing their X and Y coordinates or their location, the data entered or modified objects are stored directly in the PostGIS database. All these operations are allowed only for users who must have the access (username and password);
• draw of spatial objects (point, line, and polygon) with different symbols, colors and size.

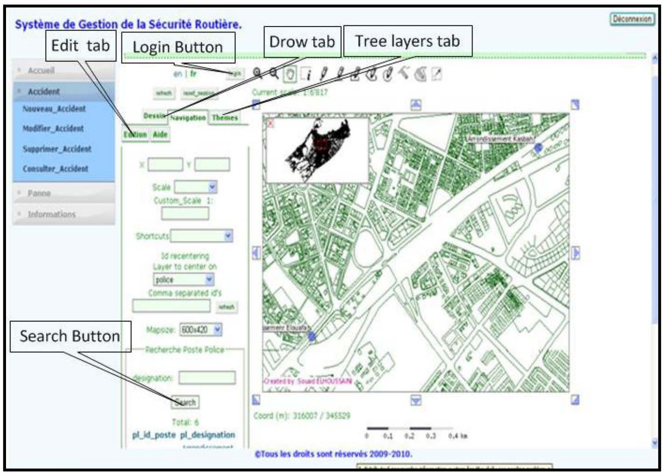

Figure 3. The GUI of different visualizations tabs.

V. IMPLEMENTATION OF DIJKSTRA'S ALGORITHM

A. *Dijkstra's algorithm*

Incorporating the efficient shortest-path algorithm within the GIS will lower our system's response time, thus increasing its viability. An operation with substantial importance for the handling of emergency accidents is the routing of the nearest monitoring station to the accident site. The optimal routes correspond to minimum required transportation times. A real-time system however, must be able to give a prompt reply to such queries. In our system, the routing service has been implemented using the Dijkstra's algorithm, it is one of the spatial optimization algorithm for finding shortest routes and it is the most widely used in GIS software packages. Its performance depends on the data structures used to implement the graph representing the spatial network [16]. The road network is represented by a graph (non-oriented in our case). Each intersection on physical road is represented as one node. Let G= (N, A) be a graph consisting of a set of nodes (N) and a set of arcs (A) each with non-negative cost C. It was designed for tracing the least-cost path (route) in G. For a given destination node in the network, Dijkstra's algorithm calculates the least accumulated cost between the destination node and every other node, and then finds the least-cost path from any origin nodes to the destination node. The logical procedure of Dijkstra's algorithm is as follows [17]:

(1) Let the node at which we are starting be called the source node. Assign to the source node an initial value of zero and to all other nodes an initial value of infinity. Mark all nodes as unvisited. Set source node as current.

(2) For the current node, consider its unvisited nodes directly connected by links having cost values and calculate their accumulated costs from the unvisited nodes to the source node. If the new accumulated cost is less than the previously recorded cost, overwrite the cost.

(3) When all nodes directly connected to the current node are completely considered, mark the current node as visited. A visited node will not be checked again so that its accumulated distance is final and the least.

(4) If all nodes have been visited, finish. Otherwise, set the unvisited node (with the least accumulated cost to the source node) as the next “current node” and continue from step 2.

The Dijkstra’s algorithm is very similar to the A* algorithm. The cost function (c) used to evaluate shortest paths in the Dijkstra algorithm is augmented by an estimator function that is used to estimate the shortest path between two given graph nodes [i.e., $c(s, d) = g(s, v) + h(v, d)$, where $g(s, v)$ is the cost from source s to v and $h(v, d)$ is the heuristic estimated cost from v to the destination d]. The estimator function is a heuristic function that can be chosen arbitrarily. If the estimator function is 0 A* turns into Dijkstra’s algorithm [18].

B. *Simulated test cases and field trial*

The algorithm was implemented with PHP in Cartoweb environment. The version of Cartoweb used is 3.5.0 and runs with Windows XP operating system. Cartoweb not only allows the handling of road maps online using user-friendly interfaces, but it also allows to implement the routing plugin nome "pgrouting", it runs client side and server side. The user can define the points of beginning and end of the shortest path by selecting their names (names of streets) from two listbox. With the button “Shortest path”, the routing operation is performed. Whenever a routing operation is performed, their names are passed as parameters from the client interface to the server (Figure 4). The server connects to the database, it prepares the request, it computes the shortest path connecting the given points, draw it on the map with a different color. Figure 5 depicts the shortest path between Boulevard "11 Janvier" and Boulevard "Sebta" in the road network in Mohammedia. Thus, Dijkstra’s algorithm is guaranteed to find a shortest path. If we selected other roads (B and C) for comparison (Figure 6), we will have the following results (TABLE I), so we gain 940m between roads A and B and 623m between roads A and C. But the shortest route is not necessarily the fastest route and the most optimal, other criteria must be considered, these include the status of the traffic (e.g. the congestion or the work of management).

