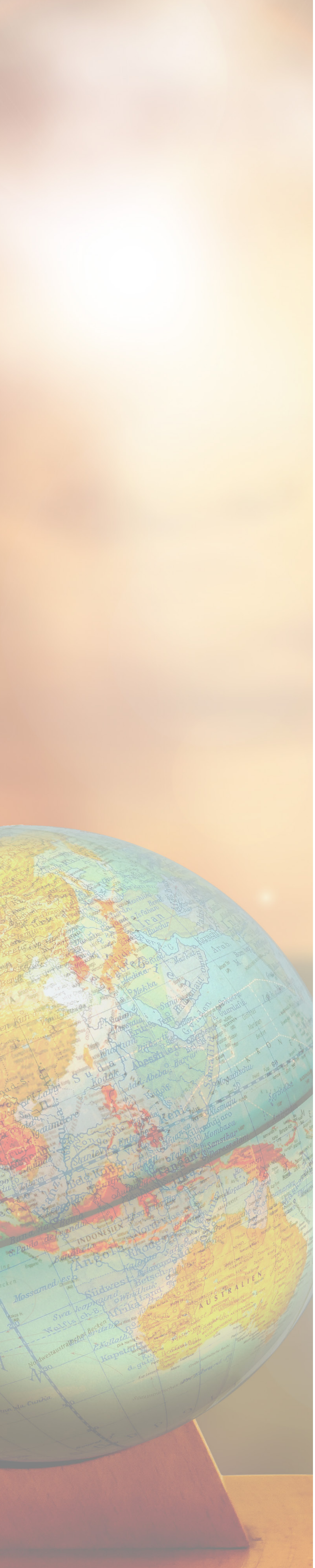

Journal of the Asian Academy of Applied Business
Vol. 5 (December, 2018), 83 – 96
ISSN 1675-9869

IDENTIFICATION OF LEAST CONGESTED AND SHORTEST DISTANCE PATH IN TRAFFIC NETWORK

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ABSTRACT

Traffic congestion, a mobility problem that exists as the traffic volume demand exceeds the capacity of the existing intersections. Conventional approaches such as building flyover and road widening might not be very effective in solving traffic congestion. Therefore, a suggested approach in this study was to change the driver's behaviour in selecting the best path. The shortest path may not be the best path. The added criterion in selecting the best path was the level of service of the path, while the included parameter that determines the level of service was the degree of saturation. Dijkstra's algorithm was applied to solve the network graph. Excel solver was used to find the solution. Percentage of difference between paths was carried out to find out the difference and significant of the paths. In conclusion, the path with combined criteria of shortest distance and least congested (degree of saturation) would be the best path, instead of solely based on the shortest distance or minimum degree of saturation.

Keywords: degree of saturation, distance, least congested, shortest path, Dijkstra's algorithm, traffic network

INTRODUCTION

Traffic congestion has been a common traffic problem for the entire world, and keeps on increasing from year to year. The World Bank estimated that traffic congestion had contributed to GDP loss of 1.1% to 2.2% a

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year in Malaysia (Morpi, 2015). There are several reasons that cause traffic congestions like bottlenecks, accidents, road conditions, road facilities, driver's driving behaviours, unrestricted owning vehicles and so forth. Traffic jam slows down traffic speed, lengthen trips time and longer queues. These phenomena are affecting the economic productivity and wastage on fuels and time (Rao & Rao, 2012). Apart from economic issues, traffic congestions are also affecting the quality of life and causing pollution to the environment. Traffic congestion used to occur during peak hours, especially from 7 a.m. to 9 a.m., and 5 p.m. to 7 p.m. respectively. This is due to people commuting to work, children going to school and others running errands during this two periods. There were other factors causing traffic congestions like accidents or road closures.

Since traffic congestions can cause so many problems, therefore city planners should come out with some ways and remedies. As there were some conventional approaches like road widening and building flyovers that might smoothen the traffic flow in a short term, but not as a permanent measure because the number of vehicles increases as population grow, 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 lessen the impact of traffic congestion especially at junctions, provided that land space is available. However, in the long run it will end up with no more room for infrastructure development. Apart from conventional approaches, drivers should add more criteria in selecting the best path. As usual, the shortest path is selected as the best path. However, traffic congestion in shortest path routes has caused the travel time to take even longer than the other longer distance routes. Therefore, this study has combined the criteria of distance and the level of service in selecting the best path to travel to avoid congestions.

