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Journal of Environmental Biology

ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Determining efficient delivery routes in specific time-frames using Geographic Information System

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Publication Info

Paper received:
16 February 2016

Revised received:
27 April 2016

Re-reevised received:
05 May 2016

Accepted:
23 June 2016

Abstract

Perishable products must be transported quickly from its production area to the markets due to the climatic conditions of Malaysia. Deterioration of fresh produce is affected by temperature and delivery time. The cost to achieve such timely delivery of perishable food can affect the revenue of suppliers and retailers. Choosing an efficient delivery route at right time can reduce the total transportation cost. However, insufficient attention has been given to transportation issues with regards to fresh food delivery of greater Kuala Lumpur. The present study involves adoption of the Geographic Information System (GIS) modelling approach to determine the fastest delivery routes for fresh products to several hypermarkets. For this purpose, ArcGIS software was adopted for solving the problem of a complex road networks. With a goal of realizing the shortest time for delivery route planning, impedance function would be integrated by taking into account the time emphasized in the study. The main findings of this study include determination of efficient routes for delivery of fresh vegetables based on minimal drive time. It has been proposed that the fastest route model for delivery of fresh products is based on comparing two time frames within a day. The final output of this research was a map of quickest routes with best delivery time based on two time frames.

Key words

Delivery routes, Fresh vegetables, Geographic information system (GIS), Network analysis

Introduction

Urban consumer demand in Malaysia for fresh, high-quality produce has increased along with higher income and greater awareness of health and nutrition (Tey 2009; Sanusi *et al.,* 1996). In fact, the changes in consumer demands for quality and freshness give rise to significance of an improved delivery of fresh vegetables (Tey, 2009). Prompt delivery of fresh vegetables to the hypermarkets in the city centre to meet this increasing demand is vital.

The present study is focused on the application of network analysis to determine optimal routes based on drive time as related to two specific time frames within the day. The anticipated effect of this research include improvement in the delivery of fresh vegetables to the specified hypermarkets in Kuala Lumpur from the farms located in the study area.

The Malaysian population has experienced remarkable growth and a corresponding increase in car ownership and accompanying traffic congestion (Tey, 2003; Sheng *et al.,* 2008). Transportation via private car is a popular choice and viewed as more convenient than the public transportation currently available in the Klang Valley (Ariffin and Zahari, 2013). Parking and transportation facilities in most urban areas of Malaysia are inadequate (Tey, 2003). This trend seems to be continuing in future if the environment remains the same (Tey, 2003).

Perishable products are affected by temperature variation and transportation time. Hence, it is very important that transportation time is well planned in order to maintain the characteristics of the products when they are received by the consumers (Pimenta, 2010). Perishable produce requires effective decision-making on selecting the best routes for delivery, taking expected delivery time into account. An efficient delivery system can decrease the chances of vehicle to encounter high traffic density on their route. This can be applied to main routes leading to Kuala Lumpur which hold traffic peaks in certain time-frames.

The model proposed in the present study assessed and evaluated traffic congestion patterns among possible produce delivery routes as compared between two separate time frames of the day. Thus, the decision maker was equipped with results generated from GIS model, which assisted them in deciding the most efficient route in terms of time-efficiency and accumulated distance. The most significant reason for applying network analysis and route planning in transportation is that the businesses are interested in determining the best route to minimize cost and time (Memon, 2005).

Fresh products often deteriorate, due to extended travel times and frequent stops to serve customers, during the delivery process (Hsu *et al.,* 2007). This is especially true in tropical climates prevailing in Malaysia. The main objective of the present research was to identify the quickest route for delivery of fresh vegetables in this part of Malaysia, taking selected time frames into consideration.

Visualization helps people to approach problems in the dimensions of space and time in the form of digital maps instead of dimensionally-restricted data tables and graphs (Han, 2001). Digital maps are based on ideas such as layers; projection, generalization, and symbolization which are prevalent in GIS and account for a large proportion of the capabilities in GIS (Goodchild *et al.,* 2007).

The cost of fossil fuel has rose over the past few decades. Vehicle fuel consumption is approximately 30% greater under heavy congestion conditions, especially during peak hours, resulting in delay. A research was conducted on the effect of different levels of traffic on delay time to identify the ideal routes in static and dynamic traffic networks, with the parameters consisting of drive time and fuel cost. The program approach in visual basic guides and the users to select the best routes after the user pick up from the origin and deliver to the destination (Shokri *et al.,* 2009).

Winyoopradist and Siangsuebchart (1999) developed a model on Network Analyst based on vehicle speed at different times of the day. In their work, the Network Analyst tool has the capability of calculating the shortest traveling time between two locations by specifying the starting time. The focus was on the speed patterns on some roads at different times of a day and different days of the week. (Echols, 2003) developed a GIS application to determine the quickest route between two destinations based on distance and travel time. However, Echols' application did not include land use as a variable for calculating optimal transportation routes.

