Towards the Design of GIS-Based Routing System

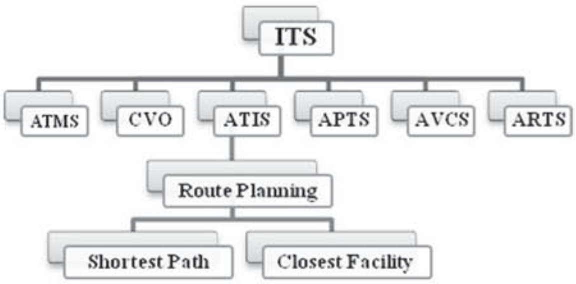
Gohari, A.,[1] Ahmad, H. A.,[1] Hashim, M. G.,[1] Kheirandish, S.[1] and Kumar, L.[2]
[1]Department of Geoinformatic, Faculty of Geoinformation Science and Engineering,
Universiti Teknologi Malaysia, 81310, Skudai, Johor, Malaysia, E-mail: adel.gohari@gmail.com
[2]Ecosystem Management, School of Environmental and Rural Science, University of New England,
Armidale, NSW 2351, Australia.

Abstract
Travel in urban and suburban areas is an important activity in an individual's daily life. Each trip is preceded by a planning process for selecting an optimal route from the origin to the destination. An 'Optimal' route can take many forms, such as shortest time or shortest distance. Route planning aids travellers in choosing the optimal path to their destinations in terms of travel distance or travel time. In this paper, a GIS-based route planning system is presented to enable shortest path and closest facility analysis, which form the most significant parts of a route planning system, for the Taman Universiti and Taman DesaSkudai, Johor, Malaysia. The analysis is made by adopting the model builder to automate all the steps of data processing and analyzing, and also provides the conditions that enable users to use the system interactively.

1. Introduction

Intelligent Transport Systems (ITS) is the name given to the application of computer and communications technologies to transport problems. In a rapidly changing society, the emphasis on road technology improvements to assist in road management has been identified as a key issue. The rapid advances in ITS technologies have enabled the collection of data or intelligence which provides relevant and timely information to road managers and users. Advanced Traveler Information Systems (ATIS) are among the most widely deployed ITS user services (Toppen et al., 2004 and Kristof et al., 2005). With ATIS information, drivers make informed decisions and are better equipped to plan their route and estimate their travel time. Route planning is an essential component of ATIS, aiding travellers in choosing the optimal path to their destinations in terms of travel distance and travel time. This system provides shortest path and path to closest facility based on distance and drive time.

ITS includes many categories, but its major ones can be divided into six categories (Ricci, 1995), as illustrated in figure 1. Route planning services need to provide three facilities: route computation, route evaluation and route display. The goal of route computation is to locate connected sequences of road segments from current location to the destination. Route computation may be based on criteria such as shortest travel distance or smallest travel time. The goal of route evaluation is to find the attributes of a given route between two points. These attributes may include travel time and traffic congestion information, and thus route evaluation is useful for selecting travel time by a familiar path. The goal of route display is to effectively communicate the optimal route to the traveller for navigation. The purpose of this study was to analyze the shortest path and closest facility functions on real road networks and compare the results with modeled data in a busy and typical housing area in Malaysia.



- Advanced Traffic Management Systems (ATMS)
- Commercial Vehicles Operation (CVO)
- Advanced Travellers Information Systems (ATIS)
- Advanced Public Transportation Systems (APTS)
- Advanced Vehicles Control Systems (AVCS)
- Advanced Rural Transports Systems (ARTS)

