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WEIGHTED METHODS OF MULTI-CRITERIA VIA DIJKSTRA'S ALGORITHM IN NETWORK GRAPH FOR LESS CONGESTION, SHORTER DISTANCE AND TIME TRAVEL IN ROAD TRAFFIC NETWORK

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ABSTRACT

Drivers tend to face road mobility problems known as traffic congestion when the traffic volume exceeds its capacity at any road intersections. Drivers then tend to select a path, normally by just considering a single criterion like distance, for example, without considering other factors which affect traffic congestion. Ultimately, drivers endeavour to reach their destination, and hence their need to select the most appropriate path in the road traffic network, since the wrong path selection might affect the goals of their endeavours, like having to reach meetings and appointments on time, saving fuel costs, and attaining quality productivity time. Therefore, a suggested approach in this study is to include multi-criteria in selecting the best path. The multi-criteria in selecting the best path in this study are the degree of saturation (level of service), route distance and time travel of the path. The network graphs with the different parameters are solved using the weighted methods, namely Weighted-Sum Method (WSM) and Weighted-Product method (WPM) via Dijkstra's algorithm. In conclusion, the path with combined multi-criteria of distance, time travel and degree of saturation would be the best way to select the best path, instead of solely choosing either one of the criteria, namely, on the shortest distance, travel time or minimum degree of saturation.

Keywords*:* *Multi-criteria, Dijkstra's Algorithm, Network Graph, , Weighted methods, Road Traffic Network.*

I. INTRODUCTION

Generally, drivers tend to assume that the path with the shortest distance will be the best path to travel from their desired origin to destination. In fact, it might not be the best path because it was just considering only single criterion in path selection. Besides, different road user might have different demand in choosing the best path. Sometimes, the shortest distance path is not the desired path for the drivers because different conditions of demand. For example, Logistics Companies may take the road safety factor, and cost as the criterion in selecting the best path. Hence, multiple criterions should be considered in selecting the best path.

Congestion level is closely related to road traffic congestion in this study. Traffic congestion is a common traffic problem that happens when vehicles stop on road for a period of time. Drivers are trapped in long queues, and the overall speed of the cars on road decreases. Hence, drivers tend to take longer trip times even though travelling for a short distance trip. Moreover, traffic congestion is increasing annually as the human population and number of cars increases. According to the World Bank, traffic congestion had contributed GDP loss of 1.1% to 2.2% a year in Malaysia (Morpi, 2015). There are several reasons that caused traffic congestion such as weathers, poor traffic facilities, driver's driving behavior, unrestricted owning of private vehicles and others. Traffic congestion is affecting the economic productivity especially in the logistic sector. For example, a logistic company cannot send the postage by the promised time due to traffic congestion that slows down the sending process. Furthermore, traffic congestion increases the economic cost for both invisibles and the visibles. The visible cost of the traffic congestion is the delay of speed in traffic. The hidden cost of congestion is that people tend to forgo their travel need just to avoid traffic congestion. Then, people could not have the benefits of living in a city. For example, they could miss a better job opportunity and better amenities in the city (Dachis, 2015). Regardless of economic issues, traffic congestion contributes the emissions of greenhouse gases which are affecting natural environment. The air quality would decrease which thus affect the quality of life for the people. Other than pollution, it would also cause wastage of natural resources such as fuels (Rao & Rao, 2012).

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

The objective of this study is to find an alternative best path by using combined parameters of degree of saturation value, time travel and distance. Weighted-sum and weighted-product methods are used and compared when combining the multi-criteria parameters. The network graph is being categorized into five different types of parameters and then performed in this study. These five different parameters are distance, degree of saturation, time travel, weighted sum and weighted product combined parameters. Five different network graphs are formed based on the types of the parameters. Dijkstra's algorithm, a basic shortest path algorithm is applied in this study to solve the road networks. The combined criteria between distance, time travel and the level of service in selecting the best path to avoid congestions are therefore main focus in this study.

