Route selection for road vehicle real-driving emissions test using GIS

N Yusof[1], M A Abas[2], N A Rohana[1] and M R Mohd Perang[2]

[1] Faculty of Built Environment and Surveying, University Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[2] Automotive Development Centre, Institute for Vehicle Systems and Engineering, University Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Corresponding author: azman.abas@utm.my

Abstract. The European Commission has developed a Real-Driving Emissions (RDE) test for road vehicles that complies with the urban, rural and motorway criteria to ensure the exhaust emission produced could be accurately evaluated. Therefore, careful measures are taken in selecting the best routes to ensure the testing fulfils the targeted criteria. As there is no common method exist to select the testing route, analysis on the testing route selection was implemented using Geographic Information System (GIS) platform that is capable to deal with large vector data. Thus, the proposed framework facilitates the testing route selection process which is difficult to determine without a proper spatial analysis of network data. Specific route information comprises of road categories, route speed range and route classes were collected from the Open StreetMap (OSM) database. The generated route density and the topological route network structure were used to further analyse the suitability route as the requirement of Real-Driving Emissions test. As a result, five candidates of Real-Driving Emissions test route have been selected in Malaysia as a case study using GIS platform.

1. Introduction

Drive cycles are commonly derived from vehicle data collection during actual driving condition along predetermined routes within the area of study [1]. As a result, a drive cycle may not represent other areas than the intended areas. The influential factors of an area, such as the development of infrastructures, topography, population and economic growth may evolve through time which is expected to affect the traffic congestion [2, 3] and consequently vary the driving conditions and upset the representative of the emission results produced by the drive cycles. Discrepancies of drive cycle type-approval test results have been reported due to the differences in driving behaviour, ambient conditions and vehicle used conditions. In 2012, the International Council on Clean Transportation (ICCT) has reported discrepancies up to 21% between type-approval and real-world fuel consumption in Germany [3] while other studies also highlighted on the discrepancies of the representativeness of drive cycles [4-6]. Latest investigation in 2016 conducted by the Department of Transport UK has identified the emission results based on the New European Driving Cycle (NEDC) test conducted on a track are considerably higher compared to the test conducted in a laboratory. This clearly proves there are certain substantial conditions that are not best being simulated in a laboratory. Even with the latest improvements, drive cycles have not reached a level to represent a perfect world driving condition [4]. As such, there is a necessity to have a genuine assessment that could evaluate the exhaust emission produced during real-world driving instead of controlled environment in laboratory. Thus, the European Commission has developed a RDE test as the contingency to complement the World-wide harmonized Light duty vehicles Test Procedure (WLTP) in ensuring that the exhaust emission being produced on actual 37 road could be accurately evaluated.

RDE is a vehicle emission test to measure the tailpipe pollutant during real-world driving on actual roads which have been selected to cover broader coverage conditions than the WLTP [7]. The RDE is conducted by driving the vehicle over the normal driving pattern and payload while measuring the exhaust emission using an installed Portable Emission Measurement System (PEMS) in the vehicle. On the other hand, WLTP is conducted under a controlled environment in a laboratory following certain procedures to ensure consistency and repeatability of the test. Contrary to the WLTP, the RDE is conducted in the actual environment conditions; traffic, climate, infrastructures and topography which is why it is believed that RDE has a higher priority [8]. As reported in [9], other regions of the world have also started to digest the RDE according to respective legislations. China especially, remaining as the world's largest car market [10] has adopted the RDE test with modifications by including China driving conditions. The conformity factor for nitrogen oxide (NOx) and particle number (PN) have been set to 2.1 but will not be enforced until 2023. In India, the draft version of Bharat VI was developed based on the RDE which will be implemented in 2020. Meanwhile, South Korea and Taiwan are still considering in adopting the RDE testing requirements into the upcoming vehicle emission legislations. According to the RDE test procedure specified in Commission Regulation EU 2016/427, the trip requirement must be consisted of urban, rural and motorway sections as listed in Table 1 while Table 2 highlights the boundary conditions. Complying with the European Union requirements, careful measures on the method to select the route was taken in this study. Therefore, this paper aims to provide a provision for the possible implementation of RDE in Malaysia vehicle emission legislation in future as a case study. Driving routes within Malaysia were analytically selected in this study to perform the Malaysia RDE test according to the guideline provided in EU 2016/427. This study has utilized the detail route geometry information of the study area for identifying the most suitable driving route. The route selection analysis was implemented using GIS) platform that is capable to deal with large vector data. Thus, the proposed framework can facilitate the driving route selection process which previously difficult to determine without a proper spatial analysis of network data.

Table 1. General requirements of RDE test.

