Real Time Route for Dynamic Road Congestions

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Abstract

Minimizing service delivery and travel time during rush hours downtown is strategic target for several organizations, especially the emergency organizations. This paper presents an On-line and Real-time Dynamic Route System (ORDRS) which benefits from the advantages and integration between information system and communications technology. It utilizes Global Positioning System (GPS), Geographical Information Systems (GIS), and Global System for Mobile communications (GSM); for producing the real time routes for vehicles. GPS-Tracker is the main input device for ORDRS. It is fixated in a vehicle, sends vehicle's movement data (Geo-info) to the control center wirelessly through either Short Message Service (SMS) or General Packet Radio Service (GPRS). Geo-info includes time, date, longitude, latitude, speed, and etc., these data is classified over time during weekdays into interval time slices, each slice is 30 minutes. Speeds are treated by GIS tools to determine historical and real time speeds for each street segment in the road network which is being used for calculating time impedance (cost matrix) for each street segment dynamically. ORDRS uses a cost matrix of the current time slice for determining the best route to each vehicle in duty attached. Several algorithms was used to calculate the shortest route, a comparison between Dijekstra and Yen algorithms was studied.

Keywords: *GIS, GPS, GSM, Real time routing, dynamic road, road congestions.*

1. Introduction

Traffic congestion is a dynamic phenomenon. Congestion does not occur everywhere, all-at-once. Instead, congestion occurs in specific locations and propagates through network over time as congested conditions on a link spread to nearby links. In addition, since many urban transportation networks are operating at near capacity, they are especially vulnerable to congestion occurring as the result of unplanned incidents such as accidents and infrastructure failures (e.g., bridge closings, construction). These incidents result in congestion patterns that propagate from a localized incident through many portions of the network, potentially resulting in serious flow disruption. The increasing ubiquity and complexity of urban congestion combined with its severe negative impacts suggests the need for new tools to analyze and predict congestion patterns. These tools are important both for tactical operations and strategic planning. Tactical operations systems require tools for optimal routing and timing given expected traffic patterns [1].

The main characteristics of Geographic Information System (GIS) that differentiate it from other information systems are its spatial data and geo-statistical analyses [2]. Such analytical functions usually present the best solutions to the users of GIS. Integration of these analyses with high visualization capabilities lead GIS to be widely used in decision making process [3].

The last decade has witnessed the rapid emergence of Internet-enabled mobile terminals, mobile computing, location aware technologies like GPS, and GIS capabilities. As a result of this integration, a new generation of GIS named mobile GIS have been developed which are capable of delivering geographic information and analyses to mobile users via the Internet and wireless networks [4]. Generally, Mobile Geospatial Information Systems (MGIS) is a type of GIS which its main research is about non-geographic moving object in geographical space. This research works on relationship between moving object and geographic entity, or moving object between another moving object. The main difference between a mobile GIS and traditional (static) GIS is the existence of a mobile agent [2].

Finding the optimal path is one of the most important analyses which are used in mobile GIS [3]. It is also one of the widely used applications in transportation problems. Finding optimal path is defined as "How to determine the optimal path from one or more places in network to other locations." [5].

In many researches for finding the optimal path, time is regarded as a static parameter that leads to obtain similar solutions for a shortest path problem in different times [6]. Since traffic congestion changes continuously in a transportation network, so travel time of the links changes continuously in all the network locations. If the user needs to find a path with minimum travel time based on cost of travel, the previous methods will lose their efficiency and new structure must be developed to manipulate dynamic networks. The current article examines the spatial analysis of finding optimal path between two specific locations in a network which its traffic congestion changes continuously.

The problem of finding the optimal path (route) has been studied a lot during the years. Although many algorithms have been proposed for solving this problem, the main basis of these algorithms is similar and is based on Dijkstra's method. This thesis adopts the experiment of calculating the shortest path via both of Dijkstra's algorithm and Yen's algorithm (*k* shortest path algorithm) [7, 8].