II. LITERATURE REVIEW

According to Jain et al. (2012), the problem of traffic congestion in high congestion hotspots in developing area was addressed. Road traffic jams were being mentioned as a major problem in cities, especially in developing countries. It caused massive effects such as traffic delays, wastage of fuels and monetary losses. A poor traffic management and discipline became a major problem that caused the elongated traffic jams. A simple automated image processing mechanism was used to detect the level of service through images that captured through the CCTV camera on the spot. The identified congestion collapsed through the live CCTV on multiple traffic intersections was shown as evidences. A local de-congestion protocol was a suggested method which could coordinate traffic signal behavior of the selected area to alleviate the problem of congestion collapse. After a simulation based analysis, it showed that the local de-congestion protocol could improve the intersections capacity and hence, minimize congestion level by controlling the flow of traffic into the near-congested regions.

Popoola et al. (2013) had investigated the causes, effects and remedies of highway traffic congestion in Nigeria (Mowe/Ibafo section of the Lagos-Ibadan expressway). The data were collected through questionnaires among the residents in Mowe/Ibafo. The completed questionnaires were analyzed by the relative importance Index. The results showed that inadequate road capacity, poor road pavement, road accidents, poor traffic control management, poor drainage system, bad driving behavior, poor road network, poor parking habit, religious/special event along the road and presence of heavy vehicles are the greatest causes of traffic congestion in Nigeria. Effects of traffic congestion are time wastage, fuel consumption, road rage, relocation, night driving, environmental pollution,delay movement, stress, accident, and inability to forecast travel of time. To drastically reduce these negative effects, there must be provision for adequate parking space, construction of proper drainage, enlarging the width of the road, rehabilitate all roads needing attention, public enlightenment, traffic education, hack down all illegal buildings/shops built on the right of way (ROW), create a separate/alternative root for trucks and heavy vehicles, provision of pedestrian facilities, in-depth training of transport/traffic personnel, ban all forms of road trading/hawking, and reduce the number of bus stops where necessary. The traffic congestion in Nigeria was thus improved with this study.

Neumann (2014) presented a method of path selection in network graph. In his study, the Dijkstra's algorithm was used to find alternative paths among nodes in the maritime network. Since it involved a single criterion, distance in selecting the best path, therefore the shortest path was not always the best alternative path. Hence, other parameters such as average time, number of indirect vertices were 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 used in the method that could be applied to combine data and evidences.

Tofallis (2014) stated that methods on ranking could be done by additive and multiplicative approach with consideration of multi criteria. Simple additive weighting approach is a one of the common method in multi criteria decision making. However, this approach might lead to rankings disturbance due to the normalization undergone. Hence, he proposed the multiplicative approach, that had been ignored for too long. He avoided the normalization process, and allowed the modelling of the more realistic preference behavior. He applied the multiplicative approach using data from business schools. Overall, the multiplicative approach had eliminated the problem of normalization and thus performed an advantage in aggregating the ratings of panel members.

III. MATERIALS & METHODS

Kota Kinabalu traffic network is discussed in this study. Traffic congestion in Kota Kinabalu happens due to slow improvement of facilities and abundance vehicles on the road. Traffic congestion can be categorized into two types which are recurring congestion and non-recurring congestion. Recurring congestion is a type of congestion which include excess demand for travel and shortage of intersections supply. Recurring congestion are used to occur during peak hours, especially from 7am to 9am, and 5pm to 7pm. This is because during these peak hour periods, people tend to go for work or back from work to their homes. Another type of traffic congestion is the non-recurring congestion which are caused by special cases such as accidents or road closures. This paper would illustrate in detail the modelling procedures and its outputs for comparisons of the differents senarios of the parameters input of traffic.