Level of Service (LOS) is a qualitative measurement for the quality of the traffic flow (Mathew & Rao, 2006). It is closely related to service volume, the maximum number of vehicles that can be accommodated by the road or intersection. According to the Highway Capacity Manual, level of service divides the quality into six different levels which ranges from level A to level F. LOS A represents a traffic road allowing 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 capacity and degree of saturation, delay time and queue length (Rodegerdts et al., 2004). However, capacity and degree of saturation were selected and discussed in this study.

The degree of saturation is a direct measure of congestion level*,* and the use of this criterion for lane flow estimation implies that drivers can choose the lanes with minimum congestion levels. Degree of saturation is also referred to as the volume/capacity ratio. It represents the sufficiency of an intersection to accommodate the vehicular demand (Akcelik, 1989).

Traffic congestion is a mobility problem that causes drivers to take longer time travel to their desired destination. The shortest path is not the best path selection. Level of congestion was important to be as an added requirement to select the best path. The objective of this study is to find an alternative best path with combined parameter of degree of saturation value and distance. In this study, the network graph will be categorized into three different types. This first network graph will be the distance parameter network graph. The second is the degree of saturation parameter network graph. The last one is the combination between distance and degree of saturation parameter network graph. Dijkstra's algorithm was applied to solve the network graph with the different parameters. Results would show that the best path with shorter distance and less congested.

LITERATURE REVIEW

Rewadkar and Ratnaparkhi (2015) had performed a study on traffic estimation and least congested alternate route-finding using GPS and non-GPS vehicles through real-time data on Indian roads. From the study, GPS devices mounted on vehicles were used to predict the traffic condition. Through the real time traffic data set in GPS, number of vehicles and vehicles' locations could be analysed. The advanced traffic management system and advanced traveller information system were used to perform accurate prediction of the current traffic. The algorithms that were applied were location-based distance calculation, vehicle tracking method and heuristic search algorithm. With the algorithms and systems, the alternate route with the least congested, shortest distance and minimal delay path would be suggested to road users.

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

Rohila, Gouthami, and Priya (2014) applied the Dijsktra's shortest path algorithm in road network. In urban and city environments, traffic condition was unpredictable from time to time, for example accidents, weather conditions, and so forth. Therefore, solutions were needed instantly to maintain traffic flow balance. The problems revealed could be solved through shortest paths by using Dijkstra's algorithm. The traffic networks had become bigger and complex due to the advancement of technology, and the surge of population. Hence, an applet in Java programming language was implemented in this paper to solve the shortest path problem for road networks. Applet is a tool that could be further enriched and applied in more algorithms for both directed and undirected graphs.

Gupta, Mangla, K., Jha, and Umar (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 applied in computer networking in Google Maps to get the shortest possible paths. MATLAB Software is used to implement the Dijkstra's algorithm. However, the Dijkstra's algorithm does have limitations, namely longer computation time and its inability to handle negative edges of a network.

Sangaiah, Han, and Zhang (2014) presented a performance of Dijkstra and Floyd Algorithms in National City Traffic Advisory Procedures in China. The goal was to provide optimal decision and transport advisory to the passengers. Dijkstra's algorithm and Floyd algorithm were implemented in Microsoft Visual Studio to find the shortest path and the lowest cost to reach the desire destination. The time and cost parameter among the various cities in China was needed for shortest path identification. Comparing the time-cost of the selected algorithms, Dijkstra's algorithm performed better than Floyd algorithm.

