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Weighted Sum-Dijkstra's Algorithm in Best Path Identification based on Multiple Criteria

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Abstract: People faced decision making in choosing a suitable path for their own preferences. Usually, more than one criterion is involved in order to match with the preferences of the decision makers. The main objective of this paper was to identify the best path selection based on multiple criteria instead of a single criterion. Dijkstra's Algorithm is a shortest path algorithm that considers a single criterion only. Weighted Sum Method (WSM) is one of the weighting methods to solve the multi criteria decision making problems (MCDM). In order to achieve the objective, Weighted Sum-Dijkstra's Algorithm (WSDA), a combination method between WSM and Dijkstra's Algorithm is applied to solve multiple criteria network problems. In this paper, Dijkstra's Algorithm and WSM are reviewed and compared as to the WSDA. In addition, two examples with equal criteria values to evaluate the performances of the approach are presented. Results show that WSDA performed better in terms of the criteria concerned as it was compared to the Dijkstra's algorithm. Moreover, the results could be directly found without considering all the alternative paths of the problem. WSDA can be user friendly to users from non-mathematical background. It is not only applicable to urban road problems, but other network problems such as pipelines and bandwidth network problems. When come to large scale data problems, Maple software is used to solve it with ease.

Keywords: multiple criteria, weighting method, combination, weighted sum-dijkstra's algorithm, best path.

1. Introduction

Different road users may have different preferences to achieve their objectives. For example, a food delivery company will need to make sure that the food delivered fresh. Hence, time travel is the main criteria for food delivery company to deliver their food. However, in this present dynamic and uncertain environment, single criterion is no longer enough to solve the problems. If a single criterion is considered in urban road networks, the results may not be ideal because of external factors, examples are such as traffic congestion, road safety, and etc. As [1] mentioned that the shortest path might not be the best path selection. Experience tells road users to think that shortest path is the shortest time travel path. However, this may not be the case based on different conditions and scenarios. In [1], the best solution for single criterion was not enough in solving a ship routing network problem. Therefore, multiple criteria such as distance, number of indirect vertices and average time were considered in identifying the best solution for ship routing network.

2. Objective

The main objective in this paper is to identify the best path from routing network using the multi criteria based approach. The Weighted Sum-Dijkstra's algorithm is thus suggested in this paper. It can identify from the beginning node to the destination node of a network graph based on multiple criteria. If distance and cost criteria are considered, then the identified best path would be associated with the least distance or cost. Hence, a combined algorithm of Weighted Sum Method and Dijkstra's algorithm, namely as the Weighted Sum-Dijkstra's algorithm is then applied.

3. Related Works

Dijkstra's algorithm is one of the common shortest path algorithms. It can handle single source shortest path, but cannot deal with the negative edge [2]. Computation for Dijkstra's algorithm will increase gradually with the increasing network complexity [3]. Hence, it cannot meet the needs in dynamic environment condition. Besides, it performs a blind search which wastes a lot of time [4]. Application of Dijkstra's algorithm can be applied in different fields such as evacuation, construction, urban road, and network flow. [5] used Dijkstra's algorithm for vehicle evacuation in a dynamic road network model. [6] applied Dijkstra's algorithm in finding efficient path between two locations in providing support for the construction site planning task based on multiple criteria. Weighted sum method was used as cost evaluation function by combining the multiple criteria into new cost score for further optimization. [7] applied Dijkstra's algorithm into urban road network to prototype, based on multi criteria approach by identifying the desire routes for different preferences.

Weighted Sum Method (WSM) is one of the Multi Criteria Decision Making (MCDM) methods. Multi criteria decision making is a sub-topic of Operation Research that evaluate multiple criteria in decision making. There were some related studies about weighted sum method that can be applied in different fields. Weighted Sum Method was applied in mobile cloud database environment so as to obtain a good query execution plan with consideration of multiple objectives, such as monetary cost, energy consumption and query execution time [8]. Multi Criteria decision making (MCDM) methods such as Weighted Sum Method (WSM) and Weighted Product Method (WPM) were implemented in food choices so as to solve the food shortage problem [9]. Both methods however, produce the same decision. Besides, MCDM methods were applied in investment for stock selection based on different sectors [10]. The WSM and WPM employed selection of the best elementary schools in Indonesia that aimed to spur the growth and quality of primary school [11]. MDCM was applied by [12] in new employer recruitment. The execution time for WSM was relatively faster than WPM. However, in [13] there were three effects of WSM that caused rank reversal. The first effect was the change of normalization method. The second effect was the removal of unwanted alternatives. The third effect was all rounders overlooked in favor of unbalanced alternatives.