A. Research design

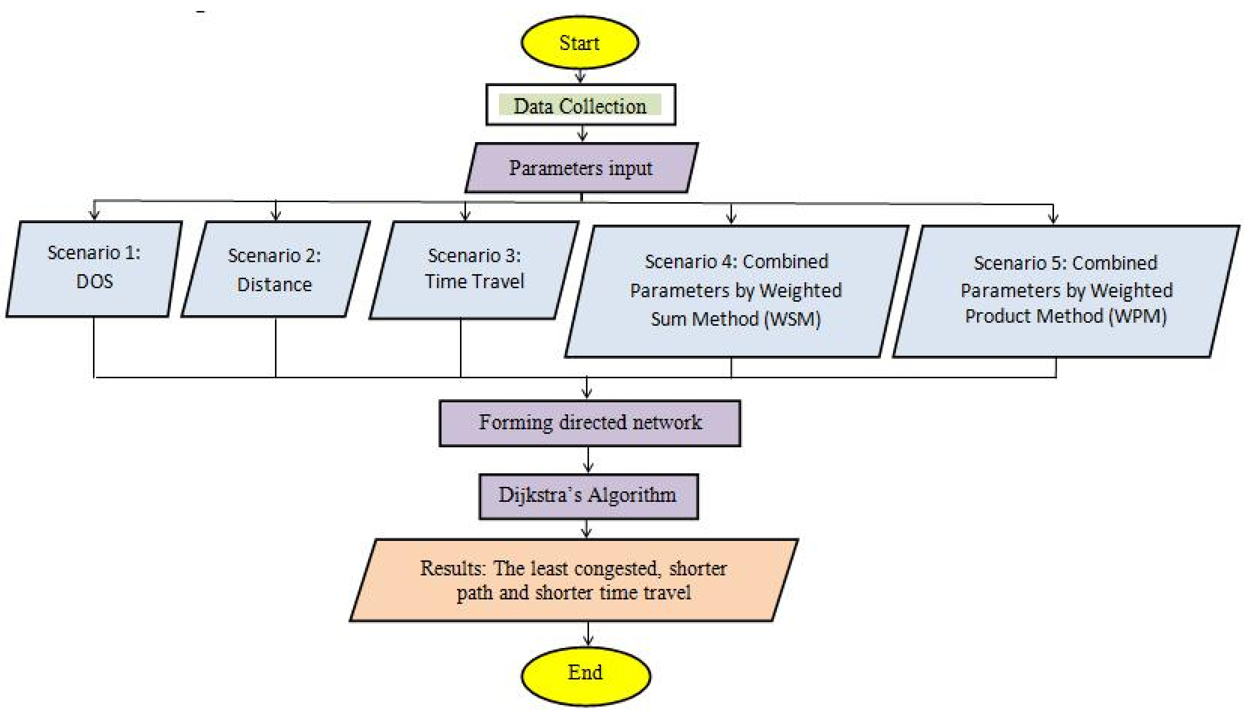

Figure 1: Flowchart of Research Design

A basic flowchart is shown in Figure 1. In this study, traffic data are collected and prepared in Kota Kinabalu during the 5pm to 7pm peak hours. From the data, there are five different parameter inputs which are distance, degree of saturation, time travel, weighted sum and weighted product combined parameter methods. With all the collected data, five different types of directed network graphs are formed. Then, the traffic networks are solved both using the Dijkstra's algorithm and Excel Solver. The results of five different parameters are then compared. Finally, the combined parameters with a balance or equilibrium between all the criteria are showed as in the result section.

B. Conceptual theory

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 $1,2\ldots,n-1,n$ 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, starting node, which act as the supply of units produced. v_n is the sink node or called ending node act as a node that 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 (Goemans, 1994), with conditions as:-

Capacity constraint :

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

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 v_1 to node v_n. The label of node j connected with node, i is defined as the pair of elements $[SD_v,i]=\min_u[SD_u+d_{uv},u]$. 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 (Bose, 2005). With these definitions, the method consists of the following steps:-

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Step 1. Label starting node, v_1 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 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 queues and delay conditions may occur. Once the demand exceed capacity (degree of saturation more than 1.0), congested traffic, long queues and excessive delay are expected. The formula for degree of saturation is given by: $Degree\ of\ saturation = volume\ /\ capacity$…….(Rodegerdts et al., 2004).

Definition of Weighted Sum Method

Simple weighted sum method is simply the sum of these variables. It implies that there is a fixed trade-off rate between each pair of criteria. Most commonly used normalization method is dividing the values by the total of all the values of the criterion to get the proportion of some whole. After the normalization, attach the weights to the criteria and add together the weighted values to produce corresponding scores and ranks. The weighted sum formula is given by: $Weighted\ Sum\ Method = W_1X_1 + W_2X_2 + \ldots + W_nX_n$ where W_n stands for the weight value of a criterion, and $X_n$represents the overall score of the criterion, respectively (Nagar & Tawfik, 2007).