Figure 1: Components of ITS and meaning of its abbreviations

2. An Evaluation of Shortest Path Algorithms using Real Road Networks

The development, computational testing, and efficient implementation of shortest path algorithms have remained important research topics within related disciplines such as operations research, management science, geography, transportation, and computer science (Dijkstra, 1959, Dial et al., 1979, Glover et al., 1985, Ahuja et al., 1990 and Goldberg and Radzik, 1993). When faced with the task of computing shortest paths, one must decide which algorithm to choose. Among the evaluations of shortest path algorithms (Glover et al., 1985(a), Gallo and Pallottino, 1988, Mondu et al., 1991 and Cherkassky et al., 1993), a study by Cherkassky et al. (1993) is the most comprehensive. In their experiment, Cherkassky et al., 1993 tested 17 algorithms on a number of randomly generated networks with different characteristics. The main observation from their study was that no single algorithm consistently outperformed all others over the various classes of simulated networks. Among their conclusions, they suggested that the Dijkstra algorithm implemented with double buckets (DIKBD) was the best algorithm for networks with nonnegative arc lengths, and that the Goldberg–Radzik algorithm with distance updates during topological ordering (GOR1) was a good choice for networks with negative arc lengths. Zhan and Noon (1996) used a test environment similar to that of Cherkassky et al., (1993) as a starting point with the difference that they used real road networks rather than randomly generated networks. All of the algorithms evaluated in their study were based on the labeling method, but they differed according to the rules used to select labeled nodes for scanning and in the data structures used to manage the set of labeled nodes. The specific algorithms evaluated in their study were Bellman-Ford-Moore (BF and BFP), Dijkstra (DIKQ, DIKB, DIKBM, DIKBA, DIKBD, DIKF, DIKH, and DIKR), Incremental Graph (PAPE and TWO_Q), Threshold Algorithm (THRESH), and Topological Ordering (GOR and GOR1).Two road network datasets were created and used in their study. The two sets differed in the size of networks included. The road networks were stored and maintained as a set of nodes and bidirectional links in a geographic information system. Their result showed that certain implementations should be avoided altogether when solving shortest paths on real networks, namely, BF, BFP, and DIKQ. The Bellman–Ford–Moore implementations (BF and BFP) had serious difficulties on large networks. They recommended TWO_Q implementation for one-to-all shortest path situation, but for the one-to-one or one-to-some situations, if the maximum arc length was less than 1500, implementation of DIKBA, and if the maximum arc lengths were greater than 1500, DIKBD and DIKBA should be applied.

3. Description of Area

This paper focuses on shortest path and closest facility analysis in the Taman Univesiti and Taman Desa Skudai, Johor Bahru, Johor, Malaysia. This area is located between 1° 31′40″ and1° 32′ 26″ latitude and between 103° 36′ 56″ and 103° 38′ 26″ longitude of Johor state, as shown in figure 2. We deliberately selected an area in and around a housing area so that the modelling could be more realistic and mimic what is generally found in a real world situation, with disturbances from pedestrians and other traffic in smaller roads.

4. Methodology

The work flow of route planning was conducted in two phases. In the first phase, data collection and validation was done, together with geodatabase design and network dataset creation. Data validation was about testing the derived data such as travel time of road segments. The second phase involved the designing of a model for analyzing the shortest path and the closest facility by using model builder, and preparing the user interface environment that would enable a user to select the origin and destination or incident and facility interactively.

4.1Required Data

Necessary data for the study included the digitized layer of streets and points of interests (POI) of the study area, which were obtained from the Department of Geoinformatic, UTM. Other essential types of data were speed limit of the streets and street directions, which were obtained through field data collection. Direction of each street could be one-way (along or against) or bidirectional. These data are depicted in figures 3(a) and 3(b).

4.2 Derived Data and Validation

The length of the streets and travel time of each street segment comprised of the derived data from the raw data. The unit of street length in the raw data was in decimal degrees as shape length, and it was required to be converted to meter. Since the radius of the semi major axis of the earth at the equator is 6,378,160 meters, resulting in a circumference of 40,075,161.2 meters, and the equator is divided into 360 degrees of longitude, each degree at the equator represents 111,319.9 meters or approximately 111 km. To convert the unit of data from decimal degree to meter, the following equation was applied.

$$Street\_length = (Shape\_length \times 111) \div 0.001$$

Equation 1

Another derived data was the time that was spent on passing each segment of the street based on identified speed limits. The unit of speed limit was in kilometer per hour. This travel time could be calculated by using the following equation.

$$Travel\_time = Street\_length \div (Speed\ limit \times (1000 \div 3600))$$

Equation 2

Since the purpose of this study was to analyze the shortest path and closest facility on the real road networks, it was essential to compare the mentioned derived data with the real ones. To achieve this objective, some of the street segments were selected for the test. These streets were travelled by a vehicle at the identified speed limit and on the condition that there was no traffic in those streets at the time of the test. As an example, Jalan Kebudayaan 1 and Jalan Kebudayaan 7 were selected. The practical travel times were 33.58 seconds and 18.15 seconds respectively, while calculated ones were 32.66 seconds and 18.19 seconds. To ensure that the calculation was correct, the results of the practical testing would be approximately the same as the result from the calculation.