GIS technology was applied to determine optimal transportation routes and proposed a GIS model for nuclear waste transport route selection. The weighting method was applied in this process. Akay *et al.* (2012) proposed a GIS model based on a Decision Support System (DSS) to assist fire-fighters. Akay's research found that the GIS approach did not mitigate the routing problem. Memon (2005) also applied GIS to the field of transportation to determine optimal roads among sets of routes. In Memon's research, the average speed of vehicles was not considered for the road networks. One factor included in this study that was not included in the GIS application Akay, Memon is the average speed of vehicles from the estimation process of determining the final routes. We believe that this factor will aid in the application of GIS to determine the best routes at the best time period studied.

To solve the routing problems and find the most suitable paths for dispatching fresh produce, several methods have been applied. Although the GIS system provides calculations that result in visual solutions, which users can utilize to make prompt decisions. Osvald and Stirn (2008) studied distribution of fresh vegetables. Belenguer *et al.,* (2005) studied delivery routes for meat industry, while Tarantilis and Kiranoudis (2001) analysed distribution of fresh milk. The objective of their study was route scheduling to find a set of routes that minimize the total cost of delivering fresh milk from a single factory to supermarkets. Incidentally, Tarantilis and Kiranoudis (2002) solved a fresh meat distribution problem by applying several algorithms from their milk delivery system to identify optimal sets of routes for meat delivery. The objective was to frame a set of routes that minimized the total travelling by vehicle. Some issues regarding the food distribution studies are that network analysis was not applied in mapping the most appropriate routes, and spatial data like road networks was not utilized in determining optimal routes. Moreover, other parameters that have impact on traffic issues, such as population density, were not considered.

Study on milk collection in dairy industry was also conducted (Butler *et al.,* 2005). The adoption of Information Technology (IT) in Butler's finding facilitated the data collection, manipulation, and building of DSS to support logistics management in milk collection sector. However, Butler's study did not include drive time based on traffic data, which might have further aided the researchers in solving the milk routing problem. The present study included this parameter for further utilizing IT and GIS as tools to solve the problems of food distribution.

Application of the ArcGIS Network Analysis tool for modelling route optimization was developed by Bhambulkar (2011) to identify the best routing and has been applied to municipal waste collection. Sharifi (2009) identified site selection of hazardous waste disposal using GIS technology for land use suitability and presented a multi-criteria decision analysis with spatial data for the best selection of suitable sites for waste material landfills. In trip generation, a study was conducted to determine the peak hour trip and models in the area of UTM campus. The main goal of this study was to establish the trip generation from off campus residential area to the center of the campus by students and employees (Tey, 2003).

Using regression model in traffic management, Sofia *et al.* (2013) analyzed the problem of optimal routes associated with transportation. Minimizing the distance and drive time at the same time was the main goal of their study.

Approaches to address bus routing problems include estimation of bus route and network travel time using micro-simulation (Hawas, 2013). This contribution predicted the effectiveness of bus route design using traffic indicators.

Materials and Methods

Study area : The study area is Kuala Lumpur, and it encompasses producers of fresh vegetables, as well as hypermarkets as final delivery destinations together with road networks. The main fresh vegetable production area is a 5 ha farm located in Labu area in Seremban, approximately 60 km from designated hypermarkets and supermarkets in Kuala Lumpur. Fig.1 represents the map of the current study area. Most of the hypermarkets are located in this area.

Data collection : The first column in Table 1 details the spatial data that is included in the base map, namely the road network data. The road network data was spatially organized by a contracted GIS map vendor. This data was then layered with spatial land use data including market locations.

The non-spatial data consisted of attributes that were complementary and related to the spatial data. In this regard, the factor comprising distribution cost was drive time. Drive time included several parameters such as specific travel distance and vehicle speed along the way. The other parameter considered in the model was the time frames affect on drive time. For collecting data on speed of a vehicle along the road network, the average speed of vehicles in two periods were taken into account. Data regarding time frames was gathered from the Ministry of Transportation and traffic management (DBKL), while data regarding time frames for missing roads was collected from several field trips and surveys. All the data on average speed was stored in an attribute table in ArcGIS software for further analysis.

With the shortest time as a goal of route planning for delivery purposes, the impedance functions was integrated by taking into account the road length and average speed of a transportation vehicle that affected driving efficiencies .

To calculate drive time based on the average speed of a vehicle, the distance was divided by average speed of each vehicle. The travel times towards all destinations were determined by collecting data as per different parameters. The results for drive time were in minutes, that means the time that a vehicle would spend on a path from one point to another is also given in minutes. The calculation was based on the following formula :

(Length /Average speed based on time patterns) x 60 ... Eq. 1

The aforementioned formula describes length as the distance for each road networks and average speed of a vehicle in two time frames in a day along a road. The result was the drive time for each road network in the database of ArcGIS.