On-line and Real-time Dynamic Route System (ORDRS) presents a functionality based on spatial data structure, which utilizes ArcGIS tools for creating a real time route, it solves the traffic congestion problem dynamically as congestions varies as the time slice over weekdays.

2. System Overview

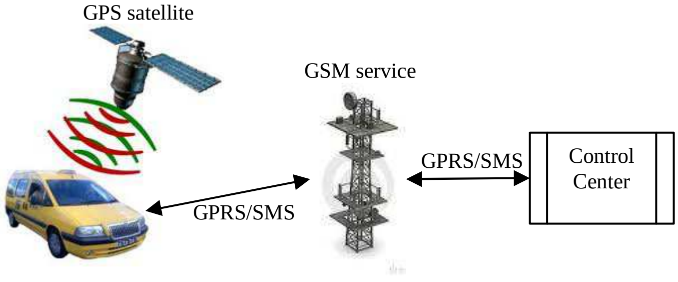

Figure 1, Integration among GPS, GPRS, GIS (Control center).

This paper utilizes multiple technologies combined to address a real time routing for dynamic congestion road network. The paper presents a system that receives geographical information from a Global Positioning System (GPS) through Global System for Mobile Communications (GSM) services (Short Message Service (SMS), or General Packet Radio Service (GPRS)). The system utilizes the integration among GIS, GPS, and either SMS or GPRS technologies for creating on-line route, Figure 1.

2.1. GPS

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites (Garmin.com). In 1973 GPS was intended for USA military applications, but in the 1980s, the government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS [9].
From NASA (2009): The uses of GPS have extended to include both the commercial and scientific worlds. Commercially, GPS is used as a navigation and positioning tool in airplanes, boats, cars, and for almost all outdoor recreational activities such as hiking, fishing, and kayaking [9].

2.2. GIS

In 1956, a mapping department of Austria began to build its geographic information database by using computer. And then, with the development of computer science, some land mapping and administration departments started to use this technology for land management, which was called Land Information System (LIS). In fact, the concept of GIS is first created by a Canadian in 1962. He is the first person to implement operational geographic information system in Canada, which is named as CGIS at that time. It was used to store, analysis, and process land inventory data in Canada. Canada Land Inventory aimed to measure and enhanced analysis of land ability by mapping the information about soil, agriculture, water, forest, land, and so on. Finally, the first worldwide operational GIS system was developed by federal department of energy, mines, and resources in Ottawa of Canada. This means a new area has come since this system was not only for mapping but to make analysis according to the spatial data possible. Nowadays, it is a new period that we can no longer use a paper map but a digital one.
A GIS can provide different kinds of information with descriptions unlike a paper map which can only provide what is presented on paper. GIS (Geographic Information System) is about scientific investigation of geography. It is combing computer hardware, software and geographic data together to capture, display, investigate, analyze and manage all the kinds of geographic information. It is not a very newly developed discipline but it should belong to a practical science and full of business opportunities, which may be estate assessment, risk management, city planning, and targeting market segment selecting. Geography can help people to make a better decision in many disciplines. We can see that GIS has the large areas of using. It has now applied in Resource Management, Resource Configuration, Urban Planning and Management, LIS, cadastral application, environmental management, geosciences, and business marketing, etc… [10].

2.3. GSM

GSM is a digital cellular communication system that prevails throughout Europe and much of the rest of the world. At present, cellular communication system has become a new trend for many varieties applications. GSM system is divided into three parts: mobile station, base station subsystem and network subsystem. At present, the commercial GSM communication systems can provide many services: voice communication between several users, and data messages exchange in either Short Message Service (SMS) or General Packet Radio Service (GPRS) [11].

2.4. GPS Tracker

A GPS Tracker, is the main input unit of system, it consists of GPS receiver and GSM circuits.
GPS device is a small unit that receives signals from satellites and sends other signals to GSM towers. This devise is a major part of the system and it will be installed into the vehicle which is responsible for capturing the Geo-info (date, time, latitude, longitude, speed, bearing, etc.) for the vehicle. This device is also responsible for transmitting this information to the Tracking Server located anywhere in the world [12].
The GSM chip is used for sending the GPS data (latitude, longitude, speed, date, time, and GPS receiver's ID) to the Tracking Server through SMS or GPRS.

