TRAFFIC CONGESTION PROBLEM OF ROAD NETWORKS IN KOTA KINABALU

[1]TING KIEN HUA, [2]NORAINI ABDULLAH

[1]Centre of Postgraduate Studies, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[2]Faculty of Science & Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
Email: tingkienhua@gmail.com, [2]noraininiabdullah.ums@gmail.com

Abstract: Traffic congestion is anurban mobility problem that happened when the traffic volume exceeded the capacity of the road. In this century, human population is in surge, people tend to own private vehicles which cause traffic congestion. Besides, the poor management and road facilities worsen the traffic flow. In this study, maximum flow, bottleneck and shortest path are identified. Network from Indah Permai (IP) to Kota Kinabalu International Airport (KKIA) is the scope of this study. The capacity and distance of the routes within the scope are obtained from Dewan Bandaraya Kota Kinabalu (DBKK) and Google Map. With all the data, capacitated and weighted network graph formed. The objectives of this study are to find maximum flow, bottleneck and shortest path. Hence,Ford-Fulkerson algorithm, Max flow-Min cut theorem and Dijstra's algorithm are applied. Next, the maximum flow and the shortest path problem were formulated intoa linear programming model, and solved by using excel solver in Microsoft Excel. With theresults, traffic congestion problem minimized and traffic flow became smooth.

Keywords: Traffic Congestion, Maximum flow, Bottleneck, Shortest Distance

I. INTRODUCTION

Traffic congestion is a common traffic problem in the entire world from year to year. There are several reasons that cause traffic congestions like bottlenecks, accidents, road conditions, road facilities, driver's driving behaviors, unrestricted owning vehicles and so forth. Traffic jam causes the traffic speeds slower, long trips time and long queues on the traffic. These phenomena are affecting the economic productivity and wasting of fuels and time. Apart from economic issues, traffic congestionsalso affected the quality of life and polluted the environment. There are two types of traffic congestion, namely, recurring congestion and non-recurring congestion. Recurring congestion is used to happen in the area of Central Business District (CBD)during peak hours of weekdays. Non-recurring congestion is an unexpected congestion due to accidents, sudden road closures, and maintenance which will slow the traffic flow. Moreover, non-recurring congestion is an unpredictable and troublesome traffic problem because it reduces the roadway capacity [1]. Hence, recurring congestion are considered and discussed in this study.
As reported by the Borneo Post, traffic congestion problem in Kota Kinabalu has becoming a major economic hindrance which stated by World Bank [2].The contributing factor of traffic congestion was the abundance of vehicles on the road and inefficient public transportation in Kota Kinabaluwhich stated by Bernama[3].The decrement of road capacity will decrease of maximum traffic flow and causing long queues and the dramatic drop of vehicle's speed in traffic. The scope of this study is the network from Indah Permai-IP (source node) to KotaKinabalu International Airport-KKIA (sink node) where all the routes between source and sink node are established.

In Figure 1, the red spots are the selected major intersections which are assigned as the nodes of the network graph. Thisscope area in is selected because this area is part of a central business district for Kota Kinabalu where the demand of traffic is higher than the other locations.

Figure 1: Scope of study (Within Kota Kinabalu Area)

Hence, the objectivesof this study are to find the maximum flow of the desired routesas well as their bottlenecks, and determine the shortest path to reach the destination.Ford-Fulkerson algorithmcomputethe maximum flow while the max-flow and min-cut theorem identify thebottlenecks, and Dijstra's algorithm is used to find the alternative shortest path.

II. LITERATURE REVIEW

An optimization of traffic flow within an urban traffic light intersection with Genetic algorithm in Kota Kinabalu, Sabah was studied [4]. The increase of on-road vehicleswsorsened congestion problems in Kota Kinabalu. Traffic light systems were built to control and ensure the smoothness of traffic flows at the intersections. However, traffic light systemcannot afford the increases of traffic flow and caused the long queue and congestion at intersection. The suggested solution was rebuilt of new traffic infrastructure like new roads and lanes but it became more difficult due to the limited land available. Hence, the better solution was to study and design a traffic light controller to optimize the traffic flow. The data like queue length, green time, cycle time and amber time was observed and studied through simulations. Genetic algorithm was selected to find the optimized solution of traffic flow. Throughout the simulation results, it showed that the Genetic algorithm gives fast and good respond to the change of queue length at the intersection.