Definition of Weighted Product Method

Weighted Product Method is a straight forward and flexible approach because it can directly ignore the normalization.The weight seems to be the exponents of the criteria. The formula for weighted product method is given by: $Weighted\ Product\ Method\ = X_1^{W1}X_2^{W2}\ldots X_n^{Wn}$ where W_n and X_n are representing the weight value and overall score of a criterion respectively (Tofallis, 2012).

IV. RESULTS

Study site

The selected scope in this study is the network from Inanam, a suburb town (source node) to Centre Point which form as the Central Business District (CBD) in Kota Kinabalu city (sink node). All the routes between source node and sink node of the scope are established. In Figure 2, the red spots are part of the selected major intersections in Kota Kinabalu which are assigned as the nodes of the network graph.

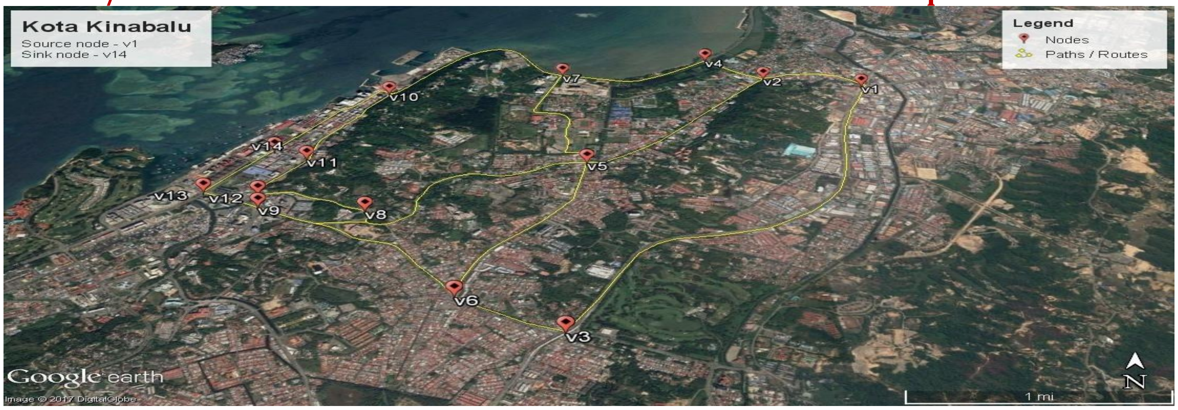

Figure 2: Part of Traffic Network in Kota Kinabalu

Data Collection

The data as shown in Table 1 are collected on the road and through Google Maps. Distances of the paths are collected from the Google Maps by putting the pointers on the intersections. In addition, the degree of saturation is collected through on the road videos taken during evening peak hours (5pm to 7pm) in the week days for six months (March-August, 2017). The volume, saturation headway, cycle time, green time and intersection geometry are collected in order to compute the degree of saturation (volume/capacity ratio). Time taken is collected through real time traffic flow in Google Maps during the evening peak hours.

Table 1: Collected Data

Path	From	To	Volume	Capacity	DOS value	Distance (km)	Time Travel (Minutes)	Weighted-Sum Value	Weighted-Product Value
1	V1	V2	3072	3536	0.869	1.00	2	0.028314	1.202089
2	V1	V3	1167	918	1.272	5.20	7	0.086235	3.586253
3	V2	V4	1026	1254	0.818	0.60	1	0.020730	0.788989
4	V2	V5	1377	1809	0.761	2.40	4	0.045173	1.939088
5	V5	V2	1686	1798	0.938	2.40	6	0.055004	2.379459
6	V3	V6	1710	1904	0.898	0.85	2	0.027538	1.151279
7	V4	V7	3777	2152	1.755	1.50	2	0.045673	1.738704
8	V7	V5	783	734	1.067	2.10	5	0.050934	2.235809
9	V5	V7	321	1512	0.212	2.10	5	0.038081	1.305347
10	V8	V5	1584	1302	1.217	2.40	5	0.055613	2.442132
11	V5	V8	1663	2466	0.674	2.40	2	0.036695	1.478417
12	V6	V5	1290	1475	0.875	2.30	4	0.046079	2.002765
13	V5	V6	639	643	0.994	2.30	6	0.055037	2.391715

