

Multi-Criteria Using Dijkstra's Algorithm to Determine Optimal Time Paths in Vehicle Route Optimization

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Abstract—This research is the development of a Road Traffic Network using one of the methods in Mathematics, namely Dijkstra's Algorithm, Weighted Sum Method (WSM), and Weighted Product Method (WPM). Meanwhile, the parameters used are route, volume, capacity, DOS, distance, and travel time. The objective of this research is to find the fastest route alternative from one place to another. The recommended results using Dijkstra's algorithm combine values of distance, travel time, and congestion degree with the weighted-sum and weighted-product methods, each calculated accordingly. The shortest route is 1→2→4→7→10→14, the route with the least congestion and shortest travel time is 1→2→5→6→9→13→14. This research combines these three parameters to obtain a balanced route between congestion level, short travel distance, and short travel time for the driver. By combining these parameters, the best route from this study is route 1: 1→2→5→8→12→11→14 with a total distance of 28.77 km, a saturation degree value of 5.421, and a travel time of 28 minutes. Thus, the research results indicate that the best route will have a combination of multiple criteria, such as short distance, short travel time, and less congestion simultaneously. The Weighted-Sum Method (WSM) and Weighted-Product Method (WPM) can produce different outputs, with WPM being superior to WSM in terms of computational steps.

Keywords—Dijkstra's algorithm; multi-criteria; road traffic network; Weighted Sum Method (WSM); Weighted Product Method (WPM); mathematics

I. INTRODUCTION

Currently, in solving shortest paths, several complicated mathematical methods are used, and certainly need to be efficient, one of which is wCDN. The proposed algorithms are MRD labeling and MRCCSPP. The route is evaluated at confidence levels of 0.45 and 0.85. Three criteria: distance, cost, and time are used. Paths are calculated for all criteria. Simulation shows the efficiency of the MRD algorithm for larger examples [1]. The research conducted by Syarif Surejo et al. (2024) discusses the comparison between Dijkstra's algorithm and the genetic algorithm to determine the distance between points on two alternative routes to Guci. The results of the study indicate that Dijkstra's algorithm is superior in this case, but in general, the genetic algorithm has potential for more complex optimization problems [2]. This research will focus on

the development of the study conducted by Noraini Abdullah & Ting Kien Hua (2018) on transportation issues. To reduce transportation costs related to the shortest path problem by applying Dijkstra's algorithm, extensive research has been conducted, including a study by M. Afdhaluzzikri et al. (2024). [3]. Besides transportation, even the search for the shortest route in the case of election logistics distribution has also been carried out. Based on the results of this study, the shortest route for distributing election logistics from the Kesugihan District Office to each Village Head Office in Kesugihan District was found [4].

Meanwhile, the research by Yann Disser et al., titled "Multi-criteria Shortest Paths in Time-Dependent Train Networks", used a synthetic dataset with 1,000 random test cases. Realistic dataset with 1,000 one-hour interval tests. Real dataset from Deutsche Bahn AG with 14,000 connection queries. Train schedule data from Germany, 2007 (56,994 trains). With multi-criteria generalization of Dijkstra's algorithm, a speedup factor of 20 for label creation was achieved. A speedup factor of 138 for label insertion was achieved. This new approach is competitive with the time-extended method. Performance improves with the addition of more criteria [5], [49].

Dijkstra's algorithm is one of the algorithms used to solve the shortest path and does not have a negative cost [6]. The Dijkstra algorithm is effectively used to find the shortest and most cost-effective routes for intercity flights, demonstrating a high success rate in identifying the best paths for intercity transportation in a shorter time and at a lower cost. Through simulations, the algorithm demonstrated a 95% success rate in quickly determining the most suitable flight routes, regardless of the number of cities involved in the network, highlighting its efficiency and reliability in optimizing flight routes [7]. Meanwhile, the research related to Dijkstra's Algorithm for Determining the Shortest Route from Surabaya City Center to Historical Sites aims to find the shortest route from the city center of Surabaya to historical sites using Dijkstra's algorithm, which helps reduce travel time [12] and is efficient for visitors. The Dijkstra algorithm was chosen for its ability to determine the shortest path in a weighted graph with positive weights, starting from one point to all desired points. This study found five shortest routes starting from Gubeng Station,

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demonstrating the practical application of Dijkstra's algorithm for tourists and locals visiting historical sites. Previous research has also applied Dijkstra's algorithm in various contexts, such as water meter reading routes and school bus routes, demonstrating its versatility in optimizing travel and costs [8].

