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[Ting & Noraini, 6(12): December, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

LEAST CONGESTED AND SHORTEST DISTANCE PATH IN KOTA KINABALU TRAFFIC NETWORK, SABAH, MALAYSIA

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DOI: 10.5281/zenodo.1087342

ABSTRACT

Mobility Problem such as traffic congestion exists when the traffic volume demand exceeds the capacity of the existing intersections. Solving traffic congestion using conventional approaches, such as building flyover and road widening might not be very effective in the long term. Therefore, a suggested approach in this study is to change the driver's criteria in selecting the best path. The best path in this study has the criterion of not only the shortest path, but it also includes another criterion like congestion level. The added criterion in selecting the best path is the level of service of the intersection. The additional parameter is the degree of saturation which is defined as the level of services. Dijkstra's algorithm is applied to solve the network graph. Maple Software is used to find the best solution. In conclusion, the combined parameters of route distances and degree of saturation have signified that the best optimal path chosen is the one with the least congested and distance routes, instead of just solely selecting the shortest distance or lowest traffic congestion level.

KEYWORDS: Degree of Saturation, Least Congested, Shortest Distance, Dijkstra's Algorithm, best optimal path, Traffic Network.

I. INTRODUCTION

Traffic congestion is a common traffic condition that takes longer trip times, slower speeds and long queue. It keeps on increasing from year to year as the population increases. According to the World Bank, traffic congestion had contributed GDP losses of 1.1% to 2.2% a year in Malaysia (Morpi, 2015). The occurring of traffic congestion can caused several reasons like bottlenecks, road accidents, poor road condition and facilities, driver's driving behavior, unrestricted owning private vehicles and so forth. Traffic congestion phenomena are affecting the economic productivity and wastage on fuels and time (Rao *et al.*, 2012). Apart from economic issues, traffic congestions also affect the quality of life and polluted the environment. There are two types of traffic congestion which are recurring congestion and non-recurring congestion. Recurring congestion typically occurred during peak hours, especially from 7am to 9am, and 5pm to 7pm respectively. This is because people tend to go for work or back to their homes during these time periods. There are special cases that would cause traffic congestions like accidents or road closures, and these are classified as non-recurring congestion.

Level of Service (LOS) is one of the qualitative measurements to test the quality of the traffic flow (Mathew & Rao, 2006). LOS defines the quality of the traffic through service volume, the maximum number of vehicles that allow passing through the intersections or paths. According to the Highway Capacity Manual, level of service is divided into six different levels which are from level A to level F. LOS A represents a smooth traffic road that allows the driver to have free flow speed. On the other hand, LOS F represents the worst quality of traffic flow or congested traffic. Level of service of the road or intersection is determined by three different measures. Those three measures are degree of saturation, delay time and queue length (Rodegerdts *et al.*, 2004). Degree of saturation is one of the selected measures, and is being discussed in this study. Degree of saturation is a direct measure of congestion level. With this criterion in estimating the lane flow, it thus implies that drivers can choose the lanes with minimum congestion levels. Degree of saturation is also called as volume/capacity ratio. It represents the vehicular demand of an intersection (Akcelik, 1989).

The objective of this study is to find an alternative best path with the combined parameters of degree of saturation value and distance. The network graph is being categorized into three different types of parameters

ISSN: 2277-9655
Impact Factor: 4.116
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and are being discussed in this study. The first network graph is the distance parameter network graph. The second network graph has the degree of saturation parameter, while the last network graph is the combined parameter, distance and degree of saturation. Dijkstra's algorithm is applied to solve the network graphs with the different parameters. Results would show that the best optimal path would have the criteria of relatively short distance and less congested.

II. LITERATURE REVIEW

Rewadkar & Ratnaparkhi (2015) had studied about traffic estimation and finding least congested alternate route using GPS and Non-GPS vehicles through real time data on Indian roads. GPS devices were mounted on vehicles were used to predict the current traffic condition of road. Through the real time traffic data set in GPS, number of vehicles and vehicles' location could be analyzed. An accurate prediction of the current traffic was performed using the advanced traffic management system and advanced traveler information system. Location based distance calculation, vehicle tracking method and heuristic search algorithm were applied to suggest the road users the alternate route with the least congested, shortest distance and minimal delay path.

Neumann (2014) presented a method of path selection in the graph. In his study, the Dijkstra's algorithm was used to find additional paths among nodes in the maritime network. Since it involved a single criterion which is distance, therefore the shortest path was not always the best alternative path. Hence, other parameters such as average time, number of indirect vertices were calculated and considered in selecting best alternative path. Multi-criteria decision making was used in this study for selecting one desirable path from several paths. Dempster-Shafer theory was suggested as a method that could be applied to combine data and evidences.