The maximum flow problem and solution algorithm, Ford-Fulkerson algorithm in Ethiopian Airlines was investigated [5]. The maximum flow problem was solved by Ford-Fulkerson algorithm, the obtained maximum flow value was the same but number of augmenting paths, and flow of augmenting path might be different. It meant that the maximum flow value of the maximum problem was unique but it could have different augmenting path and different number of augmenting path.

The maximum flow in road networks with speed dependent capacities was applied to Bangkok traffic [6].A traffic maximum flow problem had arcs represented as capacity of road (maximum vehicles per hour) that were functions of the traffic speed (kilometer per hour) and traffic density (vehicles per kilometer), empirical data on safe vehicle separations for a given speed were usedto estimate road capacities for a given speed. A modified version of the Ford-Fulkerson algorithm was developed to solve maximum flow problems with speed-dependent capacities, with multiple source and target nodes. It was found that the maximum safe traffic flow occurs at the speed of 30 km/hr.

A method of path selection in the graph was presented [7]. In this paper,Dijkstra's algorithm was used to find additional paths among nodes in the maritime sector. Since it involved 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 makingused in this study for selecting one desirable path from several paths. Dempster-Shafer theory was a method that could be applied tocombine data and evidences.

The simplest and smallest network on Fold-Fulkerson Maximum Flow procedure might fail to terminate [8]. Ford-Fulkerson is a labeling method that can always terminate networks graph that have rational capacity of the edges. However, it might fail to terminate in the sense that it has an infinite sequence of flow augmentations.The results suggested that network with real-valued capacities contain the subgraph homeomorphic and irrational capacities. Therefore, Ford-Fulkerson algorithm might fail to terminate it.

Moreover, basic theory of highway traffic capacity and followed by the method of maximum flow algorithm to calculate the highway capacity was studied [9]. In traffic route map analysis, road capacity refers to the maximum number of vehicles at particular paths or edges. Traffic capacity of multi point, multi destination network is transformed to single starting point and single end point network problem. Network simplification process was performed to obtain the maximum flow of the network. It concluded that the results are the same as the results of the labeling method. Contribution of this paper is the transformation of the highway network capacity into a specific mathematical model and solved by simple maximum flow algorithm.

A research on method of traffic network bottleneck identification based on Max-flow Min-cut Theorem was performed [10]. It allows the weak section of the road to be identified and provide a solution for the traffic problem. The traffic networks must be formed into the map of graph theory before identification of bottleneck. It applied the Max-flow Min-cut Theorem to find out the bottleneck of the network. This theorem stated that the minimum cut is the smallest capacity of the road section. Therefore, it determines the maximum capacity of the whole network. The identified weak parts of the road allow traffic planar to know that which parts of the road need to be widened. The results show that identification of bottleneck based on Max-flow Min-cut Theorem can find out the bottleneck effectively.

An applied minimum-cut maximum-flow using cut set of a weighted graph on the traffic flow network [11]. A capacitated graph with a real number of capacity serves as a structural model in transportation. The traffic control strategy of minimal cut and maximum flow is to minimize number of edges in network and maximum capacity of vehicles which can move through these edges. The technique of minimal cut in traffic network allowsshortening the waiting time of traffic participants and providing a smooth and uncongested traffic flow.

III. METHODOLOGY

3.1 Network Graph

Network is formed with edges that are connected with nodes. Capacitated network graph and weighted network graph are needed in this study to get the shortest path and maximal flow. First, a capacitated network graph formulates with all the edges. Each of the edges has a non-negative capacity, $c(u,v) \geq 0$ and flows $f(u,v)$ that cannot be more than capacity of the edge. The source node, s and sink node, t of a network are starting point, and ending point respectively. A capacitated network must fulfill the conditions below: First, the capacity constraint, $\forall (u,v) \in E \; f(u,v) \leq c(u,v)$ which flow of the edges must not exceed its own capacity. Then, the next condition is skew symmetry, $\forall u,v \in$

$V, f(u,v) = -f(v,u)$ which net flow from u to v and from v to u must be opposite to each other. Lastly, flow conservation constraints, $\forall u \in V: u \neq s \text{ and } u \neq t => \sum_{(s,u)\in E} f(s,u) = \sum_{(v,t)\in E} f(v,t)$ is the net flow to a node is zero except source node and sink node and the flow from the source node must be equal to the flow at the sink node. Weighted network graph is a network graph that formulates by the edges with the non-negative distances. It is almost the same as the capacitated network graph [12].