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14	V6	V9	1680	3843	0.437	2.10	4	0.037878	1.541932
15	V8	V12	879	1162	0.756	0.90	2	0.025807	1.108035
16	V12	V8	75	504	0.149	0.90	1	0.013097	0.512193
17	V7	V10	1261	2660	0.474	2.30	4	0.040050	1.63296
18	V10	V11	570	1028	0.554	1.30	6	0.040343	1.628007
19	V11	V10	1394	1002	1.391	1.30	4	0.045755	1.932667
20	V11	V12	1224	2308	0.53	0.65	2	0.020390	0.883338
21	V12	V11	1784	2094	0.852	0.65	3	0.028815	1.184181
22	V12	V9	1680	3962	0.424	0.23	1	0.011817	0.460647
23	V9	V12	1518	1692	0.897	0.23	1	0.018928	0.591201
24	V9	V13	1656	1777	0.932	0.50	3	0.028806	1.118031
25	V13	V14	1026	1431	0.717	0.85	1	0.021232	0.847978
26	V11	V14	804	752	1.069	0.30	2	0.025664	0.862529
27	V10	V14	1995	3086	0.646	1.50	8	0.050512	1.977765

'Path' in Table 1 stands for the path from node to node. The V1 to V14 are the nodes or so called intersections in traffic network. 'Volume' stands for amount of vehicle that occupies on particular path on particular time. 'Capacity' stands for the maximum volume of vehicles that can pass through the particular intersection or path. Next, the Degree of Saturation (DOS) 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. 'Weighted-Sum value'stands for the value of the combination between degree of saturation, time travel and distance by the Weighted-Sum Method (WSM). In addition, 'Weighted-Product value' stands for the combined value of multi-criteria by the Weighted-Product Method (WPM).

Outputs of Dijkstra's Algorithm

The network graph in Figure 3 is with the parameter on degree of saturation (DOS). Degree of saturation is a volume to capacity ratio. The red highlighted path in Figure 3 above is the path with the least degree of saturation (DOS=0.869+0.761+0.212+0.474+0.646) which indicates as the least congested path, $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$ with a total DOS value of 2.962.

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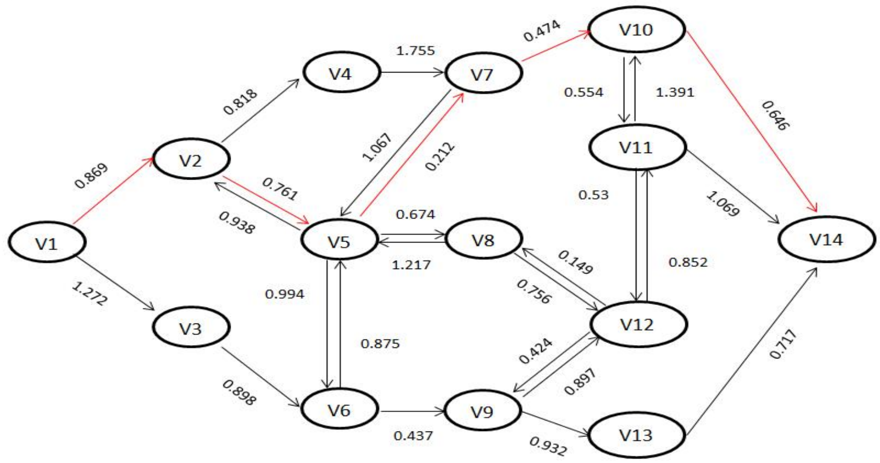

Figure 3: Output of Dijkstra's algorithm (Degree of Saturation Parameter Network Graph)

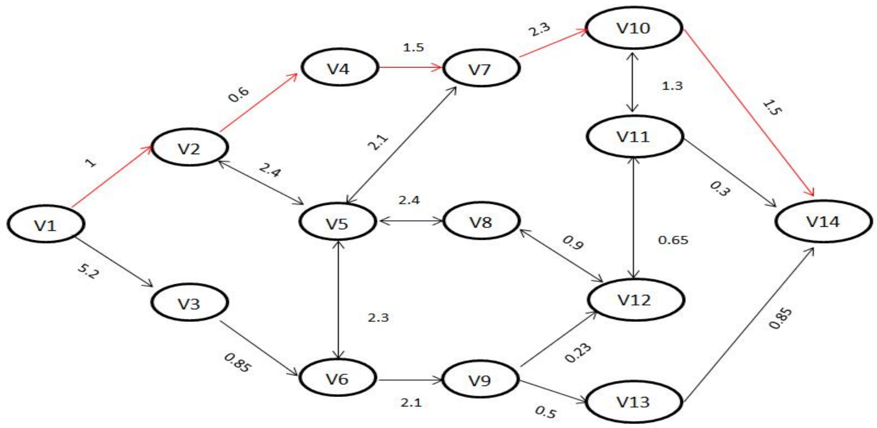

Figure 4: Output of Dijkstra's algorithm (Distance Parameter Network Graph)