Table 1 : Attribute table of spatial and non spatial data

Type of data	
Spatial data (Feature)	**Non-Spatial Data (Theme)**
Base Map • Road Network	Drive Time: • The average speed along the routes • Drive time • Time patterns for delivery
Land use Map • Market locations	• Name of the hypermarkets

The travel time fluctuated during day, was affected by different factors of traffic, such as vehicle volumes. It classified all the roads into four classes of speed. The maximum average speed for a truck or lorry in this study was not be more than 80 km hr^{-1}. This speed limit is the highest speed allowed in Malaysia for road vehicles. National speed limits are a set of speed limits applicable on Malaysian express ways, federal roads and municipal roads (Syafiq, 2007). For data were collect from Ministry of Transportation and traffic management (DBKL).

Figure 2 shows the average speed of the vehicle for all road networks in Selangor District. The Map illustrates classification of average speed of the vehicles for the whole road networks. The speed for roads was categorized into four classes. The maximum speed along the road networks was 80 km hr^{-1} according to the speed limit regulation in Malaysia for the Lorries. The minimum speed of the vehicle was 10 km hr^{-1} for the same roads in Kuala Lumpur. Like any other countries in the world, failing to obey the speed limits on Malaysian roads and expressways is an offence as per Malaysian Road Safety Act 1987. The calculation below is based on the average speed of the car for selected roads.

ArcGIS Software : ArcGIS software was used for solving the problem of a complex network. Using ArcGIS software with the extension of Network Analyst was the primary key to explore the data. Its basic mapping functionality and advanced GIS capabilities allow the user to create maps, showing the created maps, showing the data and integrate them and finally to see the data in a powerful way. ArcGIS enables to propose the research attractively. It has been found that geographical communication is a powerful way to inform and motivate others.

Model development : The initial development process for spatial data contained information about the base map (digital map) : Road networks and transportation layer and Land use layers.

All these layers overlapped each other and needed accurate classification in order to prepare the data for analysis.

The next process was preparation of non–spatial data, which was made up of the following information: The number and names of hypermarkets in the study location; speed of the car between 7 a.m. to 10 a.m.; speed of the car

Table 2 : Attribute table of data analysis in ArcGIS

Route	Number of markets	Time 7 to 10	Time 10 to 12	Distance 7 to 10	Distance 10 to 12	Distance impedance	Time for the distance impedance
1	3	25 min	19 min	20.6 km	21 km	19.1 km	19 min
2	4	36 min	26 min	31.2 km	31.6 km	27.7 km	27 min
3	5	47 min	35 min	38.5 km	39 km	35 km	37 min
4	6	56 min	42 min	44.1 km	44.9 km	40.6 km	45 min
5	7	1 Hr	45 min	47.1 km	47.9 km	43.6 km	48 min
6	8	1 Hr & 3 min	47 min	49 km	49.8 km	45.3 km	50 min
7	9	1 Hr & 16 min	56 min	58.4 km	59.1 km	54.6 km	59 min
8	10	1 Hr & 18 min	57 min	60.5 km	61.2 km	56.6 km	1 Hr 1 min
9	11	1 Hr & 25 min	1 Hr 1 min	63.2 km	63.9 km	59.2 km	1 Hr 5 min
10	12	1 Hr 35 min	1 Hr 7 min	71.5 km	71 km	66 km	1 Hr 16 min
11	13	1 Hr 43 min	1 Hr 14 min	75.8 km	75.4 km	70 km	1 Hr 52 min
12	14	2 Hr 2 min	1 Hr 26 min	90.7 km	90.7 km	84.5 km	1 Hr 40 min
13	15	2 Hr 14 min	1 Hr 35 min	98.7 km	98.7 km	92.5 km	1 Hr 49 min
14	16	2 Hr 19 min	1 Hr 39 min	101.2 km	101.2 km	95 km	1 Hr 54 min
15	17	2 Hr 25 min	1 Hr 45 min	104.8 km	104.8 km	98.6 km	2 Hr
16	18	2 Hr 32 min	1 Hr Hr 50	109 km	109 km	102.8 km	2 Hr 5 min
17	19	2 Hr 48 min	2 Hr 2 min	118.9 km	119.5 km	112.2 km	2 Hr 18min
18	20	3 Hr 3 min	2 Hr 11 min	125.1 km	125.8 km	118.5 km	2 Hr 29 min
19	21	3 Hr 9 min	2 Hr 14 min	128.9 km	128.2 km	120.9 km	2 Hr 31 min
20	22	3 Hr 20 min	2 Hr 21 min	134.4 km	133.7 km	125 km	2 Hr 39 min
21	23	3 Hr 22 min	2 Hr 23 min	135.4 km	134.7 km	126 km	2 Hr 41 min
22	24	3 Hr 30 min	2 Hr 30 min	140.9 km	140.3 km	131.6 km	2 Hr 49 min
23	25	3 Hr 33 min	2 Hr 33 min	143.6 km	142.9 km	134.1 km	2 Hr 51 min
24	26	3 Hr 50 min	2 Hr 45 min	157 km	157 km	147.6 km	3 Hr 4 min
25	27	3 Hr 53 min	2 Hr 47 min	160 km	160 km	149.9 km	3 Hr 6 min

between 10 a.m. to 12 noon and the drive time

After combining spatial and non-spatial data with the help of GIS technology, distribution management was conducted and optimal routes based on the study requirements were selected. GIS helps the users to think geographically as opposed to analyze data which is critically important in distribution planning. The system development approach applied in this study and the group of procedures in general is presented in Fig. 3.