Rohila *et al.* (2014) had applied the Dijsktra's shortest path algorithm in traffic networks in both urban and city environments, whereby unpredictable events such as accidents, and weather conditions that might happen from time to time, and thus affecting the traffic conditions. Therefore, remedies were needed immediately to maintain the traffic flow balance where these traffic problems were solved through the shortest paths using the Dijkstra's algorithm. The advancement of technology and the surge of population had caused the traffic network to be bigger and complex. Hence, an applet in java programming language was implemented in this study to solve the shortest path problem for road networks. Applet is a tool that could be further enriched and applied in many algorithms for both directed and undirected graphs.

Gupta *et al*. (2016) had applied the Dijkstra's algorithm in the routing process to get the shortest path. Routing is a process to find a path from vertices in order to fulfil the objectives of data transmission. Among various routing algorithms, Dijkstra's algorithm is one of the methods that is applied in computer networking in google maps to get the shortest possible paths. The Matlab Software is used to implement the Dijkstra's algorithm. However, the Dijkstra's algorithm does have limitations which is basically it has longer computation time, and its inability to handle negative edges of a network.

Selim & Zhan (2016) had presented a study towards shortest path identification on large networks. In this massive growth of technology and population society, big data has become a necessity to be analysed in detail to give some insight of what the data represent. Selim & Zhan focused on reducing data at nodes in large network by computing data similarity computation and maximum similarity clique. The standard approach, Dijkstra's algorithm is a method which detects the overall path of the network by passing through all nodes. The proposed algorithm will only pass through the bounded path after computing maximal similarity clique. Finding the shortest path by using shortest path algorithm would be much faster and simpler once the big network is reduced.

Patel & Baggar (2014) presented a survey paper of shortest path algorithm in GIS (Geographic Information System) application. The selected algorithms for finding shortest path were Bellman-Ford Algorithm and Dijkstra's Algorithm. GIS tools were used in traffic planning and analyzing, and hence, widely used in different countries. From the results, Dijkstra's algorithm took shorter running time compared to Bellman Ford algorithm. When discussing about space complexity, the Bellman Ford Algorithm consumed more space than the Dijsktra's Algorithm. Overall, the Dijkstra's Algorithm performed better than Bellman Ford Algorithm in identifiying the shortest path.

Mathur *et al.* (2014) studied shortest path finding algorithms for real road network. There were several algorithms discussed which were Dijkstra, Bellman-Ford, A* and Floyd-Warshall. The Bellman-Ford algorithm

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

could handle negative weight edges, while the Dijkstra's algorithm and Floyd-Warshall could not. In real road networks, there were various parameters used, such as time taken to travel, traffic status, costs and so forth. Floyd-Warshall algorithm could provide acceptable time and space even in bad case scenarios. This was because it could provide optimal path in a shorter time and hence, less human thought process were involved.

III. STUDY SCOPE

Kota Kinabalu traffic network is discussed in this study. The ever increasing of traffic congestion in Kota Kinabalu is caused by abundance of vehicles on the road. Statistics showed that in 2000, there were only 77,000 vehicles entering and leaving the city in a day. Currently, an estimated 140,000 vehicles ply the city's street daily based on cumulative calculations. According to the fact mentioned above, car ownership has been increasing from 3 to 4 percent each year. According to the Sabah Road Transport Department (JPJ) statistics, there were 1,026,867 registered vehicles in 2012, and had increased to 1,273,788 registered vehicles in 2016. Herdiansah Abdul Karim, director of Sabah Road Safety Department (JKJR) had mentioned that the number of registered vehicles in Sabah had increased by 246,921, or 18.38 percent from 2012 to 2016 respectively. The increase of vehicles ownership is becoming a reflection of improvement of nation's affordability. Therefore, nations tend to take their own vehicle, instead of public transportation in order to get a more comfortable, convenient and efficient way to reach their destinations. If this situation remains consistent, the traffic congestion problem will become more serious until all the road users would take a longer time to reach their destinations, especially during peak hour periods. Eventhough the distance is short, the congestion will cause the travel time to be longer, and consequently, burning more unnecessary fuel on the road. This study thus aspires to mitigate the reduction of the air quality index of Kota Kinabalu.

There are several conventional approaches to improve traffic flow such as road widening and building flyovers. However, these conventional approaches are not long term ways to solve the problem because of the increasing population, as stated by Kalvin Liaw, director of Kota Kinabalu City Hall (DBKK) Traffic and Public Transport Department (Bernama, 2016). The conventional approaches are necessary to reduce the impact of traffic congestion especially at junctions. However, it will end up with no more land space for further infrastructure development when it comes to a long term solution. Instead of conventional approaches, there is another approach which is considering more criteria in selecting the best path. As usual, people used to select the shortest path as the best path. However, the shortest path may encounter traffic congestion due to high vehicular demand as in Noraini & Ting (2017), and thus causing the travel time to take longer than the alternate routes with a longer distance. Therefore, a combined criteria inclusive of distance and the level of service in selecting the best path to avoid congestions is considered in this study.