3.2 Ford-Fulkerson Algorithm

Maximal flow in a capacitated flow network is the total flow from a source node to a sink node. First, find an augmenting path from the source node to the sink node. After the formation of augmentation path, compute the bottleneck capacity. Lastly, augment each edge and the total flow until the capacity of sink node reaches maximum [13].

3.3 Dijkstra's Algorithm

First, assign to every node a tentative distance value. Then, label starting node with zero, and to infinity for all other nodes. Set starting node as temporary, and mark other nodes as unvisited nodes. For the temporary node, choose the unvisited arcs that are connected to the starting node with the least value. Mark the temporary node as visited as all the neighbors of the temporary node are considered. Temporarily label all the nodes that are connected to the permanent labelled nodes with the distances from starting node. Choose the temporary label of the least value. Repeat the steps until the destination node has a permanent label [14].

3.4 Maximum Flow and Minimum Cut Theorem

The minimum capacity of an (s,t)-cut is equal to the maximum value of a flow.

$$\max\{val(f) \mid f \text{ is a flow}\}$$
$$= \min\{cap(S,T) \mid (S,T) \text{ is an } \{s,t\} - cut\}$$

IV. DATA COLLECTION

Before maximum flow algorithm and shortest path algorithm being applied in this study, a network graph will be needed. To form a network graph, there were several data needed such as the name, direction,distance and capacity of the routes within selected scopes. The intersections appointed as the nodes of the network graph, the path that connected between the intersections were the edges with direction, distance and capacity of the road sections assigned according to the direction of the edges. With all the nodes, edges, direction and capacities, a directed network graph can be formed.Those data collected from Dewan Bandaraya Kota Kinabalu (DBKK), a city council in Kota Kinabaluand Google Maps. They provided the reports of some of the projects that had been carried out recently. In the report, it had included the information on the routes like capacity. In paper [15] using direct empirical method for capacity estimation but in this paper was using traffic signal timing manual to get the capacity of the road [16].

Table 1: Capacity and Distance of the selected routes from IP-KKIA

Location Name	From	To	Capacity	Distance (Meter)
JalanSepanggar	S	V1	914	1600
Jalan UMS	S	V3	3103	11500
JalanTuaran 1	V1	V2	1394	350
JalanTuaran 2	V2	V4	1905	6700
JalanTuaran Bypass (North)	V2	V5	1151	8200
JalanTuaran Bypass (South)	V5	V2	1151	8200
JalanTuaran 3	V4	V5	2161	2000
Jalan Lintas 1	V5	V8	2877	5100
JalanTuaran 4(South)	V5	V6	2559	1000
JalanTuaran 4 (North)	V6	V5	2832	1000
JalanPasir (North)	V3	V6	1533	600
JalanPasir (South)	V6	V3	2500	600
JalanTunFuad Stephen 1	V3	V7	2000	1500
JalanTunFuad Stephen 2	V7	V10	1948	2400
JalanIstiadat&JalanKompleksSukan (North)	V7	V9	846	2100
JalanIstiadat&JalanKompleksSukan (South)	V9	V7	2120	2100
JalanTuaran 5 (South)	V9	V6	1902	2300
JalanTuaran 5 (North)	V6	V9	1648	2300
JalanDamai (North)	V9	V12	1687	2200
JalanDamai (South)	V12	V9	1289	2200
JalanTuaran 6 (North)	V9	V15	1807	2200
JalanTuaran 6 (South)	V15	V9	813	2200
Jalan KK Bypass 2 (North)	V10	V13	1897	1400
Jalan KK Bypass 2 (South)	V13	V10	1394	1400
JalanTunku Abdul Rahman 1 (North)	V13	V16	1482	600
JalanTunku Abdul Rahman 1 (South)	V16	V13	2575	600
JalanLaimanDiki	V13	V14	809	290
JalanTunRazak	V10	V14	1995	1600
Jalan Coastal 1	V14	V17	2223	800
JalanKolam 1 (North)	V12	V15	2161	1400
JalanKolam 1 (South)	V15	V12	2161	1400
JalanKolam 2 (North)	V8	V12	1902	850
JalanKolam 2 (South)	V12	V8	2877	850
Jalan Lintas 2	V8	V11	2223	2000
Jalan Lintas 3	V11	V20	1561	900
JalanPenampang (North)	V11	V21	1388	2600
JalanPenampang (South)	V21	V11	1514	2600
JalanTuaran 7 (North)	V15	V18	3600	800
JalanTuaran 7 (South)	V18	V15	2726	800
JalanTunku Abdul Rahman 2 (North)	V16	V18	3757	150
JalanTunku Abdul Rahman 2 (South)	V18	V16	1482	150
JalanNenas (North)	V15	V16	1482	1100
JalanNenas (South)	V16	V15	1877	1100
JalanKemajuan	V18	V17	2262	450
JalanTunku Abdul Rahman 3 (North)	V18	V21	1078	1100
JalanTunku Abdul Rahman 3 (South)	V21	V18	3757	1100
JalanPintas 1 (North)	V20	V22	1251	1100
JalanPintas 1 (South)	V22	V20	2483	1100
JalanPintas 2 (North)	V22	V23	2200	2300
JalanPintas 2 (South)	V23	V22	1251	2300
JalanTunku Abdul Rahman 4 (North)	V21	V23	2200	350
JalanTunku Abdul Rahman 4 (South)	V23	V21	1948	350
Jalan Coastal 2	V17	V19	2559	1100
JalanSembulan (North)	V19	V23	3300	950
JalanSembulan (South)	V23	V19	1419	950
Jalan Coastal 3	V19	V24	4428	1400
Jalan Mat Salleh (North)	V23	V24	895	900
Jalan Mat Salleh (South)	V24	V23	2200	900
JalanKepayan	V24	T	2426	4000
Jalan Lintas 4	V20	T	1591	3600