Figure 2: Location of study area

Figure 3(a): Streets and points of interests

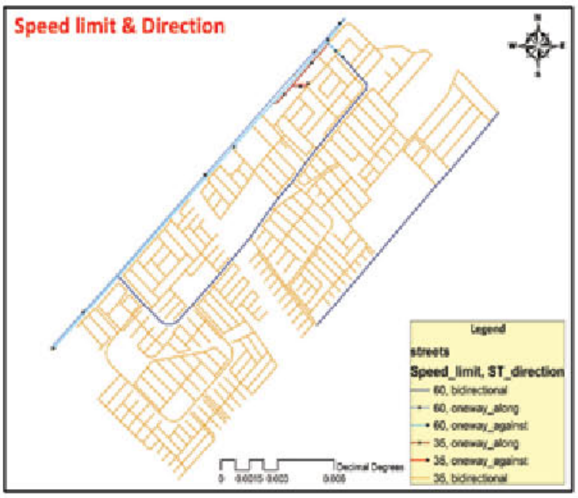


Figure 3(b): Speed limit and direction of streets

4.3 Geodatabase Design

Two different personal geodatabases in ArcCatalog were designed. Shortest path geodatabase consisted of three types of streets in terms of direction, such as oneway along, oneway against, and bidirectional. Closest facility geodatabaseis similar to shortest path geodatabase, plus the feature classes of points of interest such as banks, hotels, etc. There was a difference between a geodatabase of shortest path and closest facility in terms of bidirectional streets, because in closest facility analysis there were point features as points of interest that should be connected to the streets network. So, points of interest were connected to the streets layer by using extra lines. These lines state the distance from the middle of the street to the related point of interest and were considered as bidirectional streets.

4.4 Network Dataset

The designed network dataset for the shortest path and closest facility analysis are depicted in figures 4(a) and 4(b). The network dataset of shortest path analysis included 505 junction elements and 1324 edge elements, while network dataset of closest facility analysis included 657 junction elements and 1624 edge elements. Each route was replicated 3 times and the average results are reported.

4.5 Model Builder

Building a model by model-builder automates all the tasks that are necessary to be done by Network Analyst extension. There are two ways for model creation in model builder environment, such as model builder for exploratory project work and for building generic tools. From these two methods, exploratory project work method was selected to build models for shortest path and closest facility analysis. The designed models for the analysis of shortest path and closest facility are illustrated in figures 5(a) and 5(b) respectively.

5. Analysis and Results

The analysis was based on two assumptions. Firstly, travel time was calculated on the condition that there is no traffic jam in the streets. Secondly, maximum speed limit was used as travel speed. This study included two kinds of analysis, which are shortest path and closest facility analysis. The analysis of shortest path was carried out based on both impedance attributes (travel time and travel distance), while the closest facility analysis could be done based on travel time, travel distance and combination of cutoff value with each one of them, which is illustrated in figure 6. The result of the analysis could be represented graphically and also by text direction.

5.1 Result of the Shortest Path Analysis

The result of the analysis based on travel time showed the shortest route from the origin to the destination in terms of time of travel and the result of the analysis based on travel distance illustrated the shortest route in terms of the length of travel. As a sample, analysis was done with the origin as Jalan Kebudayaan 38 and the destination as Jalan Kebudayaan 3 for both types of shortest path analysis. The results are shown in figures 7(a) and 7(b). The comparison of results indicated that, although the total travel distance of travel time based analysis was approximately 47 meters more than travel distance analysis, but its total travel time was 33 seconds less.