The scope of this study is the network from Inanam (source node, V1) to Centre Point (sink node, V14) where all the routes between source and sink node are established. In Figure 1, the red nodes are part of the selected major intersections in Kota Kinabalu which are assigned as the nodes of the network graph.

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Figure 1: Part of Traffic Network in Kota Kinabalu

IV. METHODOLOGY

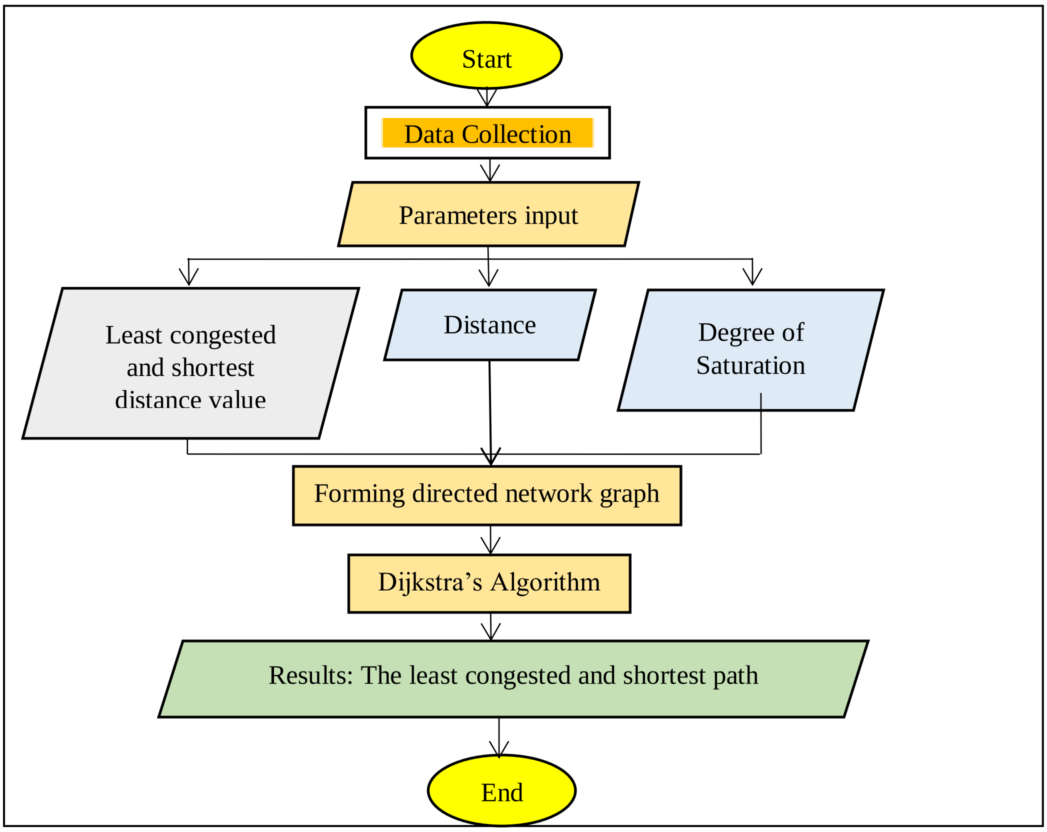

Figure 2: Flowchart

A basic flowchart is showed in Figure 2 above. In this study, it started with preparing the traffic data in Kota Kinabalu from Inanam to Centre Point, of which both are the central business districts (CBD) of the city. From the data, there are three different parameter inputs which are distance, degree of saturation (DOS) and the combination between DOS and distance. With all these data and parameters, three different directed network graphs are formed. Then each network graph is then solved by using the Dijkstra's algorithm. The results of three different parameters are therefore compared. The final results obtained would be on the combined parameters, the least congested and the shortest path as shown in the results section.

Definition of Network Graph

Let $G=(V,E)$ be a directed flow network graph in order to define the problem. In a network graph, there are vertices and edges. Network graph is a set of vertices that consist of element $1,2 \dots, n-1, n$ linked by edges. Vertices or so called nodes of the network graph are the elements of V which are denoted as $v_1, v_2, \dots, v_{n-1}, v_n \in V$. The v_1 is the source node, and v_n is the sink node, where the source node and sink node are the starting and ending nodes respectively. The source node acts as the supply of units produced and sink node is consuming all units it receives. The edges are defined by the ordered pairs (u,v). The edges (u,v) are the elements of E over these nodes of the network graph (Goemans, 1994).