3. Dynamic Route Architecture

If the shortest road based on distance measure has a traffic congestion, it might be better off to take a route that might seem longer in distance but could really get the vehicles to their destinations faster due to less traffic congestions. Hence, a thorough understanding of the problem scenario is essential for addressing this issue [13].
In order to arrive at a procedure for determining the optimal vehicle routing with real-time traffic information, a decision-making scenario is designed for building the real-time route

for dynamic road congestions. This scenario includes data acquisition tools, hardware network, database schema, and data manipulation algorithms. The time consuming of route calculation algorithm is essential for real time routing.

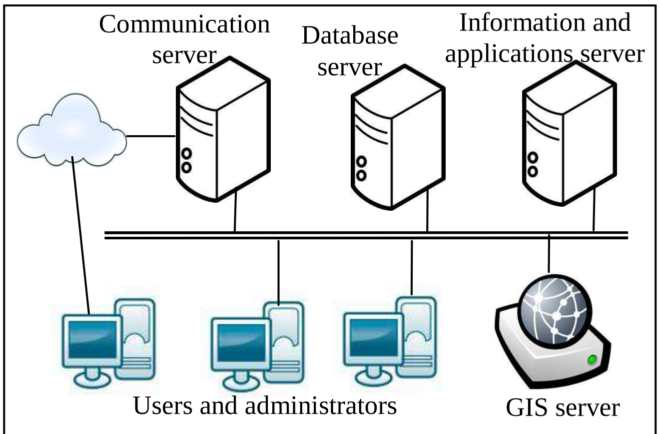

Figure 2; Control center's network diagram.

3.1. Data Acquisition

GPS tracker produces the Geo-info data, sends the data through either SMS or GPRS to the Tracking Server, which interpret the geo-info data and sends it to the database server. A GPS tracker was installed in the experimental vehicle, and used for collecting geo-info (spatial data and GPS satellites data), which are collected through different time intervals in week duration. The experimental data was collected from Abu Dhabi Island's road network. Practically, geo-info data will be collected through taxi cars, there are six taxi companies (National, Al Ghzal, Emirates, Cars, Tawasul, and Arabia taxis) in Abu Dhabi emirate, three of them have fleet of 2796 vehicles, which are moving in road network [14].

3.2. Hardware Network

ORDRS's hardware network consists of: communication server, database server, information and application server, and GIS server; Figure 2 [15].

Communication Server: A computer server connected with internet and has a real IP (Internet Protocol) address. A socket technique program is implemented, compiled, and configured to be run on server's startup. Socket's functionality is receiving GPS messages.

Database Server: A computer in a network that is dedicated to database storage and retrieval, it is a computer server connected with the communication server through TCP/IP (Transmission Control Protocol/Internet Protocol). It holds the database management system SQL Server 2008, and the databases for vehicles, GPS messages and historical data, routes, street speeds, routes directions, etc…

Information and Application Server: A computer server connected locally with other system, contains compiled procedures for all system functionality and management.

GIS Server: A computer connected locally with the system. It contains ArcGIS software version 9.3, and streets' spatial data.

Users and Administrators: Are computers have privileges to access data/application server, it is connected to the network either locally (through local area network) or remotely using TCP/IP.

3.3. Database Schema

ORDRS's database schema is based on dividing day hours into 48 intervals, 30 minutes each, on week days. Each time interval table contains the fields Object ID, Speed History Average, Speed History Weight, Current Speed Average, and Current Speed Weight, also contain a record for each street segment in streets database (Streets' spatial data).
ArcGIS produce a visual maps based on spatial data (Shape file structure, or Geo-database structure), Abu Dhabi Island streets' shape file includes streets' geometric data and attribute data. Attribute data includes Streets' Speed Limit, Length, Time needed to pass street segment (time coast), etc. time coast is calculated by using speed limit and length for each street segment, it is static time. Figure 3, shows attributes table for Abu Dhabi Island streets, it contain 12800 records (street features).