[7] determined the optimal path and accessibility between two locations, based on the combination of multiple criteria with different weights as assigned according to different preferences. The considered criteria were distance, safety, comfort and view. The combination of criteria into new cost score was performed using the cost function, WSM. Then the optimal path is identified by finding the path with the lowest total cost using the Dijkstra's algorithm. [14] had proposed a new method called multi attribute Dijkstra method. It is a combination of Technique for order preferences by similarity to the ideal (TOPSIS) method and Dijkstra's algorithm. TOPSIS is one of the MCDM that is used for ranking and selecting the routes. Multi attribute Dijkstra method performed better than the single attribute Dijkstra's algorithm with some theoretical examples. [6] presented an optimized application by finding the efficient paths between two points to ease the construction site planning task. The combination of safety, transportation cost and visibility criteria using multi criteria cost evaluation function, WSM. This was further optimized by using the mathematical search algorithms, called Dijkstra's and A* algorithms to find the optimal solutions.

4. Methodology

In this paper, definitions for weighted sum method, network graph and Dijkstra's algorithm are presented. A step by step approach of the Weighted Sum-Dijkstra's algorithm is thus described.

4.1 Multi-Criteria Decision Making: Weighted Sum Method

Most real-life decisions involve multi criteria, thus decision makers have to take into consideration of multiple factors in selecting the best choice. Weighted Sum Method is one of the weighting methods that involve summation of criteria according to the allocated weights. It implies that there is a fixed trade-off rate between each pair of criteria. WSM involves the normalization procedure. Normalization is a process that converts all criteria into the same dimension before combining with the weights. The commonly used normalization methods are division of each criterion by the largest value, range normalization, statistical standardization and division of the value by the total. Among these normalization methods, division of the value by total is chosen in this study, and the formula is shown in Equation (1). After normalization, the weights are attached to the criteria, and added together to the weighted values to produce corresponding scores and ranks [13]. Equation (2) is the Weighted Sum Method, which refers to c_{uv} as the new cost that combined the multiple criteria by the weighted sum method. w_v represents the weight value of the criteria, and r_{uv} is the normalized score of alternatives. a_{uv} represents the number of edges and the criterion. For example, a_{11} stands for the first edges with the cost value of the first criterion.

$$r_{uv} = \frac{a_{uv}}{\sum_{u=1}^{m} a_{uv}} \tag{1}$$

$$c_{uv} = \sum_{v=1}^{n} w_v r_{uv} \tag{2}$$

4.2 Definition of Network Graph

Let $G = (A, E)$ be a graph in defining a specified problem. A graph G is formed by a collection of nodes and edges. A graph can be weighted and unweighted. A weighted graph is called the network graph. A number that is assigned to the edges is called weight which indicates the extent of connectivity of the arcs. Network graph is a set of nodes that consist of elements $1,2 \dots, n-1, n$, and linked by edges. The nodes of the network graph are the elements of A which are denoted as $a_1, a_2, \dots, a_{n-1}, a_n \in A$. Then, a_1 is the source (starting) node, and a_n is the sink (ending) node. The edges are defined by the ordered pairs (i, j) . The edges (i, j) are the elements of E over these nodes of the network graph. Network problems defined by [15] are optimization problems that can be cost minimization problems or capacity maximization problems according to the data input.

4.3 Definition of Dijkstra's Algorithm

Dijkstra's algorithm is a shortest path algorithm that was created by Edsger Wybe Dijkstra in 1956, and published three years later. The further definition and description for the algorithm are showed below. Consider an edge (i, j) of cost $\mathrm{c_{ij}} > 0$. Let $\mathrm{LC_i}$ is equal to lowest cost from node 1 to node n. The label of node j connected with node i is defined as the pair of elements $[\mathrm{LC_j}, \mathrm{i}] \stackrel{\text{def}}{=} \min_{\mathrm{i}}[\mathrm{LC_j} + \mathrm{c_{ij}}, \mathrm{i}]$. If there is only one i connected to j, the right-hand side gives the label of j, and is said to be permanent. If there are several $i's$ connected to j, the label $[\mathrm{LC_i} + \mathrm{c_{ij}}, \mathrm{i}]$ for a permissible value of i is called temporary, provided a shorter connection from some other acceptable value of i 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:

1. Label starting node, s with permanent label $[0, -]$. Set $j = 1$.
2. Compute temporary labels$[LC_i + c_{ij}, i]$ for each node j that can be reached from node i. If node j has already the label $[LC_j, k]$ through another node k such the$LC_i + c_{ij} < LC_j$ then replace$[LC_j, k]$ by$[LC_j + c_{ij}, i]$. Otherwise,$[LC_i + c_{ij}, i]$is the permanent label of node j .
3. For $j < n$, set $j =$ next j, reachable from permanently labeled nodes and Go to Step 2. k

stands for the adjacent node of j. If all the nodes have permanent labels, and $j = n$, then Stop [15].