The research conducted by Israa Ezzat Salem and Maad M. Mijwil shows that Dijkstra's Algorithm is effectively used to find the shortest and most cost-effective routes for intercity flights, demonstrating a high success rate in identifying the best routes for intercity transportation in a shorter time and at a lower cost [46]. Through simulations, the algorithm demonstrated a 95% success rate in quickly determining the most suitable flight routes, regardless of the number of cities involved in the network, highlighting its efficiency and reliability in route optimization for flights [9]. The research conducted by Asrahmaulyana et al. (2020), titled "Economic Losses Due to Traffic Congestion on the Muslim Community Residing in Makassar City", concludes that the losses due to congestion include expenditures for fuel purchases under normal conditions, amounting to Rp 19,285.38 for car users and Rp 7,217.86 for motorcycle users. However, if they get stuck in traffic, the costs increase to Rp 29,428.46 per car and Rp 13,175.71 per motorcycle [10],[11].

Research related to Based Shipping Routes Using the Dijkstra Algorithm has introduced a method to identify and characterize shipping routes using data from the Automatic Identification System (AIS), which ships use to broadcast their location and movements to coastal traffic services. This method involves creating a graph where the sea area is divided into grid cells, and the movement of ships between these cells is tracked to find the most frequently used routes, which are assumed to be the safest. By applying Dijkstra's algorithm to this graph, the research successfully identified potential safe routes between two locations, which are the most frequently used paths by ships. This approach helps in determining the safest and most efficient route for maritime navigation [6].

Meanwhile, the article titled "Least Congested And Shortest Distance Path In Kota Kinabalu Traffic Network, Sabah, Malaysia" has focused on traffic estimation using GPS devices installed in vehicles to predict current traffic conditions and suggest the least congested alternative routes (Ting Kien Hua & Noraini Abdullah, 2017). The research conducted by Ting Kien Hua and Noraini Abdullah titled "Weighted Sum-Dijkstra's Algorithm in Best Path Identification based on Multiple Criteria" discusses how GPS devices in vehicles have been used for traffic estimation to predict current traffic conditions and suggest the least congested alternative routes. In this study, the Dijkstra Algorithm has been applied in maritime networks to find paths based on parameters beyond distance, enhancing the route selection process [7]. The solution proposed in this article suggests using Dijkstra's algorithm with multi-criteria to optimize vehicle routes [48]. The Weighted Product Model (WPM). The WPM is very similar to the WSM. The main difference is that instead of addition in the model, there is multiplication. Each alternative is compared to the others by multiplying several ratios, one for each criterion.[13]. Some of the objectives of this research include considering the impact of uncertain traffic conditions on driving speed. By finding the best route, travel time can be shortened [14]. Traffic

congestion can cause various negative impacts [15]. The shortest path in computer networks is a routing category that is generally used in computer networks today.[16].

The article titled "Optimal Routes in Urban Networks Using Travel Time Prediction" proposes an algorithm that determines the optimal route between the starting point and the endpoint on the road network. The goal is to minimize travel time while considering constraints such as maximum travel time and risk level [17]. Whereas the article titled "A Path Planning and Navigation Control System Design for Driverless Electric Bus" defines the concept of "path" referring to the process of planning and creating a route for a driverless bus, with the main components involved in route planning are Global Route Planning, local route planning, track creation, special routes and maneuvers, following the route and error correction [18].

The problem in Vehicle Route Optimization is very complex. The research conducted by Tegar Arifin Prasetyo (2021) explains that the problem of "Routing" or vehicle routing is approached using optimization techniques. This research successfully demonstrates how optimization methods can be applied in the real world to address logistics distribution problems by considering various constraints such as vehicle capacity, operational costs, and delivery time [19]. In urban areas, where infrastructure and population density enable extensive data collection and real-time service optimization, routing solutions can be implemented effectively [20].

This research is closely related to expert systems and Artificial Intelligence (AI) because the scientific foundation of Dijkstra's algorithm is Expert Systems and Artificial Intelligence (AI). In the article written by Jonhariono Sihotang (2020). Kecerdasan Buatan (AI) is described as a branch of computer science that focuses on automating intelligent behavior. AI enables computers to perform tasks that are usually performed by humans [21]. The use of artificial intelligence (AI) technology in organizations is becoming increasingly urgent. AI can automate processes, reducing reliance on manual intervention and increasing the speed of data processing and decision-making [22].

Whereas an expert system refers to a computer-based system designed to mimic the ability to think and make decisions of an expert or specialist in the diagnosis of sexual disorders (paraphilia) [23]. An expert system is a computer application that uses knowledge and techniques that are usually possessed by an expert to solve problems in a specific field [24]. Expert systems not only help in solving optimization problems but can also address other cases, such as in the article by Taozara Laia et al. (2022), where expert systems are used to diagnose eye diseases caused by excessive computer use, known as Computer Vision Syndrome (CVS) [25].