Development of Database Management System (DBMS) : Table 2 determines selection of hypermarkets for analyzing delivery time and distance for each group of markets. The second column of the table describes the number of hypermarkets being selected for modelling. The third column describes the time taken for selecting three hypermarkets from 7 a.m. to 10 a.m. So, the calculation of drive time takes into account of three hypermarkets. The process continues by selecting hypermarkets. The fourth column includes selection of hypermarkets between 10a.m. - 12 noon. In the 5th column, the distance for selecting of markets between 7a.m. - 10a.m has been given. The 6th column in the table describes the distance of selected markets between 10a.m.-12noon. The 7th column includes the results based on time impedance of software for selected markets. The last column describes time impedance in ArcGIS software for selected markets.

Results and Discussion

Comparison results : To evaluate the effect of impedance modeling time pattern in two different periods of time and to compare this approach with normal approach based on distance, 25 different routes, including 3 to 27 hypermarkets were considered for calculating the time and distance. The time and distance for all these 25 routes were calculated for 7.00 a.m. to 10.00 a.m., 10.00 a.m. to 12.00 noon and estimation in distance-based model. The estimated time for these three situations were compared using repeated measurements of ANOVA, and the results showed a significant difference between the average of delivery times among these 3 methods ($F= 79.605$ $p<0.01$). The lowest average of the estimated time belonged to 10 a.m.-12 noon ($M=93.2$), which was significantly lower than other methods, followed by the distance-based estimation ($M=105.4$), while the highest estimated delivery time was observed for 7a.m. to 10a.m. ($M=129.76$). Table 3 shows that the drive time in 7 a.m.-10 a.m. was greater than 10 a.m.-12 noon. The results of statistical analysis in Table 3 shows the significance at 0.05 level in comparison with the two time frames.

Fig. 4, shows the estimated time for these three approaches for all 25 routes and for all 27 hypermarkets in Selangor. The delivery services starts with three hypermarkets, and in every process, one hypermarket were added to the network analysis tool. As shown in the graphical representation (Fig. 4), whenever the amount of hypermarkets increased, then the total drive time for 7-10 a.m. increased as well. If the speed of a vehicle along a route at 1000-1200 differed, then the calculation for selecting the best routes for the delivery of fresh vegetables differed as well. This part of analysis resulted in decreased drive time on the roads for the delivery of fresh vegetables. From statistics, it was determined that times between 10.00 am-12.00 noon significantly influenced the total travel time, which makes it necessary for us to model the best routes for delivery purposes based on GIS. The system was capable of adjusting the location of the hypermarkets as per destinations at any possible time.

The first selection of routes for the delivery of fresh vegetables was based on the distance as its impedance. The final result obtained from statistical analysis revealed that distance has significant value, and influenced drive time for delivery purpose. The estimated distance for these three situations were compared using repeated measurement by ANOVA, and the results showed significant difference between the averages of distance among these three methods ($F= 177.016$ $p<0.01$). There was no significant difference for the distance between two impedance patterns, and distance based model had lower estimated distance for all the routes.

Fig. 5 shows the estimated distance for these three approaches for all 25 routes for all 27 hyper markets. The

Table 3 : Bonferroni post hoc test for comparing among different models for estimated time

(I) time	(J) time	Mean Difference (I-J)	Std. Error	P value
7a.m. to 10a.m.	10am to 12noon	36.560*	3.863	<0.01
7a.m. to 10a.m.	Distance based	24.360*	2.874	<0.01
10a.m. to 12noon	Distance based	-12.200*	1.764	<0.01

Table 4 : Bonferroni post hoc test for comparing among different models for estimated distance

(I) time	(J) time	Mean Difference (I-J)	Std. Error	P value
7a.m. to 10a.m.	10a.m. to 12a.m.	-0.112	0.11	<0.01
7a.m. to 10a.m.	Distance based	6.064*	0.489	<0.01
10a.m. to 12noon	Distance based	6.176*	0.414	<0.01