Subject	Urban	Rural	Motorway
Vehicle speed range	≤ 60 km/h	61 – 90 km/h	≥ 91 km/h
Trip composition	34%	33%	33%
Average vehicle speed	15 – 40 km/h		
Distance	≥ 16 km/h	≥ 16 km/h	≥ 16 km/h
Distance share	29% – 44%	23% – 43%	23% – 43%
Road type	Paved or street only		
Driving time	Weekdays with recommendation at 07:00 am		
Total trip duration	90 – 120 minutes		

2. Methodology

The test routes selection in this study were initiated by interpreting the information obtained from a traffic survey in Road Traffic Volume Malaysia (RTVM) report [11]. The report consists of statistics over most and important routes in Malaysia which quantifies the characteristics of the traffic flow such as the vehicle volume, vehicle categories, time and infrastructures. The surveys are mostly conducted by the government or city authorities as part of urban and transportation infrastructure development.

From the total of 554 traffic census stations conducted in 2014 on Federal Roads and Stated Roads across Malaysia, Kuala Lumpur as the capital state of Malaysia has the highest average count of 182,900 vehicles per station, where 78.8% of the counted vehicles are passenger cars and 6.6% are small vans and utilities. Meanwhile Selangor state is known to have the highest population in Malaysia [11], has the highest census; 127 station counts of 357,032 vehicles over the period of 16 hours (06:00 am – 10:00 pm), where 79% of the counted vehicles are passenger cars and 4.9% are vans and utilities. Therefore, Kuala Lumpur and Selangor states which are situated next to each other have been selected as the area for this study. To classify the urban, rural and motorway environments within the Kuala Lumpur and Selangor states, this study refers to the urban and rural areas based on the topographic map published by the Department of Survey and Mapping Malaysia. Whereas for the motorway operation, it refers to the declaration of expressway by the Ministry of Works Malaysia.

The overall framework for selecting RDE test route consists of three main phases. Firstly, the types of routes within the study area were identified and then, these routes were grouped into specific classes according to the route characteristics. Secondly, the route density was produced for mapping the entire route patterns and divided the density map into sub-areas. Finally, the identification of optimal route for RDE test was performed according to the standard trip composition guideline and topological structure of route network. The detail description for each phase is explained in the following sub-sections.

Table 2. Highlights of RDE boundary conditions.

Conditions	Requirement
Vehicle payload	Consist of driver, a witness and test equipment.
Moderate ambient	Altitude lower or equal to 700 m above sea level. Altitude elevation range between start and end point ≤ 700 m. Ambient temperature 0 – 30 °C.
Dynamic	Verification of road grade, headwind and driving dynamics.
Vehicle and operation	The air conditioning system or other auxiliary devices shall be operated normally. The recommended temperature for the comfort of the passenger is in the range of 20 – 24 °C. Use market fuel, oil and reagent following the recommendations of the vehicle manufacturer. Recommended to use the predominant mode, the *D* (drive) mode for automatic transmissions. Vehicles should not be tested with an empty battery. The tyre types and pressure shall be according to the vehicles manufacturer recommendations.

2.1 Route Network Categories

For conducting the Malaysia RDE test, specific driving routes were selected within the Klang Valley. The Klang Valley is the second-largest economy hub in Malaysia. It has the highest average count of vehicles and the largest route network in Malaysia. The vector data of route networks were obtained from the OSM. OSM is a freely available open-world map database for public users [12]. The route networks within the study area were downloaded and stored in the GIS platform. The route network structures are determined by the function serves from the network. Typically, the route structures are changed based on the location and therefore, the connection with different types of street network can be different too. Since the varying degree of connectivity in different region, study on route network structure has mainly focused on three elements: hierarchical structure, connection structure and layout structure [13, 14]. In this study, the hierarchical and connection structures were considered for analysing the topological relationship of the route network. Generally, Malaysia route networks are categorized into urban and rural where each category is characterized based on their hierarchical network structure

[15] as shown in Table 3. Based on the general requirement of RDE test (Table 1), the distribution of vector routes map was generated from five different route levels which have been selected according to speed range. For generalization, these routes were categorized into three main categories: urban, rural and expressway as shown in Table 4.

Table 3. Route network categories.

Rural	Urban
Expressway	Expressway
Highway	Arterial
Primary road	Collector
Secondary road	Local street
Minor road	

Table 4. Route types associated with vehicle speed range.