This research analyzes Dijkstra's algorithm for solving shortest paths by comparing other similar research and finding a point of novelty, by completing the entire research design using algorithms that are more complete than before, some of which are the Weighted Sum Method (WSM) and the Weighted Product Method. Method development is necessary to improve effectiveness, in addition to novelty, and also a higher level of precision [52],[53].

II. THEORY

A. Dijkstra's Algorithm

Research conducted by Angshuman Guin, et al. about travel time measurement uses three types of travel time measurements: (a) Instantaneous Travel Time (ITT): calculated based on the average instantaneous speed on each road segment, (b) Reactive Travel Time (RTT): based on the travel time of vehicles that have just exited the corridor, and (c) Actual Travel Time (ATT): measured through Bluetooth data, which provides actual travel time in the field. The ITT, RTT, and ATT data were analyzed for each 5-minute interval during the evening congestion period on the I-285 corridor in Georgia. The comparison between ITT, RTT, and ATT shows that simulation-based predictions are more consistent with actual travel time (ATT), especially during congestion [34].

In graph theory, Dijkstra's algorithm is a graph traversal algorithm introduced by Dutch computer scientist Edsger W. Dijkstra in 1959. The Dijkstra algorithm is also known as the single-source shortest path algorithm, similar to Prim's algorithm. Using Dijkstra's algorithm to find the shortest path in a directed graph with non-negative weights is one of the fundamental issues in algorithmic problems. Peter W. Eklund introduced a modified Dijkstra algorithm that includes static and dynamic components, which are simultaneously used to route emergency vehicles in an earthquake simulation in Okayama, Japan. In the article by Peyer, S., Rautenbach, D., and Vygen, J, a new algorithm called Generalized Dijkstra is introduced, which is a fast technique for the Dijkstra algorithm [35]. Penelitian yang dilakukan oleh Ramiz ASSAF, dkk. (2017), tentang Vehicle-Routing Optimization For Municipal Solid Waste Collection Using Genetic Algorithm: The Case Of Southern Nablus City.

B. Degree of Saturation (DoS)

DOS or traffic density is an indicator of traffic flow with a range between 0 and 1. The range of DOS values is between 0 and 1. A saturation degree of less than 0.85 essentially indicates that the capacity is still sufficient for the traffic volume demand. However, when the density approaches 1.0, traffic flow may become unstable, with queues and delay conditions occurring. When demand exceeds capacity (density greater than 1.0), traffic will experience congestion, long queues, and excessive delays. Here is the DOS as Eq. (1):

$$\text{Degree of Saturation} = \frac{\text{Volume}}{\text{Capacity}} \quad (1)$$

C. Weighted Sum Method (WSM)

The simple WSM method is the summation of these variables. This implies that there is a level of trade-off remaining between each pair of criteria. The most commonly used normalization method is dividing the values by the total of all criterion values to obtain a proportion of the whole. After normalization, assign weights to the criteria and sum the weighted values to produce the appropriate scores and rankings. The WSM equation is shown in Eq. (2):

$$\text{Weighted Sum Method} = W_1 X_1 + W_2 X_2 + \dots + W_n X_n \quad (2)$$

D. Weighted Product Method (WPM)

Yoon in Kusumadewi et al. (2006) explains the WPM method using multiplication to link attribute ratings, where the rating of each attribute must first be raised to the power of the corresponding attribute weight. This process is similar to the normalization process. The WPM method is a straightforward and flexible approach because it can directly ignore normalization. The weight seems to be an exponent of the criteria. WPM is shown as in Eq. (3):

$$\text{Weighted Product Method} = W_1^{w_1} W_2^{w_2} \dots W_n^{w_n} \quad (3)$$

E. Time Travel

The article written by (Hyungjoo KIM, et al. 2013) discusses the concept of travel time. This article focuses on the travel time estimation methods used to monitor vehicle speeds on highways, particularly in South Korea. Sample-Travel Speed is measured by re-identifying vehicles using transponder electronic toll collection (ETC), which allows for accurate travel time measurements over a certain distance [39].

Meanwhile, another study on travel time estimation using the Instantaneous Model estimation method with the local speed survey method (Spot speed) has been conducted, and the results of this study estimate the travel time for vehicles crossing the studied road segment during the first 5-minute interval from 12:00 to 12:05 WIB from upstream link 1 to downstream link 3 as $2.346 + 2.498 + 2.521 = 7.364$ minutes [40].