Conditions:

1. Capacity constraint :

$$\forall (u,v) \in E, 0 \le f(u,v) \le c(u,v) \quad \dots\dots\dots \quad (1)$$

All the edges (u,v) of a network are the elementS of E. Each non-negative flow, $f(u,v)$ through an edge must not exceed its own capacity, $c(u,v)$ as represented by equation (1)

2. Flow conservation:

$$\forall u \in V \setminus \{s,t\}, \sum_{v \in V:(v,u)\in E} f(u,v) = \sum_{v \in V:(u,v)\in E} f(u,v) \quad \dots\dots\dots \quad (2)$$

Or

$$\forall u \in V \setminus \{s,t\}, \sum_{v \in V} f(u,v) = 0 \quad \dots\dots\dots \quad (3)$$

Or

$$\forall u \in V \setminus \{s,t\}, \sum_{v \in V:(v,u)\in E} f(v,u) - \sum_{v \in V:(u,v)\in E} f(u,v) = 0 \quad \dots\dots\dots \quad (4)$$

Equations (2) to (4) represent the traffic flow conservation. The total weight of edges directed into the vertex equals the total weight of edges directed out of the vertex. $\sum_{v \in V:(v,u)\in E} f(v,u)$ stands for flow into u and $\sum_{v \in V:(u,v)\in E} f(u,v)$ stands for flow out of u. It is applied to the entire nodes of the network except the source node, s and the sink node, t which are the starting and ending node of the network.

Definition of Dijkstra Algorithm

Consider an arc (u,v) of length $d_{uv} > 0$. Let SD_u is equal to shortest distance from node 1 to node i. The label of node j connected with node, i is defined as the pair of elements as shown in equation (5).

$$[SD_v, i] = \min_u [SD_u + d_{uv}, u] \quad \dots\dots\dots \quad (5)$$

If there is only one u connected to v, the right hand side gives the label of v, and is said to be permanent. If there are several $u's$ connected to v, the label $[SD_v + d_{uv}, u]$ for a permissible value of u is called temporary, provided a shorter connection from some other permissible value of u can be found. If no shorter connection

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

can be found, it is as before, called a permanent label. With these definitions, the method consists of the following steps:

Step 1. Label starting node, s with permanent label $[0,-]$. Set $v=1$.

Step 2. Compute temporary labels $[SD_u + d_{uv}, u]$ for each node v that can be reached from node u. If node v has already the label $[SD_v, w]$ through another node w such that $SD_u + d_{uv} < SD_v$, replace $[SD_v, w]$ by $[SD_u + d_{uv}, u]$ Otherwise $[SD_u + d_{uv}, u]$ is the permanent label of node v.

Step 3. For $v < n$, set $v = w$, reachable from permanently labeled nodes and Go to Step 2. w is stands for the adjacent node of v. If all the nodes have permanent labels and $v = n$, Stop.

Definition of Degree of Saturation

Degree of Saturation is a traffic flow indicator with a range in between 0 to 1. The degree of saturation with less than 0.85 basically indicates that the capacity is still sufficient for the traffic volume demand. However, as the degree of saturation reaches 1.0, traffic flow comes to an unstable condition, normally with long queues and delay may occur. Once the demands exceed capacity (degree of saturation is more than 1.0), congested traffic, long queues and excessive delay are expected. The least congested and shortest distance value is the value of the combination of degree of saturation and distance. The formulae for degree of saturation and least congested and shortest distance values are given by equation (6) (Rodegerdts *et al*., 2004), and (7) respectively.

$$Degree\ of\ saturation = volume\ /\ capacity \ \ldots\ldots\ldots\ldots \quad (6)$$

$$Least\ congested\ and\ distance\ value = Degree\ of\ saturation \times Distance \ \ldots\ldots\ldots\ldots \quad (7)$$

Maple Software Computation

With all the data collected, Maple software is used to compute the output of the results. Maple Source Codes are needed to run the software to come out with the outputs. The Maple source code to solve the problem with the Dijkstra's algorithm is shown below.

```
>with(GraphTheory):
>C:=Graph({[[s,t],w]})
>DijkstrasAlgorithm(C,s,t)
>DrawGraph(C)
```

Example

```
>with(GraphTheory) :
>C1 := Graph({[[1, 2], 1], [[2, 3], 2], [[3, 4], 3], [[1, 5], 4], [[5, 6], 5], [[4, 6], 6]})
```

Graph 1: a directed weighted graph with 6 vertices and 6 arc(s)

```
>DijkstrasAlgorithm(C1, 1, 6)
```