Road levels	Speed (km/h)	Category
Local street	40 – 60	Urban
Collector road	60 – 70	Urban
Arterial	70 – 80	Urban
Primary road	70 – 80	Rural
Express highway	90 – 110	Expressway

2.2 Spatial Analysis for Input Data

2.2.1 Route Density. Further analysis was performed on these route networks before the final RDE route test can be obtained. The initial step was to generate the route density within the study area. The density analysis is intended to spot the existing of peaks in the network distribution [16] and the possible to associate them with the distribution of traffic flow. The route density was computed using line density analysis. Line density refers to the ratio of the total length of the centreline of routes to the land area. The applied density formula is (Equation 1) [17]:

$$Density = \sum_{n=1}^{n} L_i \,/ \sum_{j=1}^{n} A_j \quad (1)$$

where L is the total of the road centreline in km, and A is the land area in km^2. The line density is widely used method for line features to compute the value of a unit area in the form of grid-based surface. The route density unit is based on the linear unit of the output spatial reference, length per unit of area. The spatial resolution of the route density raster layer was 30 m *x* 30 m. The generated route density can provide a better understanding of spatial patterns drawn by the networks. These spatial patterns are used to visualize the concentration of route networks at different locations in the study area.

Based upon the route density, the equal interval classification method was used to generate route patterns. The route patterns were presented into three main density classes: Low, Moderate and High. The produced density classes were used to discriminate the actual state of spatial route networks distribution and thereby distinguished the degree of connectivity within the routes in different regions in the city [18]. High density normally indicates high composition of route networks, while low density area is mainly due to simple layout structure of the networks.

To facilitate the route selection, an additional grid layer was used to overlay the route density raster layer. This grid layer comprised of 5 *x* 5 sub-grids that were used to divide the study area into equal size of subset area.

2.2.2 Distribution of Vehicle Samples from GPS Collection. Digital data collection using in-vehicle Global Positioning Sensor (GPS) is widely used due to their large coverage, good continuity, low cost and informative on the vehicles' movements [19] (Bandeira et al. 2013). For instance, [20, 21] have used in-vehicle GPS in their study for mapping vehicle trajectories. Currently, most in-vehicle GPS is equipped with high-frequency receiver (less than 15 second interval) that can provide more accurate estimation because it reflects the instantaneous vehicles condition (i.e., acceleration, deceleration, cruise and idle). In this study, 17 number of passenger vehicles with different models (below 1.3 L) were used to map their daily travelling within the study area. The GPS data was collected from 7th November 2017 until 8th November 2018. This data consists of four reading parameters namely, logged data, logged time, longitude, latitude and speed. To visualize the vehicles movements, the collected data was transformed into point features using GIS software so that these features can be overlaid on the route networks. Hence, the resulted map of vehicle movement can gain insight of human driving behaviour such as their preferred or common routes to travel in daily basis.

2.3 Route Selection for RDE Test

The examination of selecting suitable RDE test route was done in two steps: 1) comparison between areas (sub-grids) with different network structures, and 2) comparison between different route conditions within the sub-grid that deriving the network space. The following sections explain the detail procedures in each step.

2.3.1 Step 1: Selection of Suitable Area (Sub-Grid). To identify a sub-grid with optimized route network, the percentage of each route category (P_c) correspond to each sub-grid was computed. The percentage is calculated using the following formula (Equation 2):

$$P_c = Dist_c / Dist_r \quad (2)$$

where $Dist_c$ is referred as route distance for each route category *c* and $Dist_r$ is the total route *r* distance within the sub-grid area. The percentage values of sub-grid were compared with the standard trip composition guideline in Table 1. Then, the similarity for selecting the optimal sub grid is quantified.

2.3.2 Step 2: Selection of Suitable Route. Based on a regular trip, the route choice is considered either optimized by time or distance [22]. However, both optimum time and distance travels are not considered as priority during the RDE route selection. As for this case, only the physical route network is considered where the topological route network is considered. The route network topology will ensure the connection between different routes are according to orderly connecting rules during the route selection process. Using the composition of tree-like and grid-like street network structure [23, 24], the suitable route was identified based on these topological rules. Thus, applying these topology structures may resulting orderly running in our local traffic conditions as well as guaranteeing the safety of entries when crossing into different route types. The route connection was designed based on the following arrangement:

a) Highway route can only join directly to an arterial route
b) An arterial route can only join directly to collector route or primary route
c) Collector route can connect to local route
d) Primary route can link up with arterial and collector routes

Figure 1 depicts the topological route network based on the route connection arrangement. Prior to route selection, five sets of specific location were located randomly in the selected sub-grid. Each set of location consists of two points that consist of origin and destination (*O-D*). Origin is the starting point of the trip, while destination will be the end point of this RDE test. The route selection was conducted through visual identification using network tool in the GIS software.