F. Path

The article, titled "Optimal Paths in Urban Networks Using Travel Time Predictions", proposes an algorithm that determines the optimal path between the starting point and the end point in a road network. The goal is to minimize travel time by considering constraints such as maximum travel time and risk level. This study shows that the proposed algorithm efficiently finds the optimal path for urban networks, taking into account travel time and risk constraints [41].

Meanwhile, the article entitled "A Path Planning and Navigation Control System Design for Driverless Electric Bus" defines the concept of "path" as referring to the process of planning and creating a path for a driverless bus, with the main components involved in path planning being global path planning, local path planning [36], path creation, special paths and maneuvers, path following and error correction. This entire process ensures that driverless buses follow a safe, smooth, and efficient path while adapting to dynamic road conditions. [42].

G. Distance

In the article "AIS-Based Shipping Routes Using Dijkstra's Algorithm", the term "distance" refers to the weights of the sides in a graph that represent the movement of ships between cells in a grid. This weight is inversely proportional to the frequency of ship movement between cells, which means the more often the ship moves between two grid cells, the lower the weight (or "distance") between those cells in the graph [43].

H. Route

When traveling, the question often arises as to which route is the fastest. In answering this question, the criterion that is

often used is distance because the shorter the distance, the faster the travel time. In research conducted by Tetra Widiyanto, et al. The best route is one that considers the shortest distance and the availability of public facilities. The needs in question are user preferences for available public facilities. Based on the two scenarios that have been run, the resulting routes are the best in each scenario, calculated using Dijkstra's algorithm with a weighted sum input [44].

I. Calculation of Vehicle Volume

Research conducted by Hj Indra Harun discusses the effect of traffic volume on the noise level at the Bastiong highway intersection. The calculation of vehicle volume based on time was carried out at 3 different points for 10 hours, as seen in

TABLE I. COMPARISON BETWEEN LV, HV, AND MC

Time	Vehicle Type			
	LV (Samples/hours)	HV (Samples/hours)	MC (Samples/hours)	(Samples/hours)
07.00-08.00	447,00	34,80	452,25	934,05
08.00-09.00	435,00	66,00	421,75	922,75
09.00-10.00	345,00	18,00	427,50	790,50
10.00-11.00	333,00	48,00	556,25	937,25
11.00-12.00	529,00	116,40	631,50	1276,90
12.00-13.00	500,00	66,00	587,50	1153,50
13.00-14.00	394,00	84,00	524,00	1002,00
14.00-15.00	529,00	122,40	555,25	1206,65
15.00-16.00	459,00	121,20	610,50	1190,70
16.00-17.00	593,00	135,60	758,50	1487,10
Total	4564,00	812,40	5525,00	10901,40

Data source: Disser, Y., Müller-Hannemann, M., & Schnee, M. (2008).

III. METHODS

A. Solving the Routing Problem

The Relevant articles are identified using the keywords "Dijkstra", "Shortest Path", "Multi Criteria", "Weighted Sum Method", "Weighted Product Method", "Distance", "Optimal Path", "Routing Problem", "Time Travel", Degree of Saturation (DOS), or Density. After being identified, the papers were classified using the framework developed by [26]. Traffic congestion is a common problem that requires traffic compliance [27]. The research conducted by Nurwan et al. (2021) discusses the optimal bus schedule starting from 6:30 AM to 5:00 PM. Each bus has 4 (four) departure sessions and 4 (four) return sessions, with a travel time of 60 minutes for each session. The research results show that the shortest route was obtained $V1 - V2 - V5 - V8 - V9 - V10 - V13 - V16$ [28].

Moreover, Traffic congestion in the city of Pekanbaru occurs due to the high number of vehicles on the road and the slow improvement of road facilities; for example, the road capacity remains the same while the number of vehicles continues to increase. Traffic congestion can be categorized into two types: recurring congestion and non-recurring congestion. Recurring congestion is a type of congestion that includes excess demand for travel on four-wheeled and two-wheeled vehicles, as well as a shortage of intersection supply

Table I, Table II, and Table III. Based on the LHR calculation using formula 2, it shows that the highest vehicle volume occurs at point A during the day. Based on the vehicle volume table at point A, the increase in the number of vehicles occurs at 10:00 WIT, this is influenced by police activities that are conducting ticketing operations at 07:00 - 10:00 WIT around the research location [37], against drivers who violate traffic rules, especially two-wheeled vehicles, so that many two-wheeled drivers do not pass through this road segment in the morning. 00 WIT in the vicinity of the research location, against drivers who violate traffic rules, especially two-wheeled vehicles, so that many two-wheeled drivers do not pass through this road section in the morning [45].

on every road. Recurring traffic jams usually occur during peak hours or working hours, especially from 07:00 AM to 09:00 AM, and from 04:30 PM to 07:00 PM. This is caused during peak hours when people tend to go to work, children go to school, and parents drop off and pick up their children from school, or workers return from their workplaces to go home. Another type of traffic congestion is non-recurring congestion caused by specific cases such as accidents or road closures. The literature review in this article will detail the modeling procedures and their outputs for comparing various traffic parameter input scenarios [50], [51].