4.4 Step by Step Computation for Weighted Sum-Dijkstra's algorithm

1. Presenting data in matrix form based on m edge and n criteria such as cost, distance and etc.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad (3)$$

2. Normalization

$$r_{uv} = \frac{a_{uv}}{\sum_{u=1}^{m} a_{uv}} \quad (4)$$

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \vdots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (5)$$

3. Weighted sum method

$$c_{uv} = \sum_{v=1}^{n} W_v r_{uv} \quad (6)$$

$$X = \begin{bmatrix} w_1 r_{11} + & \cdots & + w_n r_{1n} \\ \vdots & \vdots & \vdots \\ w_1 r_{m1} + & \cdots & + w_n r_{mn} \end{bmatrix} = \begin{bmatrix} c_1 \\ \vdots \\ c_m \end{bmatrix} \quad (7)$$

X= WSM values

4. Using the WSM value in forming a directed network graph.
5. Network graph solved by Dijkstra's algorithm as shown in Sub-title 4.3.
6. Best path is identified.

The step by step procedures are shown above. In the results section, there are two examples of network graphs that are used to test the WSDA method, and exemplify for illustration purposes [16].

5. Results

In Figure 1, it shows the overall flow chart of WSDA in this paper. Firstly, it started with data collection. Next, the collected data is solved by the Weighted Sum-Dijkstra's algorithm in order to get the best path with the considered multiple criteria.

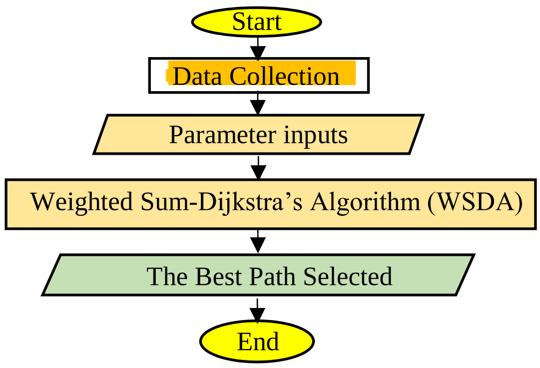

Figure 1. Flow chart Using WSDA

5.1 Example 1

Network graph in Figure 2 below is formed using 6 nodes and 7 edges. It is an example for urban road network problem. The criteria that are considered in this study are cost, distance and time travel.

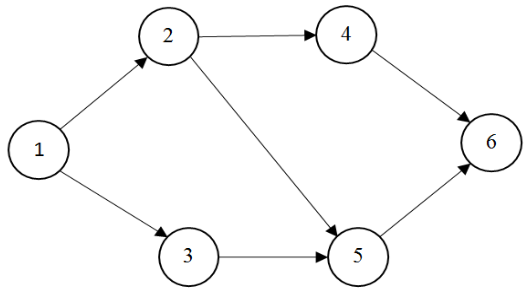

Figure 2. Network graph of Example 1

Preliminary data in Table 1 are obtained by randomly generated data using Microsoft Excel. The chosen normalization method is the division of each criterion by the total of the criterion.

Table 1. Preliminary Data for Example 1

Edge	From	To	Cost	Distance	Time Travel
1	1	2	49	11	4
2	1	3	25	10	8
3	2	4	30	12	5
4	2	5	27	18	9
5	3	5	36	18	4
6	4	6	41	14	6
7	5	6	31	14	8
Total of criterion			239	97	44

There are some examples of normalization, and WSM value computation that are as shown below.

Normalization of cost criterion for edge 1 in Table 1

$$= \frac{49}{239} = 0.20502$$

Normalization of distance criterion for edge 1 in Table 1

$$= \frac{11}{97} = 0.11340$$

Normalization of time travel criterion for edge 1 in Table 1

$$= \frac{4}{44} = 0.09091$$

Weighted Sum Method value for edge 1 in Table 1

$$=0.20502\times\frac{1}{3}+0.11340\times\frac{1}{3}+0.09091\times\frac{1}{3}=0.136443$$

The results of normalization computation are displayed in Table 2 below.