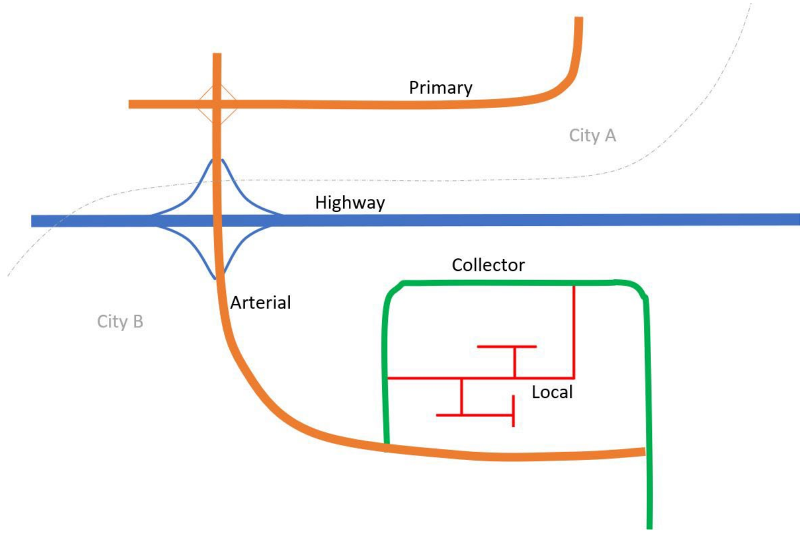


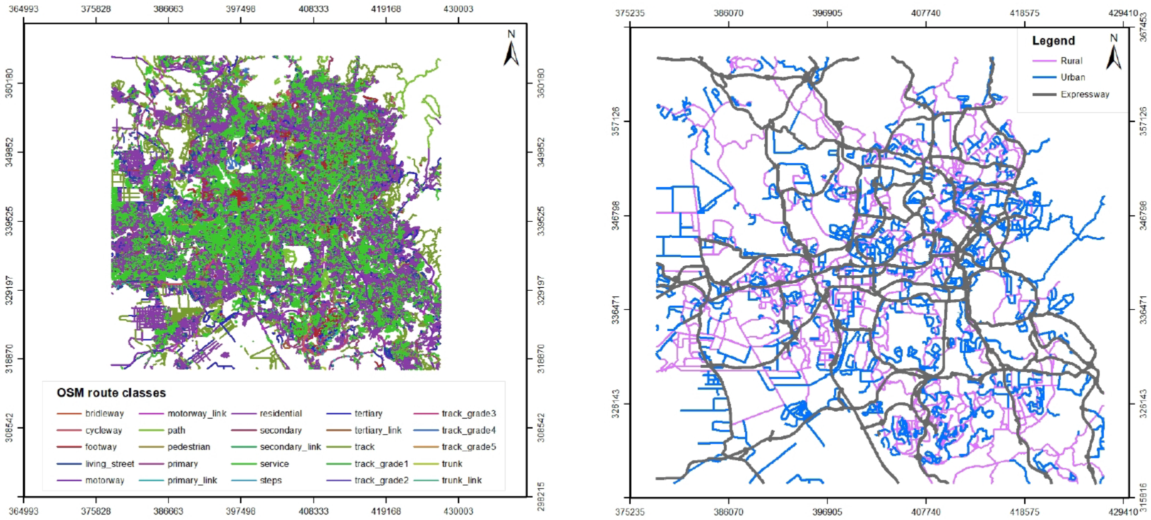
Figure 1. Topological route network structure for selecting RDE test route.

Furthermore, each RDE test route was set to a single direction trip to travel from the origin to destination. This implementation will ensure the trip will penetrate every route category where the traffic conditions might be varies because of their locations and the time of the RDE test is carried out. The identification of route directions was based on the information provided in the OSM and validated with Malaysia road map developed by Malaysia Public Works Department. In certain cases, the traffic stream could be affected by non-recurrent events such as accident, disable vehicles, construction zones and poor weather conditions. These events may impose travel time variability during the test. Hence, extracting of short-term traffic forecasting is vital for early preparation to avoid a long delay during the test since the estimation trip should be between 90 and 120 minutes. Finally, the P_c values for every selected route were computed. The optimal route is recognized when the selected route has fulfilled the RDE requirements (Table 1).

3. Results and Discussion

3.1 Route Classes

Figure 2a shows the downloaded vector route layer from the OSM for the study area. This original vector layer consists of 15 different types of routes. Based on the grouping (Table 4), the route features that shared similar characteristics are grouped into the same category. For other route features that are not considered for the RDE test guideline were excluded from the route map. After the route filtering process, only five route types were extracted from the OSM route layer. The final route network is illustrated in Figure 2b. From the extracted routes, rural category has the longest route length with 2,395.83 km, while the highway and urban categories consist of 2,218.89 km and 1,678.78 km length, respectively.