Network Graph in Figure 4 with the distance parameter is formed by using the collected data in Table 1. The source node is node 1, and sink node is node 6. From Figure 4, the path highlighted in red is denoted by $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$ which is the shortest path that has a total distance of (1.0+0.6+1.5+2.3+1.5) equals to 6.9 kilometers.

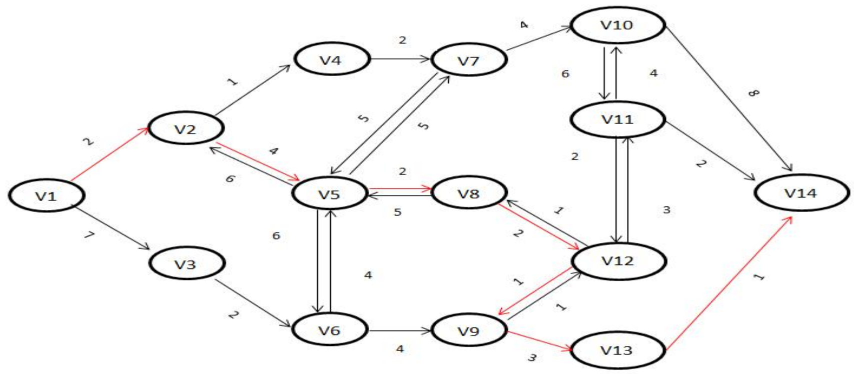

Figure 5: Output of Dijkstra's algorithm (Time Travel Parameter Network Graph)

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In Figure 5, the time travel parameter network graph is shown together as the alternative path. The alternative path that has the shortest time travel is the path, $V1 \rightarrow V2 \rightarrow V5 \rightarrow V8 \rightarrow V12 \rightarrow V9 \rightarrow V13 \rightarrow V14$. The total time travel taken is 15 minutes, travelling from $V1$ to $V14$ respectively.

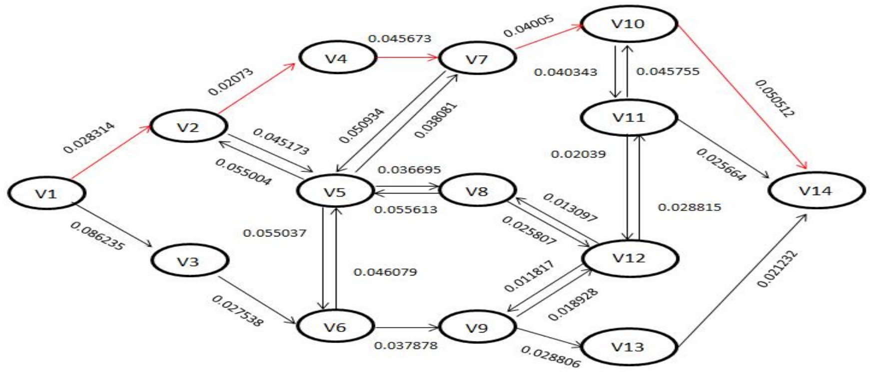

Figure 6:Output of Dijkstra's algorithm (Weighted-Sum Method)