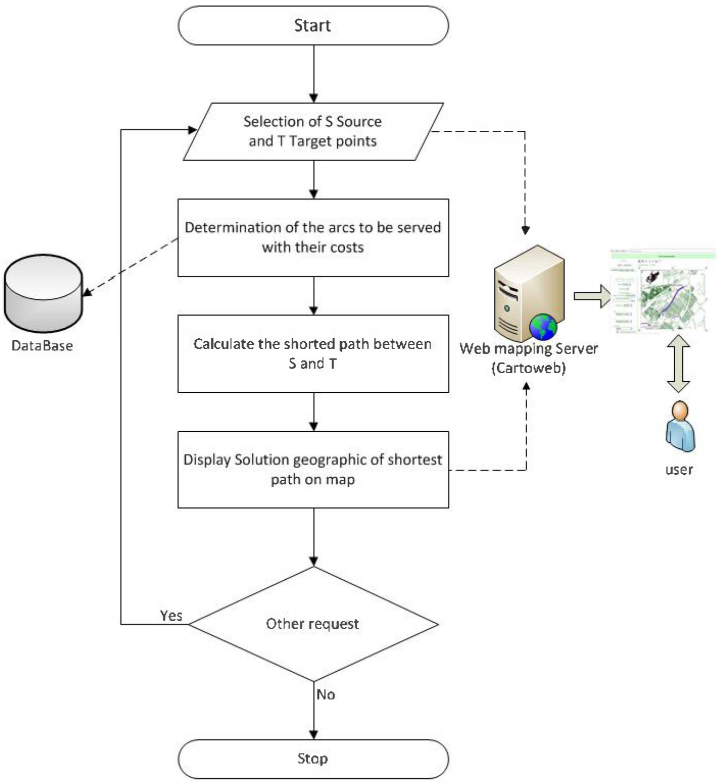

Figure 4. The proposed routing solution with Dijkstra’s algorithm.

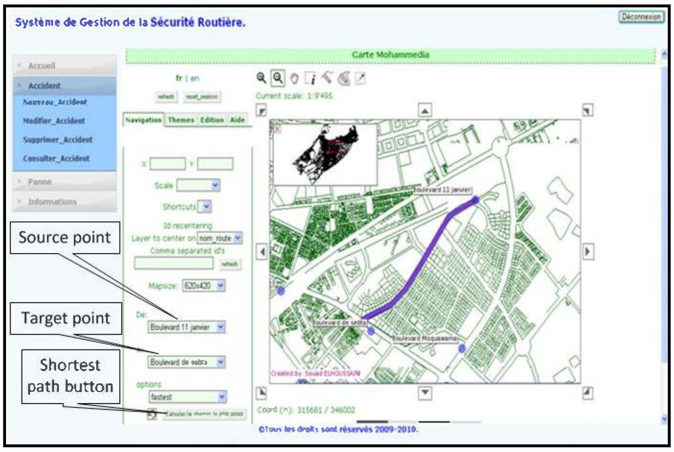

Figure 5. Visualization of the shortest path.

TABLE I. RESULTS OF DISTANCE OF ROADS A, B AND C

	Route A	**Route B**	**Route C**
Distance (m)	1014	1954	1637

VI. CONCLUSION

In this study, we describe an intelligent monitoring and control system for the organization of a location and routing services management of roads accidents in the city of Mohammedia in Morocco. This was carried out by the use of Information and Communication Technologies (ICT’s technologies): web and GIS. They constitute a new scientific area of information systems applications developed to support semi-structured or unstructured decisions. The improved efficiency by GIS reduces the task of maintaining paper maps. The system has been tested in a real-life case study, its architecture involves an integrated framework of Geographical Information System (GIS) and a Relational Database Management System (RDBMS) equipped with interactive communication, however, the prototype database has conducted a physical structure that can accommodate new data and particularly an update. The Web-based GIS framework facilitates the orientation of the nearest monitoring station to the location of the accident. There are several advantages of the developed system. First, it is a Web-based GIS model which means that the access to the data and the utilization of the system could be achieved by multiple users. The control and the information retrieval do not belong to one user; every related person with access rights can utilize the system and share the information easily. Time saving and flexibility are other important merits of the system. The system is Object-Oriented (OO), understandable and flexible, it has potential to be integrated with the other roads networks and to be expanded to a national base, so the model can be extended to all cities of Morocco using the GIS technology with RDBMSs. In doing so, the national road network will benefit from information technologies that are vital to development and economic growth.

The proposed approach has demonstrated an important step towards improvement on roads accidents management, there is still room for improving this approach. For example, this approach could be implemented using:

-Combine GPS with various electronic map navigation systems. That could be applied to the road network analysis, the roads accidents treat and so on.

-Location Base Service uses the personal telecommunication device, such as cellular phone and PDA. These personal devices combine GIS and GPS to know the precise location of the nearest monitoring station and the location of the accident.

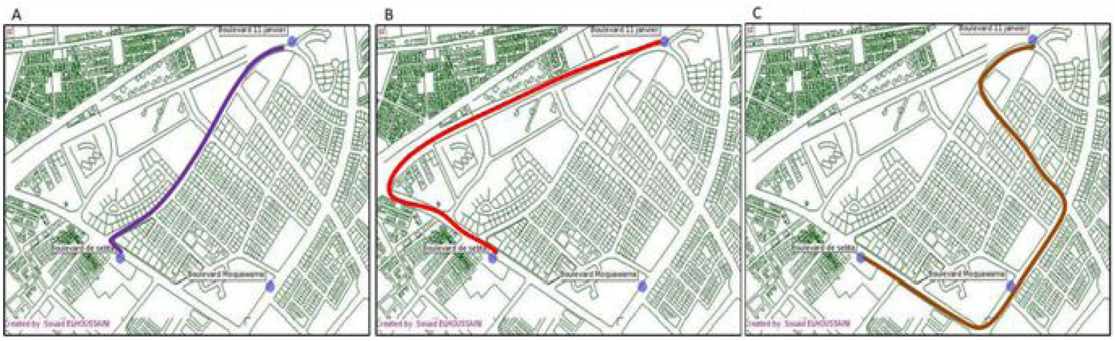

Figure 6. Comparison between the shortest path (A) and other routes (B and C) between Boulevard "11 Janvier" and Boulevard "Sebta".

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