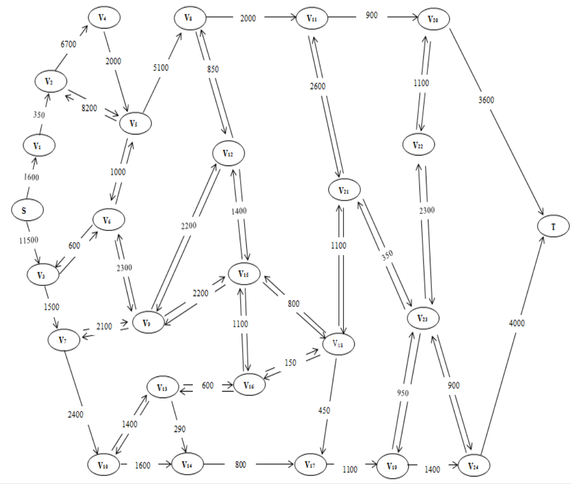

Figure 2: Weighted Directed Network Graph from IP to KKIA

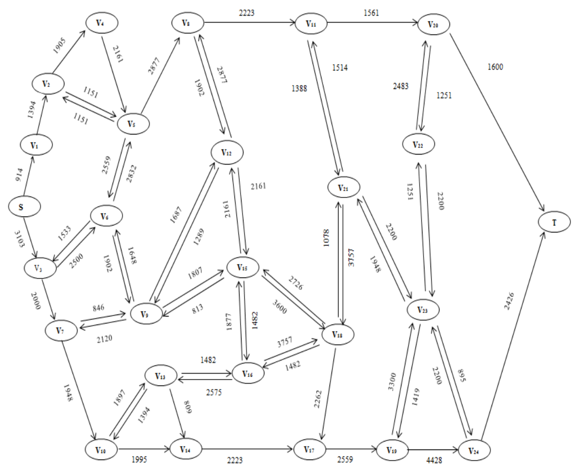

Figure 3: Capacitated Directed Network Graph from IP to KKIA

The data in Table 1 were used to form a weighted and capacitated directed network graph as shown in Figure 2 and Figure 3 respectively.