(a) (b)

Figure 2. a) Route networks from OSM with various route categories within the study area, and b) Selected route networks with three major categories: urban, rural and expressway.

3.2 Route Density Map

The resulted density map from the extracted route networks is displayed in Figure 3. The route density values were classified into three number of classes: Low, Moderate and High density of route features. The results showed that the regions with the densest routes were clustered together in the south-central region. For regions at the eastern part of the study area showed relatively low route density. Furthermore, only four sub-grids (C, D, H and I) contain all three density classes, while the other three sub-grids (A, T and Y) have indicated low density route network. For the remaining sub-grids, the route density shows a mixed between low and moderate classes that were distributed across the central region of Klang Valley area. The general trend of route network is that the farther an area from the city centre, the lower the route density became.

The computed route category percentage P_c for every sub-grid is shown in Table 5. From this statistic, the P_c value for every route category in sub-grid Q almost identical with the RDE requirement. The route length for each category also exceeds the minimum distance of 16 km. Hence, this sub-grid was chosen for further analysis of route selection within this grid coverage area.

3.3 Selection Routes for RDE Test

3.3.1 Frequent Route Identification. Additionally, vehicle samples were utilized during the determination of selecting potential routes. These samples were obtained from passenger cars that are equipped with in-vehicle GPS. This procedure was to ensure the selected routes are relatively influenced by routes that are frequently used to travel within the sub-grid (Figure 4a). To identify common routes, the distribution of vehicle samples was plotted on the geographical map. Figure 4b indicates that most of the route networks in sub-grid Q are frequently used by travellers. However, this indication is relied primarily on relative route geometries without considering travellers effort to minimize route length and efficiency (i.e., complexity, traffic and density) to plan their travel from an origin to destination. Figure 4b also depicts the vehicle speed based on routes. High vehicle speed (> 90 km/h in dark red) can be clearly observed in main express highway trunk crossing from north to southern direction of the study area. For urban and rural routes, vehicles are normally travelled in moderate speed within 50 to 60 km/h. This evidence indicates that any route within the sub-grid Q can be selected as preference routes for the RDE test.

IOP Conf. Series: Earth and Environmental Science 1143 (2023) 012027 doi:10.1088/1755-1315/1143/1/012027

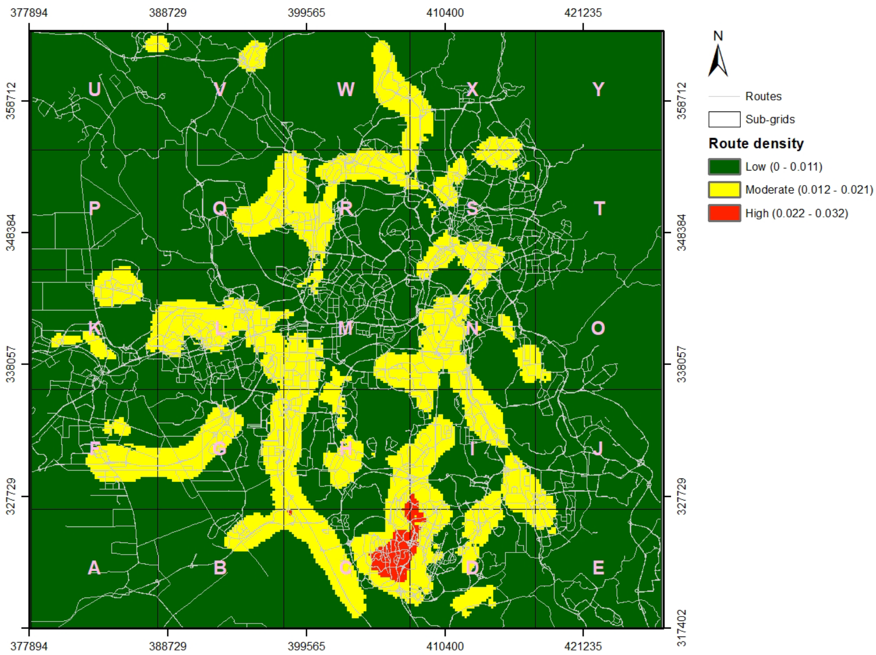
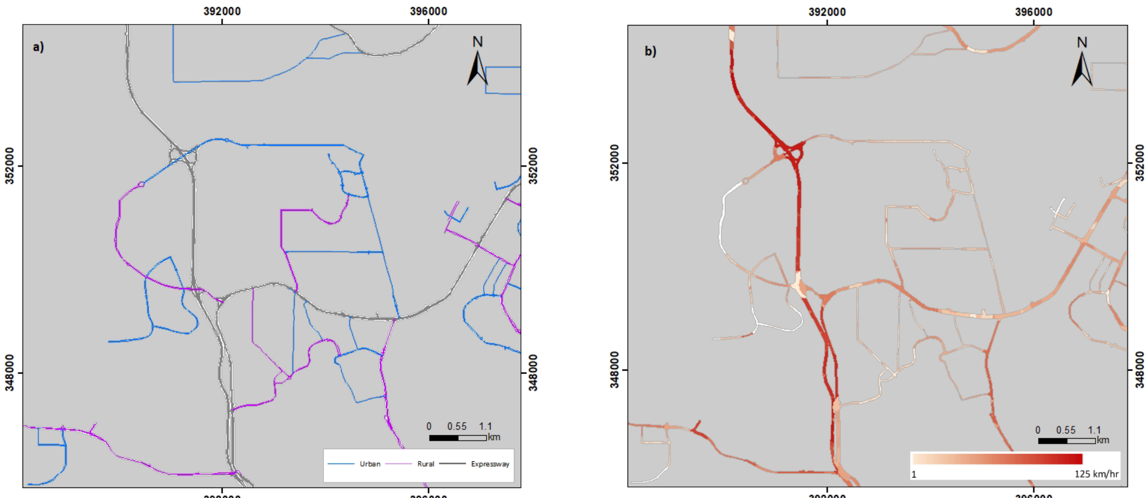