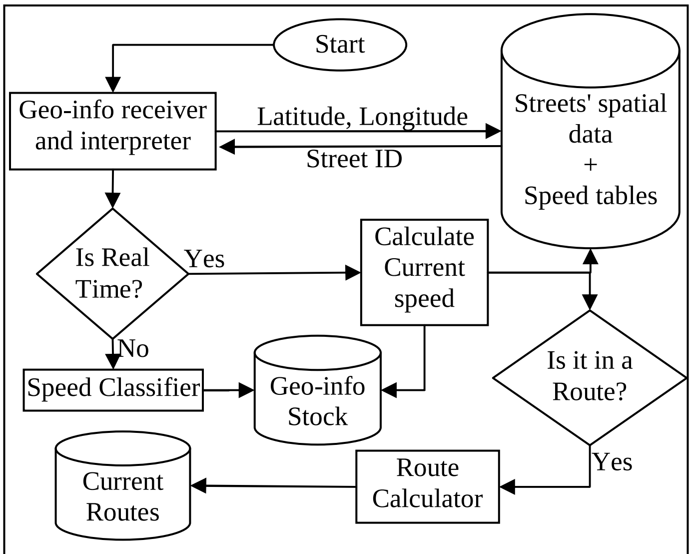

Figure 3: Flowchart of GPS data acquisition module.

3.4. Data Manipulation Algorithms

ORDRS's functionalities are achieved through algorithms' implementation that could affect real time performance of the route (shortest path). These algorithms are: Geo-info receivers and interpreters (GPS data acquisition algorithms), Current speed calculator, Speed classifier, Route calculator, etc…, figure 3.

Geo-info Receivers and Interpreters: Are procedures for receiving GPS message in either SMS or GPRS form, interpreting the message and split it to time, date, latitude, longitude, speed, etc.; using latitude and longitude for calling streets shape file and determining the street segment (FID – feature ID), using the time to determine the type (real time or stock data) of message, and sending message's components to either Calculate Current Speed or Speed Classifier procedure.

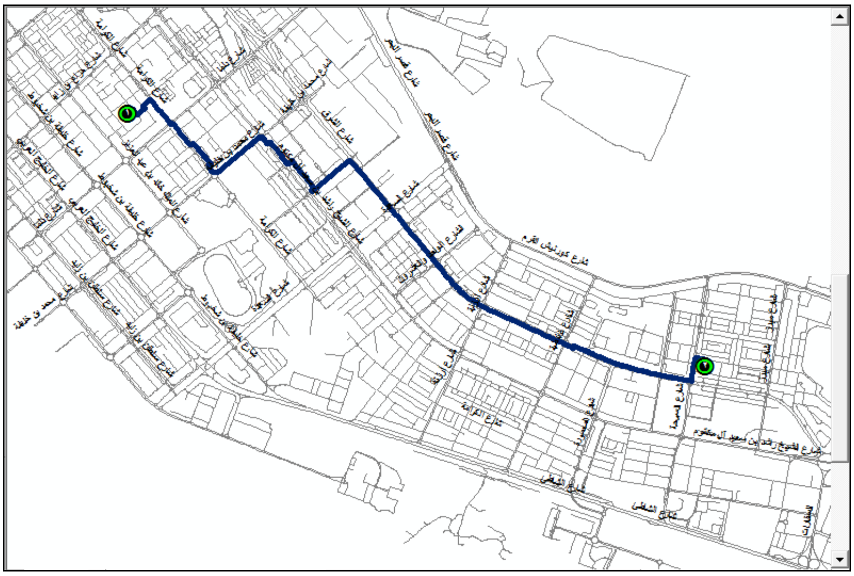

Figure 4: the path between points 1 and 2, at the interval time 13:30 – 14:00, Sunday afternoon.

Current Speed Calculator: Is the procedure interact with a speed table of the current interval; it calculates current speed average and current speed weight fields, calculates street segment's time, and triggers Route Calculator.