B. Research Design

The research conducted refers to the previous study by Dr. Noraini Abdullah & Ting Kien Hua (2018) [29]. With different data and location, previous research created the following research design, as shown in Fig. 1.

Flowchart or research design in Fig. 1. Conducted by Dr. Noraini Abdullah & Ting Kien Hua (2018), it can be explained as follows: traffic data was collected and prepared in Kota Kinabalu during peak hours from 5:00 PM to 7:00 PM. From the data, there are five different input parameters, namely distance, DOS or density, travel time, WSM combined parameter method, and WPM. With all the collected data, five different types of directed network graphs were formed. Then, the traffic network was solved using the Dijkstra algorithm and

both methods. The results of the five different parameters were then compared. Finally, the combined parameter with WSM or the equilibrium between all criteria will be shown in the results section.

The development of the research that will be conducted from the previous study by Dr. Noraini Abdullah & Ting Kien Hua (2018) [30],[31],[32] includes innovations by adding variables related to Time Travel, which previously only considered travel time. It will later be developed to include the fastest time, longest time, and average time. Additionally, there will be the addition of variables related to Elevation or Altitude by calculating the road slope data obtained from Google Earth Pro or the Google API. Furthermore, there will be the addition of traffic lights at intersections, which will be counted in terms of the number of red lights and the duration of the red lights (in

seconds). The research conducted by Hyungjoo KIM, et al., about Assessment of Travel Time Estimates based on Different Vehicle Speed Data: Spot Speed vs. Sampled Journey Speed in South Korean expressways, compares two methods of measuring vehicle speed on South Korean highways, namely instantaneous speed measured with loop detectors and actual journey speed measured with electronic toll collection (ETC) transponders. The research was conducted on the Gyeongbu expressway section from Anseong to Giheung-Dongtan, covering a distance of 26.4 km. Speed data were collected through 23 loop detector stations that measure average time speed (instant time at a fixed location) and 8 ETC reader points that measure average distance speed (calculated from travel time between readers). The results of this study indicate that loop detectors are less sensitive to congestion compared to the ETC method [33].