[[1, 5, 6], 9]

```
>DrawGraph(C1)
```

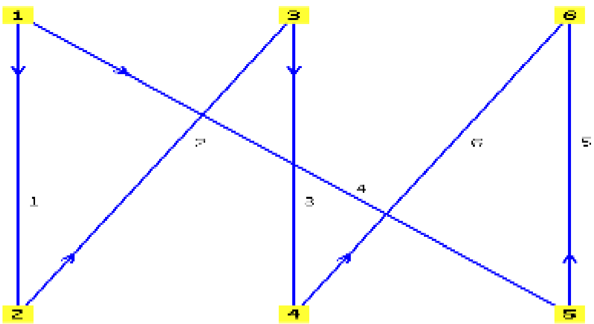

Figure 2: Example of Network Graph Using Maple

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The Graph Theory in Maple sofware package is a collection of paths for creating, drawing, manipulating and testing graphs for different purposes and properties. The network graphs are formed by sets of vertices (nodes) that are connected by edges. The package serves both directed and undirected graphs except multigraphs. The edges in the graphs can be weighted or unweighted. The Maple procedure 'with' used to impose the exported names of a package globally. It allows users access to the package without typing the package prefix.If G is a weighted graph, DijkstrasAlgorithm$('C','s','t')$ returns the lowest weighted path from node 's' to node 't' in graph C. 'C' stands for graph, while's' and 't' are the vertices of the graph G. 's' is the source vertices and 't' is the sink vertices. If a path from 's' to 't' exists, the output is a list of the form$[[s,\ldots,t],w]$ where $[s,\ldots,t]$ is the path and 'w' is the weight of that edge. If no such path exists the output is$[[],\infty]$. DrawGraph displays the vertices and edges of a graph G as a Maple plot.

V. RESULTS AND DISCUSSIONS

Table 1: Collected Data

Path	From	To	Volume	Capacity	DOS	Distance	Least Congested & Distance Value
1	V1	V2	3072	3536	0.869	1.00	0.8690
2	V1	V3	1167	918	1.272	5.20	6.6144
3	V2	V4	1026	1254	0.818	0.60	0.4908
4	V2	V5	1377	1809	0.761	2.40	1.8264
5	V5	V2	1686	1798	0.938	2.40	2.2512
6	V3	V6	1710	1904	0.898	0.85	0.7633
7	V4	V7	3777	2152	1.755	1.50	2.6325
8	V7	V5	783	734	1.067	2.10	2.2407
9	V5	V7	321	1512	0.212	2.10	0.4452
10	V8	V5	1584	1302	1.217	2.40	2.9208
11	V5	V8	1663	2466	0.674	2.40	1.6176
12	V6	V5	1290	1475	0.875	2.30	2.0125
13	V5	V6	639	643	0.994	2.30	2.2862
14	V6	V9	1680	3843	0.437	2.10	0.9177
15	V8	V12	879	1162	0.756	0.90	0.6804
16	V12	V8	75	504	0.149	0.90	0.1341
17	V7	V10	1261	2660	0.474	2.30	1.0902
18	V10	V11	570	1028	0.554	1.30	0.7202
19	V11	V10	1394	1002	1.391	1.30	1.8083
20	V11	V12	1224	2308	0.53	0.65	0.3445
21	V12	V11	1784	2094	0.852	0.65	0.5538
22	V12	V9	1680	3962	0.424	0.23	0.0975
23	V9	V12	1518	1692	0.897	0.23	0.2063
24	V9	V13	1656	1777	0.932	0.50	0.4660
25	V13	V14	1026	1431	0.717	0.85	0.6095
26	V11	V14	804	752	1.069	0.30	0.3207
27	V10	V14	1995	3086	0.646	1.50	0.9690

Table 1 showed the data collected in the scope of study. 'Path' in Table 1 stands for the paths from node to node. The V1 to V14 are the nodes or so called intersection in traffic network. 'Volume' stands for the amount of vehicle that occupies on a particular path at a particular time. 'Capacity' stands for the maximum volume of vehicles that can pass through the particular intersection or path. Next, DOS (Degree of Saturation) is the volume/capacity ratio which is an indicator of the current traffic condition. 'Distance' stands for the length of the path from node to node. 'Least congested and shortest distance value' stands for the value of the combination between degree of saturation and distance.

Subsequent illustrations below are the results in Maple based on the three network graphs for comparisons, namely, the distance parameter network, the degree of saturation (DOS) parameter network, and finally, the combined DOS and distance parameter network. The outputs are then compared.

ISSN: 2277-9655
Impact Factor: 4.116
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a) Maple Output: Distance Parameter Network Graph

> *with*(*GraphTheory*) :

> *C1* := *Graph*({[[*v1*, *v2*], 1], [[*v1*, *v3*], 5.2], [[*v2*, *v4*], 0.6], [[*v2*, *v5*], 2.4], [[*v5*, *v2*], 2.4], [[*v3*, *v6*], 0.85], [[*v4*, *v7*], 1.5], [[*v7*, *v5*], 2.1], [[*v5*, *v7*], 2.1], [[*v8*, *v5*], 2.4], [[*v5*, *v8*], 2.4], [[*v6*, *v5*], 2.3], [[*v5*, *v6*], 2.3], [[*v6*, *v9*], 2.1], [[*v8*, *v12*], 0.9], [[*v12*, *v8*], 0.9], [[*v7*, *v10*], 2.3], [[*v10*, *v11*], 1.3], [[*v11*, *v10*], 1.3], [[*v11*, *v12*], 0.65], [[*v12*, *v11*], 0.65], [[*v12*, *v9*], 0.23], [[*v9*, *v12*], 0.23], [[*v9*, *v13*], 0.5], [[*v13*, *v14*], 0.85], [[*v11*, *v14*], 0.3], [[*v10*, *v14*], 1.5]})