Figure 3. The route density map overlaid with the grid layer together with the grid.



(a) (b)

Figure 4. a) Route networks distribution in sub-grid Q according to route categories and b) Range of vehicle speed based on vehicle samples collected from in-vehicle GPS device.

3.3.2 Selected Routes.

Five sets of O-D positions were randomly located in the selected sub-grid. Thus, five different route networks that connected the O-D points were identified. These selection routes were according to the defined topological route network structure. Figure 5 shows the candidates of RDE routes test in sub-grid Q.

The P_c values for every candidate of RDE test route were computed. Table 6 shows the comparison between the computed P_c and the target P_c. These finding showed that Route 5 is the most suitable route for conducting the RDE test. The travel direction for Route 5 is illustrated in Figure 6.

Since traffic conditions are highly changeable at specific locations over the time, the travelling duration for a single RDE test is not computed in this study. Even though the travel time is more tangible to driver in estimating the complete cycle of the RDE test, due to the stochastic nature of the traffic, it makes hard to reflect the actual degree of congestion in each route category [25]. The travel duration can only be quantified after the vehicle is tested over real-world driving.

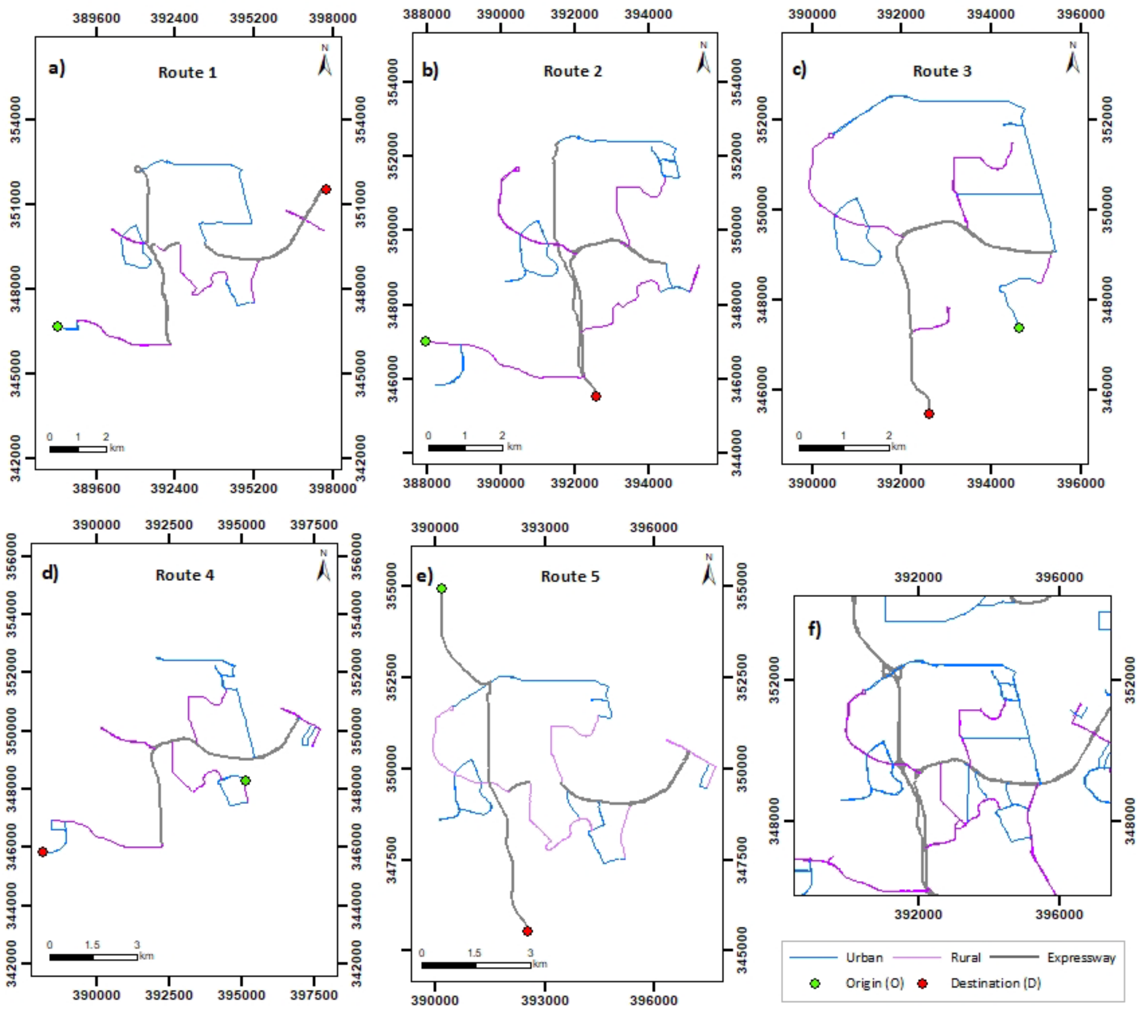


Figure 5. Five candidates of RDE test route (a-e), and (f) the overall route networks in sub-grid Q.

Table 5. Route Category Percentage P_c for each sub-grid in the study area.