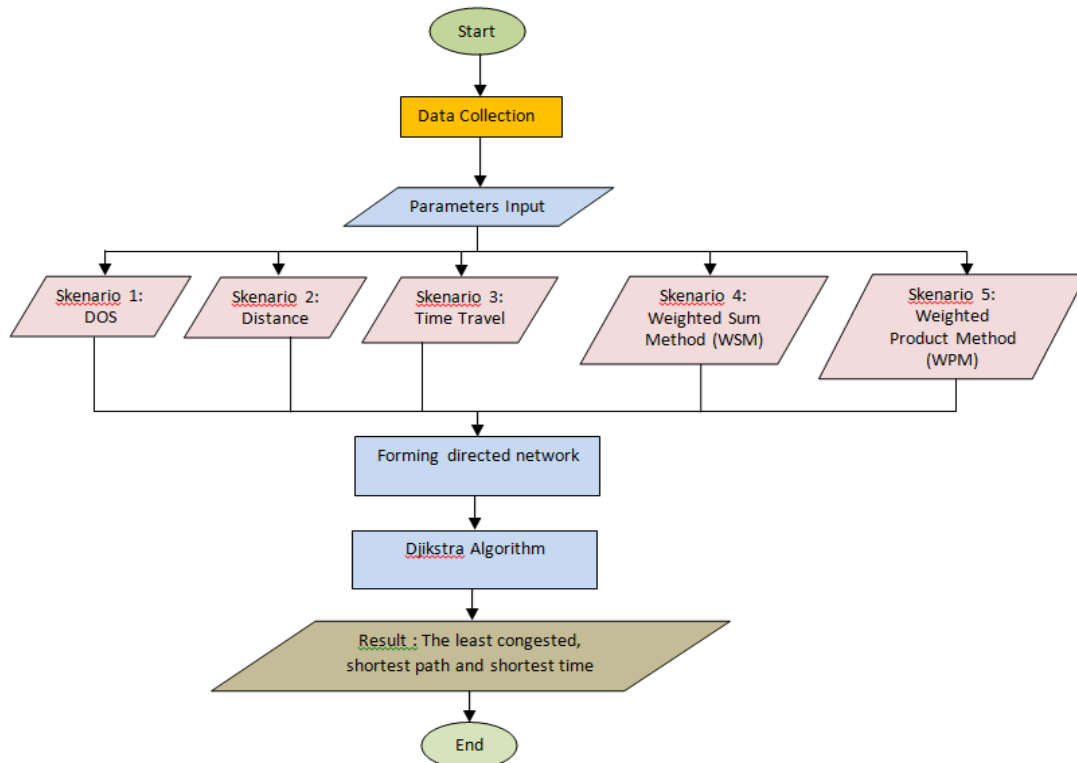


Fig. 1. Research design.

IV. RESULT AND ANALYSIS

A. Research Location

In previous research conducted by [47], the scope selected in the study was the network from Inanam, a suburban city (source node), to Centre Point, which forms the Central Business District (CBD) in the city of Kota Kinabalu (receiver node). Meanwhile, the research conducted in this study is in the city of Pekanbaru, Riau Province, Indonesia. All routes between the source node and the receiving node of the coverage are defined. In Fig. 2, the yellow dot is part of the main intersection selected in the city of Pekanbaru, Riau Province, Indonesia, which is defined as the network graph node.

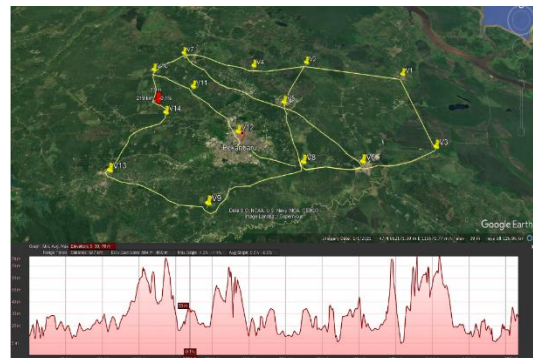


Fig. 2. Traffic network in Pekanbaru City, Riau Province, Indonesia.

B. Data Collection

Data, as shown in Table II, was collected on the road and through Google Maps. Lane distances were collected from Google Maps and relevant agencies, for example, on the official website <https://www.pekanbaru.go.id/> [38]. Volume, saturation distance, cycle time, green time, and intersection geometry were collected to calculate the density level (volume/capacity ratio). The time required was collected through real-time traffic flow on Google Maps and Google Earth during the afternoon rush hour.

In Table II, it can be explained that V is a node that is a path from node to node. V1 to V14 are nodes or intersections in the traffic network in Pekanbaru, Riau Province, which were taken with the tools of Google Earth. 'Volume' is the number of vehicles occupying a particular lane at a particular time. 'Capacity' is the maximum volume of vehicles that can pass through a particular intersection or lane. Furthermore, the

Degree of Saturation (DOS) is the volume/capacity ratio, which is an indicator of current traffic conditions. 'Distance' is the length of the path from node to node. The 'Weighted Sum Value' is the combination of degree of saturation, travel time, and distance using the Weighted Sum Methods (WSM). In addition, the 'Value of Weighted Product Methods (WPM)' is the combined value of several criteria using the Weighted Product Methods (WPM).

C. Dijkstra's Algorithm Output

The network graph in Fig. 3 has a degree of saturation (DOS) parameter. Degree of saturation is the ratio of volume to capacity. The yellow-highlighted path in Fig. 3 below is the path with the smallest degree of saturation ($DOS = 1.003 + 1.006 + 0.126 + 0.087 + 0.409$), which indicates the least congested path, namely $V1 \rightarrow V2 \rightarrow V4 \rightarrow V7 \rightarrow V10 \rightarrow V14$ with a total DOS value of 2.631.