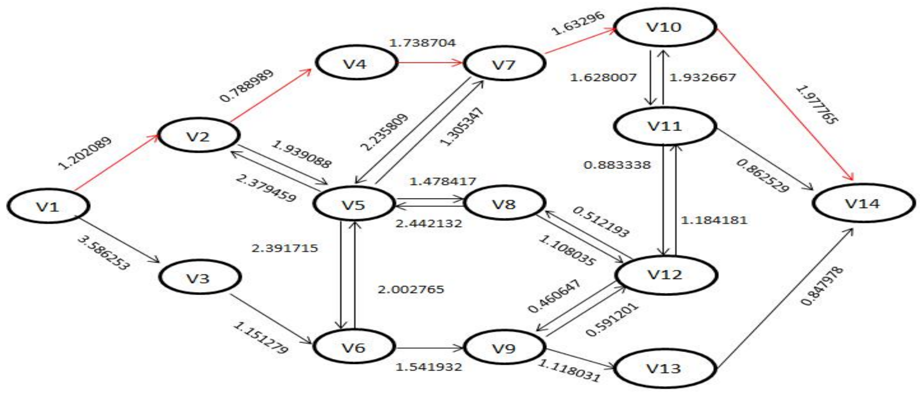

Figure 7: Output of Dijkstra's algorithm (Weighted-Product Method)

In Figure 6 and Figure 7, the dijkstra algorithm using the combined values between distance, time travel and degree of saturation by the weighted-sum and weighted-product methods are executed respectively. From the outputs in Figure 6 and 7 for both methods, the path with less congestion, shorter distance and shorter travel time is given by $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$. The total distance of this alternative path is 6.9 kilometers with the total degree of saturation, 4.562 and 17 minutes of travel time.

Table 2: Comparison between the Distance, Degree of Saturation and Time Travel

Parameter	Path	Distance (km)	DOS*	Time Travel (Minutes)
Distance	Path 1: $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$	6.90	4.562	17
DOS	Path 2: $V1 \rightarrow V2 \rightarrow V5 \rightarrow V7 \rightarrow V10 \rightarrow V14$	9.30	2.962	23
Time Travel	Path3: $V1 \rightarrow V2 \rightarrow V5 \rightarrow V8 \rightarrow V12 \rightarrow V9 \rightarrow$	8.28	5.133	15

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	$V13 \rightarrow V14$			
Combined Parameters (Weighted Sum Method & Weighted Product Method)	Path 1: $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$ (Selected)	6.90	4.562	17

*DOS=Degree of Saturation

As shown in Table 2, there are three different paths chosen depending on the selected parameters. With the distance parameter network graph, Path 1 is the selected path with the shortest distance. Path 2 is the selected path with the lowest Degree of Saturation (DOS), while Path 3 is the path with the shortest time travel. With the combined parameters between DOS, time travel and Distance, Path 1 is selected because it has achieved the balance or equilibrium between distance, time travel and DOS. In other words, drivers can decide the optimum right path which is less congested, has shorter time travel and shorter distance, so as to reach their desired destination. The differences between the paths in percentages are then calculated to find the significant differences between them.

Formulae Percentage of Difference

$$Increase = New\ Number - Original\ Number$$
$$Decrease = Original\ Number - New\ Number$$
$$Percentage\ of\ Difference = (Increase\ or\ Decrease) \div Original\ Number \times 100$$

Calculations of Percentage of Parameters of the Paths

$$Difference\ of\ percentage\ of\ Distance\ between\ Path\ 1\ and\ Path\ 3 = \frac{8.28 - 6.9}{8.28} \times 100 = \mathbf{16.67}\%$$

$$Difference\ of\ percentage\ of\ Distance\ between\ Path\ 1\ and\ Path\ 2 = \frac{9.3 - 6.9}{9.3} \times 100 = \mathbf{25.81}\%$$

$$Difference\ of\ percentage\ of\ Degree\ of\ Saturation\ between\ Path\ 1\ and\ Path\ 3 = \frac{5.133 - 4.562}{5.133} \times 100 = \mathbf{11.12}\%$$

$$Difference\ of\ percentage\ of\ Degree\ of\ Saturation\ between\ Path\ 1\ and\ Path\ 2 = \frac{4.562 - 2.962}{5.133} \times 100 = \mathbf{31.17}\%$$

$$Difference\ of\ percentage\ of\ time\ travel\ between\ Path\ 1\ and\ Path\ 3 = \frac{17 - 15}{17} \times 100 = \mathbf{11.76}\%$$

$$Difference\ of\ percentage\ of\ time\ travel\ between\ Path\ 1\ and\ Path\ 2 = \frac{23 - 17}{23} \times 100 = \mathbf{26.09}\%$$