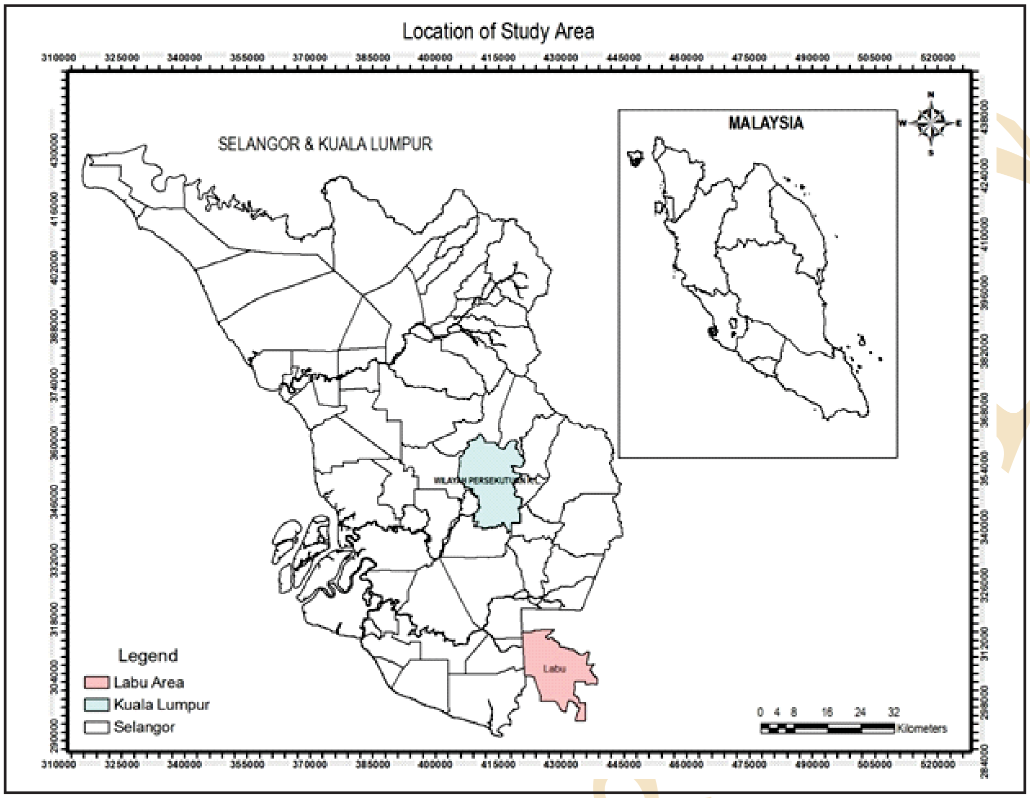

Fig. 1 : Study area

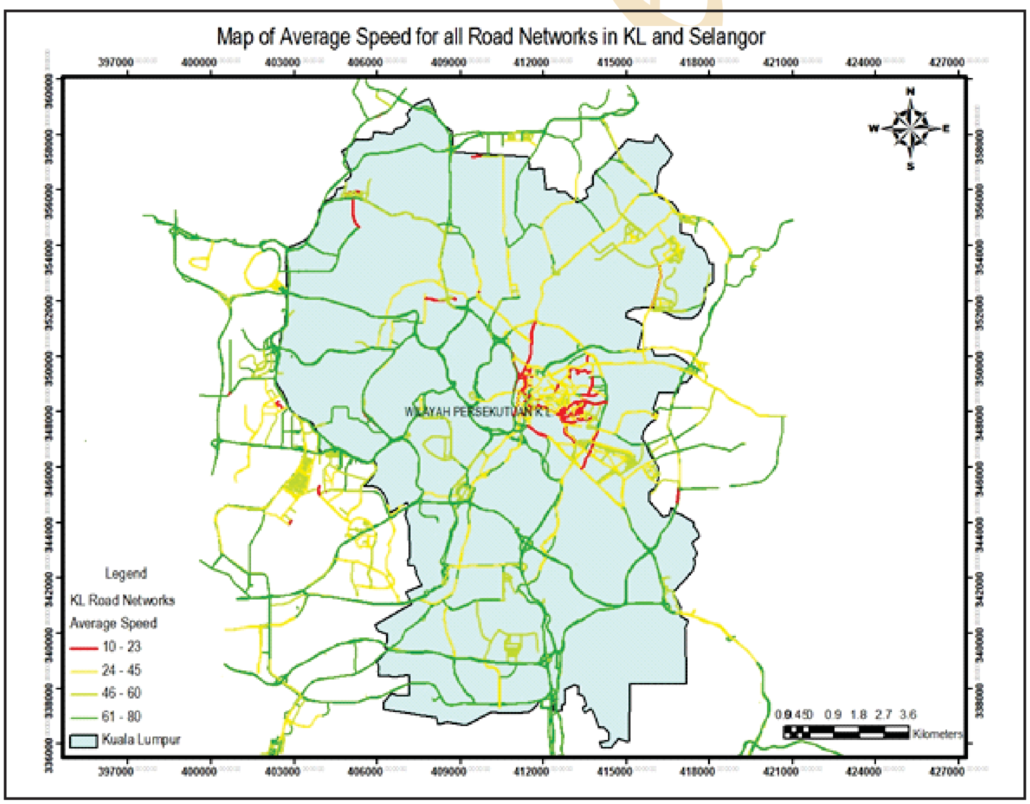

Fig. 2 : Map of Average speed for road networks

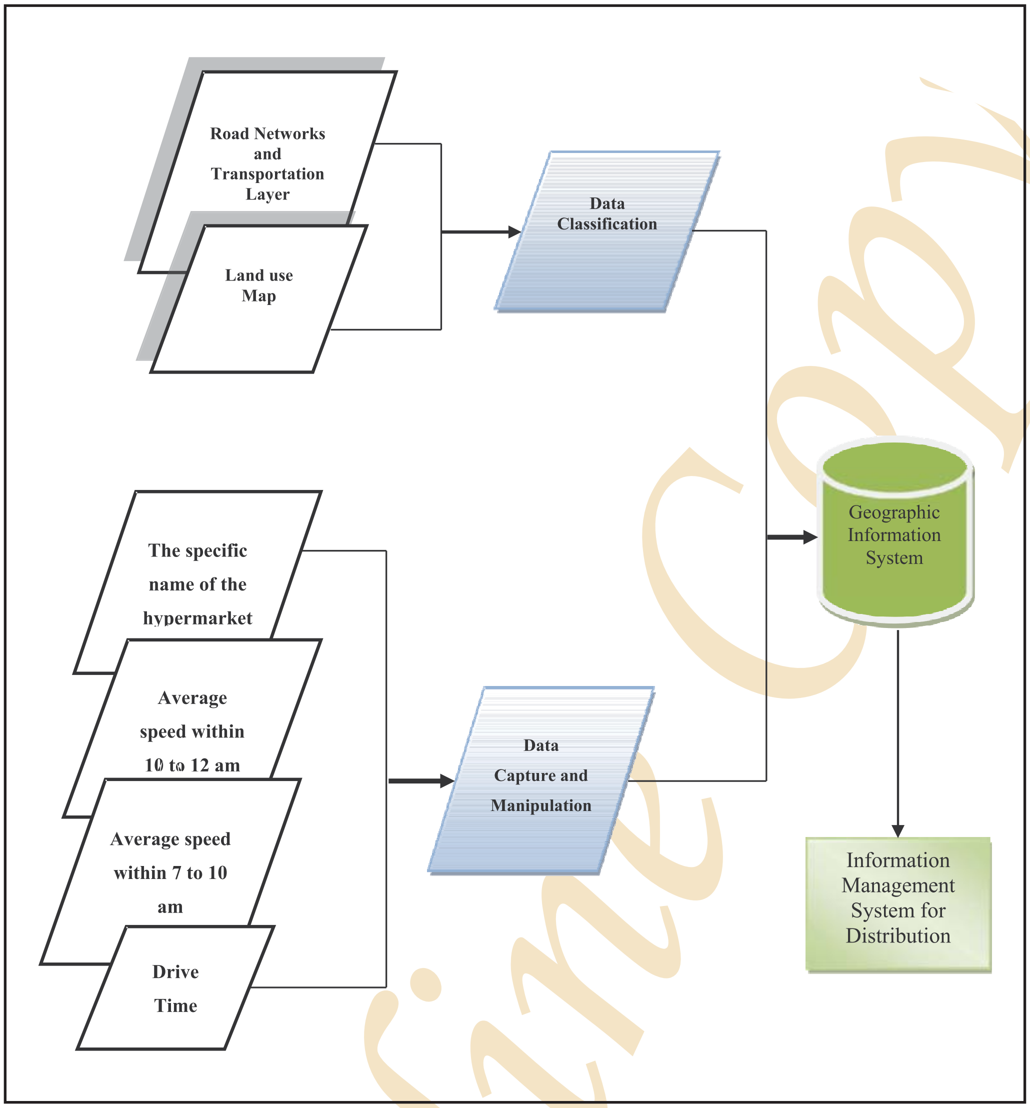

Fig. 3 : Conceptual framework

figure shows that there were no significant differences when distance as impedance in GIS was considered. In addition, comparing the two time frames based on distance means, there were no significant difference in this case.

GIS modelling : Figure 6 depicts the best routes after taking into account the time frame variable on the road network. The average drive time was calculated by dividing the speed of the vehicle by the traveled distance. The average speed of a vehicle was affected by several parameters on the road. The figure also describes the delivery routes and their directions during 10 a.m. to 12 noon traffic time pattern. The black colors indicates the road networks in Kualampur and Selangor areas. The transparent yellow color indicates the routes according to time impedance for delivery of fresh vegetables. However, for Carrefour markets, it was compulsory that the delivery services reached the customers before noon each day. This prompted the delivery manager of the company to send all the fresh vegetables to markets before noon. The hypermarkets refused to accept any fresh vegetables after noon, as per the rules and regulation in Malaysia.

The total time and the total driving time in every possible delivery directions at 10 a.m.-12 noon is detailed in the timetable of Fig. 7. The final destinations or the hypermarkets were selected by the delivery manager based on their respective demands and corresponding time. It was determined that the total time a vehicle would have to spend on a road was 2 hrs and 47 mins for a total distance of 159.9 km.