METHODOLOGY

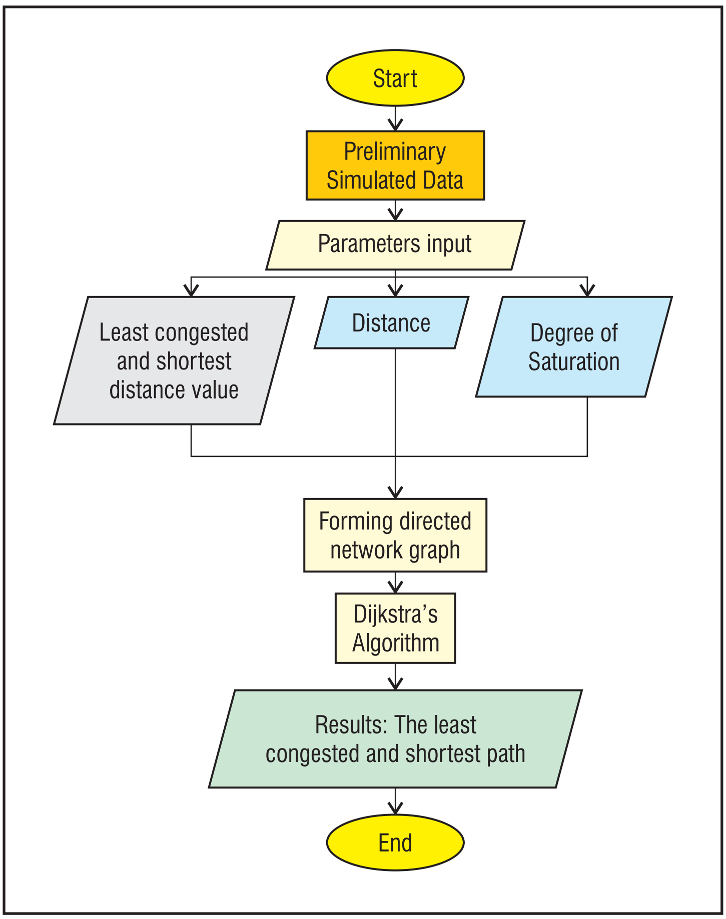

Figure 1 Flowchart

A basic flowchart showed in Figure 1. In this study, it started with preparing preliminary simulated data. From the data, there are three different parameter inputs which are distance, degree of saturation and least congested and shortest distance value (combination of distance and degree of saturation). By using those data and parameters, directed network graph was formed. Then it was solved by using Dijkstra's algorithm. The results of three different parameters were compared. The final result showed the combined parameters, the least congested and shortest path.

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,…, n linked by edges. Vertices or so-called nodes of the network graph are the elements of V which denoted as $v_1, v_2, \ldots, v_{n-1}, v_n \in V$. 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, respectively. The source node acts as the supply of units produced and sink node is consuming all units it receives. The edges defined by the ordered pairs (u, v). The edges (u, v) are the element of E over these nodes of the network graph.

Conditions:

Capacity constraint :

$$\forall (u,v) \in E, 0 \leq f(u,v) \leq c(u,v)$$

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

Flow conservation:

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

or

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

or

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

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 source node, s and sink node, t which are the starting and ending node of 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 element $[SD_v, i] = \min_u[SD_u + d_{uv}, u]$.

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 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 $[SD_v + d_{uv}, u]$ 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 $v = w$ is reachable from permanently labelled nodes and go to Step 2. w stands for the adjacent node of v. If all the nodes have permanent labels and $v = n$, then Stop.

Definition of Degree of Saturation

Degree of Saturation is a traffic flow indicator with a range in between 0 to 1. The range of the degree of saturation value is between 0 and 1. The degree of saturation less than 0.85 basically indicates that the capacity is still sufficient for the traffic volume demand. However, as the degree of saturation approaches 1.0, traffic flow may not be stable, with queue and delay conditions may occur. Once the demands exceed capacity (degree of saturation more than 1.0), congested traffic, long queue and excessive delay are expected. The formula for degree of saturation showed below.

Degree of saturation = volume / capacity

Preliminary Simulated Data

Table 1 Preliminary Simulated Data

Road	Volume	Capacity	Degree of saturation	Distance (meter)	Least congested and shortest distance value
1 -> 2	1000	1400	0.71	1000	710
2 -> 4	1120	1400	0.8	1200	960
3 -> 5	1400	1800	0.78	600	468
4 -> 6	1510	1800	0.84	900	756
5 -> 6	1240	1400	0.88	700	616
1 -> 3	900	1200	0.75	1230	922.5
2 -> 5	790	1000	0.79	600	474
3 -> 4	1300	2000	0.65	900	585

'Road' in Table 1 stands for the path from node to node. The numbers 1 to 6 are the nodes or so called intersection in traffic network. 'Volume' stands for the amount of vehicle that occupies a particular path at a particular time. 'Capacity' stands for the maximum volume of vehicles that passes through the particular intersection or path. Next, 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. The formula is shown below.

$$\text{Least congested and shortest distance value} = \text{Degree of saturation} \times \text{Distance}$$