Table 3: Comparison of Percentage of Differences between Paths

	Percentage of Difference		
Comparison between Paths	Distance	DOS	Time Travel
Path 2 & 1	↑ 25.81 %	↓ 31.17%	↑ 26.09%
Path 3 & 1	↑ 16.67 %	↑ 11.12 %	↓ 11.76 %

As shown in Table 3, Path 1 has 26.09% shorter time travel and 25.81% shorter distance, but 31.17% higher of congestion level than Path 2. It means that Path 1 has a shorter time to travel with a shorter distance, but higher congestion level than Path 2. In addition, Path 1 is shorter in distance too for about 16.67% compared to Path 3. For comparison between Path 1 and Path 3, Path 1 is 11.12% less congested than Path 3, but longer 11.76% in time travel compared to Path 3. Hence, Path 1 is selected as the best path because it has the balance between travelling a relatively short time travel with a shorter distance and less congestion. As Neumann (2014) had mentioned that 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 and time travel are added to distance in order to select the best path, instead of just selecting the shortest path based on distance as the best path, eventhough similar results are obtained.

V. DISCUSSIONS AND CONCLUSION

According to the statistics in 2000, there were only 77,000 vehicles entering and leaving the city in a day. In 2016 alone, the number of vehicles that ply in city's street had increased to an estimated 140,000 vehicles, based on cumulative calculations. According to the above fact, car ownership had increased 3 to 4 percent annually. According to the Road Transport Department (JPJ) statistics, there were 1,026,867 registered vehicles in 2012 and 1,273,788 registered vehicles in 2016 (Razan, 2017). 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. The increase of vehicles ownership is a reflection of the improved nation's affordability. Besides that, the public transportation poor facilities are another reason that caused the number of private vehicles on road increased. Hence, road users tend to take their own vehicle ,instead of public transportation in order to be more comfortable, convenient and efficient way to reach their destinations. Road users might take longer time to travel a short distance due to the congestion problem. The traffic congestion problem will become more serious if this situation remains consistent.

With all the effects of traffic congestion that have been stated, remedies and ways should be suggested to solve or minimize the problem. There are several conventional approaches that are used to improve traffic flow such as road widening and building flyovers. However, Kalvin Liaw, director of Kota Kinabalu City Hall (DBKK) Traffic and Public Transport Department had stated that these approaches can only be used in the short term, and not in the long term way because the population had increased dramatically (Bernama, 2016). Even though the conventional approach might not be the best way, but it is necessary to reduce the impact of traffic congestion especially at junctions and intersections. However, the conventional approach will use up all the space until there are limited space for further improvement as it goes for long term situation. Apart from conventional approaches, there is another approach which is by adding and considering more criteria in choosing the best path. As usual, drivers tend to choose the shortest path to travel to their destination but it might not be the best path. This is because the shortest path might encounter traffic congestion problem and caused the travel time longer than expected.The alternative routes may longer in distance, but smoother in traffic flow ,and shorter in time travel.

The routes with the shortest distance may not be the best path, as in Ting & Noraini (2017) where two different parameters had resulted in two different paths but the best path selected was based on distance and least degree of saturation criteria. However, in this study, travel time as an additional criterion is being considered. Paths with three different parameters have been compared and have resulted in three different paths. From the results, the shortest path is $V1 \to V2 \to V4 \to V7 \to V10 \to V14$, the least congested path is $V1 \to V2 \to V5 \to V7 \to V10 \to V14$ and the shortest time travel is $V1 \to V2 \to V5 \to V8 \to V12 \to V9 \to V13 \to V14$. Hence, this study has combined these three parameters together to obtain a path that is the balance between congestion level, short distance and short time travel for the drivers. With the combined parameters, the best path from this study is found to be $V1 \to V2 \to V4 \to V7 \to V10 \to V14$ with a total of 6.9 km, degree of saturation value of 4.562 and 17 minutes of time travel. Results have thus shown that the best path would have the simultaneous combined multi-criteria of short distance, short time travel and less congestion. Even though, the Weighted-Sum Method (WSM) and Weighted-Product Method (WPM) can come out with the same output, WPM was superior as compared to WSM in terms of computational steps. The Weighted-product method can also be user friendly, in agreement with Tofallis (2012), and further avoid the problem of normalization that may cause rank reversal which is usually faced by the weighted-sum method.

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