Next interval operations: Is a procedure running each 30 minutes (an interval time slice). Its responsible for disjoin the current speed table, use current speed to calculate new historical speed, finally join the new interval's speed table to streets shape file and calculate time for each street segment. Street segment's time is calculated by using street segment's length and speed. Speed is selected with a priority sequence as current speed, historical speed, and speed limit.

Route Calculator: is the most important module that because it rebuilds network coast matrix and calculate the shortest path for each vehicle on duty. This module is triggered at three situations: At time slice's start/end, i.e. at of Time interval separator startup; while the vehicle has a route and moves in line segment that's not in the determined route; and whenever street line segment's current speed is changed, and that segment is an element of a route. This module was calculated via Dijkstra and Yen (*k* shortest simple paths) algorithms.

4. System's Output and Results

OLDRS calculates a route dynamically, depending on streets' current/historical speeds, so a route from Origin to Destination is varies as time slice, this variation is cleared, especially, on routes which include major arterial roads. The system is simulated in Abu-Dhabi Island (Abu Dhabi emirate, United Arab Emirates), where GPS data is collected through **different times a day, for a week days.**

Figure 4 illustrates the output route from point 1 (origin) to point 2 (destination) for a vehicle, that route was calculated at 1:37 pm on Sunday. This route's length is 8761.8 meters, takes about 10 minutes (10:03 minutes).

The same calculated route between origin and destination, figure 4, in the rush hour (Sunday 2:18pm) will take about 17 minutes time. That's why ORDRS calculates time dependent route by real time and historical speed analysis. In this context (for this sake), ORDRS calculate an alternative route between origin and destination, depending on time and day/week.

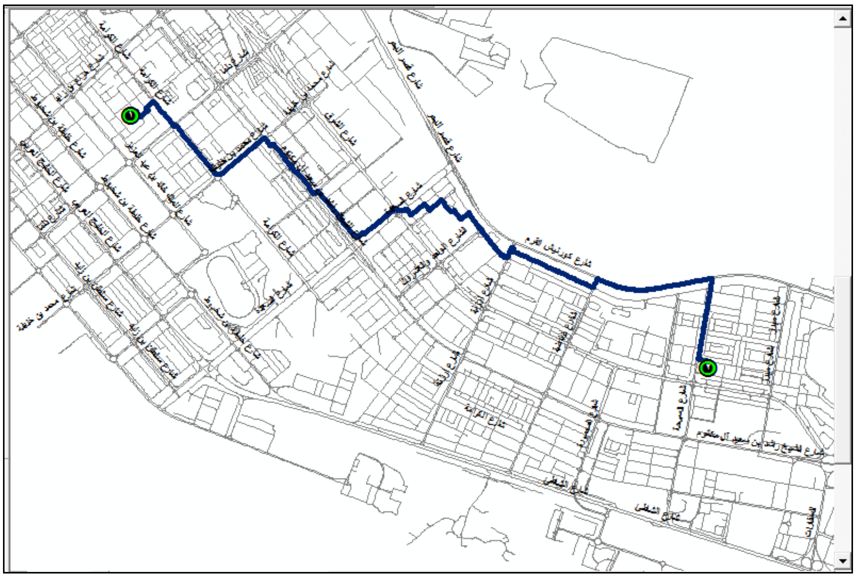

Figure 5: The path between points 1 and 2, at the interval time 14:00 – 14:30, Sunday afternoon.

Figure 5, shows the route calculation at 2:18pm (on Sunday) from same origin to same destination , its length is 9682.7 meters and takes about 15 minutes (exactly 14:47 minutes) duration. This result shows that **route time consuming was reduced by 2:03 minutes (12.09%)**.

ORDRS is applied on several routes and different timing intervals. A sample of three different routes' lengths and time taken during both normal and rush time are listed in Table 1; it shows that OLDRS saves time during rush hours between 12% and 17%.

Table 1: Time needed to pass a route in both normal and rush time, and the saved time.