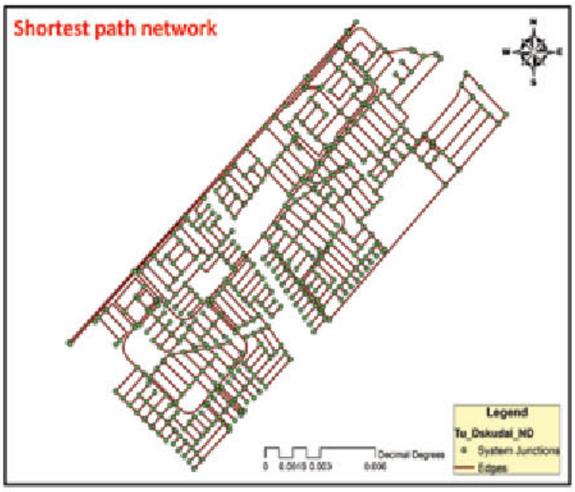
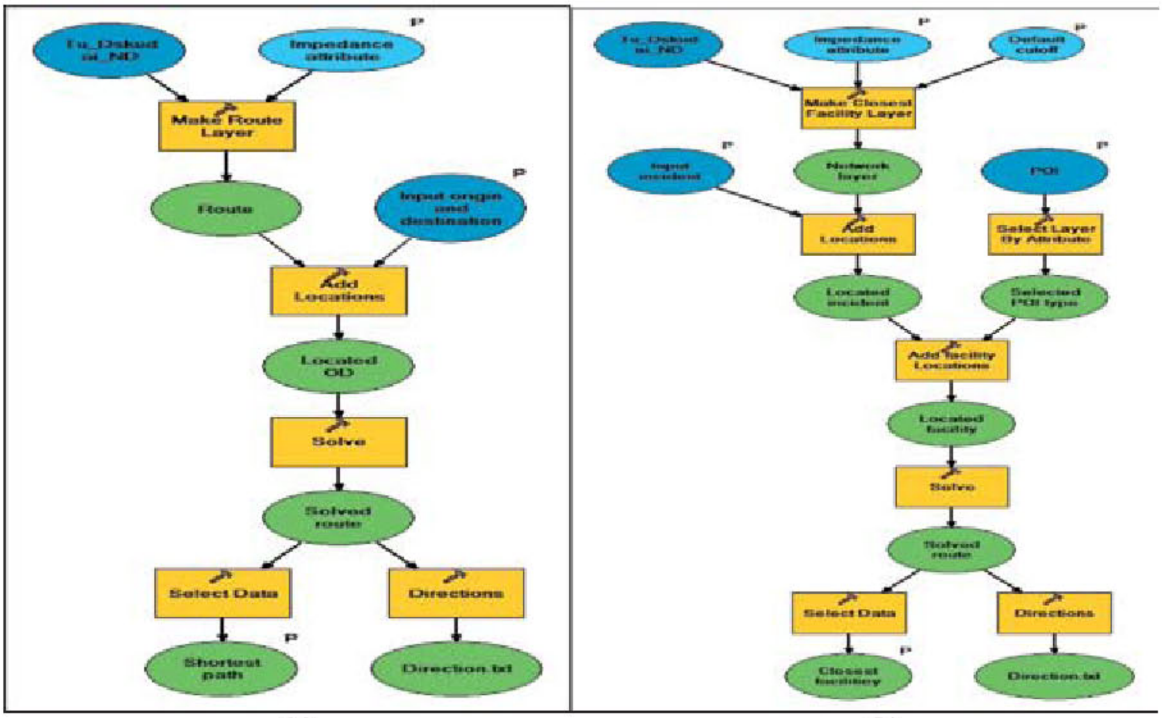


Figure 4(a): Network datasets of shortest path analysis

Figure 4(b): Network datasets of closest facility analysis



(a) (b)

Figure 5: (a): Designed model for the shortest path analysis, (b): Designed model for closest facility analysis