Graph 1: a directed weighted graph with 14 vertices and 27 arc(s)

> *DijkstrasAlgorithm*(*C1*, *v1*, *v14*)

[[*v1*, *v2*, *v4*, *v7*, *v10*, *v14*], 6.9]

> *DrawGraph*(*C1*)

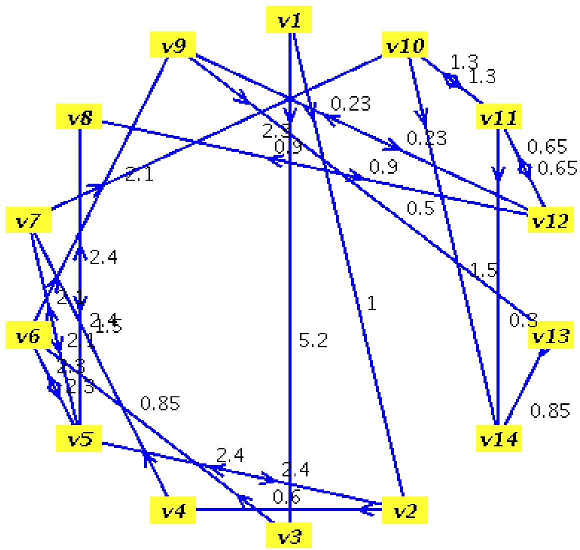

Figure 3: Distance parameter network graph

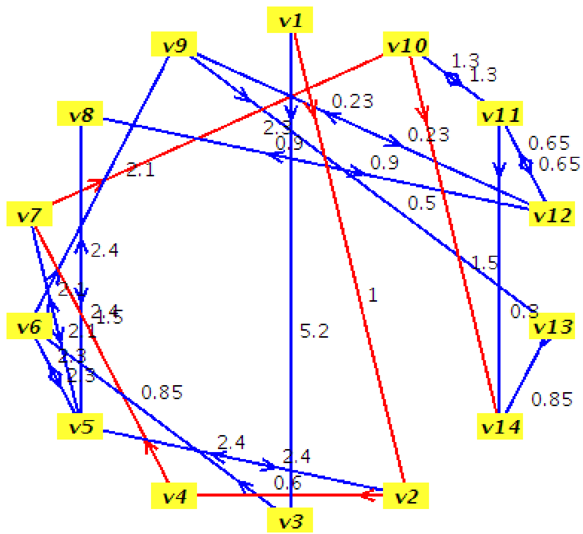

Figure 4: Output of Dijkstra's algorithm (shortest path)

Network Graph in Figure 3 with the distance parameter is formed by using the collected data in Table 1. In Figure 3, the source node is node 1, and the sink node is node 6. From Figure 4, the path $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$ is the shortest path with a total distance of 6.9 kilometers.

b) Maple Output: Degree of Saturation (DOS) Parameter Network Graph

> *with*(*GraphTheory*) :

> *C2* := *Graph*({[[*v1*, *v2*], 0.869], [[*v1*, *v3*], 1.272], [[*v2*, *v4*], 0.818], [[*v2*, *v5*], 0.761], [[*v5*, *v2*], 0.938], [[*v3*, *v6*], 0.898], [[*v4*, *v7*], 1.755], [[*v7*, *v5*], 1.067], [[*v5*, *v7*], 0.212], [[*v8*, *v5*], 1.217], [[*v5*, *v8*], 0.674], [[*v6*, *v5*], 0.875], [[*v5*, *v6*], 0.994], [[*v6*, *v9*], 0.437], [[*v8*, *v12*], 0.756], [[*v12*, *v8*], 0.149], [[*v7*, *v10*], 0.474], [[*v10*, *v11*], 0.554], [[*v11*, *v10*], 1.391], [[*v11*, *v12*], 0.53], [[*v12*, *v11*], 0.852], [[*v12*, *v9*], 0.424], [[*v9*, *v12*], 0.897], [[*v9*, *v13*], 0.932], [[*v13*, *v14*], 0.717], [[*v11*, *v14*], 1.069], [[*v10*, *v14*], 0.646]})

Graph 2: a directed weighted graph with 14 vertices and 27 arc(s)

> *DijkstrasAlgorithm*(*C2*, *v1*, *v14*)

[[*v1*, *v2*, *v5*, *v7*, *v10*, *v14*], 2.962]

> *DrawGraph*(*C2*)