V. RESULTSAND DISCUSSIONS

5.1 Results of Maximum Flow Problem Using Algorithms

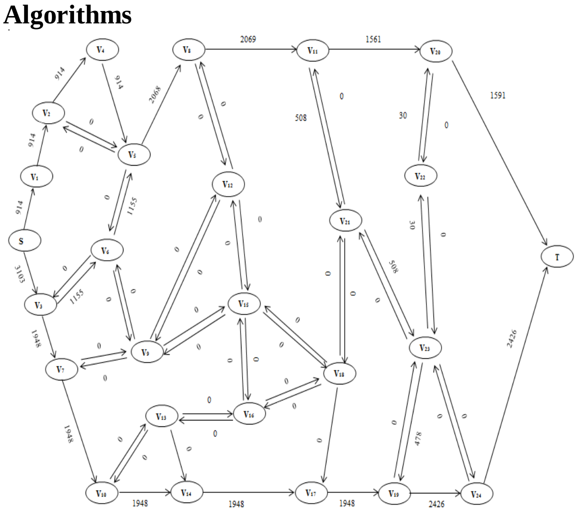

Figure 4: Optimal Solution of Maximum Flow Problem

Figure 4 showed the first augmenting path fromS →V1→V2→V4→V5→V8→V11→V20→T.Second augmenting path was S→V3→V6→V5→ V8→V11→V20→T. Third augmenting path was S→V3→V6→V5→V8→V11→V21→V23→V19→ V24→T. Fourth augmenting path was S→V3→V6→V5→V8→V11→V21→V23→V22→ V20→T. Fifth augmenting path was S→V3→V7→V10→V14→V17→V19→V24→T.The maximum flow of first, second, third, fourth and fifth augmenting pathswere914, 647, 478, 30 and 1948 vehicles respectively. The total maximum flow of the whole network was 4017 of vehicles per hour.

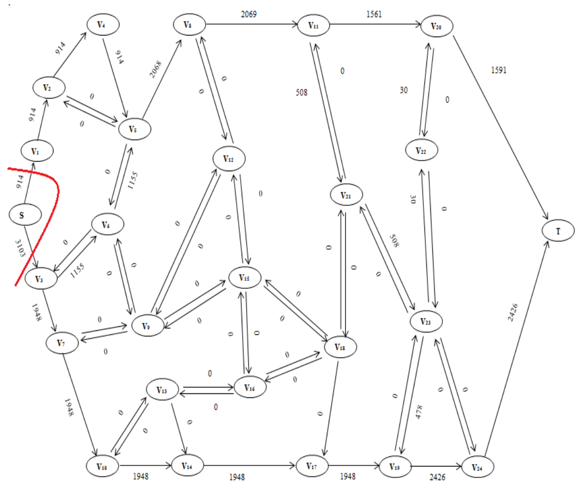

Figure 5: Bottlenecks of capacitated network graph

From Figure 5, the bottlenecks of the network were S→ V1 and S→V3 because it had the smallest flow which was equal to the total maximum flow. S→V1 was JalanSepanggar, and S→V3 was Jalan UMS.

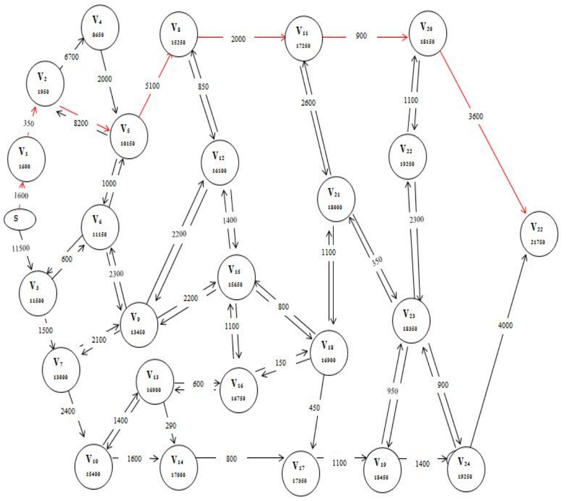

Figure 6: Results of Dijkstra's algorithm

From Figure 6, the shortest path in this weighted network graph was S→V1→V2→V5→V8→V11 →V20→T. It was about 21.75kmfrom Indah Permai to Kota Kinabalu International Airport.