Table 2. Normalization and WSM value

Edge	Normalization			WSM value
	Cost	Distance	Time Travel	
1	0.20502	0.11340	0.09091	0.136443
2	0.10460	0.10309	0.18182	0.129837
3	0.12552	0.12371	0.11364	0.120957
4	0.11297	0.18557	0.20455	0.167697
5	0.15063	0.18557	0.09091	0.142370
6	0.17155	0.14433	0.13636	0.150747
7	0.12971	0.14433	0.18182	0.151953

As mentioned earlier, the objective of this paper is to find the best path with the concerned multiple criteria. Hence, equal weight is assigned to each criterion. There are three criteria used in this paper, therefore equal weight of 1/3 is assigned equally to each criterion as shown in Table 3.

Table 3. Weight allocation of Different Criteria for Example 1 and Example 2 [6]

Criteria	Cost	Distance	Time Travel	Total
Weight	1/3	1/3	1/3	1

The equal allocation of weight is to find the optimal path with equally concerned of each criterion [6]. Table 3 is not only applied in Example 1, but also in Example 2. The identified best path by Dijkstra's algorithm is shown in Figure 3.

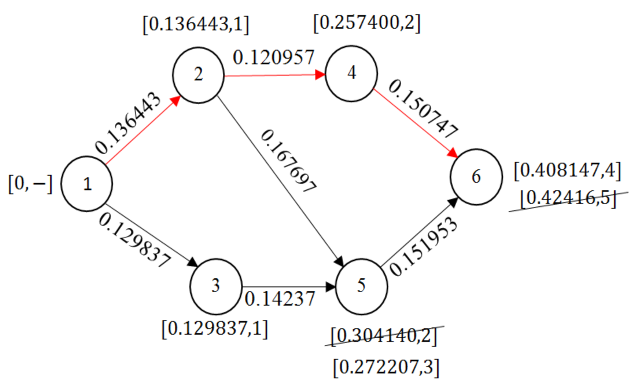

Figure 3. Optimal Path of Example 1

In Figure 3, node 1 is labeled as the permanent label [0, −]. Node 1 is approached to node 2 with the label [0.1364431,1]. Node 3 is joined with node 1 with label [0.129837,1]. Next, node 2 and node 3 are connected to node 5 with the labels [0.304140,2] and [0.2772207,3], respectively. The label of node 2 to node 5 were eliminated due to bigger cost than another node from node 3. Node 2 is joined to node 4 with label [0.257400,2]. The last node, node 6 is joined from node 4 and node 5. Node 4 with the minimum total cost label [0.408147,4] is chosen in order to meet the requirements of this study. The identified optimal path was 1 → 2 → 4 → 6 with the minimum WSM value. It means that the optimal path was the best path with consideration of the three criteria with equal weight in Table 1 and 2. All results were displayed in Table 6.

5.2 Example 2

In Figure 4, a network graph of 10 nodes with 15 edges was formed. The aim is to find the path with the least WSM cost value. Network graph in Figure 4 was an urban road network problem that was alike the network graph in Figure 2. The network graph in Figure 4 was bigger with more nodes and branches compared to network graph in Figure 2 in order to test the efficiency of the WSDA method.

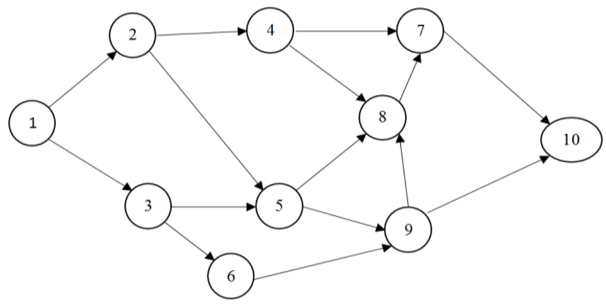

Figure 4. Network graph for Example 2

Each edge has its attributes, such as cost, distance and time travel, presented in Table 4. The normalization is performed by the division of total for each criterion and presented in Table 5. The WSM value represents the new cost which is the summation of normalized criteria that are computed by the weighted sum method. Preliminary data in Table 4 are obtained by random generation of data in Microsoft Excel.