Grid	P_c	Urban (34%)	Rural (33%)	Expressway (33%)	Total
A	Distance (km)	27.33	1.86	36.63	65.82
	%	41.52	2.82	55.66	100
B	Distance	71.01	6.2	36.77	113.98
	%	62.3	5.44	32.26	100
C	Distance	60.54	90.68	99.03	250.24
	%	24.19	36.24	39.57	100
D	Distance	83.3	203.32	27.33	313.96
	%	26.53	64.76	8.71	100
E	Distance	55.79	86.61	55.22	197.62
	%	28.23	43.82	27.94	100
F	Distance	57.72	122.04	47.2	226.96
	%	25.43	53.77	20.79	100
G	Distance	58.12	157.29	60.54	275.95
	%	21.06	57	21.94	100
H	Distance	94.47	116.82	107.09	318.38
	%	29.67	36.69	6.53	72.89
I	Distance	110.86	120.23	144.31	375.39
	%	29.53	32.03	38.44	100
J	Distance	64.26	56.55	143.68	264.49
	%	24.3	21.38	2.47	48.15
K	Distance	74.97	88.96	126.81	290.74
	%	25.79	30.6	43.61	100
L	Distance	80.08	220.47	128.99	429.54
	%	18.64	51.33	30.03	100
M	Distance	138.93	212.66	188.92	540.5
	%	25.7	39.34	34.95	100
N	Distance	117.32	111.07	258.57	486.96
	%	24.09	22.81	53.1	100
O	Distance	61218.61	22.19	21.99	61262.78
	%	99.93	0.04	0.04	100
P	Distance	33.67	40.21	0	73.88
	%	45.57	54.43	0	100
Q	Distance	64.11	52.73	55.71	172.55
	%	37.16	30.56	32.29	100
R	Distance	107.18	138.09	221.22	466.49
	%	22.98	29.6	47.42	100
S	Distance	142.81	293.68	168.2	604.69
	%	23.62	48.57	5.34	77.52
T	Distance	62.3	24.43	22.73	109.46
	%	56.92	22.32	20.77	100
U	Distance	36.08	52.45	39.52	128.05
	%	28.18	40.96	30.86	100
V	Distance	21.75	45.67	97.29	164.71
	%	13.21	27.73	59.07	100
W	Distance	13.28	52.01	51.07	116.35
	%	11.41	44.7	43.89	100
X	Distance	40.15	78.91	79.04	198.1
	%	20.27	39.83	39.9	100
Y	Distance	1.52	0	1.04	2.56
	%	59.37	0	40.63	100

Table 6. Comparison between the target and computed P_c values for RDE test route candidates.