RESULTS AND DISCUSSIONS

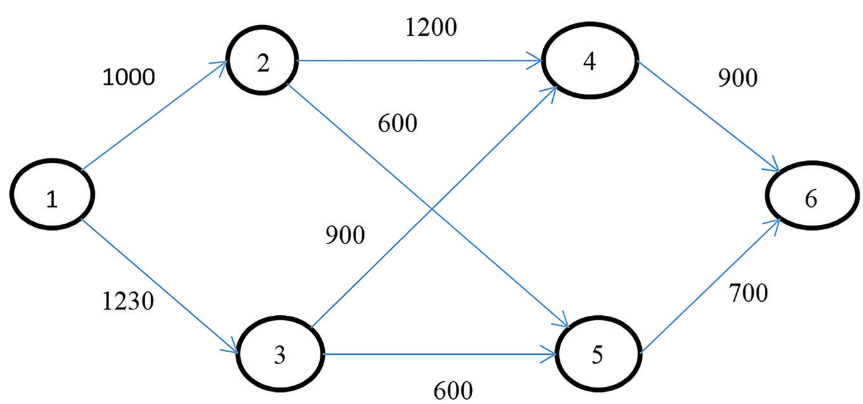

Figure 2 Distance parameter network graph

Network graph in Figure 2 with the distance parameter was formed by using the simulated data in Table 1. In Figure 2, the source node was node 1 and sink node was node 6.

From	To	On Route	=	Route Distance (Meter)
1	2	1	=	1000
2	4	0	=	1200
3	5	0	=	600
4	6	0	=	900
5	6	1	=	700
1	3	0	=	1230
2	5	1	=	600
3	4	0	=	900

SHORTEST PATH: 2300

Node	Net Flow	Supply/Demand
1	1	1
2	0	0
3	0	0
4	0	0
5	0	0
6	-1	-1

Figure 3 Excel output (Shortest path)

In Figure 3, column F represented the distance from node to node. The objective function was the cell F13 which contained the formula of '=SUMPRODUCT (D4:D11,F4:F11)'. The cells from I4 to I6, the net flow, were the constraints cells. The 'On Route' from cell D4 to cell D11 were the variable cells. The number '1' showed in the column of 'On route' denoted for the route selected, and number '0' denoted for route unselected. Hence, the selected routes for shortest path were from 1 → 2 → 5 → 6. In the supply or demand column, that source node was set as number '1' and the sink node was set as number '−1' because both of the nodes were the starting and the ending nodes.

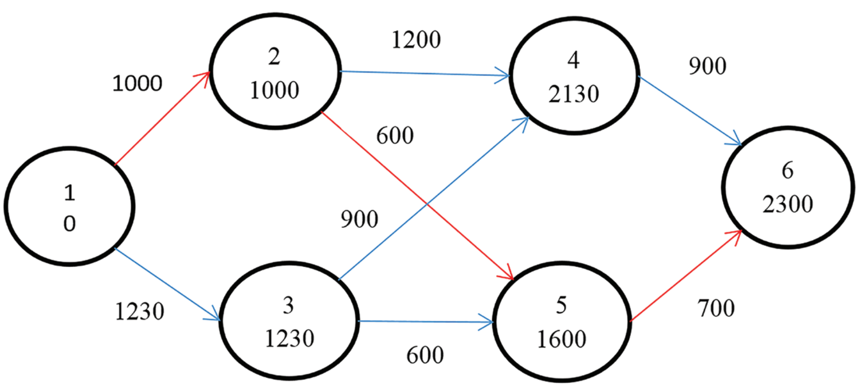

Figure 4 Output of Dijkstra's algorithm (shortest path)

From Figure 4, the path 1 → 2 → 5 → 6 was the shortest path with total 2300 metre.