5.2 Results of Maximum Flow Problem Using Excel Solver

	From	To	Unit of Flow	≤	Capacity	Node	Net Flow	Supply/Demand
4	S	V1	914	≤	914	S	0	0
5	S	V3	3103	≤	3103	V1	0	0
6	V1	V2	914	≤	1394	V2	0	0
7	V2	V4	914	≤	1905	V3	0	0
8	V3	V6	1155	≤	1533	V4	0	0
9	V6	V3	0	≤	2500	V5	0	0
10	V2	V5	0	≤	1151	V6	0	0
11	V5	V2	0	≤	1151	V7	0	0
12	V3	V7	1948	≤	2000	V8	0	0
13	V7	V9	0	≤	846	V9	0	0
14	V9	V7	0	≤	2120	V10	0	0
15	V7	V10	1948	≤	1948	V11	0	0
16	V6	V9	0	≤	1902	V12	0	0
17	V9	V6	0	≤	1648	V13	0	0
18	V6	V5	1155	≤	2832	V14	0	0
19	V5	V6	0	≤	2559	V15	0	0
20	V4	V5	914	≤	2161	V16	0	0
21	V5	V8	2069	≤	2877	V17	0	0
22	V8	V12	0	≤	1902	V18	0	0
23	V12	V8	0	≤	2877	V19	0	0
24	V9	V12	0	≤	1687	V20	0	0
25	V12	V9	0	≤	1289	V21	0	0
26	V9	V15	0	≤	1807	V22	0	0
27	V15	V9	0	≤	813	V23	0	0
28	V15	V12	0	≤	2161	V24	0	0
29	V12	V15	0	≤	2161	T	0	0
30	V10	V13	0	≤	1897			
31	V13	V10	0	≤	1394			
32	V10	V14	1948	≤	1995			
33	V13	V14	0	≤	809			
34	V13	V16	0	≤	1482			
35	V16	V13	0	≤	2575			
36	V16	V18	0	≤	3757			
37	V18	V16	0	≤	1482			
38	V18	V21	0	≤	1078			
39	V21	V18	0	≤	3757			
40	V16	V15	0	≤	1877			
41	V15	V16	0	≤	1482			
42	V15	V18	0	≤	3600			
43	V18	V15	0	≤	2726			
44	V18	V17	0	≤	2262			
45	V11	V21	508	≤	1388			
46	V21	V11	0	≤	1514			
47	V20	V22	0	≤	1251			
48	V22	V20	30	≤	2483			
49	V8	V11	2069	≤	2223			
50	V11	V20	1561	≤	1561			
51	V21	V23	508	≤	2200			
52	V23	V21	0	≤	1948			
53	V23	V19	478	≤	1419			
54	V19	V23	0	≤	3300			
55	V14	V17	1948	≤	2223			
56	V17	V19	1948	≤	2559			
57	V19	V24	2426	≤	4428			
58	V24	T	2426	≤	2426			
59	V20	T	1591	≤	1600			
60	V23	V24	0	≤	895			
61	V24	V23	0	≤	2200			
62	V23	V22	30	≤	1251			
63	V22	V23	0	≤	2200			
64	T	S	4017	≤	99999999			
67	Maximum Flow				4017			

Figure 8: Maximum flow problem Excel Output

In Figure 8, column G represented the capacity for each edge. The objective function was the cell G67 which contained the formula of '=E64'. Cell E64 was the maximum flow from node "s" to node "t". The cell J4 to cell J29 represented the net flow which was the constraints cells. The units of flow, from cell E4 to cell E64, were the variable cells. Those variable cells that equal to zero were the unutilized paths. For the solver parameters, the cell G67 was set as the Objective. The maximum button was chosen in order to maximize the maximum flow problem. The changing variable cells were the cells from E4 to E64. Next, constraints were the Unit of Flow (cell E4 to E64) less than or equal to Capacity (cells G4 to G64) and Net Flow (cells J4 to J29) must equal to the Supply/Demand (cells K4 to K29). Simplex Linear Programming was selected as the solving method. The augmenting path of the maximum flow path by excel solver might not be the same as the augmenting path of the Ford-Fulkerson algorithm. However, the maximum flow value for Ford-Fulkerson algorithm and excel outputs were expected to be the same [17].