P_c(Target)	Urban (34%)	Rural (33%)	Expressway (33%)	Total
Route 1				
Distance (km)	18.08	21.09	15.92	55.09
P_c(Computed)	32.81	38.28	28.91	100
Route 2				
Distance (km)	16.11	18.61	21.22	55.94
P_c(Computed)	28.8	33.27	37.93	100
Route 3				
Distance (km)	20.73	16.98	16.77	54.49
P_c(Computed)	38.05	31.17	30.78	100
Route 4				
Distance (km)	21.5	19.98	16.18	57.65
P_c(Computed)	37.29	34.65	28.06	100
Route 5				
Distance (km)	17.18	17.18	18.83	53.19
P_c(Computed)	32.3	32.3	35.4	100

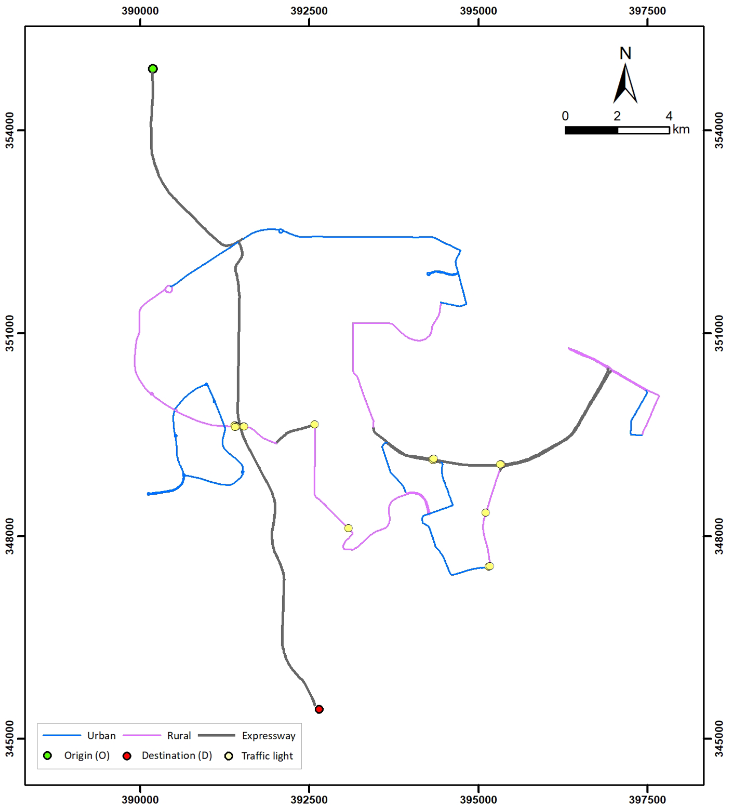


Figure 6. The final RDE test route.

4. Conclusion

As there is no common standard in selecting the test routes for RDE, the approach varies between countries and areas. Nevertheless, the selection must go through certain processes in identifying the best route that meets the RDE criteria. This paper presents an approach to select the test route using GIS platform. Specific route information comprises of road categories, route speed range and route classes according to the network hierarchy were collected from the OSM database. The generated route density and the topological route network structure were used to further analyse the suitability route which referred to the requirement of RDE test. However, these steps are related to the strictly physical nature of the network structure on which the RDE test will be carried out. Since the route networks in the study area are unlikely to change substantially in short term and therefore, derived results are adequately reflecting the driving cycle in Malaysia context. Apart from that, several exogenous factors including weather conditions, topography and incident events can also influence the traffic flow in different ways. These additional factors can reflect more realistic situations of the driving condition. Thus, further RDE route test development could consider such aspects.

Moving forward, with the availability of advanced technologies, this paper suggests the usage of big data through crowdsourcing which enables the accessibility of creating the possibility to a living drive cycle that constantly evolves based on factors such as population, climate, infrastructure and economy. Alternatively, big data obtained from the crowdsourcing solution has a huge potential to further enhance the data collection by improving the quantity and representativeness of data with a lower investment in cost and time. Today, crowdsourcing has become one of the popular sources of information at different levels and various industries. Similar benefits towards the available advanced technologies, crowdsourcing can provide a solution with access to the latest data trend and dynamics of the subject under study. With the in-trend usage of location services, an application installed in a smartphone allows the coordinates and travelling of actual drivers of the community under study to be tracked, managed, and stored in a data server. Instead of spending time selecting the routes, instrumentation, and managing test vehicles, setting up the system for big data from the crowdsourcing is expected to be more effective and productive. However, the only downside of the crowdsourcing via smartphone location services application is the availability of other parameter measurements such as engine speed, engine load and fuel consumption.

Acknowledgments: The Authors would like to acknowledge and thank for the support/fund by the Ministry of Higher Education Malaysia under Fundamental Research Grant Scheme (FRGS/1/2019/TK10/UTM/02/8).

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