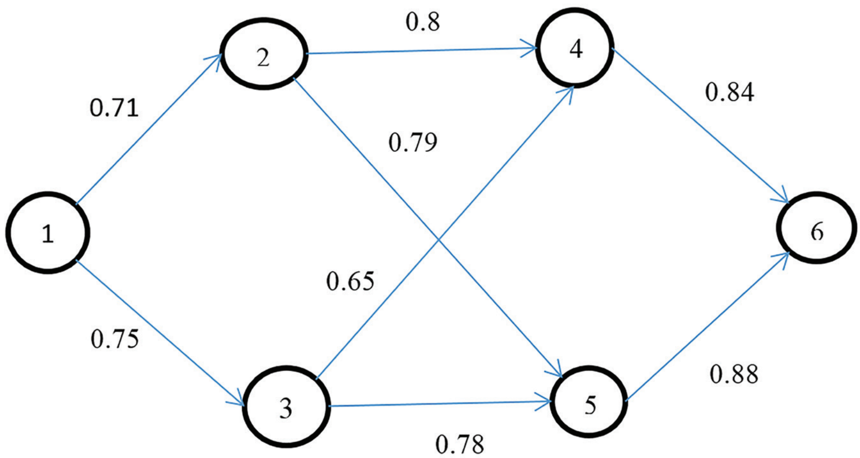

Figure 5 Degree of Saturation Parameter Network Graph

Figure 5 was a network graph with the parameter of degree of saturation. Degree of saturation is a volume to capacity ratio.

	A	B	C	D	E	F	G	H	I	J	K
1											
2											
3		From	To	Selected Path	=	Degree of Saturation		Node	Net Flow	Supply/Demand	
4		1	2	0	=	0.71		1	1	1	
5		2	4	0	=	0.8		2	0	0	
6		3	5	0	=	0.78		3	0	0	
7		4	6	1	=	0.84		4	0	0	
8		5	6	0	=	0.88		5	0	0	
9		1	3	1	=	0.75		6	-1	-1	
10		2	5	0	=	0.79					
11		3	4	1	=	0.65					
12											
13		SHORTEST PATH:				2.24					
14											

Figure 6 Excel output (The path with minimum degree of saturation)

In Figure 6, column F represented the degree of saturation from node to node. The objective function was the cell F13 which contained the formula of '=SUMPRODUCT (D4:D11,F4:F11)'. The constraints cells are cell from I4 to I6. The 'Selected Path' from cell D4 to cell D11 were variable cells. In column of 'Selected Path', the number '1' and '0' are selected route and unselected route respectively. Hence, the path 1 → 3 → 4 → 6 is the selected route with the minimum degree of saturation. The path with minimum degree of saturation is the least congested path. The source node was set as number '1' and the sink node was set as number '−1' in the supply or demand column.

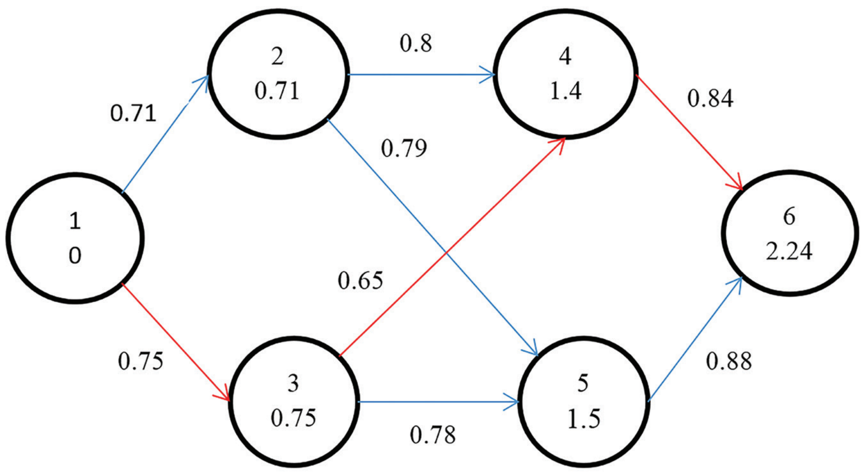

Figure 7 Output of Dijkstra's algorithm (The Least Degree of Saturation Path)

The red highlighted path in Figure 7 was the path with the least degree of saturation (the least congested) was 1 → 3 → 4 → 6.