TABLE II. COMPARISON OF THE DATA COLLECTED

Path	From	To	Volume	Capacity	DOS (Value)	Distance (Km)	Time Travel (minute)	Weighted Sum Method (WSM) (Value)	Weighted- Product Method (WPM)(Value)
1	V1	V2	191482	191000	1,003	4,25	4	0,021338	2,573442702
2	V1	V3	3338	3238	1,031	8,54	8	0,032522	4,129705815
3	V2	V4	87481	87000	1,006	8,32	7	0,030575	3,883338819
4	V2	V5	929431	929231	1,000	5,16	5	0,023837	2,955092343
5	V5	V2	794	1798	0,442	5,16	6	0,022280	2,711023624
6	V3	V6	44432	43432	1,023	5,39	5	0,024357	3,020982905
7	V4	V7	145	1152	0,126	18,57	16	0,046586	3,344124748
8	V7	V5	27750	26750	1,037	19,07	17	0,058156	6,954185511
9	V5	V7	537034	527030	1,019	19,07	10	0,040923	5,124951434
10	V8	V5	360	1302	0,276	5,60	5	0,016794	1,978259148
11	V5	V8	39596	37466	1,057	5,60	4	0,020076	2,265351286
12	V6	V5	1081	1475	0,733	22,94	17	0,059691	6,587065817
13	V5	V6	26251	27151	0,967	22,94	2	0,016089	1,706505584
14	V6	V9	365454	36800	9,931	1,77	2	0,109002	3,275890584
15	V8	V12	302	1162	0,260	1,85	2	0,007805	0,987038697
16	V12	V8	27009	25004	1,080	1,85	10	0,039843	5,032614609
17	V7	V10	145	1660	0,087	9,60	8	0,023933	1,88599431
18	V10	V11	19097	10287	1,856	9,10	8	0,041852	5,131794566
19	V11	V10	340967	310025	1,100	9,10	6	0,029381	3,702238625
20	V11	V12	146	2308	0,063	3,60	3	0,009294	0,880738407
21	V12	V11	26271	25094	1,047	3,60	2	0,015621	1,464454856
22	V12	V9	161	200	0,805	6,76	6	0,025158	3,196180338
23	V9	V12	15194	16924	0,898	6,76	17	0,055632	6,524738915
24	V9	V13	300584	177785	1,691	12,45	12	0,049856	6,321310361
25	V13	V14	206	250	0,824	3,55	2	0,015789	1,801891017
26	V11	V14	21365	20265	1,054	8,30	2	0,024000	2,596299516
27	V10	V14	126	308	0,409	53,00	50	0,139605	10,27279372
28	Amount		3006202	2506097	31,8246	273,06	236	1,000000	100,3080083

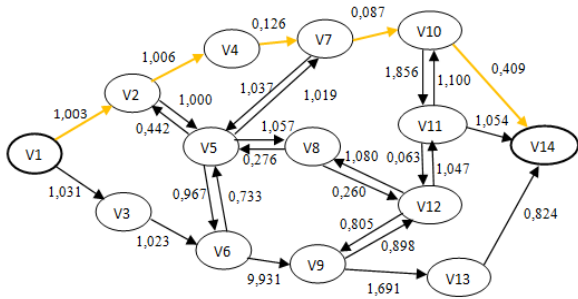


Fig. 3. Output of Dijkstra's algorithm (degree of saturation parameter network graph).

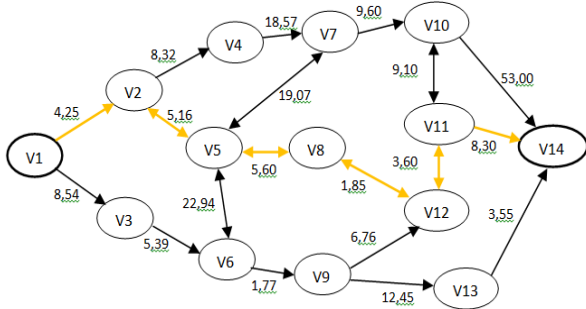


Fig. 4. Output of Dijkstra's algorithm (distance parameter network graph).

The Network Graph in Fig. 4 with distance parameters is formed using the data collected in Table II. The source node is node 1, and the receiving node is node 14. From Fig. 4, the path marked in yellow is represented by 1→2→5→8→12→11→14, which is the shortest path with a total distance (4.25+5.16+5.60+1.85+3.60+8.30) equal to 28.77 kilometers.

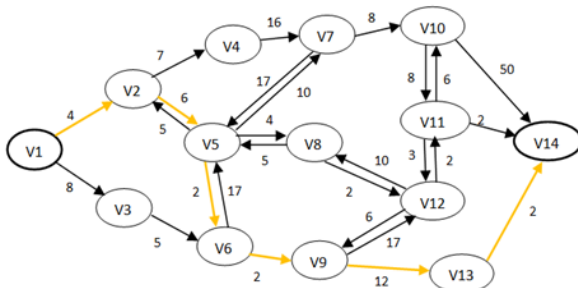


Fig. 5. Output of Dijkstra's algorithm (time travel parameter network graph).

In Fig. 5, the time travel parameter network graph is shown together as an alternative path. The alternative path with the shortest travel time is path 1→2→5→6→9→13→14. The total travel time is 28 minutes, traveling from 1 to 14, respectively.