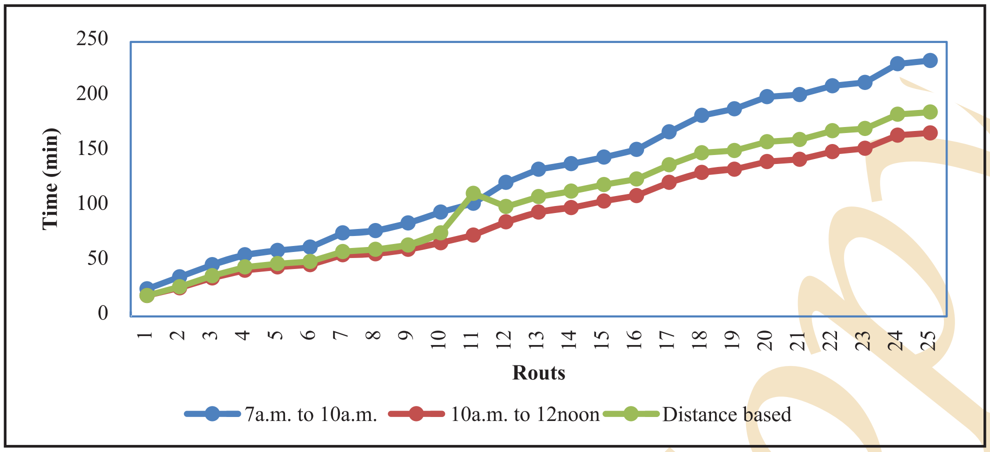

Fig. 4 : Comparing of delivery time among three methods

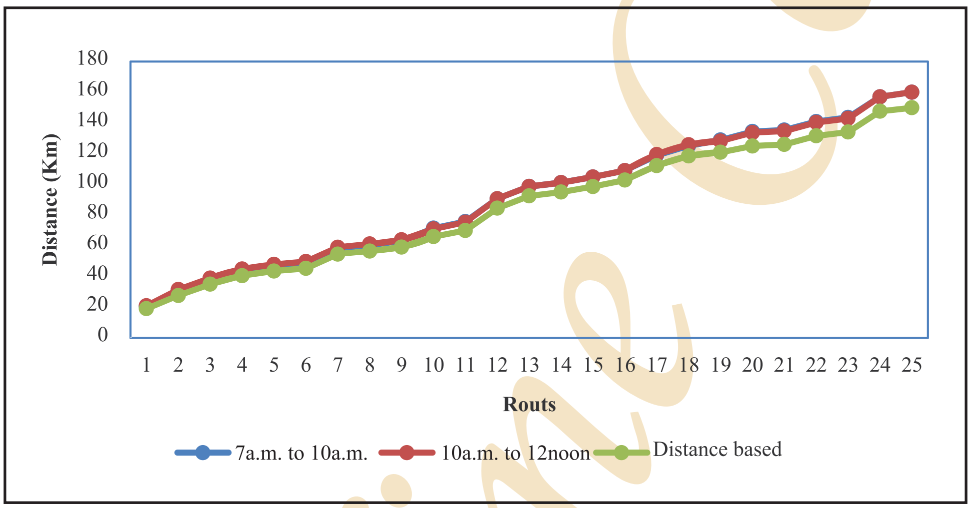

Fig. 5 : Comparing of estimated distance among three methods

According to the coefficients obtained from statistical analysis for the independent variables, it was observed that two variables for the velocity of the vehicles were at a significant error level of 1% and the sign obtained from them confirmed this anticipation. In other words, considering the obtained negative coefficient, it has been concluded that the increased speed of automobile reduces transportation time of the product. But, since the absolute value of the obtained coefficient for the speed during 10 am to 12 noon was higher than the speed during 7 am to 10 am, it is concluded that change of speed during 10 am to 12 noon had a higher effect in reducing the transportation time. Based on the amounts of coefficients, 1% increase of speed between 7am to 10 am would reduce transportation time up to 6%. That's why 1% increase of speed during 10 am to 12 pm caused 53% reduction in the transmission time. The time period of 10 am to 12 pm was more suitable time for transportation of vegetables, considering the need for minimization of travel time for perishable products.

Conclusion : In this study it has been demonstrated how GIS is applied in order to obtain the best calculation results to derive the fastest delivery service routes. It has been recognized that the shortest distance does not always provide the best solution due to extra time consumed as a result of traffic conditions. The GIS network analysis illustrates that the time period of 10 am to 12 noon is regarded as a more suitable time for the transportation of vegetables as compared to the time during 7 am to 10 am. The result showed that the total drive time for a vehicle during 7am to 10 am is greater during 10 am to 12 noon. This is due to the fact that the average speed of a truck becomes slower during 7 am to 10 am along the roads compared to timing during11 am to 12 pm. Moreover, this study demonstrates how a decision maker should choose the best routes to deliver fresh vegetables based on the criteria and constraints presented in this analysis. Network analysis helps users to identify the shortest distances and simultaneously the fastest routes to markets, and also provides information about road directions based on