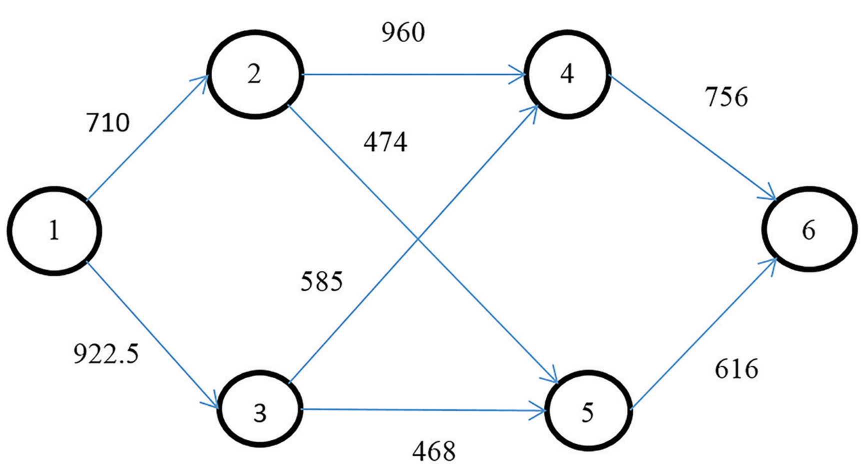

Figure 8 Least congested and shortest distance parameter network graph

In Figure 8, the combined parameters between distance and degree of saturation were used to form a new network graph as performed in Excel (Figure 9) and shown in Figure 10.

From	To	Selected Path	=	Least Congested and Shortest Distance Value	Node	Net Flow	Supply/Demand
1	2	1	=	710	1	1	1
2	4	0	=	960	2	0	0
3	5	0	=	468	3	0	0
4	6	0	=	756	4	0	0
5	6	1	=	616	5	0	0
1	3	0	=	922.5	6	-1	-1
2	5	1	=	474			
3	4	0	=	585			
SHORTEST PATH:				1800			

Figure 9 Excel output (the path with least congested and shortest distance)

The least congested and shortest distance value from node to node was performed in Figure 9. The objective function, F13 which contained the formula of '=SUMPRODUCT (D4:D11,F4:F11)'. The net flow cells from I4 to I6 were the constraints cells. The 'Selected Path' column in Figure 9 was the variable cell. The number '1' showed in the column of 'Selected Path' denoted for the route selected, and number '0' denoted for route unselected. In the supply or demand column, that source node was set as number '1' and the sink node was set as number '−1' because both of the nodes were the starting and the ending nodes. Hence, the selected route is $1 \rightarrow 2 \rightarrow 5 \rightarrow 6$ with the minimum least congested and shortest distance value. The path with minimum least congested and shortest distance value is the best path selection which both distance and level of congestion were considered.

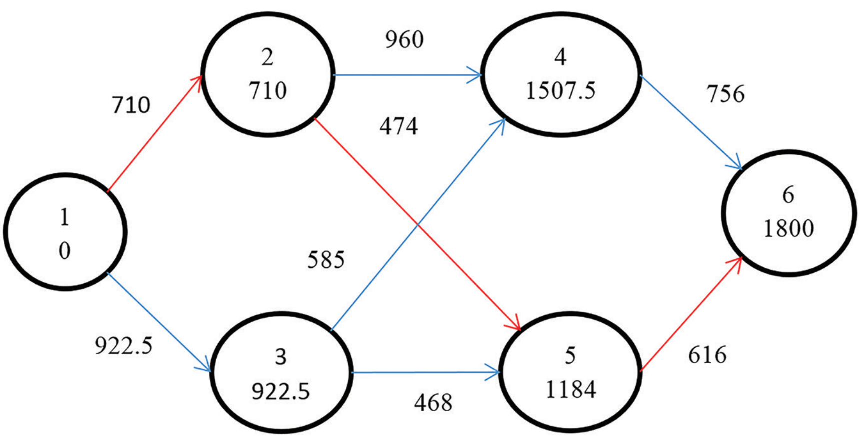

Figure 10 The network graph with the least congested and minimum distance path

In Figure 10, the alternative path with the least congested and shortest path was $1 \rightarrow 2 \rightarrow 5 \rightarrow 6$. The total distance of the alternative path was 2300 metres with the total degree of saturation of the alternative path is 2.38.

Table 2 Comparison between the distance and degree of saturation

Parameter	Path	Distance (Meter)	Degree of Saturation
Distance	Path 1: $1 \rightarrow 2 \rightarrow 5 \rightarrow 6$	2300	2.38
DOS	Path 2: $1 \rightarrow 3 \rightarrow 4 \rightarrow 6$	3030	2.24
Combined Parameter	Path 2 Selected	2300	2.38

As shown in Table 2, there were three different paths that were chosen depending on the parameters. With the distance parameter network graph, Path 1 was the selected path with the shortest distance. The path 2 was the selected path with the lowest Degree of Saturation (DOS). With the combined parameters between DOS and Distance, path 2 was selected because it achieved equilibrium between distance and DOS. In other words, drivers can decide the right path with less congested and shorter distance path to reach their desired destination. The percentage difference was then calculated as per below.