In Fig. 6 and Fig. 7, the Dijkstra algorithm uses a combination of distance, travel time, and density values with the weighted-sum and weighted-product methods, respectively, executed. From the output in Fig. 6, the shortest distance and travel time is 1→2→4→7→10→14, while the output in Fig. 7 is the path with less density, shorter distance, and shorter travel time, namely the path 1→2→5→6→9→13→14. The total distance of this alternative route is 28.77 kilometers with a total saturation degree of 5.421 and a travel time of 28 minutes.

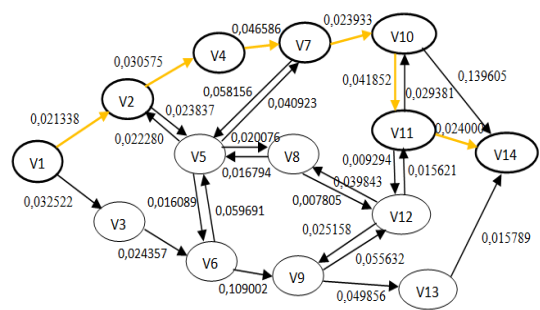


Fig. 6. Output of Dijkstra's algorithm (weighted-sum method).

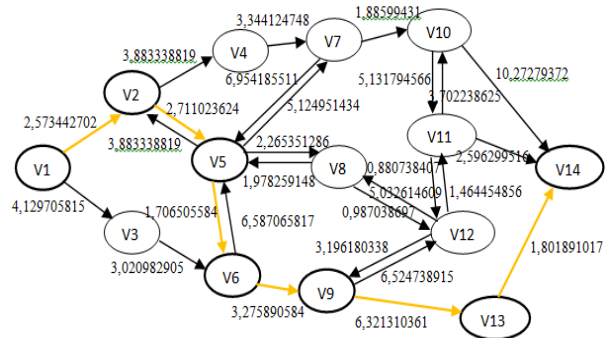


Fig. 7. Output of Dijkstra's algorithm (weighted-product method).

TABLE III. COMPARISON OF DISTANCE, DENSITY, AND TRAVEL TIME

Parameter	Specifics Parameter			
	Path	Distance (km)	DOS (Degree of Saturation) (Density)	Time Travel (Travel Time/Minute)
Distance	Path 1: 1->2->5->8->12->11->14	28,77	5,421	28
DOS	Path 2: V1->V2->V4->V7->V10->V14	93,74	2,631	85
Time Travel	Path 3: 1->2->4->7->10->14	50,12	15,416	28
Weighted SUM Method	1->2->4->7->10->14	58,14	2,631	85
Weighted Product Method	1->2->5->6->9->13->14	50,12	5,421	28

Data source: Personal Research Data

As shown in Table III, there are three different paths selected depending on the selected parameters. With the distance parameter network graph, Path 1 is the path selected with the shortest distance. Path 2 is the path selected with Degree Of Saturation (DOS), while Route 3 is the route with the shortest travel time. With the combined parameters of DOS, travel time, and distance, Route 1 was chosen because it has achieved a balance between distance, travel time, and DOS. In other words, the driver can decide on the optimal right lane that is not too congested, has a shorter travel time, and a shorter distance. The difference between the paths in percentage is then calculated to find significant differences between them.

V. CONCLUSIONS

The shortest distance route may not be the best; two different parameters result in two different routes, but the best route is chosen based on distance and the lowest saturation level criterion. However, in this study, travel time is an additional criterion. Routes with three different parameters have been compared and result in three different routes. From these results, the shortest route is 1→2→4→7→10→14, the least congested route, and the shortest travel time is 1→2→5→6→9→13→14. This study combines these three parameters to get a balanced route between congestion level, short travel distance, and short travel time for drivers. By combining these parameters, the best path from this study is path 1: 1→2→5→8→12→11→14 with a total distance of 28.77 km, a saturation degree value of 5.421, and a travel time of 28 minutes. Thus, the results show that the best path will have a multi-criteria combination of short distance, short travel time, and fewer simultaneous traffic jams. The Weighted-Sum Method (WSM) and the Weighted-Product Method (WPM) can produce different outputs, with WPM being superior to WSM in terms of computational steps. The Weighted Product Method can also be user-friendly, and avoids normalization issues that can cause the reversal of rankings usually faced by the Weighted-Sum Method.

VI. FUTURE RESEARCH

The calculation results on Time Travel on the graph become three (3) graphs, namely the fastest time, the longest time, and the average time in minutes, while altitude affects speed. The more sloping the road conditions, the longer it will take, and it is not recommended, because it will affect not only costs but can also affect time and reduce the bad energy caused by vehicle exhaust fumes. Then the number of red lights will also affect the time of arrival at the destination. This is calculated based on the number of red lights and the length of time in seconds on the red light indicator on the road.

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