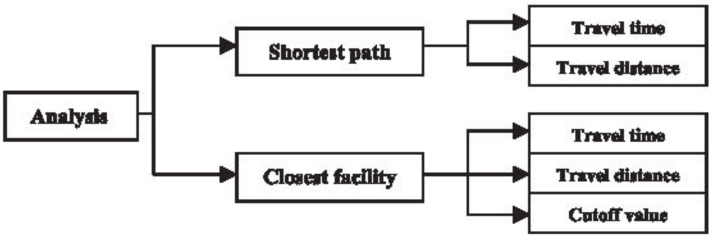


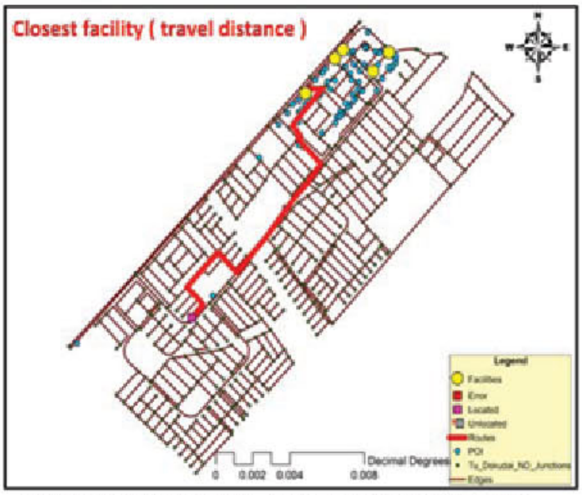
Figure 6: Analysis types

Total travel time: 154.331706 Total travel distance: 1530.854271

Figure 7(a): Graphical representation of travel distance-based shortest path analysis

Total travel time: 121.655518 Total travel distance: 1577.092605

Figure 7(b): Graphical representation of travel time-based shortest path analysis

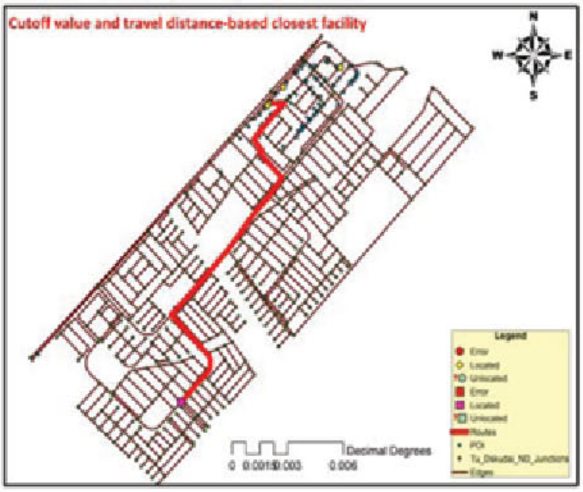


Total travel time: 183.971699 Total travel distance: 2110.796377

Figure 8(a): Graphical representation of travel distance-based closest facility analysis

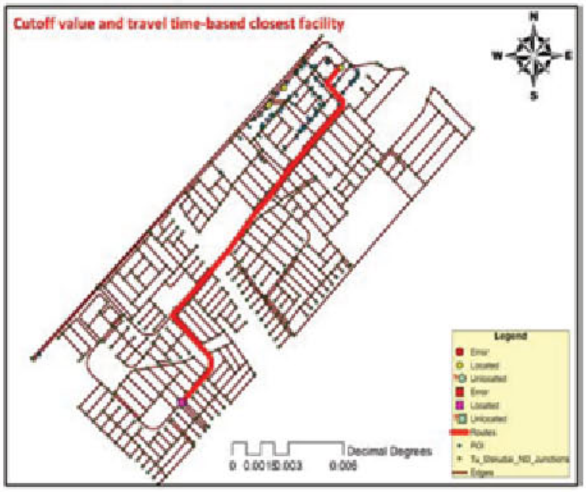
Total travel time: 156.149511 Total travel distance: 2115.737416

Figure 8(b): Graphical representation of travel time-based closest facility analysis



Total travel time: 199.722705 Total travel distance: 2360.744327

Figure 9(a): Graphical representation of travel-distance based closest facility analysis with cutoff value



Total travel time: 187.629452 Total travel distance: 2535.948535

Figure 9(b): Graphical representation of travel-time based closest facility analysis with cutoff value

The reason behind this was that in the travel time analysis, shortest time is preferred rather than shortest distance, while in travel distance analysis, length of travel is the most important factor. So, the route result of travel time analysis passed through the street (Jalan Kebudayaan) that its speed limit is 60 kilometers per hour to reduce the total time of the trip, while the result of travel distance analysis showed the route that has a shortest distance to the destination, although the speed limit of the route result is 35 kilometers per hour. Hence, two different routes have been selected as a result of analysis.

5.2 Result of the Closest Facility Analysis

The travel time analysis could find the shortest route from an incident to the required closest facility type, and travel distance analysis identified the shortest route from an incident to the required closest facility type regarding the shortest distance. As an example of closest facility analysis without cut-off value, an incident was selected as Jalan Kemajuan 25 and facility type was the bank. The results of the analysis are depicted in figures 8 (a) and 8(b). The result of travel time based on closest facility analysis identified that the closest bank to the Jalankemajuan 25 was the Hong Leong bank with total travel time of 156 seconds and total travel distance of 2115 meter, while in the travel distance based analysis, Muamalat bank was the closest facility to an incident, with total travel time of 183 seconds and total travel distance of 2110 meter.