ISSN: 2277-9655
Impact Factor: 4.116
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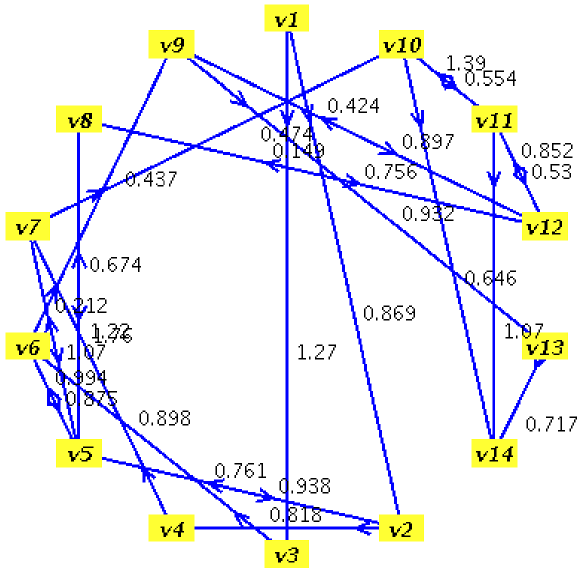

Figure 5: Degree of Saturation network graph

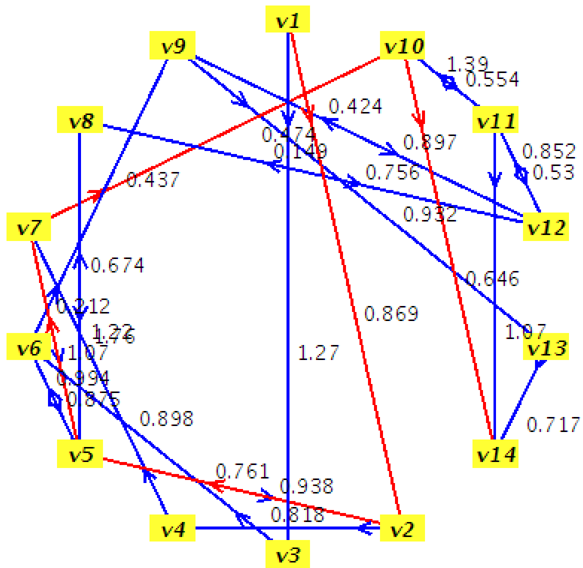

Figure 6: Output of Dijkstra's algorithm Parameter Network Graph(The Least DOS Path)

Figure 5 is a network graph with the parameter of degree of saturation. Degree of saturation is a volume to capacity ratio.The red highlighted path in Figure 6 is the path with the least degree of saturation (the least congested), given by $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$ with a total distance of 9.3 km.

c) Maple Output: Combined DOS and Distance Parameter Network Graph

>*with*(*GraphTheory*) :

>

C3 := *Graph*({[[*v1*, *v2*], 0.869], [[*v1*, *v3*], 6.6144], [[*v2*, *v4*], 0.4908], [[*v2*, *v5*], 1.8264], [[*v5*, *v2*], 2.2512], [[*v3*, *v6*], 0.7633], [[*v4*, *v7*], 2.6325], [[*v7*, *v5*], 2.2407], [[*v5*, *v7*], 0.4452], [[*v8*, *v5*], 2.9208], [[*v5*, *v8*], 1.6176], [[*v6*, *v5*], 2.0125], [[*v5*, *v6*], 2.2862], [[*v6*, *v9*], 0.9177], [[*v8*, *v12*], 0.6804], [[*v12*, *v8*], 0.1341], [[*v7*, *v10*], 1.0902], [[*v10*, *v11*], 0.7202], [[*v11*, *v10*], 1.8083], [[*v11*, *v12*], 0.3445], [[*v12*, *v11*], 0.5538], [[*v12*, *v9*], 0.09752], [[*v9*, *v12*], 0.20631], [[*v9*, *v13*], 0.466], [[*v13*, *v14*], 0.60945], [[*v11*, *v14*], 0.3207], [[*v10*, *v14*], 0.969]})

Graph 3: a directed weighted graph with 14 vertices and 27 arc(s)

>*DijkstrasAlgorithm*(*C3*, *v1*, *v14*)

[[*v1*, *v2*, *v5*, *v7*, *v10*, *v14*], 5.1998]

>*DrawGraph*(*C3*)

ISSN: 2277-9655
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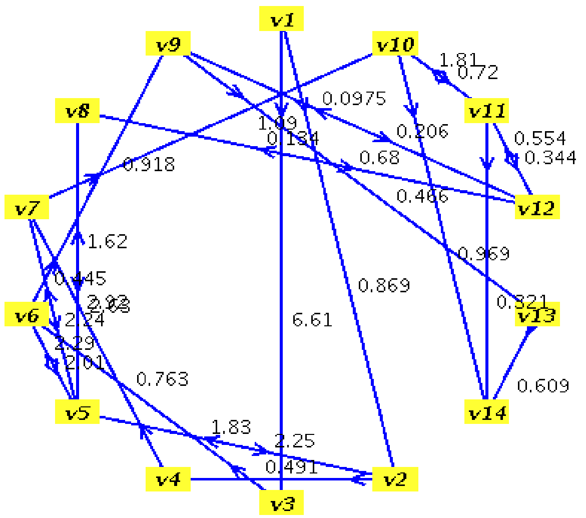