5.2 Results of Shortest Path Problem Using Excel Solver

	From	To	On Route	=	Route Distance (Meter)	Node	Net Flow	Supply/Demand
4	S	V1	1	=	1600	S	1	1
5	S	V3	0	=	11500	V1	0	0
6	V1	V2	1	=	350	V2	0	0
7	V2	V4	0	=	6700	V3	0	0
8	V2	V5	1	=	8200	V4	0	0
9	V5	V2	0	=	8200	V5	0	0
10	V4	V5	0	=	2000	V6	0	0
11	V5	V8	1	=	5100	V7	0	0
12	V5	V6	0	=	1000	V8	0	0
13	V6	V5	0	=	1000	V9	0	0
14	V3	V6	0	=	600	V10	0	0
15	V6	V3	0	=	600	V11	0	0
16	V3	V7	0	=	1500	V12	0	0
17	V7	V10	0	=	2400	V13	0	0
18	V7	V9	0	=	2100	V14	0	0
19	V9	V7	0	=	2100	V15	0	0
20	V9	V6	0	=	2300	V16	0	0
21	V6	V9	0	=	2300	V17	0	0
22	V9	V12	0	=	2200	V18	0	0
23	V12	V9	0	=	2200	V19	0	0
24	V9	V15	0	=	2200	V20	0	0
25	V15	V9	0	=	2200	V21	0	0
26	V10	V13	0	=	1400	V22	0	0
27	V13	V10	0	=	1400	V23	0	0
28	V13	V16	0	=	600	V24	0	0
29	V16	V13	0	=	600	T	-1	-1
30	V13	V14	0	=	290			
31	V10	V14	0	=	1600			
32	V14	V17	0	=	800			
33	V12	V15	0	=	1400			
34	V15	V12	0	=	1400			
35	V8	V12	0	=	850			
36	V12	V8	0	=	850			
37	V8	V11	1	=	2000			
38	V11	V20	1	=	900			
39	V11	V21	0	=	2600			
40	V21	V11	0	=	2600			
41	V15	V18	0	=	800			
42	V18	V15	0	=	800			
43	V16	V18	0	=	150			
44	V18	V16	0	=	150			
45	V15	V16	0	=	1100			
46	V16	V15	0	=	1100			
47	V17	V18	0	=	450			
48	V18	V17	0	=	450			
49	V18	V21	0	=	1100			
50	V21	V18	0	=	1100			
51	V20	V22	0	=	1100			
52	V22	V20	0	=	1100			
53	V22	V23	0	=	2300			
54	V23	V22	0	=	2300			
55	V21	V23	0	=	350			
56	V23	V21	0	=	350			
57	V17	V19	0	=	1100			
58	V19	V23	0	=	950			
59	V23	V19	0	=	950			
60	V19	V24	0	=	1400			
61	V23	V24	0	=	900			
62	V24	V23	0	=	900			
63	V24	T	0	=	4000			
64	V20	T	1	=	3600			
66	SHORTEST PATH:				21750			

Figure 9: Shortest path problem solved by using simplex linear programming in Microsoft excel

In Figure 9, column F represented the distance of the edge. The objective function was the cell F66 which contained the formula of '=SUMPRODUCT (D4:D64,F4:F64)'. The cell from I4 to I29 represented the net flow were the constraints cells. The 'On Route' from cell D4 to cell D64 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 S→V1→V2→V5→V8→V11→ V20→T. In the supply or demand column, that source node, "s" was set as number '1' and the sink node, t was set as number '-1' because both of the nodes were the starting and the ending nodes.

For the excel solver parameters part, the cell F66 was set as the Objective. Since the goal was to find the shortest path, therefore the minimum button was chosen in order to minimize the shortest path problem. The changing variable cells were the cells from D4 to D64. Next, the constraints of the Net Flow (cells I4 to I29) must be equal to Supply/Demand (cell J4 to J29). Before clicking on the solve button, Simplex Linear Programming was selected as the solving method. The output of the shortest path by using the excel solver would be the same as the output of the Dijkstra's algorithm [15].

CONCLUSION

In conclusion, the maximum flow of the capacitated network was 4017 vehicles per hour, while the identified bottleneck paths wereJalanSepanggar and Jalan UMS. Besides, the number of augmenting path can be different but the maximum flow was still the same which is same result as [5]. Next, the shortest path in this weighted networkgraphwas,S→V1→V2→V5→V8→V11→V20→ Tviz. JalanSepanggar→JalanTuaran→JalanTuaran Bypass (North)→Jalan Lintas →Jalan Lintas →Jalan Lintas →Jalan Lintas, and it took about 21.75km from origin, IPto destination, KKIA in Kota Kinabalu. Thus,with these outputs, traffic planar couldthink of the ways to improve the identified bottlenecks, and traffic drivers could avoid the bottleneck and chose the shortest path as their desire route.

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