Table 4. Preliminary Data for Example 2

Edge	From	To	Cost	Distance	Time Travel
1	1	2	33	14	3
2	1	3	44	14	9
3	2	4	30	20	4
4	2	5	46	16	3
5	3	5	35	13	8
6	3	6	26	16	7
7	4	7	20	18	7
8	4	8	39	16	8
9	5	8	43	12	6
10	5	9	33	20	5
11	6	9	43	18	7
12	7	10	44	17	3
13	8	7	25	20	8
14	9	8	38	17	7
15	9	10	25	10	9
Total of Criterion			524	241	94

The example of normalization and WSM value computation in Table 5 are shown below.

Normalization of cost criterion for edge 1 in Table 4

$$=\frac{33}{524}=0.14103$$

Normalization of distance criterion for edge 1 in Table 4

$$= \frac{14}{241} = 0.12613$$

Normalization of cost criterion for edge 1 in Table 4

$$= \frac{3}{94} = 0.07317$$

Weighted Sum Method value for edge 1 in Table 4

$$= 0.14103 \times \frac{1}{3} + 0.12613 \times \frac{1}{3} + 0.07317 \times \frac{1}{3} = 0.11344$$

The results of the normalized WSM value for Example 2 are displayed in Table 5.

Table 5. Normalization and WSM value for Example 2

Edge	Normalization			WSM Value
	Cost	Distance	Time Travel	
1	0.14103	0.12613	0.07317	0.11344
2	0.18803	0.12613	0.21951	0.17789
3	0.12821	0.18018	0.09756	0.13532
4	0.19658	0.14414	0.07317	0.13797
5	0.14957	0.11712	0.19512	0.15394
6	0.11111	0.14414	0.17073	0.14200
7	0.08547	0.16216	0.17073	0.13945
8	0.16667	0.14414	0.19512	0.16864
9	0.18376	0.10811	0.14634	0.14607
10	0.14103	0.18018	0.12195	0.14772
11	0.18376	0.16216	0.17073	0.17222
12	0.18803	0.15315	0.07317	0.13812
13	0.10684	0.18018	0.19512	0.16071
14	0.16239	0.15315	0.17073	0.16209
15	0.10684	0.09009	0.21951	0.13881

In Figure 5, node 1 as starting node is labeled as permanent label $[0,-]$. Node 1 is connected to node 2 and node 3 with labels $[0.17789,1]$ and $[0.11344,1]$ respectively. Node 5 is connected from node 2 and node 3 with labels $[0.25141,2]$ and $[0.33183,3]$ respectively. Label from node 2 to node 5 is chosen as the label with the lower cost. Node 5 and node 6 are joined to node 9. Node 9 that is connected from node 5 with the label $[0.39913,5]$ is selected. In node 8, node 4, 5 and 9 are the nodes that are connected to it. Node 5 with label $[0.397485,5]$ that is connected to node 8 is chosen. Next, node 7 is labeled with $[0.38821,4]$ that is joined from node 4. Lastly, the ending node, node 10 is labeled $[0.52633,7]$ that is joined from node 7. Overall, the path $1 \to 2 \to 4 \to 7 \to 10$ is the identified best path for Example 2. It has the minimum WSM value by the Dijkstra's algorithm.

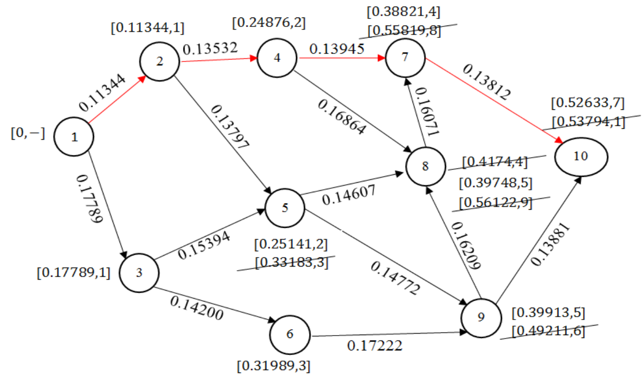

Figure 5. Optimal Path for Example 2

In Table 6, comparative results of the Dijkstra's algorithm with different attributes, and the WSDA method are displayed. The weight allocation for these methods is of equal weights according to the number of criteria. The criterion with more weight is considered more important amongst all of criteria. If the weight of one criterion is 1, and those of the other attributes are 0, the obtained result will be the same with the single criteria Dijkstra's algorithm. The path $1 \to 3 \to 5 \to 6$ is the lowest cost path with consideration of cost criterion only in network graph of Example 1. The path with the lowest distance and time travel is $1 \to 2 \to 4 \to 6$ in Example 1. With consideration of multiple criteria by Weighted Sum-Dijkstra's algorithm, path $1 \to 2 \to 4 \to 6$ is the ideal path compared to path $1 \to 3 \to 5 \to 6$ because path $1 \to 2 \to 4 \to 6$ has achieved the balance between three criteria in this study. In Example 2, path $1 \to 2 \to 4 \to 7 \to 10$ is the identified path with the lowest cost and time travel. Path $1 \to 3 \to 5 \to 9 \to 10$ is the path with concern of single distance criterion only. Overall, path $1 \to 2 \to 4 \to 7 \to 10$ is the best path selected using the modified Weighted Sum-Dijkstra's algorithm which has included three criteria.