Figure 7: Least Congested and ShortestDistance

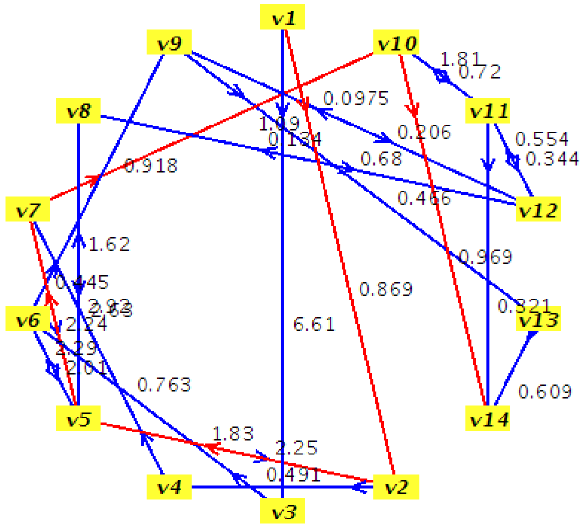

Figure 8: The Network Graph with the Least Parameter Network Graph Congested and Minimum Distance Path

The combined parameters between distance and degree of saturation are used to form a new network graph as shown in Figure 7. In Figure 8, the highlighted path, $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$ is the path with the least congested and shortest path. The total distance of the highlighted path is 9.3 kilometers, with the total degree of saturation as 2.962. Table 2 below shows the comparisons between the three network graphs of different parameters.

Table 2: Comparison between the three different parameter

Parameter	Path	Distance	Degree of Saturation
Distance	Path 1: $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$	6.9	4.562
DOS	Path 2: $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$	9.3	2.962
Combined DOS & Distance	Path 3: $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$	9.3	2.962

As shown in Table 2, there are two different paths chosen depending on the parameters itself. Path 1 is the selected path with the shortest distance. The Path 2 is the selected path with the lowest Degree of Saturation (DOS). With the combined parameters between DOS and Distance, Path 3 is selected because it has achieved an equilibrium between distance and DOS. In other words, drivers can decide a balance in making their right choices of routes to reach their destinations optimally. The difference between the paths in percentages are then calculated to signify the importance of the added criterion (ie. DOS) towards improvement of road traffic networks.

$$Difference\ of\ percentage\ of\ Distance\ between\ Path\ 1\ and\ Path\ 3 = \frac{9.3 - 6.9}{9.3} \times 100 = \mathbf{25.81\%}$$

$$Difference\ of\ percentage\ of\ Degree\ of\ Saturation\ between\ Path\ 1\ and\ Path\ 3$$
$$= \frac{4.562 - 2.962}{4.562} \times 100 = 35.07\%$$

As shown above, the difference of percentage for Degree of Saturation between Path 1 and Path 3 has achieved a higher percentage (35.07%) compared to the difference of percentage for distance (25.81%). This means that the congestion level can be avoided by 35.07%, eventhough the distance is longer by 25.81%. Hence, to avoid the conggested routes, Path 3 is selected as the best optimal path because it has the balance between travelling a relatively short distance, but less congested path. As Neumann (2014) had mentioned that the shortest path in distance cannot be the best path selection. There should be more criteria to be added in selecting the best path. Examples of such criteria are safety, less edges, level of congestion and so forth. Therefore, as in this study, the criterion Degree of Saturation (DOS) is added to distance in order to select the best path with least congestion, an avoidance level by 35.07%, instead of just selecting the shortest path in distance as the best path.

VI. CONCLUSION

The shortest path is $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$, but the least congested path is $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$. The paths or routes with the shortest distance may not be the best path if the congestion level is not being considered. Hence, this study has combined these two parameters together to obtain a path that is the balance between congestion level and short distance for the drivers. With the combined parameters, the best path from this study is found to be $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$ with a total of 9.3 km.

VII. ACKNOWLEDGEMENTS

The authors would like to thank Universiti Malaysia Sabah for funding this research under the grant code GUG0139-1/2017. The authors would like also to acknowledge the contributions of the Sabah Road Transport and Safety Department for giving their statistics in this study.

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CITE AN ARTICLE

Ting, K.H., & Noraini Abdullah. LEAST CONGESTED AND SHORTEST DISTANCE PATH IN KOTA KINABALU TRAFFIC NETWORK, SABAH, MALAYSIA. INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY, 6(12), 104-114.