Difference between path 1 and path 2 in term of Distance Parameter

$$= \frac{3030-2300}{\frac{2300+3030}{2}} \times 100 = 27.39\%$$

Difference between path 1 and path 2 in term of DOS Parameter

$$= \frac{2.38-2.28}{\frac{2.38+2.28}{2}} \times 100 = 6\%$$

As shown above, path 1 and path 2 have a difference of 27.39%, 6% in terms of distance and DOS parameter, respectively. From the results shown above, path 1 has shorter distance of 27.39% from path 2. Even though path 2 has the advantage of 6% from path 1 in terms of DOS parameter, path 2 was selected as the best path because it has achieved equilibrium between Distance and DOS.

In summary, the shortest path was selected as the best path in Figure 4. The least congested path was selected which was shown in Figure 7. The last one is the network graph in Figure 10 showing the selection of the best path between level of congestion and distance together. From the three different network graphs, the distance parameter network graph in Figure 4 showed the selection of the shortest distance as the best path. Secondly, the degree of saturation parameter network graph in Figure 7 chose the path with less congested condition. As Neumann (2014) mentioned that shortest path cannot be the best path selection. There should be more criteria to be added in selecting the best path. For example, safety, less edges, level of congestion and so forth. As the results of this study had shown, the proposed modified parameter with network graph in Figure 10, the least congested and shortest distance network graph, achieved a balance between two important criteria to select the best path.

CONCLUSION

The shortest path was $1 \rightarrow 2 \rightarrow 5 \rightarrow 6$ but the least congested path was $1 \rightarrow 3 \rightarrow 4 \rightarrow 6$. The route with the shortest distance might not be the best path if the traffic flow was not considered. Hence, this study had combined these two parameters together to obtain a path that was the least congested and still a shorter path for the driver. With the combined parameters, this provided a balance between the degree of saturation and distance. The best path from this study was found to be $1 \rightarrow 2 \rightarrow 5 \rightarrow 6$.

REFERENCES

Akcelik, R. (1989). On the estimation of lane flows for intersection analysis. *Australian Road Research*, *19* (1), 51 – 57.

Bernama. (2016, December 28). Traffic woes haunt KK residents daily. *The Borneo Post*. Retrieved from https://www.theborneopost.com/2016/12/28/traffic-woes-haunt-kk-residents-daily/

Gupta, N., Mangla, K., Jha, A. K., & Umar, M. (2016). Applying Dijkstra's algorithm in routing process. *International Journal of New Technology and Research* (IJNTR), *2* (5), 122 – 124.

Mathew, T. V., & Rao, K. V. K. (2006). Introduction to transportation engineering. *National Programme on Technology Enhanced Learning* (NPTEL). Retrieved from https://nptel.ac.in/downloads/105101087/

Morpi, M. (2015, July 3). World Bank report highlights worsening KK traffic woes. *The Borneo Post*. Retrieved from http://www.theborneopost.com/2015/07/03/world-bank-report-highlights-worsening-kk-traffic-woes/

Neumann, T. (2014). Method of path selection in the graph-case study. *International Journal on Marine Navigation and Safety of Sea Transportation*, *8* (4), 557 – 562.

Rao, A. M., & Rao, K. R. (2012). Measuring urban traffic congestion: A review. *International Journal for Traffic & Transport Engineering*, *2* (4).

Rewadkar, D. N., & Ratnaparkhi, P. M. (2015). Traffic estimation and least congested alternate route finding GPS and non-GPS vehicles through real time data on Indian roads. International *Journal of Innovative Research in Computer and Communication Engineering*, *3* (7), 6686 – 6691.

Rodegerdts, L. A., Nevers, B., Robinson, B., Ringert, J., Koonce, P., Bansen, J., ... Courage, K. (2004). *Signalized intersections: Informational guide* (Technical report No. FHWA-HRT-04-091). Washington, DC: Federal Highway Administration.

Rohila, K., Gouthami, P., & Priya, M. (2014). Dijkstra's shortest path algorithm for road network. *International Journal of Innovative Research in Computer and Communication Engineering*, *2* (10), 6139 – 6144.

Sangaiah, A. K., Han, M., & Zhang, S. (2014). An investigation of Dijkstra and Floyd Algorithms in National City Traffic Advisory Procedures. *International Journal of Computer Science and Mobile Computing*, *3* (2), 124 – 138.