Table 6. Comparative Results of the WSDA with Dijkstra's algorithm

Example	Dijkstra's algorithm with each attribute			Objective function of WSDA method
	Cost	Distance	Time Travel	
1	1-3-5-6 (92,42,20)	1-2-4-6 (120,37,15)	1-2-4-6 (120,37,15)	1-2-4-6 (120,37,15)
2	1-2-4-7-10 (127,69,17)	1-3-5-9-10 (137,57,31)	1-2-4-7-10 (127,69,17)	1-2-4-7-10 (127,69,17)

Table 7 shows the percentage of difference between identified paths in Example 1 and Example 2. In Example 1, path $1 \to 3 \to 5 \to 6$ has 30.43% lower cost than path $1 \to 2 \to 4 \to 6$. However, path $1 \to 2 \to 4 \to 6$ has 11.90% shorter distance and 25% shorter time travel than path $1 \to 3 \to 5 \to 6$. In Example 2, path $1 \to 3 \to 5 \to 9 \to 10$ has 21.05% shorter distance than path $1 \to 2 \to 4 \to 7 \to 10$. Path $1 \to 2 \to 4 \to 7 \to 10$ has 7.30% lower cost and 45.16% shorter time travel compared to path $1 \to 3 \to 5 \to 9 \to 10$.

In Example 1 and Example 2 that are presented in Table 7 shows that path 1 → 3 → 5 → 6 in Example 1 and path 1 → 2 → 4 → 7 → 10 in Example 2 have performed better.

Table 7. Comparison of Percentage of Difference between Paths

Example	Comparison between Paths	Percentage of Difference		
		Cost	Distance	Time Travel
1	1-3-5-6 & 1-2-4-6	↑ 30.43	↓ 11.90%	↓ 25%
2	1-3-5-9-10 & 1-2-4-7-10	↓ 7.30 %	↑ 21.05 %	↓ 45.16%

6. Discussions

Weighted Sum-Dijkstra's algorithm is a combination of the weighted sum method and Dijkstra's algorithm that has included multiple criteria in decision making. As referred to [14], a combination of TOPSIS and Dijkstra's Algorithm to identify the path with concern of the weights for multiple criteria is presented, and it has a similar concept as the modified algorithm that is applied in this paper. The efficiency of the WSDA in this paper is examined as it is compared with a single criteria Dijkstra's algorithm. WSDA can provide a solution based on multi criteria instead of a single criterion only. Besides, it can identify the best path without involvement of all alternatives which is better when compared to the all possible path approach that is mentioned in [17]. Conversely, path identification that has involved all possible paths as alternatives will consume a lot of time in computing the scores and ranking of the alternatives.

WSM is part of the WSDA in this paper. WSDA may not be the latest approach in finding the best path, but it is simpler and a user friendly method. Moreover, it is suitable for users of non-mathematical background. However, there are some limitations for WSDA. As referred to [13], there are different normalization methods that are widely used in WSDA. Each normalization step might come out with different results. For example, range normalized scores would destroy proportionality. Besides, z- scores will make the mean value become unrepresentative with the existence of outliers. Apparently, the WSDA may lead to difficulties and anomalies.

In general, WSDA can be applied in other fields such as networking, pipeline problems for optimization based on multiple criteria. A solution with consideration of more than one criterion would bring a better choice for decision making. Besides, it being user friendly to non-mathematical background, it can benefit for their management and operation. Softwares such as the Maple can be can be used with ease in dealing with problems that are involved with large scale data.

7. Conclusion

In conclusion, Weighted Sum-Dijkstra Algorithm can perform better in finding paths with considered of multiple criteria [16]. It could be very effective and useful in path identification as criteria are increased. Problems that are solved solely by the Dijkstra's algorithm will only solve a single criteria problem. For further work, a better approach with the combination of multi-criteria decision making and shortest path algorithm can be further investigated in finding a solution with results of both high in efficiency and accuracy.

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