5.3 Result of the Closest Facility Analysis with Cut-off Value

Any desired value for cutoff was related to the type of analysis. In fact, the cutoff value identified the travel time buffer or travel distance buffer from an incident to the location. As an example of travel-time and travel-distance based closest facility analysis with respect to cut-off value, an incident was selected as Jalan Kemuliaan and facility type was the hotel with the travel time cut-off value of 200 seconds and travel distance cut-off value of 3000 meters respectively. The result of the analysis is depicted in figures 9(a) and 9(b). The outcome showed that the nearest hotel to the selected incident in terms of travel time was the Rose Cottage hotel, but on travel distance basis, the closest hotel was the U hotel.

6. Conclusion

Over the years, Geographic Information Systems (GIS) technology has been implemented for a variety of purposes within the transportation industry. Most transportation agencies now use GIS, and GIS-T is one of the largest users of GIS technology. The significant innovation that GIS provides is the ability to manage data spatially in layers and then create the network layer to perform network analysis for the purpose of route planning systems. Therefore, all layers can be stored in a geodatabase and a roads layer can be integrated with a points-of-interest layer, enabling a different type of network analysis on the designed network dataset. The other capability of GIS is that enabling the user to create, edit, manage, and automate all the tasks that should be done for the specific analysis in the Model Builder environment. Two of the most popular models are the shortest path and closest facility, which are the main parts of route planning systems. Designing the route planning system, aiding travellers in choosing the optimal path to their destinations in terms of travel distance and travel time has important social and economic benefits. This study showed that a simple user-friendly system can provide complete information of the study area, such as road network and points of interests, and provide vital information about travel time and distance. The travel times on the selected routes showed that the actual travel times were within 3% of the modelled times. For the closest facility analysis with a pre-determined cut-off time, the average difference in time was within 6% and the travel distances were within a 2% difference. These results show that a GIS based routing system can be used with a high degree of confidence.

References

Ahuja, R. K., Mehlhorn, K., Orlin, J. B. and Tarjan, R. E., 1990, Faster Algorithms for the Shortest Path Problem,*JACM*37, 213–223.

Cherkassky, B. V., Goldberg, A. V. and Radzik, T., 1993, *Shortest Paths Algorithms: Theory and Experimental Evaluation*, Technical report 93-1480, Computer Science Department, Stanford University.

Dial, R. B., Glover, F., Karney, D. and Klingman, D., 1979, A Computational Analysis of Alternative Algorithms and Labeling Techniques for Finding Shortest Path Trees, Networks9, 215–248.

Dijkstra, E. W., 1959, A Note on Two Problems in Connection with Graphs, *Numeriche-Mathematik*,1, 269–271.

Gallo, G. and Pallottino, S., 1988, Shortest Paths Algorithms, Ann. Oper. Res. 13, 3–79.

Glover, F., Klingman, D. and Philips, N., 1985, A New Polynomially Bounded Shortest Paths Algorithm, Oper. Res. 33, 65–73.

Goldberg, A. V. and Radzik, T., 1993, A Heuristic Improvement of the Bellman–Ford Algorithm, Appl. Math.Lett.6, 3–6.

Kristof, T., Lowry, M. and Rutherford, G. S., 2005, Assessing the Benefits of Traveller and Transportation Information Systems, Washington State Transportation Center (TRAC), University of Washington, Seattle, Washington, USA, rep. no. WA-RD 597.1, 1- 3.

Mondou, J. F., Crainic,T. G. and Nguyen, S., 1991, Shortest Path Algorithms: A Computational Study with the C Programming Language, Comp. Oper. Res. 18, 767– 786.

Ricci, 1995, Marketing Intelligent Transportation Systems (ITS).*ITE Jornal*, Institute of Transportation Engineers., Graduate Student Papers on Advanced Surface Transportation Systems.

Toppen, A., Jung S., Shah, V. and Wunderlich, K., 2004, Towards a Strategy for Cost- Effective Deployment of ATIS, Transportation Research Record, *Transportation Research Board*, Washington, DC, no. 1899, 27-34.

Zhan, F. B. and Noon, C. E., 1996, Shortest Path Algorithms: An Evaluation using Real Road Networks.