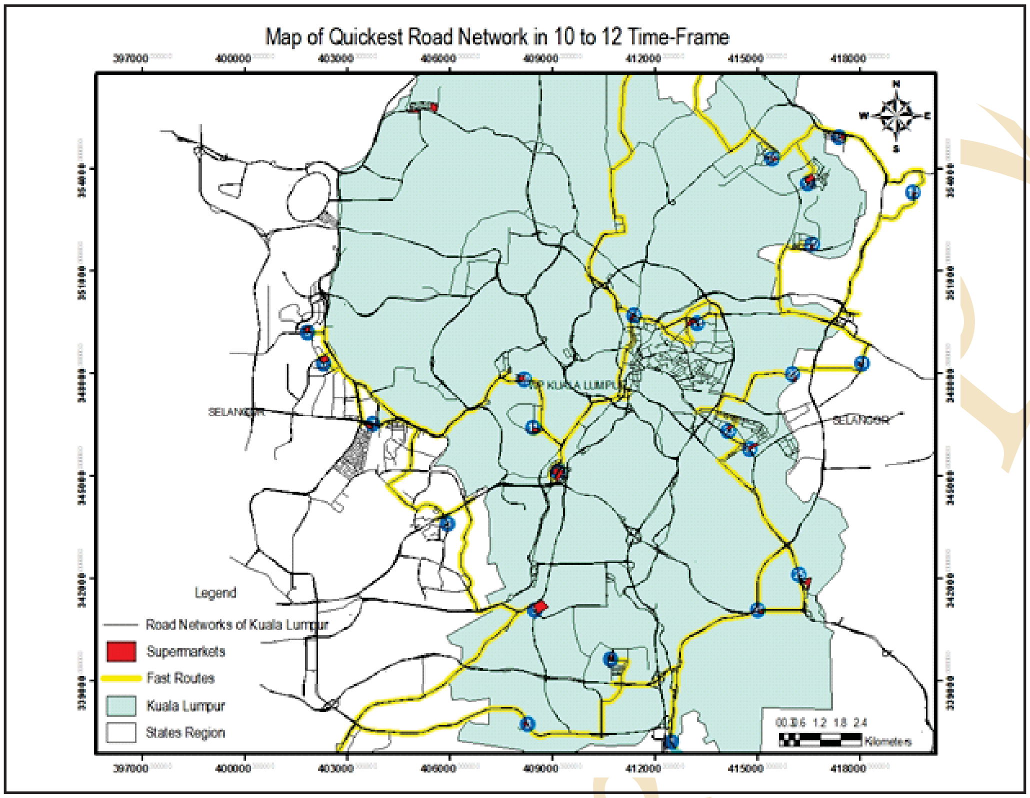

Fig. 6 : Map of Fast routes at 10-12 time

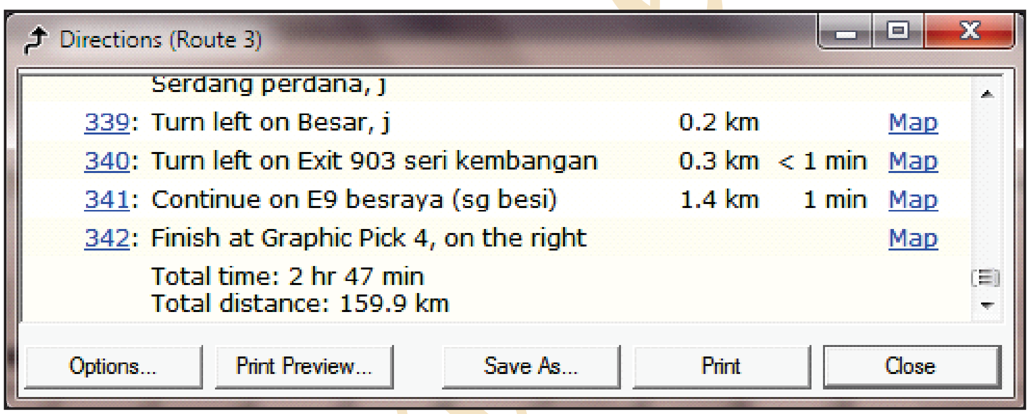

Fig. 7 : Directions and total distance and time at 10a.m.-12noon

data collected in the attribute table by different types of maps. The advantage of the present study is that the focus was directed toward the use of spatial data to provide visual output by producing several maps and analyzing the results. It is expected that this GIS application can be disseminated to the farmers that will to help them in their decision-making regarding transportation of produce to the hypermarkets of Kuala Lumpur. If this finding is effective in helping farmers to transport their fresh produce to meet the growing demand in Kuala Lumpur, the data analysis methods can be used in other municipalities elsewhere to improve the efficacy of transportation of produce. The possibilities of this GIS model could help is nutrition and food security issues worldwide.

Acknowledgments

I would like to thank the center of production vegetables "Sime Darby Bhd" for providing generous support of data collection, guidance and valuable references of market places in Kuala Lumpur city and Selangor district. I especially appreciate the Ministry of Transportation and traffic monitoring management (DBKL) in Kuala Lumpur

for providing the traffic data as well the average speed of the cars in different time.

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