#	Route of normal time		Time Taken (normal time route) in Rush Intervals	Route of rush time		Saved Time (minutes)	Saved Time's Percent
	Length (meters)	Time Taken (minutes)		Length (meters)	Time Taken (minutes)		
1	8761.8	10:03	16:49	9682.7	14:47	2:03	12.09%
2	10248.1	9:12	15:40	11324.4	13:25	2:15	14.36%
3	6185.7	7:57	12:05	8251.2	10:11	1:54	15.72%

Since route calculation's algorithm is essential for determining the best route on real time. So the calculation time consuming must be as minimum as possible. An ArcGIS network analysis tool calculates the shortest path via Dijkstra algorithm. Yen's algorithm (k shortest path) is chosen to be used for shortest path.

Although Yen's algorithm calculate k alternative routes but the first path is the same as Dijkstra's algorithm calculation. Therefore at k=1, Yen's algorithm is equivalent to Dijkstra's algorithm, but it takes more processing time. Figure 6 shows that, the route from node 42 to node 12 is 42-23-19-12; road cost is 0.1642908 hours (9 minutes, 51.45 seconds) for both Yen and Dijkstra algorithms. It shows also the processing time for Dijkstra's algorithm is 0.03 second and for Yen's algorithm is 0.11 seconds.

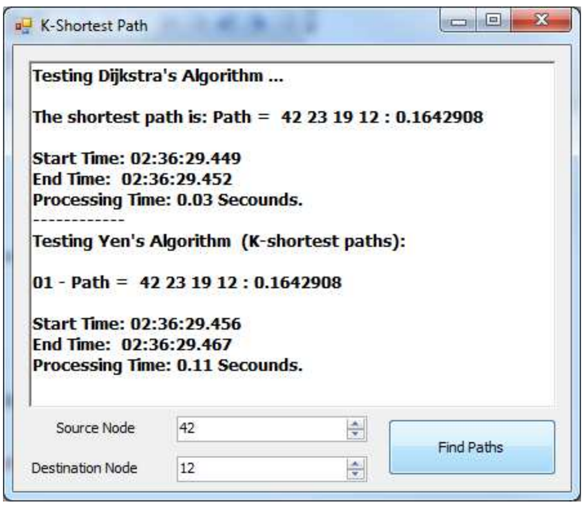

Figure 6: Results of Yen's algorithm at k=1 and Dijkstra's algorithm.

A network of 50 nodes and 1183 edges is used for check the processing time consuming for both Dijkstra and Yen algorithms. Table 2 shows experimental sample of time consuming and the percentage between the algorithms. Dijkstra algorithm processing time is 77% with respect to Yen algorithm processing time.

Table 2: Algorithms Processing Time Consuming.

Processing Time Consuming (Sec)						
Dijkstra (D)	0.03	0.02	0.07	0.04	0.06	Averag
Yen (Y)	0.11	0.17	0.24	0.15	0.22	
(Y-D)/D	73%	88%	71%	73%	73%	76%
Dijkstra (D)	0.05	0.02	0.03	0.06	0.03	Averag
Yen (Y)	0.18	0.14	0.16	0.17	0.21	
(Y-D)/D	72%	86%	81%	65%	86%	78%

5. Conclusion

This paper introduces an On-line Real-time Dynamic Route System (ORDRS). It uses Geo-info data (date, time, latitude, longitude, speed, and etc.) which are collected from GPS-Tracker, and classified over day times and week days into database tables. Each table represents the average of historical speeds at a time slice interval (30 minutes) for each street segment in a city, these intervals covers different slices a week, i.e. 336 tables. OLDRS is designed and implemented to join a speed table to streets' shape file. So, real time speed of each street segment is saved in the current speed field and is used to determine the real time route for each vehicle in duty, dynamically. Although OLDRS determine the best route depending on time coast, but this route usually takes long time in rush hours, especially for routes which passes through major arterial streets. So, at peak intervals of traffic OLDERS determine an alternative route which is longer in distance, but saves 10-20% of time. Routes dynamically are recalculated (to the shortest one) while speeds data are received and/or time slice is changed. By comparison of Dijkstra and Yen algorithms for calculating real time route, OLDRS adopts the Dijkstra's algorithm because its processing time performance is 77% of processing time of Yen's algorithm.

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